And now for something completely different: the Elementary Process Theory

Revised, updated and extended 2$^{\text{nd}}$ edition of the dissertation with almost the same title

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Permission in writing has been given by Monty Python for the use of their catchphrase 'and now for something completely different' in the title of this 2nd edition.

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Or is it?

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Preface to the 2$^{\text{nd}}$ edition

> “*It will not surprise you that after reading this pathetic stuff I come to this conclusion: this is all nonsense, this dissertation contains nothing worth publishing.*”—Andries Brouwer (2008b), eminent mathematician, on my 2007 concept-dissertation

A world with repulsive gravity: what would it be made up of, and how would it function? For me, that’s the most fascinating topic there is. In 1996—when I was still in my 20s—I was struck out of the blue by what René Descartes called a ‘clear and distinct idea’ about the outside world while pondering about repulsive gravity, and ever since I have considered it my calling to develop that idea into a consistent theory of the fundamental workings of a world with repulsive gravity. And for over 25 years I’ve followed that calling, like a servant of the Lord follows his calling—that is, without striving for worldly pleasures like recognition, fame or fortune. I did not, however, follow any traditional career path. Nowadays one is expected to start out an academic career in physics as a PhD student who develops a preexisting idea of a professor, and to wait with the development of one’s own ideas until a certain level of seniority has been reached. But I am not here to live up to the expectations of my contemporaries. Not that I consider myself to be above everybody else, but right from the start I wanted to develop that clear and distinct idea into a theory. And that’s what I did, and my research work did bear fruits: not material fruits (money), but immaterial fruits that come in the form of theories and models (and together these form a *research program* as meant by Imre Lakatos). This research monograph integrates all my work into a coherent whole; it can be viewed as a revised, updated, and extended 2$^{\text{nd}}$ edition of my dissertation, which I defended in 2011 at the Vrije Universiteit Brussel.

I honestly believe that my work has yielded some good results or, with another word, some good news: within this research program,

(i) we have a candidate for a unifying scheme—the Elementary Process Theory (EPT)—that applies to all four fundamental interactions (gravitational, electromagnetic, weak, strong);

(ii) man has a free will—I consider that God's greatest gift to mankind, although we certainly still have to learn how to use it;

(iii) there is a cyclic process by which energy contained in the vacuum can be harvested, something that one day may be used in technology.

Nevertheless, I have experienced a resistance from the academic community that few before me have experienced. My main opponent Gerard 't Hooft foresaid that "in biblical terms", a "road of suffering" would await me if I would proceed with my research (2009). Now he has lashed out at me many times, but that was the only time he was right: I have experienced resistance to such a degree, that at some point I had the idea that God Himself was pleased with my misery. In the Netherlands alone a one-page article on my work in a university weekly led to a controversy that came to exceed the now historical controversies following the publications of the works of Descartes and Spinoza in the 17^{th} century: it is only a slight exaggeration to say that in 2008 it became a new literary genre in the Netherlands to write an attack against me and my work—note that my work remained unpublished until 2010. But the resistance I've experienced was not limited to the Netherlands: I have also encountered it in the peer review of papers submitted for publication and of proposals submitted for funding. And apart from a handful of individual exceptions, even those working on the topic of repulsive gravity didn't want to have anything to do with me. They all held me in low esteem: they put me on a par with those crackpots who, without relevant education, claim to have proven that modern physics is false and should be replaced by their pseudoscientific theories. Eventually this resistance made me give up all hope for a paid position at a university to do my research work—a hope I had cherished from the moment I started my research endeavor. And I would like to emphasize, as others have done (e.g. Charles Bukowski), that one doesn't give up hope overnight: it's a slow process, like a tree slowly losing his leaves until the very last one, until there isn't even anything left for death to take.

But of course, no one else but me provided the *casus belli* for this collision with the establishment. First of all, the starting point of my research work, the hypothesis that there exists a matter-antimatter repulsive gravity, is impossible from the perspective of widely accepted theories of modern physics. So, upon learning that I worked on a theory that could explain repulsive gravity—note that one can learn that from a superficial reading of my work or even from hearsay—many of my opponents immediately jumped to the conclusion that I didn't know the first thing about physics. Now if I would have worked on any of the open problems of a mainstream research program in physics, those very same people would have embraced me as a new member of the academic community; but as it is, I preferred to work on the problem that arises from considering that, against all odds, repulsive gravity is a fact of nature and asking by which fundamental principles this would be possible, and that fact alone led to much resistance. But I have applied existing methods for theory development, and in addition the development of the EPT has been supervised by a physicist (Sergey Sannikov): let no one say that he didn't know the first thing about physics.

Secondly, en route to identifying the principles by which repulsive gravity would be possible, the first question to be answered was: *how* does repulsive gravity take place? The answer came in the form of the EPT: it consists of seven process-physical principles that abstractly describe the elementary processes by which interactions have to take place for repulsive gravity to exist. However, the abstract-mathematical formulation of these principles—in other words: the generic description of an interaction process—required the development of a new formal language for physics. For that matter, I had to apply mathematical logic to physics: the EPT is formalized in a mathematical-logical framework and is therefore mathematically more abstract than theories of modern physics. This abstractness and the fact that most physicists are not familiar with mathematical logic did not contribute to the accessibility of my work: several opponents have therefore *from a superficial glance at the formalism* jumped to the conclusion that the mathematics in my work are not mathematics at all. But the formalisation has been done by the book under the supervision of an expert (Harrie de Swart), and once one has a grasp of the formalism one sees that at this degree of abstractness the process-physical principles of the EPT are mathematically of great simplicity.

Thirdly, for the EPT to be a theory of physics the formalism had to have a physical interpretation. For that matter, new physical concepts had to be developed and it turned out to be very hard to get it all conceptually coherent. I had to make amendments to my 2010 paper in *Annalen der Physik* in 2011 and 2016 (both were published in the same journal) but that's not all: in this monograph I present a final version of the EPT that differs from the twice revised version in *Annalen der Physik*—the differences concern only details, but still. What turned out to be the main issue, however, was not the newness of the terminology but the fact that the objects postulated to exist in the physical universe are *four-dimensionalistic*, which is to say that these are objects that are extended in time—or, in other words: these are objects that have a time span (like the life of a free neutron). Such four-dimensionalistic objects are called *occurrents*. As it turned out, I myself view the world intuitively in terms of occurrents, and it never occurred to me that others didn't. Of course I knew that the overwhelming majority doesn't look at the world through *four-dimensionalistic glasses* but through *three-dimensionalistic glasses*, which is to say that the overwhelming majority views the world in terms of *continuants*, i.e. three-dimensional objects that continuously move through time (like chairs, tables, molecules, atoms, particles, quarks, bosons, leptons, etc.). But it is only recently that I've discovered the niche in the philosophical literature with publications about four-dimensionalism—I now use the term but I know it only since recently—and so I only thenceforth understood that a four-dimensionalistic world view is completely counterintuitive for the overwhelming majority. And so I now know why several opponents of mine have espoused the view (both in public and behind closed doors) that my physical interpretation of the formalism is bizarre, gibberish, absurd, etc. So in hindsight I consider it a shortcoming of my papers in *Annalen der Physik*, of my 2007 concept-dissertation, and of my 2011 dissertation that four-dimensionalism has not been discussed, and that I have only mentioned in passing that the objects postulated to exist in the universe are extended in time: for that I apologize, and I hope to make up for it with this monograph which uses ample space to introduce the four-dimensionalistic terminology. So, now I can say that the EPT consistently describes the world not in terms of *elementary particles and interactions*, but in terms of *atomic occurrents and transitions*—the atomic occurrents are called 'phase quanta'.

Fourthly, *even if* one was willing to consider repulsive gravity, *and* had mastered the formalism, *and* had understood its physical interpretation, it was still not obvious that the EPT would withstand the test if we would check it against existing knowledge about the universe. In my earlier works (my 2007 concept-dissertation, my Annalen papers, and my 2011 dissertation) I indicated only summarily *how* the EPT could be checked against existing knowledge, but I didn't do any actual checking: that, namely, is not entirely simple. The problem is that the EPT cannot possibly satisfy the *correspondence principle* as commonly understood: due to the abstractness of its mathematical formulation it cannot possibly be proven that the EPT reduces to an existing theory (e.g. Newtonian mechanics) by applying some limit procedure—there is, thus, no easy way to show that the EPT agrees with the knowledge of the physical world that derives from the experimentally successful predictions of existing theories of physics. Therefore, I considered the development of the EPT and the development of a proof that it agrees with existing knowledge to be two distinct research projects. So, on the one hand I did briefly but exactly describe how the EPT could in principle be tested by a scientific method (refined falsificationism), but on the other hand I did not present a proof that the EPT agrees with anything that we already know. That latter fact now led several of my opponents to conclude that the EPT could be dismissed right away as not worthy of further consideration—and they were quite vocal about it, depicting my work as despicable. I consider their conclusion premature, but I understand where it comes from; so, let me apologize for having been summarily about this topic in my earlier works, and let me express my hope that this monograph makes up for it. In my postdoctoral research I have developed a new principle of correspondence, called the 'weak correspondence principle', and I have developed a rigorous proof method for it: to prove that the EPT agrees with the existing knowledge that derives from the successful predictions of an accepted theory of physics, we have to apply that proof method to show that the EPT corresponds weakly to that theory. Part IV of this monograph focusses on this theme, and it contains a completely worked-out proof that the EPT corresponds weakly to Einstein's special relativity. The finale is a model of the EPT that quantitatively models a process of gravitational interaction: this is a concrete step towards a proof that the EPT corresponds weakly to Einstein's general relativity.

That being said, while I take full responsibility for having provided the stimulus that elicited the response from the academic community, I do not agree with the things that have been said about me and my work. It is my sincere opinion, namely, that the right to freedom of opinion and expression does not imply a right to make false statements of fact. My opponents may be men of science, and it may be that none of them would have crossed a line if I would not have come forward with my EPT; but as it is, my opponents have made numerous false statements of fact about me and my work in the mass media, in pamphlets that circulated behind closed doors, and in confidential peer-review reports that served as a proof of the scientific quality of my work. And these false statements cannot be downplayed as 'honest mistakes', since my opponents have not even made an attempt to apply basic principles of good scientific practice: in their responses to my work, my opponents have merely blurted out whatever came first to mind in an emotional outburst without checking the truthfulness of their statements and without carefully reading my work—in some cases even without reading my work at all. To their defense, upon a superficial reading or learning about my work from hearsay, my opponents despised both me and my work. But for a professional scientist—who, in distinction to a layman, should be able to look beyond a first emotional reaction—that is no excuse for violating the commandment "*thou shalt not bear false witness against thy neighbor*" (Exod. 20:16). Yet that is what they did. I have let it known publicly that I do not condone such behavior, e.g. in (Cabbolet, 2008a, 2011c; Cabbolet and De Swart, 2013; Cabbolet, 2014d), but to no avail: in reply I have only been accused of accusing my opponents of 'unethical practices' because I cannot stand criticism. But false statements of fact have nothing to do with criticism. Moreover, I know how I got the idea for my theory, I know the methods of theory development I've used, I know my theory, and I know how to solve its open issues: that means that I *know* when someone has fabricated "facts" about my work. My opponents, on the other hand, do not know how I got the idea for my theory, they never looked at how I developed it, they don't know what it is, and they don't know what the open issues are or how to solve them. Nevertheless, in the grand scheme of things their wrongdoings may still serve a benign purpose: namely, as paradigmatic examples of dystopian behavior in academia they can teach future generations what to avoid.

Now according to the Scripture, Jesus forgave his opponents when he spoke the words "*Father, forgive them, for they do not know what they are doing*" (Luke 23:24). But given the widespread acceptance of principles of good scientific practice in recent decades, professional scientists can be expected to be familiar with the principle of carefulness: with regards to commenting on someone else's work, professional scientists *know* that they should first carefully study the work and that there is no 'anything goes' when commenting on it. Therefore I did—and I still do—expect my opponents to remain within the borders of a scientific discussion. And although I do not consider that an expectation that no one *can* fulfill, it turned out to be an expectation that virtually no one *did* fulfill. I have therefore filed four complaints about the behavior of my opponents at a scientific integrity committee (SIC)—nearly every university in the West has such a SIC to deal with complaints about violations of scientific integrity. But my experiences are incredibly negative: none of them—with the notable exception of the SIC of Eindhoven University of Technology—had any intention to actually investigate the violations of scientific integrity that I reported. In particular the LOWI headed by Kees Schuyt (the LOWI is the national SIC of the Netherlands co-founded by the Royal Dutch Academy of Sciences) didn't do what it should have done, to wit: investigating my complaint about scientific misconduct in the cancelation of my PhD defense in 2008 from the perspective of the principles of good scientific practice, and will deny *ad infinitum* what it actually has done, to wit: dismissing my complaint to protect the reputation of elite scientists. And this is not about subtle nuances as the following typical example demonstrates:

> "*I immediately had the impression that this is the work of a charlatan*"—Andries Brouwer, eminent mathematician, on the 2007 concept-dissertation (2008a).
>
> "*The judgement emailed by Brouwer ... and the choice of words therein do not provide any ground for the conclusion that this constitutes a violation of scientific integrity.*"—the LOWI dismissing my complaint about Brouwer (Schuyt et al., 2009).

Of course, an explanation of this decision by the LOWI might be that its members are of the opinion that the use of the word 'charlatan' is completely acceptable in a scientific discussion. To test that, I wrote everyone involved a letter in which I called *him* a "charlatan": it will probably come as no surprise to you that their reactions made clear that this is *not at all* their opinion. But to the defense of Schuyt c.s., I can tell you how they have come to their decision: instead of judging *my complaint*, they asked external referees to judge *my concept-dissertation*; and having learned that they also had objections, Schuyt c.s. held me in low esteem too and they simply dismissed my complaint to prevent that the reputation of Brouwer got tainted by a complaint about a reevaluation procedure by a crackpot whose PhD graduation was rightfully canceled *even though* the procedure by which the cancelation took place might not have been optimal. This is just one example, but what I have against all these SICs who dismissed my complaints is that their decisions create a *Sadean libertinism* in academia, in which principles of good scientific practice are to be obeyed in original research that is to be made public, but can be disregarded with impunity in the back rooms of academic institutions where research on research—such as peer review—takes place that is to remain confidential. (In his novels, the philosopher and writer Marquis de Sade described a libertinism: laws are to be obeyed in the public domain, but what is allowed on private property is *entirely* to the discretion of the libertines, i.e. the property owners. I assume the metaphor is clear.)

All that being said, one might be complacent with the situation that academia finds itself in—worldwide, more PhDs are produced than ever before (Cyranoski et al., 2011), more postdocs are employed at universities and research institutes than ever before (Powell, 2015), and the annual output of research, as measured by the number of publications, is higher than ever before and continues to grow (Sarewitz, 2016)—but I am not. It is my sincere opinion that the enormous ease with which my opponents time and time again flouted the basic principles of good scientific practice in their reactions to my work is symptomatic of an academic community that has gone astray, with virtually everyone on his or her own path in a completely compartmentalized landscape of research programs guided by the desire to pursue a career. With that in mind I've added an appendix on the controversy about my work in the Netherlands to the front matter of this monograph, and I've added a section 'Objections and Replies' to every chapter of its main part: therein the wrongdoings I've encountered are made explicit, in the hope that it leads to changes for the better—these sections contain referenced quotes from published sources and from unpublished pamphlets for which I never signed a confidentiality agreement, and anonymized quotes from confidential files such as peer-review reports. Now my opponents may cry out that these parts of my work are invalid, because I bear witness of myself. But these parts are about *my work*, not about *myself*. And I can *truthfully* discuss my work because I know my work: without passing judgment on my opponents I can demonstrate *in objective language* that their statements about my work are false, just like any professional physicist who knows Einstein's work can demonstrate in objective language that the claims by laymen about inconsistencies in relativity are false—even if you don't believe in my theory, you can still see that it is true that my opponents made false statements of fact about my work.

Of course, if one of the experimental projects at CERN would establish that gravity is attraction only, none of my work is of any value for physics. There is not a shadow of doubt in my mind that if CERN would put out a press release to that extent, then *even before the ink has dried up* my opponents will shout in national newspapers that my work has been rightfully opposed, rejected and ignored by the community. And indeed, it should then be rejected as a purely hypothetical construction with no relation to reality whatsoever—the question whether or not my opponents have fabricated "facts" when they rejected my work is then entirely moot.

However, should a repulsive gravitational force between matter and antimatter be detected, a completely different scenario unfolds. Just think about these cases that you read about in the news every once in a while, when a tribe, which for centuries has lived completely isolated from the rest of the world, comes in contact with what we call 'western civilization': then they find out that eagles are not gods, that rabbits are not creatures that can turn into stones, etc. And when they realize that, their world view collapses: everything they ever believed in turns out to be not true. That is one of the most serious things, if not *the* most serious, that can happen to a group of people. Interestingly, if repulsive gravity were to be detected experimentally at CERN, then this would happen again: not in some remote area of the Third World, but right here in the modern West. Then the world view of modern physics collapses: then all of a sudden general relativity and modern quantum physics are not true, and then there are no

Higgs bosons, no virtual particles, etc. Then it will be clear for all to see that modern society, not unlike the prediction in 2 Tim 4:3–4, has on the whole gathered itself around teachers, who are completely alienated from truth finding, and who out of self-interest have indoctrinated their students with the fables of a false religion—I'm referring here to these constantly reiterated overstatements in physics, the epitome of which is the downright hubristic claim that the 'God particle' has been observed, which I consider to be a category mistake (Cabbolet, 2018a). And make no mistake, the shock will then be just as big for modern society as it has been for those isolated tribes. In that case, and *only* in that case, my work *might* yield an advancement in our knowledge of the fundamental workings of the universe: then apart from some individual exceptions, the academic community has been *collectively mistaken* in its reaction to my work—even stronger, then the academic community has fulfilled the prediction in Matt 24:24 that false prophets will arise who will mislead the people on earth by showing great signs (such as the "image of a black hole" in 2019, which I consider to be the same category mistake as the Higgs claim). If I live to see it, then I would be happy to discuss which reforms have to be carried out in academia to restore truth finding as the highest value with those who agree with me that one chooses academia to dedicate one's life to truth finding—not to make a career that yields a high social status, not to be able to go to luxury conference resorts on tax-payers' money twice per year, and not to merely earn a living. These reforms will then have to be pushed through by external 'power elites'—be it kings, presidents, or ministers, but somewhere at that level—but that's another story.

As a final word, it is written that no one lights a lamp and puts it under a basket, but rather on a lampstand (Matt. 5:15). By publishing this non-peer-reviewed treatise as an open access monograph, I am putting my lamp on a lampstand: in God I trust that others will see my work.

Marcoen J.T.F. Cabbolet, PhD

Outline

> “*[A]nother person who went off the rails whilst pursuing a PhD ... was Marcoen Cabbolet and his ‘Elementary Process Theory’ claiming that linguistic axiomatic logic is a gateway to new insights in physics. ... The quality of contemporary academic analytical philosophy is apparent from the fact that this rubbish got published.*”—Harry Hab on crackpotwatch.wordpress.com (2018)

Although there is currently no indication that this monograph will be widely read—if it will be read at all—I have made an effort to make it the most accessible exposition of my work so far for those interested in the fundamental workings of a universe with repulsive gravity. However, a certain background in physics, philosophy, and mathematics is prerequisite:

(i) in philosophy: historical mainstream ideas, in particular Kantian philosophy; formal logic and axiomatic set theory; general philosophy of science (Popper, Kuhn, Lakatos);

(ii) in physics: thermodynamics; classical mechanics; axioms of special and general relativity; postulates of quantum mechanics;

(iii) in mathematics, besides the prerequisites for (ii): category theory; abstract algebra (groups, rings, fields); differential geometry.

As to the level, although I have, unfortunately, seen several undergraduate and graduate students commenting negatively on my work, I have never seen any (under)graduate who actually understood it—so, this work is best placed at postgraduate level. That being said, the main body of this monograph is divided into four parts. The remainder of this outline is to briefly discuss the contents of these parts.

Part I covers the introduction and the method by which the Elementary Process Theory (EPT) has been developed from the perspective of physics. The titles of the three chapters in this part refer to the phases in which René Descartes developed new knowledge in his *Meditations*.

Chapter 1 is the foundational phase: while Descartes developed an undoubtable truth—his *cogito ergo sum*—in this phase, here it will be shown that (massive) antiparticles must have positive inertial mass and negative gravitational mass under the condition that a matter-antimatter repulsive gravity is a fact of nature. This proof has already been given in the 1950s, but the controversy surrounding my work has made abundantly clear that physicists, as a rule, are not familiar with the material. In addition, the currently ongoing experimental projects, aimed at verifying whether or not massive antiparticles have the said properties, are briefly discussed.

Chapter 2 is the destructive phase: while Descartes rejected then existing knowledge in this phase—which in his work *preceded* the foundational phase—by applying radical doubt, here it is shown that modern interaction theories have to be rejected if repulsive gravity exist, because antiparticles cannot have the aforementioned combination of properties in the frameworks of these theories. In addition, this chapter engages in the destruction of pseudoknowledge by proving that it is simply not true that ultrashort-lived unstable particles postulated by the Standard Model (such as a Higgs boson) have been "observed". A short version of the argument has eventually been published in *Mod. Phys. Lett. A*, see (Cabbolet, 2018a), but the section Objection and Replies extensively treats the toe-curling arguments with which the publication has been held up for years.

Chapter 3 is the constructive phase: while Descartes extended his system in this phase, here the crucial steps are highlighted that were taken on the path from a clear and distinct idea about the fundamental workings of the universe towards an axiomatic theory about elementary processes. New physical concepts are introduced with the help of the more common terminology of *four-dimensionalism*—to keep the text self-contained, its basic notions like continuants, occurrents, and temporal parts are defined in Sect. 3.2—and the terms and predicates of the new formal language for physics, in which the EPT is expressed mathematically, are extensively discussed. This material is largely absent in the first edition and in the papers in *Ann. Phys.*

Part II axiomatically introduces the EPT as a collection of generalized process-physical principles that give an abstract yet exact description of what has to happen at supersmall scale in the individual processes by which interactions take place for matter-antimatter repulsive gravity to exist.

Chapter 4 introduces a finitely axiomatized nonstandard theory $\mathfrak{T}$—a postdoctoral research result published in (Cabbolet, 2021a)—that provides the mathematical foundation for the use of abstract constants as terms of the formal language in which the EPT is expressed. Therewith this 2$^{\text{nd}}$ edition differs from the 1$^{\text{st}}$ edition, in which this role was fulfilled by a generalization of ZF called 'set matrix theory'. The thing is that we have to learn from the controversy on my work: we will have to accept that set matrix theory, as published in (Cabbolet and De Swart, 2014), is *correct* but mathematically *not interesting*—after all, it is not stronger than ZF. The nonstandard theory $\mathfrak{T}$, on the other hand, is *stronger than* ZF—it will be precisely defined what that means. Readers who are mainly interested in the EPT and its applications can, in principle, skip this chapter largely: the EPT should be understandable after reading the informal introduction to $\mathfrak{T}$ in Sect. 4.1—the takeaway point is that in the framework of $\mathfrak{T}$, *sets* and *functions* are ultimately different things.

Chapter 5 introduces the EPT. The exposition integrates my three Annalen papers, to wit: *Ann. Phys.* **522**, 699-738 (2010); **523**, 990-994 (2011); **528**, 626-627 (2016), into a coherent whole, but with some minor revisions. First of all, to shorten the mathematical formulation of the EPT, its axioms are now expressed as *open formulas* instead of *closed formulas*. Secondly, minor changes have been made to the formalism: constants have been added that refer to monads, a unary existence predicate $\mathbb{E}$ has been added so that formulas of the type $\mathbb{E}\begin{bmatrix} t \\ \bar{t} \end{bmatrix}$ replace formulas of the type $\begin{bmatrix} t \\ \bar{t} \end{bmatrix} \in M_E$, and formulas of the type $\begin{bmatrix} t_1 \\ \bar{t}_1 \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} t_2 \\ \bar{t}_2 \end{bmatrix}$ replace formulas of the type $\begin{bmatrix} 0 \\ 0 \end{bmatrix} : \begin{bmatrix} t_1 \\ \bar{t}_1 \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} t_2 \\ \bar{t}_2 \end{bmatrix}$. Thirdly, the axiomatization of the EPT has been modified: an existential axiom has been added, and two former axioms have been merged into one new axiom. And last but not least, the term 'monad' has finally been given a satisfactory definition. This finalizes the EPT: nothing should be added to it or taken away from it.

Part III shows how the generalized process-physical principles of the EPT apply to non-relativistic physics and to the mind-body problem in philosophy. Language from systems theory is used to make the connection between the language of the EPT and the languages of existing paradigms: on the one hand, every physicist knows what is meant by a 'system made up of one electron'; on the other hand, we can describe a one-component system with the ontology and principles of the EPT.

Chapter 6 "does" non-relativistic physics in the framework of the EPT. To start with, Sect. 6.1 introduces the notion of a 'monadic system' in the formal language of the EPT, and interprets it in the language of systems theory as a one-component system. Sect. 6.2 models non-relativistic monadic systems: this gives a concrete view on what building blocks of the outside world generally referred to as "elementary particles" (e.g. electrons) are in the framework of the EPT. Next, Sect. 6.3 develops a semi-classical model of interactions by letting a monadic system evolve in an environment that can be described by classical mechanics: by quantitatively modeling the interaction between the system and the surrounding fields, this provides a concrete and quantitative answer to the question how the processes described by the EPT can be viewed as processes of interaction. Sect. 6.4 shows that the EPT, which in Ch. 5 has been proven to be *inconsistent* with orthodox quantum mechanics, is *consistent* with ψ-epistemic quantum mechanics: in the framework of the EPT, a 'quantum system' is deterministic under the surface. The final part develops principles of a quantum field theory for a free particle in the framework of the EPT. This chapter presents results of post-doctoral research that are absent in the first edition: less abstract than Ch. 5, this makes it easier to understand the EPT.

Chapter 7, on the other hand, applies the ontology and principles of the EPT to a physicalist approach to the mind-body problem. In the present-day compartmentalized scientific landscape this topic is seemingly disconnected from physics, but it is not: if an intentional thought can cause a bodily action, which is a physical action, then of course this must happen according to some physical mechanism. The present exposition differs mainly from the first edition by the inclusion of a preliminary discussion of the intelligent neutron: this oversimplified example of a system with free will is to quantitatively illustrate the rather abstract main idea. A second difference is that the work of Benjamin Libet is (briefly) discussed.

Part IV addresses the correspondence relation between the EPT and the body of existing knowledge of the physical world that derives from the successful predictions of theories of modern physics. All material in this part results from post-doctoral research, and is therefore absent in the first edition and in the papers in *Ann. Phys.*

Chapter 8 outlines the general research program aimed at demonstrating correspondence between the EPT and existing knowledge. Sect. 8.1 first precisely defines the nature of the correspondence relation that is to be proven: here the *weak correspondence principle* is introduced, which determines a new intertheory relation in physics. Next, the method is described by which the new correspondence relation is to be proved: in a nutshell, one proves that the EPT corresponds weakly to an existing physical theory T by specifying a categorical model $\mathscr{C}$ of the EPT—this notion will be precisely defined—and proving that $\mathscr{C}$ reduces empirically to T, that is, that $\mathscr{C}$ reproduces the empirically successful predictions of T. From there it is explained what the proposition 'the EPT is a Grand Unifying Scheme' means: to (dis)prove that proposition is the ultimate aim of the research program. Finally, Sect. 8.2 is devoted to the philosophy of the noumenal and the phenomenal in the framework of the EPT, which is related to the theory/model distinction: these are notions that also have a meaning in Kantian philosophy, and the difference in meaning calls for a discussion.

Chapter 9 applies the method set forth in Ch. 8 by completely specifying a categorical model of the EPT incorporating Special Relativity (SR), which rigorously proves that the EPT corresponds weakly to SR, that is, that the EPT agrees with the knowledge of the physical world obtained from the successful predictions of SR. Sect. 9.1 introduces new nonstandard mathematics: Dirac delta functions are defined as ordinary hyperreal functions of real variables. This is a result of postdoctoral research, which has been published in (Cabbolet, 2021b), and which may have applications beyond the research program on the EPT. The remainder of Ch. 9 is admittedly a tedious exercise, but it nevertheless provides a worked-out example of how to apply the proof method developed in Ch. 8.

Chapter 10 introduces a fundamentally new relativistic model of a process by which a gravitational interaction takes place between a massive system and its environment: this model predicts a matter-antimatter repulsive gravity. The exposition is self-contained, and offers an introduction to the EPT (Sect. 10.2) that is accessible without having read the preceding chapters. This version of the EPT is admittedly weaker than the full version of EPT introduced in Ch. 5 since it doesn't cover processes in which nuclear reactions (fusion, fission, decay, etc.) take place, but it has the distinct advantage that the physical interpretation of the formalism is expressed in the more accessible language of systems theory. The model of a gravitational interaction process presented in this chapter (Sect. 10.3) is a straightforward model of the EPT: as such it's devoid of mathematical elegance, but it does the trick in that it expresses principles of Planck-scale gravitational physics in a generally covariant fashion. The discussion (Sect. 10.4) has been kept to a bare minimum: let's talk further if and when repulsive gravity has been detected.

Physicists primarily interested in a quantitative model of repulsive gravity may read Ch. 10 as a stand-alone essay. Those who want to get acquainted with the research program on the EPT are recommended to read at least Ch. 1-3, Sect. 4.1, Ch. 5-6, Sect. 8.1, and Ch. 10.

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Appendix: on the controversy about my work

> "*Marcoen Cabbolet mentions Brian Martin's work on dissenting views. Me: One person's dissident is another person's crank*"— Matt Hodgkinson, head of research integrity at Hindawi (2017)

In 2011 I defended my dissertation *Elementary Process Theory: axiomatic introduction and applications* at the Free University of Brussels (VUB). The theory to which the title refers finds itself opposed by the prevailing ideas about the outside world that are usually referred to by the term 'modern physics': consequently, this theory should not be seen as a contribution to modern physics, but rather as the hard core of a fundamentally new, potentially progressive research program in physics—here the terms 'hard core', 'progressive', and 'research program' are used in the sense meant by Lakatos (1970). And because traditional criteria of quality (mathematical rigor, logical consistency, conceptual coherency, experimental testability) were satisfied, all conditions for a PhD graduation were satisfied in the eyes of the PhD committee.

Viewed in itself this is just another PhD graduation, but it happened to be the case that in January 2008 already a PhD graduation had been planned at Eindhoven University of Technology (TU/e) on the basis of virtually the same dissertation: since then the presentation has been changed a little, but not so the research result.[1] This earlier PhD graduation, however, got canceled one week before the planned date after an unusual *reevaluation* of the already approved concept-dissertation. The outcome of this reevaluation was that "the scientific quality of the research results did not justify a PhD graduation at the TU/e": those who were involved in that reevaluation concluded that pejoratives like "all nonsense", "devoid of content and devoid of meaning", "utterly unacceptable" and "a disgrace" were applicable to my work. The reevaluation of my 2007 concept-dissertation played a pivotal role in the controversy on my work, which erupted in 2008 and quickly turned into a public display of the worst impudences in science.

That said, of course there are differences between universities and faculties concerning the conditions that must have been met in order to obtain a PhD degree, but these differences are minor: there is no university where one can obtain a PhD degree on the basis of research results of bad scientific quality. This is also true for the VUB: it is not the case that I obtained a PhD degree there *despite of the fact that* my research results were of bad scientific quality. What *is* the case, however, is that the conclusions of the reevaluation of my concept-dissertation at the TU/e are completely false, yet in the decision-making process leading to the cancelation of my PhD graduation these have been uncritically treated as "*statements of fact*" that compromised the quality of my work.

The *why* of this affair is easy to see. To put it mildly, those who were involved in the reevaluation of my 2007 concept-dissertation saw nothing that they valued at first glance: I hadn't followed a PhD program in physics at any university they thought highly of, and my work hadn't yielded an advancement in pure mathematics, nor in modern physics—the EPT even *contradicted* general relativity and the standard model. So to their defense, they have concluded *from there* that my work did not even remotely qualify as a scholarly work, and they have acted accordingly to prevent that it would be officially published as a dissertation.

I have nothing against safeguarding the quality of publications—I even find that a laudable aim—but what I hold against my opponents is that they have *jumped to conclusions*: this is a *malpractice* that goes squarely against all principles of good scientific practice. So it is true that the controversy on my work fits in the tradition in the historical development of physics that new ideas first encounter fierce resistance, but neither the reevaluation of my 2007 concept-dissertation nor the public outcry that followed had anything to do with a scientific discourse—and in this case the truth does not lie in the middle. So, the purpose of this appendix is to expose the wrongdoings in the back rooms of academic institutions by giving an account of the events that led to the controversy about my work.

Prehistory

Originally educated as a physical chemist, at the end of 1996 I was drawn to physics, more specifically: to the foundations of physics, by a clear and distinct idea about the fundamental workings of the physical universe. Through a badly written letter and with some fortune I came in contact with Sergey Sannikov, a Ukrainian physicist who worked at the Institute of Theoretical Physics (ITP) of the Kharkov Institute for Physics and Technology (KIPT). He, Sannikov, was willing to supervise the further development of that idea and he set forth a tailor made study program in physics, mathematics, and philosophy to prepare me, a physical chemist, for research in the foundations of physics. I became a PhD student at the KIPT, and I did succeed in *exactly* identifying a physically complete set of generalized principles that would be universally valid if the aforementioned clear and distinct idea were to be correct. I also succeeded in formalizing these principles in the form of a first-order theory, which I called 'Elementary Process Theory' (EPT) since the generalized principles were process-physical. The plan was to publish this all as a PhD thesis at the ITP KIPT, but Sannikov got severely ill. He eventually died on March 25, 2007—see the obituary in the first edition of this book.

Since I already had the results, I wrote to some universities in the Netherlands (where I lived) asking if there were any perspectives. That way I came in 2005 in contact with the mathematical logician Harrie de Swart of the Center of Logic, Ethics, and Philosophy of Science of Tilburg University, who advised me to reformulate the EPT—which up till then was formulated as 'just' a first-order theory—in mathematical language. De Swart supervised this reformalization of the generalized process-physical principles in a very, very meticulous way: in its final version, the newly developed formalism was free of errors. I was then offered the possibility to defend the end result as a PhD thesis at Tilburg University, and so I became an *external PhD candidate* at the Philosophy Department of Tilburg University in 2006.[2] A PhD committee was established, and all but one of its members approved the dissertation: a Hungarian member abstained from voting because he thought a dissertation should be based on three published papers—which is required in Hungary but not in the Netherlands. However, one of the committee members who approved the dissertation, the physicist-turned-philosopher Stephan Hartmann, demanded some changes to the text. Truth be said: most of his comments were very good, and have been incorporated in the dissertation that was finally to be defended in 2011. But he also demanded that I dealt with his following comment:

> *Why this assumption of repulsive gravity? Why not developing a theory from the assumption that a distant planet is made of green cheese?—Cabbolet (2008b)*

Rightly or wrongly, that came across to me as *academic bullying.* I let him know that there was no way that I was going to answer that question in my dissertation, but he insisted. I then thought to myself: "I rather have no PhD degree than having to crawl on my knees for that bully." And so, I withdrew the dissertation at Tilburg University with the clearly stated reason that I felt that the behavior of Hartmann was inappropriate (although it had nothing to do with 'scientific misconduct').

Events leading to the cancelation of my PhD graduation

Without further delay I then turned to the TU/e, where I became an external PhD candidate at the faculty of Mathematics and Computer Science in 2007. At the end of that year the submitted thesis was approved unanimously by the PhD committee and a date (January 16, 2008) was set for its public defense as a dissertation in applied mathematics. Upon approval of the dissertation I received, still in 2007, the standard request by the university weekly *Cursor* to do an interview. I agreed, and a one-page article about my work appeared in the last issue of 2007 of Cursor. I was asked by the journalist, Enith Vlooswijk, if I thought my theory was going to be immediately accepted, and so in the article I was quoted to have said

> "*It is absolutely excluded that my theory will be accepted immediately. It necessitates, namely, the rejection of quantum mechanics. But the research programs based on quantum mechanics will not be terminated just like that. That requires convincing experimental evidence supporting my theory.*"—(Vlooswijk, 2007)

With the sentence "It necessitates, namely, the rejection of quantum mechanics" I meant to say that *if you would accept my theory, you'll have to reject quantum mechanics*—these two theories are, namely, incompatible. I believe that this is clear from the context. But get this: there were those at the TU/e and beyond who took this one sentence out of its context and interpreted it as if I was claiming that my theory renders quantum mechanics obsolete so that it has to be rejected. To their defense I admit that the sentence, when viewed apart from its context, can be read that way. But the point is that not a single one of them has ever asked me if he interpreted things correctly: it was not at all what I meant, but they had already judged me—for them I was a crackpot who lacked all sense of proportion and sought publicity to claim that modern physics had to be replaced by his own theory. Even eight years later, in 2016, I was still confronted with this delusion: at a conference in Varna, Dennis Dieks (Utrecht University) started to accuse me that I "had given an insane interview"—he too had jumped to conclusions on the basis of the above misinterpretation of that one sentence. Anyway, in December 2007 one of those who misinterpreted this one sentence that way was Kees van Hee, the then Dean of the faculty of Mathematics and Computer Science: he summoned me for a private meeting on January 4, 2008. During our conversation it became clear to me that Van Hee would do everything in his power to have the PhD graduation canceled: a religious person would say that Van Hee behaved as if the devil had entered into him. And indeed, later that day Van Hee distributed a circular at the faculty in which he explicitly indicated that he didn't want this PhD graduation to take place:

> "*In my opinion, this dissertation does not belong at our faculty ...* ***[Marcoen] has never had a PhD position ... and will use this dissertation as evidence of his skills. He already did that in his interview with Cursor. But it is highly likely that he will seek more publicity with his PhD graduation****. And because the physical consequences of his theory are far-reaching, there will probably be attention by the media. By granting Marcoen a PhD degree for this work, we as university in fact indicate that we believe in his theory, and that may lead to considerable damage for our reputation ...*" (emphasis added)[3]—(Van Hee, 2008b)

Within days thereafter, Van Hee had organized—entirely outside the university's PhD regulations—a *reevaluation* of the concept-dissertation as a dissertation in pure mathematics by his close colleagues Jos Baeten and

Andries Brouwer.[4] The comments by Brouwer amounted to nothing but a psychotic rant: it cannot be excluded that Van Hee *arranged* with Brouwer that he would write a scathing review. The following comment, as well as the opening quote of the Preface, stands model both for the language used by Brouwer and for the depth of his comments:

> "*He doesn't know mathematics and doesn't understand it. His style is not the mathematical style. That means that the book improves substantially if [the mathematical chapter] is thrown out. (I think that further improvement can be accomplished by deleting the rest too.)*"—(Brouwer, 2008b)

Remark I It would be a mistake to treat someone who uses this kind of language with respect. Also, the first two sentences are false statements of fact as *objectively proven* by the later publication of the subject matter in a recognized peer-reviewed journal, cf. (Cabbolet and De Swart, 2014). ■

Baeten, on the other hand, made the following comments on the mathematics in the concept-dissertation:

> "*He presents an alternative to ZF based on matrices. It seems to me that one can get this consistent, so it is probable that this can be done. But I see no reason why this is necessary. Matrices can be simply defined in ZF, and I see no reason why this wouldn't be sufficient for the author. Viewed in itself this is a mathematical exercise that has no scientific value.*"—(Baeten, 2008)

Remark II Reading "has no scientific value" as "does not constitute an advancement in pure mathematics", the first, second and last sentence of the above excerpt of Baeten's comments are more or less correct: the alternative to Zermelo-Fraenkel set theory (ZF) was correctly introduced but it does not advance *pure mathematics*. But I cannot agree with the third and fourth sentence: there was, nevertheless, a clearly stated motivation for the introduction of these mathematics—namely, to solve a *philosophical* problem with the formalization of the process-physical principles. If that wasn't clear from the text it would have been easy to explain that, but I have never been asked to: Baeten too had already judged me.[5] ■

Van Hee, having obtained the two pamphlets—I refuse to call these "peer-review reports"—written by Brouwer en Baeten, immediately used his administrative power as a Dean to officially declare the PhD committee that had approved the concept-dissertation "not authorized", and then lobbied the university administration with these two pamphlets claiming that they proved that the concept-dissertation was of insufficient mathematical quality.[6] The administration went along with Van Hee, and took the ad hoc decision to postpone the PhD graduation indefinitely.

Remark III Note that Van Hee was lying through his teeth when he lobbied the university administration: the psychotic rant by Brouwer proved nothing, and Baeten's comments at best proved that the fact that the concept-dissertation did not constitute enough of an advancement in pure mathematics to grant a PhD degree on that basis. But that does not imply that the concept-dissertation was of insufficient mathematical quality: that's a false statement of fact by Van Hee. For comparison, Einstein has applied differential geometry in his theory of general relativity, without advancing the field of differential geometry in pure mathematics. But that does not imply that Einstein's GR is of insufficient mathematical quality.[7]■

Van Hee then summoned me for a second private meeting on January 8, 2008—one week before the planned PhD defense. I was informed that the PhD graduation was postponed indefinitely because my work was of insufficient mathematical quality. The two pamphlets were kept secret—I didn't know about their existence until later—and I was also informed that there was no formal possibility to object to the decision. Furthermore, Van Hee told me that his next step was to have the concept-dissertation reevaluated as a dissertation in modern physics by the Nobel laureate Gerard 't Hooft (a former classroom mate of Van Hee) and by his acquaintance Boudewijn Verhaar. He first contacted 't Hooft, who would later declare the following:

> "*When I heard the description [of the dissertation] by phone I already got a very bad feeling. I have been asked specifically by the Dean [i.e. Van Hee]: how are the physics? It had already been looked at by mathematicians and their finding was that the mathematics in the dissertation were below par.*"—('t Hooft, 2008b)

This clearly indicates manipulation by Van Hee: when contacting 't Hooft, Van Hee didn't ask him for an impartial review, but rather instigated him to give a negative review.[8] The thus unsurprising comments by 't Hooft on the physics in the concept-dissertation came in two days later:[9]

> "*As expected, the 'theoretical physics' of this work are of the same standard as the mathematical part in the beginning, if not worse. ... A lot of 'formulas' are put forward, but I fail to see what the physical relevance thereof is. Here and there the author tries to say something about quantum mechanics and general relativity, but the few concrete statements are blatantly false. He is, for example, of the opinion that antimatter will be repulsed by the earth's gravitational field. That would completely contradict everything General Relativity stands for, and for me that can only indicate that the author has not the slightest clue of what antimatter is. Also, he talks about a 'phase quantum' for quantum mechanics, but it remains unclear how that notion has been derived and what it means physically. Summarizing, the actually existing problems concerning the unification of quantum mechanics and general relativity remain untouched, and the few concrete statements about physical phenomena do not demonstrate much understanding of these topics. Of course you can throw both QM and GR overboard, as the author seems to be doing further on, but then you are left with nothing and the author does absolutely not indicate how concrete questions about nature should then be answered by 'EPT'.*"—'t Hooft (2008c)

Remark IV 't Hooft passed off three false statements of fact about the physics part as genuine findings of an evaluation of my work.

Falsehood #1 is the claim by 't Hooft in lines 10-11 that I do not have the slightest clue about what antimatter is: this is passed off as a "fact", but it is false. The two preceding premises are correct: it is more or less correct that I, as stated in lines 7-8, am of the opinion that antimatter will be repulsed by the earth's gravitational field—it would have been better to state that I *hypothesized* it, but alas—and it is correct that this goes against General Relativity as stated in lines 8-9. But that doesn't make it a fact that I do not have the slightest clue of what antimatter is: right there, that's where 't Hooft is making stuff up. The truth is that I'm well aware of the arguments against repulsive gravity, but it just happened to be the case that I found it more interesting to consider the case that repulsive gravity *nevertheless* exists and to think through the consequences thereof.

Falsehood #2 is the claim by ‘t Hooft in lines 11-12 that I'm talking about a ‘phase quantum’ *for quantum mechanics*: this too is passed off as a “fact”, but it is indicative of a gross misinterpretation. The truth is that the EPT is **not** a quantum theory, and that the notion of a ‘phase quantum’ is a primitive notion in terms of which the physical interpretation of the formalism of the EPT is expressed. And that means that the next comment in lines 12-13, that it is unclear how it has been derived, misses the mark completely: being a *primitive notion*, the notion of a ‘phase quantum’ is not a *derived notion* that stems from something else.

Falsehood #3 is the claim by ‘t Hooft in lines 19-21 that I didn't indicate how the EPT applies to real world problems: again this is passed off as a “fact”, but it is false. The truth is that it has clearly been indicated how the EPT can be tested by the scientific method (refined falsificationism): this involves standard techniques such as developing a model of a first-order theory and then deriving testable predictions from the model.

Last but not least, ‘t Hooft's comments “Summarizing ... these topics” in lines 13-17 clearly indicate that he misinterpreted this work as an attempt to unify QM and GR—a topic where he himself is working on. Summarizing, the actual research question for this work has remained untouched by ‘t Hooft's comments, and the few concrete statements about my work do not demonstrate much understanding of it. ■

Remark V Fact of the matter is also that ‘t Hooft emailed his comments at 12:15 pm to Van Hee. His opening sentence was: “The booklet came by mail today. I've had a look at it”. Assuming that he arrived at his office at around 09:00 am (which would be normal), the conclusions are thus (i) that he came with his judgment within three hours after having begun to read the work, and (ii) that he ignored Thomas More's advice from his 1516 book *Utopia* that it should be forbidden that a man reacts to a piece on the same day that it is submitted to him, to prevent that he blurts out what first comes to mind and then spends all his energy in defending his own initial reaction under disregard of the common interest. ■

Remark VI On November 5, 2008, 't Hooft gave a lecture at the TU/e, after which he was asked about his role in the cancelation of my PhD graduation; his answer was that this cancellation was "justice" for someone who had "desecrated" the existing laws of physics (Konings, 2008b). This clearly indicates that he has reacted in an emotional outburst. When I started to investigate the assumption of repulsive gravity, I have never intended to desecrate anyone's belief system, nor have I ever had or shown any disrespect for any of those physicists who believe that gravity is attraction only. I did, however, develop a disrespect for the physics community, but only after years and years and years of being confronted with abusive peer-review reports, in which false statements of fact were passed off as genuine conclusions of a serious assessment of the quality of my work. ■

Van Hee wanted to keep the pamphlets written by Baeten, Brouwer, and 't Hooft secret, but he failed: all of a sudden I had all three pamphlets in my possession—I appeal to the *quantum tunneling effect*. Having read them, I felt that my PhD graduation—and therewith my career perspectives in science—had been canceled by an unfair judgment. And so I published an open letter to the Rector Magnificus of the TU/e, Hans van Duijn, in the university weekly Cursor. I clearly stated that my opponents were offering great cry but little wool, and I urged Van Duijn to invoke *audi alteram partem* (2008a)—I deliberately chose the format of an open letter to make sure it didn't "disappear" in a drawer in some back room of the TU/e.

In the meantime also the comments by Verhaar had come in.[10] He had the following to say about the physics part of the concept-dissertation:[11]

> "*After reading the physics part of the dissertation of Cabbolet I have arrived at the conclusion that I cannot make much sense of it. What he calls the Elementary Process Theory is extremely vague. There are no clearly defined theoretical axioms and the relation with experimental data is as good as absent. The reasoning doesn't lead to any new qualitative insight or to quantitative, experimentally verifiable predictions.*"

Remark VII From the opening sentence by Verhaar, as well as from the comments by 't Hooft, it is clear that a superficial c.q. one-time reading is not enough to get a grasp of the EPT—but of course I already knew that from the members of the PhD committee. This is also true for other physics theories: try to find someone who immediately understood quantum mechanics the first time he read it. That said, the last two sentences are false statements of fact that Verhaar has passed off as genuine findings.

First of all, the axioms of the EPT are precisely formulated in mathematical language: that was also the case in the concept-dissertation and even a monkey could have seen that. Second, the relation with experimental data is there: some observed particles and processes have been formalized in the framework of the EPT. The aim of the PhD project, however, was to identify principles that underlie repulsive gravity: its aim was thus <u>not</u> to prove that these principles agree with experimental data in every aspect. So, similar to what is the case with 't Hooft's comments, the actual research question for this work has remained untouched by Verhaar's comments. As to Verhaar's last sentence, the material *does* lead to a new qualitative insight: namely, insight in the individual processes by which interactions have to take place for repulsive gravity to exist—note that this insight remains true even if repulsive gravity turns out not to exist. And for the falsehood of Verhaar's claim of non-verifiability, see Rem. IV.■

Having obtained the pamphlets written by 't Hooft and Verhaar, Van Hee immediately lobbied the university administration to get them to cancel my PhD graduation, claiming that these latter two pamphlets proved that the physics in the concept-dissertation were of insufficient quality too. Van Duijn, head of the university administration, ignored my open letter in Cursor in which I urged him to apply *audi alteram partem*: the administration went along with Van Hee, and canceled the PhD graduation without giving me the possibility to react to the objections against my work and without giving me the possibility to appeal to the decision. Thereupon the TU/e published a press release stating that my PhD graduation had been canceled because eminent scientists had concluded unanimously that my work was of insufficient quality.

To the defense of the university administration, it is altogether of course the case that they saw themselves two times in a row confronted with the uncomfortable situation that the Dean Van Hee waved pamphlets written by eminent scientists as evidence that the already approved concept-dissertation contained grave errors and that the PhD graduate was grossly incompetent. So I do understand the panic. But what I hold against them is that they have *uncritically presumed* that the four pamphlets were scientifically accurate and that they have *equally uncritically presumed* that Van Hee was accurate with his explanation on how these comments have to be interpreted: these presumptions rest on an argument from authority, and thus embody a well-known fallacy. They should have applied *audi alteram partem*, a well-established principle in discourse ethics—as Habermas put it: every speaker knows intuitively, that an alleged argumentation is not a serious argumentation, when for example certain participants are not admitted (1991). And make no mistake: the university administration did see my open letter in which I had urged them to apply this principle.

The public controversy: the pack effect

After it became public news that my PhD graduation had been postponed and later canceled because eminent scientists, among whom the Nobel laureate ‘t Hooft, unanimously concluded that the already approved concept-dissertation was of insufficient scientific quality, the biggest public controversy about a PhD in Dutch history erupted, accumulating some 150-200 publications over the years 2008-2020—thereby even surpassing the now historical controversies following the publications of the works of Descartes and Spinoza in the 17th century.

The Nobel laureate ‘t Hooft declared my work *anathema* in a number of public attacks on my work (‘t Hooft, 2008b; Konings, 2008a,b; Scholtens, 2008a; Hover, 2008b; Hardeman, 2008)—note that my work had not even been published at that time. To the defense of ‘t Hooft, I can imagine that the thoughts have come up in his mind that I don’t know the first thing about physics and the scientific method and that my work is *illucid*, that is, so far beyond unintelligible that it defies classification: he has, namely, seen that I consider repulsive gravity in my work—which is strictly forbidden by theories of modern physics—and in addition he has failed to get a grasp of the EPT and the method of testing from a first read.[12] But what I hold against ‘t Hooft is that he has passed off these figments of the mind in the mass media and in the pamphlet that he wrote for Van Hee *as if* these are facts about me or my work: although it isn’t *intensional deceit*, fact of the matter is that his comments are outside the framework of a scientific discourse. For comparison, suppose that archeologist Jones decides to do an excavation on location X, and that archeologist Williams doesn't believe that anything is to be found there. Of course, Williams can then write an opinion piece about *why* he thinks nothing can be found there. But he does not have the right to declare in national newspapers that Jones is a crackpot who knows nothing about archeology and its methods.

Proceeding, others followed the example set by 't Hooft, thereby proving the existence of what Feynman called the 'pack effect': there was no upper limit to the creativity with which "facts" were made up to mock my work, nor to the disrespectfulness that was implied by the language with which this mockery was expressed.[13] For example, within hours after things became publicly known, a Wikipedia page had been created by Fred Lambert, lecturer at the TU/e and self-proclaimed crusader against pseudoscience, where the following was passed off as "encyclopedic knowledge":[14]

> "*Even before his PhD graduation Marcoen sought publicity in the university weekly Cursor of the TU/e. In an interview ... he compared himself with Isaac Newton ... [Gerard 't Hooft] pointed out the vagueness of most parts of the manuscript, and the inconsistency of the verifiable proofs.*"—Lambert (2008)

Remark VIII Note that it is not true that I sought publicity, nor that I compared myself to Newton, nor that 't Hooft has pointed out any inconsistency: Lambert was one of those at the TU/e who misinterpreted my quoted statement in Cursor as discussed on page xxxii and he uncritically accepted the public comments by 't Hooft as "facts". ■

Another example is the following, which was stated by Frank Witte, then lecturer at Utrecht University, under the pseudonym 'Darth Tutor' on the forum of the Dutch national newspaper *De Volkskrant*:

> "*Cabbolet's PhD graduation? The TU/e and Tilburg University should be ashamed of themselves. ... Unbelievable! What a blooper.*"—Witte, 2008

Remark IX Witte never read or even saw the concept-dissertation: like Lambert, he uncritically accepted the public comments by 't Hooft as "facts" about me and my work. ■

These are just two examples, but altogether my opponents know for sure that I am a crank, a crackpot, a charlatan, a pseudoscientist, and a fuck-up, that I know nothing of discrete transitions nor of quantum mechanics, that I had likely bribed the PhD committee, and that I'm out to intentional deceit, that my work is nonsense, based on nonsense, full of mistakes, of sophomore level, below masters level, and so on and so on—all of this was claimed by authors with a university degree (MSc or PhD) in public media or in pamphlets that they had circulated behind closed doors. And those of my opponents who did not publish an attack themselves praised others who did, or praised the administration of the TU/e for their courage to cancel the PhD graduation in such a late stage. Some examples:

> "*Calm but clear, devastating criticism of the fake PhD graduation of Cabbolet*"—MSc physics and science journalist Bruno van Wayenburg (2011), twittering his praise for the hostile opinion piece by Van Joolingen (2011c)

> "*It is evidence of a strong resolve that the TU/e has canceled this PhD graduation. I haven't read the dissertation, but I'm convinced that they have thought this through very well. I do think that people have been sleeping.*"—Herman Beijerinck, physics professor at the TU/e (2008)[15]

To the defense of my opponents it has to be understood that they had all *uncritically presumed* that those four pamphlets—in particular the one by 't Hooft—indeed had revealed "facts" that "proved" that my work was of insufficient scientific quality: **from that perspective** they published what they suspected to be the case as if it was a fact—mostly without having seen my work. So although "facts" about me and my work have been alleged that were fabricated out of thin air, there was no intention to fraud: these fabrications were *unintentional*. What I hold against them is the same as I hold against the authors of the four pamphlets: they have carelessly passed off *figments of the mind* as "facts" about me or my work.

While most of my opponents merely reacted emotionally to the news and at least believed that they were stating the truth at the moment they were making their comments, this does not hold for all of my opponents. Kees van Hee for one has been lying through his teeth, but another one is Frank

Van der Duyn Schouten, then Rector of Tilburg University. In the first week of the controversy, he had an open letter published *simultaneously* both in Cursor, the university weekly of the TU/e, and in Univers, the university weekly of Tilburg University (2008a; 2008b). In that letter he made it publicly known that prior to the affair at the TU/e, the concept-dissertation had already been withdrawn at Tilburg University: he stated that it was withdrawn after physicists—note the plural—in the PhD committee had uttered "severe criticism" to the work, and he claimed that the TU/e had been "misled" by not mentioning the prior affaire at Tilburg University. For the reader this open letter not only reinforced the impression that had emerged from the first week of the controversy—i.e. the impression that my work was of insufficient quality—but it also added a new dimension to the controversy, namely that of intentional deceit. Given his position as the highest official of Tilburg University, Van der Duyn Schouten was taken at his word: this letter therefore led to several articles along the same lines in regional and national newspapers, e.g. (Hover, 2008a; Scholtens, 2008b). But Van der Duyn Schouten was lying through his teeth in his letter. He knew damn well that I had withdrawn the thesis at Tilburg University because of a personal collision with Hartmann and not because of any criticism, and he also knew damn well that the TU/e was informed about the prior affaire at Tilburg University. In fact—I again appeal to the *quantum tunneling effect*—at some point in 2008 I all of a sudden got hold of a letter that Van der Duyn Schouten had written on December the 27$^{\text{th}}$ of 2007 (so *after* the one-page article by Vlooswijk had appeared in Cursor but *before* the controversy broke loose) to Hans van Duijn, the Rector of the TU/e: in it, he stated that Hartmann may have indeed reacted inappropriately (in Dutch: *te kort door de bocht*) and he urged the TU/e to proceed with my PhD graduation (Cabbolet, 2008b). So, make no mistake: this open letter was a *calculated, strategic action* by Van der Duyn Schouten.

Furthermore, at some point the Dutch organized skeptical movement *Stichting Skepsis* became involved, mainly (but not only) in the person of Jan Willem Nienhuys: he was hell-bent on exposing me as a pseudoscientist. It is true that Nienhuys has a PhD in pure mathematics and for some time has been a lecturer in mathematics at the TU/e, and it is true that that background may be enough for exposing quackery in medicine—e.g. when claims about the effectiveness of an alleged cure for a disease are not backed up by double blind testing on a sufficiently large group—but still that background is insufficient for evaluating new developments in the foundations of physics. But by writing about my work Nienhuys nevertheless pretended to be competent in that area, and therefore by doing so he actually engaged in the quackery he wanted to accuse me of. He produced two papers in journals of organized skeptical movements (Nienhuys, 2014, 2015): for laymen—the readership of the journals—Nienhuys' papers may come across as profound analyses of my work, but fact of the matter is that his papers lack substance to such a degree that the term 'pseudoskepticism' applies. That is, his two papers are purely aimed at winning the readership over for his preconceived conclusion that I'm a crackpot and my work is illucid. The following sarcastic statement by Nienhuys betrays this preconceived conclusion:

> "*in an interview, the candidate expressed himself very optimistically about his manuscript*"—Nienhuys (2014)

So make no mistake: Nienhuys is one of those at the TU/e who misinterpreted my statement in the one-page article in Cursor, (Vlooswijk, 2007), as discussed on page xxxii. That Nienhuys' papers are merely aimed at getting the readership to agree with that preconceived conclusion is then evident from the fact that he uses several well-known dishonest tricks, described by the philosopher Arthur Schopenhauer in his 1831 book *The Art of Being Right*, to win an audience over for one's own idea. Some examples:

> "*He could also have proposed [instead of repulsive gravity] that gravity may be caused by dancing devils (fallen angels!). Or he could have formulated his theory from the hypothesis that you can let the wand of your opponent fly upwards with the spell 'Expelliarmus'.*"—Nienhuys (2014)

> "*The great physical theories of the* 20$^{\text{th}}$ *century are built on established experimental facts that in many cases have been found by purposely searching for the boundaries of the possible. You can forget about creating new physics by merely talking in a different and extremely cumbersome way about infinite sets.*"—Nienhuys (2014)

> "*... In 2009 Cabbolet learned from Gerard 't Hooft that photons are their own antiparticles.*"—Nienhuys (2015)

The first of these quotes concerns *false metaphors*: the use of metaphors that favor one's own view is, in fact, dishonest trick #12 mentioned by Schopenhauer. In analysis, the use of metaphors is *not done.* And not just that: Nienhuys' use of false metaphors to ridicule my work is a tell-tale sign that his papers have nothing to do with an objective evaluation. The second quote concerns dishonest trick #28 mentioned by Schopenhauer: *persuade the audience, not the opponent.* Here Nienhuys wants to contrast the way I have developed my theory with the way accepted theories have been developed to expose me as someone who knows nothing about theory development. Now the readers of the journals in which he has published are not only laymen, they are also quite gullible: they take Nienhuys at his word, so in their eyes Nienhuys has ruthlessly established here that my theory is so bad that it already can be rejected by looking at the method of development—it is not even necessary to look at the theory itself. However, the quoted statement contains two false statements of fact by Nienhuys: it is **neither** the case that accepted theories of physics have been developed from experimental data, **nor** that I have developed my theory by "talking about infinite sets". To elaborate, fact of the matter is that the epistemic sources for accepted theories of physics are observations *and reasoning*—not observations alone. As a result, these theories were speculative at the moment of publication: they yielded predictions that were *absolutely not* supported by observations. It is, for example, absurd to claim that Einstein's general relativity has been developed from observations of gravitational time delay and deflections of photons by the gravitational field of the sun, or that Dirac's theory of antimatter has been developed from the discovery of the positron—it is the other way around: these observations have been done because the community wanted to test these predictions. So these accepted theories have not been built on experimental facts: what is the case is that these accepted theories are theories that initially were speculative yet rigorous and that have become accepted because crucial predictions have been confirmed by experiments. Therefore, the first claim by Nienhuys betrays incompetence in the history of physics and general philosophy of science—to his defense: he's a mathematician. As to Nienhuys' second claim, fact of the matter is that the process-physical principles of my theory, the EPT, are mathematically expressed in a framework for mathematical logic, but it is flat-out wrong to state that these process-physical principles have been *developed* by thinking about sets or matrices of sets. That is, I have *first* developed the process-physical principles and *thereafter* I have developed the mathematical-logical framework in which these can be expressed: not the other way around. So, it is not the case that I have *first* developed a mathematical-logical framework and *thereafter* have created new physics by giving it a physical interpretation. For comparison: Einstein's physical ideas of general relativity are mathematically expressed in the framework of tensor algebra, but it is flat-out wrong to state that Einstein has *developed* his general relativity by merely thinking about tensors. This second claim by Nienhuys betrays ignorance of general methods of theory development in physics—it is even questionable whether he understands the difference between *hypothesizing* that matter and antimatter repulse each other gravitationally (which is what I did) and *claiming* that repulsive gravity exists (which I didn't). The last quote is an *ad hominem attack*: this is dishonest trick #16 mentioned by Schopenhauer. And not only that: it's also a false statement of fact—back in 1997, literally the first thing that was brought up in my investigation into repulsive gravity was that photons are their own antiparticle according to the Standard Model: 't Hooft hasn't taught me that, nor has he taught me anything else. So, there you have it: the prominent member of the skeptical movement Nienhuys has himself resorted to passing off outright fabrications as "facts"—make no mistake: with the quoted statement Nienhuys wants to win his readership over for his preconceived conclusion that I'm a crackpot who is ignorant of the relevant literature. I believe my point is herewith sufficiently proven. With regards to the skeptical movement, it is one thing to expose quackery in medicine—which, I believe, is a good thing—but it is another thing to publish papers in which the author resorts to *dishonest tricks* to sway public opinion against the latest development in avant-garde science. Now that the skeptical movements are doing precisely that, the question that we can ask ourselves is this: do public libraries and university libraries really need to have a subscription to their journals paid by tax-payers' money?

A third group that has engaged in calculated, strategic action is formed by several prominent members of the Royal Dutch Academy of Sciences: their contributions to the controversy about my work have remained behind closed doors, but nevertheless these contributions were crucial in maintaining the decision to cancel my PhD graduation at the TU/e. Altogether, about a dozen members of the Royal Dutch Academy of Sciences are up to their neck in the cancelation of my PhD graduation and the decision to maintain that cancelation. As mentioned in the section ‘Events leading to the cancelation of my PhD graduation’ of this chapter, my PhD graduation at the TU/e was canceled without the possibility to appeal to the decision. So the only possibility that I had was to show that widely agreed upon principles of good scientific practice were violated in the process of reevaluation of the concept-dissertation: that would establish that the reevaluation was bogus, which in turn would establish that the reason for the cancelation of the PhD graduation was bogus. So I filed a complaint about violations of principles of good scientific practice at the Scientific Integrity Committee (SIC) at the TU/e. They ruled that 11 (!) persons, including Van Hee and Van Duijn, had violated scientific integrity in the process. Such a ruling by a SIC, however, has formally the status of an advice to the university administration: in this case, the administration of the TU/e simply ignored the advice of the SIC of the TU/e and officially decided to maintain the cancelation of the PhD graduation—note that by doing so, the university administration maintained the conclusions of a reevaluation process that by then had been established to be bogus. Then there was only one option left: namely, to take the case to the Royal Dutch Academy of Sciences. For such cases—complaints about scientific misconduct, that is—the Royal Dutch Academy of Sciences had, together with the union of Dutch universities, founded a special institute: the national organ for scientific integrity (acronym: LOWI). So, I submitted my complaint to the LOWI headed by Kees Schuyt, but what happened there really defies the idealistic presupposition that ‘truth finding’ is the highest value in academia. I was summoned for a private hearing by the LOWI, during which I was asked to first summarize my complaint: at the moment I started talking, members of the LOWI—most notably Hans Vliegenthart—already started to shake their heads in disbelief. I should have walked away right there and then: the rest was simply a waste of time and effort. Instead of evaluating the course of affairs at the TU/e from the perspective of the principles of good scientific practice, the LOWI then set up their own reevaluation of the concept-dissertation, for which they approached the physicist Carlo Beenakker—as reported in (Cabbolet, 2014d)—and a philosopher: both were (very) negative. Beenakker is undoubtedly an excellent expert in his own field, condensed matter physics, but he falsely yet firmly believes that this implies expertise in the foundations of physics—that he is no expert in that area may be evident from the fact that he gave a lecture in 2016 (which I attended) about Schroedinger's cat to introduce the quantum-mechanical notion of entanglement to the general public, thus demonstrating a lack of understanding of the difference between the notions 'superposition' and 'entanglement'. His comments on my concept-dissertation lacked substance to such a degree that the term pseudoskepticism applies. The following quote from his "review report" stands model for its scientific standard:

> "*My third objection to a PhD graduation on the basis of this manuscript is that it has not even partially been published in the scientific literature.*"—Beenakker, cf. (Cabbolet, 2014d)

The point here is that prior publication of the material in the dissertation is not a requirement for a PhD graduation in the Netherlands: Beenakker's argument is not a valid objection. The comments by the philosopher, the only non-member of Royal Dutch Academy of Sciences involved in the course of affairs at the LOWI, were also of the level of pseudoskepticism, as evidenced by the following quote from his "review report":

> "*all these definitions etc. may yield the impression that we are dealing with a carefully developed physical theory. But that is absolutely not the case. On p. xlv we read ... that the EPT cannot make quantitative predictions. ... Cabbolet admits this, but 'one should no longer think in terms of falsifiable or verifiable theories, one has to think in terms of degenerating or progressive research programs.' That ... is substandard. Typical for research programs, progressive or degenerating, is that we can speak of falsifiability and confirmability with the help of auxiliary hypotheses. ... Any indication thereof is missing*"

So, he judges my entire work as 'substandard' *because* it lacks an indication of how the EPT could be tested in a research program by means of auxiliary hypotheses. That's a false statement of fact: this was explained on p. 66 ff. of that booklet.[16] But for Schuyt c.s., the members of the LOWI, the arguments by Beenakker and the philosopher were valid enough. They *formally* gave me the possibility to reply to the objections but they *actually* ignored my reply in its entirety: the members of the LOWI simply closed ranks. That is, the members of the LOWI simply sided with the other prominent academics involved in the cancelation of my PhD graduation c.q. the controversy about my work, and the LOWI officially ruled that my complaint was baseless on all counts. To the defense of the members of the LOWI, evidently they reacted initially with disbelief to the complaint that I submitted, and of course that disbelief was strengthened by the "review reports" of Beenakker and the philosopher: they've acted correspondingly. But what I hold against the members of the LOWI is that they were never really interested in objectively evaluating the course of affairs at the TU/e from the perspective of the principles of good scientific practice: they held me in low esteem, and they *therefore* felt justified to dismiss my complaint in its entirety—that is, it was their view that my complaint should be dismissed in its entirety to avoid that the reputations of prominent academics got damaged c.q. tainted by a complaint about a reevaluation procedure by a crackpot whose PhD graduation was rightfully canceled *even though* the procedure by which the cancelation took place might not have been optimal. Schuyt c.s. will deny this *ad infinitum*, but make no mistake: the members of the LOWI have abused their discretion to rule on my complaint to protect the reputation of prominent academics and that's it. After that, I informed the then president of the Royal Dutch Academy of Sciences, Robbert Dijkgraaf, about the wrongdoings at the LOWI. However, Dijkgraaf—a former PhD student of 't Hooft—stonewalled me: he never gave any reply to me directly, but he did comment negatively on my work much later in a Belgian newspaper (Dzikanowice, 2012). Finally, in 2016 I noticed that the scope for complaints that could be submitted to the LOWI had been widened: it was henceforth also possible to submit a complaint about the LOWI itself. And so I did submit a complaint about the LOWI led by Schuyt. However, the new members of the LOWI ruled in 2016 that they could not take my complaint in consideration because too much time had elapsed since the decision by Schuyt c.s. in 2009. I, on the other hand, am of the opinion that misconduct cases cannot have an expiration date, in particular when it concerns fabrications of "facts": genuine facts, namely, contribute to the growth of knowledge, but when it concerns fabrications then these "facts" amount to a body of pseudoknowledge, that is, a body of statements falsely believed to be knowledge. I'll leave it at that.

Epilogue: speculation about causes

There are critics of the orthodoxy who, having experienced resistance from the academic establishment, accuse that academic establishment of a "conspiracy" or of forming a "modern inquisition". But even though real persons have held real meetings to thwart my research, I believe that this is a mistake: one should not attribute to conspiracy that which can be adequately explained by stupidity (Hanlon's razor). That is, the resistance that I've experienced from the academic establishment is nothing but the sum of isolated, individual responses to my work, and those isolated, individual responses to my work share the common denominator that they are (virtually) all instances of committing the same stupidity, namely passing off false statements of fact—which are nothing but figments of the imagination that popped up in an emotional outburst—as genuine "facts" about me or my work *without even having attempted to check the truthfulness of these "facts"*. And committing this stupidity is *unethical behavior* in science, since it violates the widely accepted principle of carefulness, one of the basic principles of good scientific practice.

However, I don't want to call my opponents "stupid", certainly not my main opponent Gerard 't Hooft: they are very intelligent individuals, capable of successfully working on the most advanced research programs in physics or mathematics.[17] Furthermore, the fact that they have made their comments about me and my work publicly available indicates that they are not aware that they have committed a stupidity c.q. that they are behaving unethically—as Brian Martin put it:

> "*there is [no] conscious conspiracy of evil schemers who set out to destroy dissidents. Just the opposite. Those who attack dissent sincerely believe that* ***they*** *are doing the right thing.*" (emphasis original)—Martin (1998)

That, however, raises two questions:

(1) How can any such intelligent individual commit such a stupidity *without* realizing that it is unethical?

(2) How can this unethical behavior in response to my work be *the rule* rather than *the exception*?

Below I answer these two questions without claiming an absolute truth.

Ad (1). Of course we can only speculate about what goes on in someone's mind, but fact of the matter is that the way senior physicists have responded to my work becomes a prediction if we model the workings of the mind using Spinoza's *Ethics*. This yields the following response-in-an-outburst model:

(i) as a rule, a senior physicist strives to persevere in his career, which is intimately interwoven with the assumptions that gravity is attraction only and that any new theory of physics must yield the contemporary theories of modern physics by applying some limit procedure: he believes in these assumptions himself, he teaches these to his students, and all of his research has been based on these assumptions;

(ii) given (i), a senior physicist thus *automatically* experiences sadness as soon as he finds out that my work implies that these assumptions must be wrong—and one can find that out from a superficial reading, or even from hearsay—*because* it opposes his conatus, that is, *because* if these would be wrong then his entire career would be based on falsehoods, and it would become more difficult to persevere in it;

(iii) the senior physicist then *automatically* experiences hatred towards me and my work as the cause of the sadness;

(iv) affected by the hatred, the senior physicist then *automatically* experiences the desire to mock me and/or my work;

(v) affected by that desire, *automatically* derisive thoughts come up that would joy the senior physicist if these could truly be said of my work or of me;

(vi) this desire lasts only for a short time, but the senior physicist commits the stupidity to give in to it by passing off these fabrications of his mind as if they were "facts" without even attempting to check their truthfulness and without self-reflection—this yields pseudoskepticism;

(vii) the senior physicist then feels good about it afterwards *because* he acted this way—not the other way around: it is **absolutely not** the case that he acted this way *because* he felt good about it!

This model "works" in the vast majority of cases (my estimate: 99%), so from James' pragmatic perspective it's true *instrumentally*. Physicists like to see themselves as modern scientists, yet those who have responded to my work with pseudoskeptical attacks have behaved as automata as predicted by a theory from the 17th century!

EXAMPLE X To see how the response-in-an-outburst model works, we can use it to explain how 't Hooft, in his pamphlet used for getting my PhD graduation canceled, could pass off the following fallacious one-liner as a "fact" about the mathematical part of my 2007 concept-dissertation:[18]

> "*Although I do not completely speak the language that mathematicians use in set theory, I know enough about it to see that the mathematical part of this work does not satisfy the quality standard demanded by mathematicians.*"—'t Hooft (2008c)

The crux is that 't Hooft (later admitted that he) has had no education in mathematical logic, the branch of mathematics applied in the concept-dissertation. So, listing through the concept-dissertation he has not recognized the mathematics *typographically* as mathematics that he knows. And upon that finding, affected by the desire to mock my work, the thought has popped up that it is *not mathematics at all* as in step (v) of the model. This is nothing but a fabrication of the mind, but he has passed it off *without checking its truthfulness* as a "fact" about my work, as in step (vi) of the model. And make no mistake: 't Hooft feels good about it as in step (vii) of the model—he will refuse to retract the fallacious claim quoted above even after being confronted with conclusive evidence to the contrary. ■

Question (1) on page l is herewith answered. By changing only names, a general response-in-an-outburst model is obtained for the response of an overly specialized expert to a work that opposes his connatus, that is, a work that is not in line with the basic assumptions of "his" research field.[19]

Ad (2). Individuals who have responded to my work as predicted by the response-in-an-outburst model have what I call a 'cult-of-narrowness' mindset, which *differs wildly* from the mindset of an authentic scientist.[20] The latter, namely, is committed to truth finding and is therefore aware (a) that truth finding is a joint effort to find out the truth about something and (b) that the truth that will eventually be uncovered might deviate from his own belief(s): he welcomes well-founded criticism to learn from it, and *naturally* suspends his disbelief when evaluating someone else's ideas. So, an authentic scientist simply isn't affected by a piece that dissents from his own core belief(s) as predicted by the response-in-an-outburst model.

That means that the *observable* fact that the response-in-an-outburst model "works" in the vast majority of cases indicates that a senior physicist, as a rule, is out of touch with his authentic self and alienated from truth finding. That, however, should come as no surprise in this era of overspecialization in research and education. In his book *The Path*, co-authored with Christine Gross-Loh, Harvard scholar Michael Puett warns for the danger that the ruts and patters in our interactions that we as human beings during our lives fall into, often from a young age, can define us to the extend that we falsely associate them with ourselves and start thinking of them as our personality (2016): I believe that this danger *as a rule* materializes during one's career as a researcher in modern physics.

First of all, the university educations have become too narrow. It is not necessarily a bad thing that the student is being told what to think about the physical universe, but on the other hand he never gets exposed to the landslides in human thinking caused by the greatest ideas in history, nor is he taught how to analyze a theory, how to self-reflect or how to wilfully suspend his disbelief: the analytical skills remain undeveloped. But it is not just that. From the PhD position on, over the years a physicist usually only gets to work on a series of excessively narrow research topics that are always situated within a larger research program, in which a hard core of theories immune to revision is uncritically accepted and in which the negative heuristics dictate that criticism of that hard core is *not interesting*. And so the physicist accustoms to and eventually accepts the compartmentalization of physics and the roles physicists play in the mainstream research programs. That not only limits his ability to think out of the box: the modern physicist eventually gets out of touch with his authentic self. That is, as a senior physicist he may *think* that he has aligned his life with his authentic self, yet he is *really* only being true to the ruts and patterns of the compartmentalized landscape of modern physics that he has fallen into from day one as a young student. He is not really, honestly allowing ideas other than his own to challenge his core beliefs. What he actually does is the opposite. He only considers those results from other research programs acceptable that allow him to stay true to these same ruts and patterns that have defined him—lacking the ability to wilfully suspend his disbelief, he is only committed to truth finding insofar as that truth lies within the mainstream research programs he is working on. He has locked himself into a very limited version of what he could be: he is out of touch with his authentic self and is completely alienated from truth finding. That answers question (2) on page l.

Summarizing, I believe that the overspecialization in research and education causes a 'cult-of-narrowness' mindset to prevail among physicists, and that this 'cult-of-narrowness' mindset causes individuals to respond to my work in a way as predicted by the response-in-an-outburst model on page li.[21] **But, truth be said, there still are authentic individuals in physics, <u>also</u> among those who do not support my work!**

Part I

Prolegomenon to the EPT for physicists

Chapter 1

The foundational phase

> "*[Repulsive gravity] goes completely against all our physical knowledge and is clearly wrong*"—Lawrence Krauss, (then) scientific advisor to Barack Obama, when asked to comment on my dissertation (Cabbolet, 2011b) by Pieter van Nuffel and Fabrice Luyckx of the Belgian skeptical organization SKEPP (2013)

1.1 General introduction

Ever since Thales of Miletus in the 7^{th} century B.C. started wondering whether there could be a rational explanation for natural phenomena, it has intrigued people how physical reality can be explained. Commenting on Democritus' philosophy of nature that the physical world is made up of atoms moving in a void, the Roman philosopher Cicero wrote already around 50 B.C. in his work *De finibus bonorum et malorum* that "in the study of Nature there are two questions to be asked, first, what is the matter out of which each thing is made, second, what is the force by which it is made". Slightly reformulating these two questions and adding a third gives the following three questions:

(i) What is the universe made of?

(ii) How does it function?

(iii) What is its origin?

These—and no other—are the fundamental questions of physics.

Historically, the Greek philosopher Pythagoras (±572 - ±500 B.C.) was the first to apply mathematics to a description of reality in that he assumed that all things are numbers; arguably, he was thus the first who was of the opinion that a correct description of physical reality had to be in the language of mathematics—it is unclear, however, if he ever made that opinion explicit, as no texts of Pythagoras have survived. Heraclitus of Ephesus (±550 - ±480 B.C.), another Greek philosopher, famously stated that "the Logos holds always (...)" and "all things come to be in accordance with the Logos": arguably, he was thus the first to put forward the notion of a law of nature as the logic to which all change is subjected—the interpretation of the quoted statements remains, however, subject to discussion as no works of Heraclitus have survived.

After Pythagoras and Heraclitus, it took roughly two millennia before the first actual attempt to explain physical reality in terms of mathematically formulated fundamental laws of nature took place: this landmark event can be identified with the publication in 1687 of Isaac Newton's *Principia*. Starting from experimental data, Newton had obtained three fundamental laws and a law of gravitation: these provide an answer to the aforementioned first two fundamental questions of physics, yielding the view that the universe is made up of particles and fields and evolves deterministically according to precisely states laws. Interestingly, John Norton proved that there theoretically exists a system that behaves non-deterministically within the framework of Newton's laws (2003). There is, however, no reason to assume that Norton's system exists in the real world—nevertheless, one has to realize that such a physical non-existence does not render Norton's argument invalid! The consistency of Newton's laws with experimental results lasted some 200 years, but came to an end when the absolute motion of earth in a static aether, which was predicted using Newton's laws, could not be detected by the physicists Michelson and Morley in their now historic experiment (1887). In 1905 Albert Einstein formulated special relativity (SR), in which the idea of an absolute frame of reference, such as a static aether, was rejected (Einstein, 1905). SR was consistent with the result of the Michelson-Morley experiment: this contributed to the rejection of Newton's laws as universal laws of physics. The subsequent scientific revolution had by the mid-1920's yielded two results: general relativity (GR) and quantum mechanics (QM), the cornerstones of modern physics.

The point is now that GR and QM are fundamentally incompatible, at least if we take QM to be what it is according to the most widely held Copenhagen interpretation, which henceforth will be called ‘orthodox QM’ (OQM). While this incompatibility has been extensively discussed in the literature, e.g. in (Sachs, 1988), the radical difference between OQM and GR can be illustrated by the difference between the corresponding views on how an electron, which has been observed in consecutive events at positions X_a and X_b, has got from X_a to X_b.

In the framework of GR, the particle concept of classical mechanics, i.e. a material body whose dimensions can be neglected in describing its motion, is embraced, as well as the classical idea that a particle moves on a continuous trajectory. In the worldview based on GR, the electron has thus moved on a continuous trajectory $X(t)$ from X_a to X_b, meaning that at every point of time t in between the consecutive observations the electron was in a particle state and had a definite position $X(t)$; see figure 1.1 below for a graphical illustration of the concept of continuous motion in GR.

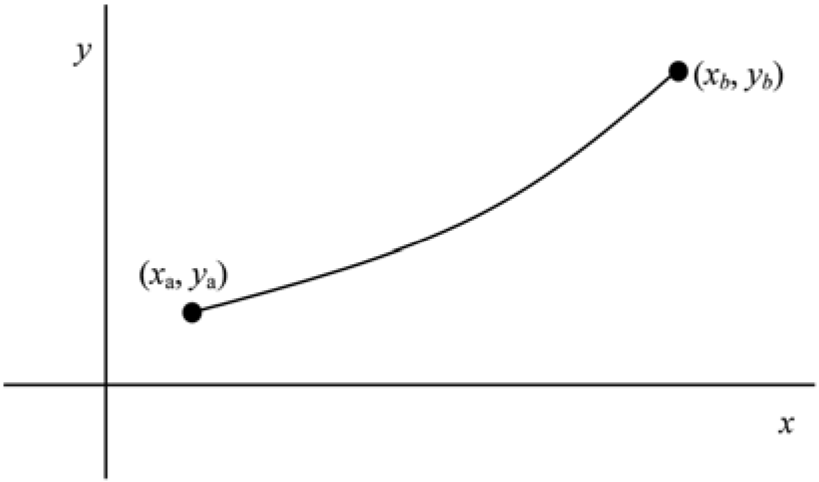


Figure 1.1: illustration of the concept of continuous motion in GR in an xy-diagram; horizontally the x-coordinate, vertically the y-coordinate; the z-coordinate is suppressed. The dot in the lower left corner at coordinates (x_a, y_a) represents the position X_a where the electron was first observed, the right dot in the upper right corner at coordinates (x_b, y_b) represents the position X_b where the electron was observed thereafter. The curve connecting the dots represents the trajectory of the electron: at every point of time in between the observations the electron had thus a definite position.

In the framework of OQM, on the other hand, the classical concept of a particle is nonexistent: instead, the new concept of a 'wave function' is applied. A wave function ψ represents the state of a quantum system, i.e. a microsystem in the framework of OQM, and can be used to compute the probabilities of possible outcomes of measurements on the quantum system. This corresponds with the position that individual processes are probabilistic of nature. But the thing is now that OQM contains a form of Berkeleyan idealism—more precisely, a Berkeleyan idealism regarding properties. The term 'Berkeleyan idealism' refers to the idea that the philosopher George Berkeley put forward in his 1710 book *Treatise Concerning the Principles of Human Knowledge* by the famous dictum *esse est percipi* ("to be is to be perceived"): an object exists **if and only if** it is observed. So, the point now is that regarding properties that have more than one possible value, the following theorem can be proven from the postulates of OQM:

Theorem 1.1.1. *OQM entails a Berkeleyan idealism regarding properties (BIRP): absent special preparations, a quantum system 'has' a property X with quantitative value x_j* ***if and only if*** *a measurement of the property X has just been done with outcome x_j.* ■

Proof: This theorem follows from two postulates of OQM, the Standard Property Postulate (SPP)—which is tacitly assumed in most textbooks on QM (Muller, 2014)—and the Projection Postulate (PP):

Postulate 1.1.2. (SPP) *a quantum system 'has' a property X with quantitative value x_j* ***if and only if*** *it is in the eigenstate $\mid x_j \rangle$ of the associated operator $\hat{X}$* (Dirac, 1947; Muller and Saunders, 2008).[22,23] ■

Postulate 1.1.3. (PP) ***if*** *a measurement of the property X has been done with outcome x_j,* ***then*** *immediately after the measurement the quantum system is in the eigenstate $\mid x_j \rangle$ of the associated operator $\hat{X}$* (Dirac, 1947; Von Neumann, 1955; Muller and Saunders, 2008). ■

Obviously, the logical form of the SPP is that of a proposition of the type

$$P \Leftrightarrow E \tag{1.1}$$

with the proposition letters P and E denoting 'a quantum system has a property X with quantitative value x_j' and 'the quantum system is in the eigenstate $\mid x_j \rangle$ of the associated operator $\hat{X}$', respectively. The PP, obviously, has the logical form of an implication

$$E \Leftarrow M \tag{1.2}$$

with the proposition letter M denoting 'a measurement of the property X has just been done with outcome x_j'. In addition, the PP is **the only** postulate of OQM that tells us *how* a quantum system can get in the required eigenstate $\mid x_j \rangle$: it is, thus, ruled out that the quantum system is in the eigenstate $\mid x_j \rangle$ of the operator $\hat{X}$ *without* a measurement of the property X having been done with outcome x_j.[24] In other words, because the PP is the only postulate of OQM that tells us *how* a quantum system can get in the required eigenstate, we have the additional proposition

$$\neg(E \wedge \neg M) \tag{1.3}$$

which is equivalent to

$$E \Rightarrow M \tag{1.4}$$

Now expressions (1.2) and (1.4) yield

$$E \Leftrightarrow M \tag{1.5}$$

From expressions (1.1) and (1.5) we get

$$P \Leftrightarrow M \tag{1.6}$$

This expression (1.6) is precisely the BIRP. Ergo, OQM entails a BIRP. ■

So on the one hand, the 'if' part of the BIRP guarantees that the quantum system 'has' the property X with value x upon a measurement of that property X with outcome x. But on the other hand, the 'only if' part of the BIRP *forbids* to say that a quantum system 'has' a certain quantitative property when that property hasn't been measured.

Now back to the discussion about the views on how an electron, which has been observed in consecutive events at positions X_a and X_b, has got from X_a to X_b. In the framework of OQM, the electron had thus no definite position in between the measurements—the observations are position measurements—due to this Berkeleyan idealism regarding properties. That is, at every intermediate time t the electron had in every region U of the whole space X a possibly nonzero probability $p(U) \in [0, 1]$ of being found there; for any region U this real-valued probability $p(U)$ can then be calculated using the wave function $\psi(t)$ of the electron at the time t. See Fig. 1.2 below for an illustration of this concept of wave motion. So, from this quantum-mechanical point of view there is no such thing as the trajectory of the electron: it had a definite position only at X_a and X_b, and had these *because of* the acts of measurements—these acts of measurement "forced" the electron to assume the definite positions X_a and X_b. This illustrates the radical difference between GR and OQM.

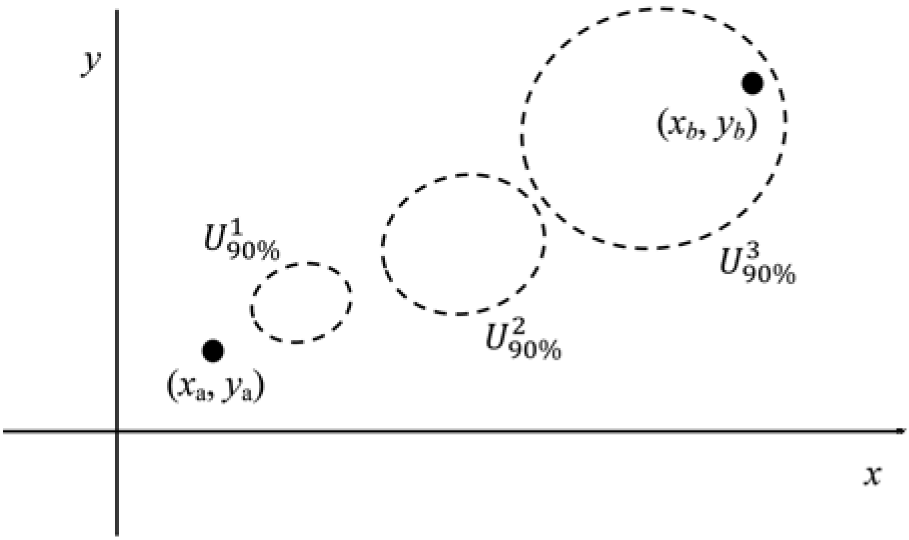


Figure 1.2: illustration of the concept of wave motion in QM in an xy-diagram; the z-coordinate is suppressed. The two dots represent the positions X_a and X_b where the electron was successively observed. The three ovals labeled $U^1_{90\%}$, $U^2_{90\%}$, and $U^3_{90\%}$ represent three environments with a possibility of 90% of finding the electron there at intermediate times t_1, t_2, and t_3, respectively, in between the two measurements.

Remark 1.1.4. Suppose that we have set out to measure the value x of a property X of a microsystem. The measurement problem in QM is then the issue posed by the fact that

(i) on the one hand the state of the microsystem evolves in absence of observation in time according to the Schroedinger equation, so that the state of the microsystem *just before* the measurement is a superposition of definite states, that is, a superposition of states with a definite value of the property X;

(ii) on the other hand the microsystem is upon observation *always* found to be in a definite state, that is, in state with a definite value of the property X.

Resolving the measurement problem then boils down to describing what it is that an observation "does" to a microsystem. That said, from the perspective of the BIRP the measurement problem resolves in a natural way, because it is *by observation* that a microsystem acquires the property X with a definite value x. *By observation* the state of the quantum system changes from the prior state $|\,\psi\,\rangle$, in which it *didn't have* the observed property, to the state in which it *does have* the property x, which by the SPP is $|\,x\,\rangle$: this transition $|\,\psi\,\rangle \to |\,x\,\rangle$ is the collapse of the wave function. ■

Remark 1.1.5. One of the key motivations for introducing quantum logic (QL) is the idea that the 'excluded middle principle' is violated in the framework of OQM: we can have that a disjunction $P \vee Q$ of propositions P and Q is true while neither of its members is true—this goes back to the original paper by Birkhoff and Von Neumann (1936). A standard example used by the QL community is this: let P be the proposition '*the spin of the particle in x-direction is* $\frac{1}{2}$' and Q the proposition '*the spin of the particle in x-direction is* $-\frac{1}{2}$'; then we have that $P \vee Q$ is true while neither P is true nor Q is true. Similar examples can be given with position. E.g. in a one-dimensional system with the position x of the particle ranging in the interval $(-L, L)$ we can let P be the proposition '$x \in (-L, 0)$' and Q the proposition '$x \in [0, L)$'; then again the idea is that we have that $P \vee Q$ is true while neither P is true nor Q is true.

However, an inevitable consequence of the Berkeleyan idealism for properties is that this whole idea is ill-conceived: the point is, namely, that the particle **does not have** the property in absence of observation. So, if we use the above example with spin in the x-direction, then the only propositions that are true are $\neg P$, $\neg Q$, and $\neg P \wedge \neg Q$. That is, it is not the case that the spin of the particle in x-direction is $\frac{1}{2}$, and it is not the case that the spin of the particle in x-direction is $-\frac{1}{2}$. More importantly, the disjunction $P \vee Q$ is *false*: the particle *doesn't have* the property spin in absence of measurement, so it is not at all the case that the spin of the particle in x-direction is $\frac{1}{2}$ or $-\frac{1}{2}$. Note that classical logic thus applies to the quantum system. QL could be saved by modifying the above propositions to '*upon measurement it is the case that ...*'; this is, as I have understood, the Bohrian view on QL. In the above example with spin, P then becomes the proposition '*upon measurement it is the case that the spin of the particle in x-direction is* $\frac{1}{2}$' and Q the proposition '*upon measurement it is the case that the spin of the particle in x-direction is* $-\frac{1}{2}$'. We then indeed get that the conjunction $P \vee Q$ is true *before* the measurement, while it is not the case that one of its members is true *before* the measurement because the value that the property 'spin' gets *upon* measurement is not yet determined *before* that measurement has taken place—it is the measurement that 'forces' a definite value of spin on the particle in a purely probabilistic way. But when modified this way, the physical meaning of the proposition letters has changed fundamentally: an atomic proposition of QL is then no longer an assertion about a quantitative property that the particle 'has' *before* the measurement.

Concluding, QL, with its atomic propositions being assertions that the particle 'has' a definite quantitative property, *does not* reflect the nature of physical systems described by orthodox QM. The point of departure is the tacit assumption made in QL that the particle <u>does</u> have one of the possible properties in absence of measurement: Th. 1.1.1 has shown that it <u>does not</u> have any of those properties. QL has, thus, to be viewed as a quantum theory on its own. Alternatively, consistency of QL with orthodox QM can be restored when the atomic propositions are modified to propositions about possible properties *upon* measurement. ■

Further developments in quantum physics led in the 1940's to Quantum Electrodynamics (QED): in QED one performs calculational procedures, which are formalized in the framework of quantum field theory, to calculate possibilities of outcomes of measurements on microsystems in which the electromagnetic interaction is predominant. So, in QED one considers a microsystem in an initial configuration, and one considers a possible outcome of a measurement on the system: one then calculates the possibility $P(\mathcal{E})$ that the event $\mathcal{E}$ takes place that the measurement gives the outcome under consideration. The idea is that there are infinitely many processes by which this possible outcome can happen, with each such process contributing to $P(\mathcal{E})$. So, each process is associated with a *contributing Feynman diagram* (named after Richard Feynman): these can be labeled 1, 2, 3, etc. starting with the lowest-level Feynman diagram (the simplest process), and the probability amplitude a_n for the n^{th} contributing Feynman diagram can then be calculated. $P(\mathcal{E})$ can then be calculated from these a_n's, but in practice an approximation from only finitely many a_n's will do since

$$\lim_{n\to\infty} a_n = 0 \tag{1.7}$$

Thus speaking, at an abstract level we can view QED as a countable set of rules, which applies to each microsystem and to each possible event $\mathcal{E}$:[25]

Definition 1.1.6. *For every $n \in \{1, 2, 3, \ldots\}$, **rule n of QED** is that the probability amplitude $a_n \in \mathbb{C}$ of the n^{th} contributing Feynman diagram can be inferred from a finite set of premises $\Sigma_n = \{\Psi_n^1, \Psi_n^2, \ldots, \Psi_n^{p(n)}\}$:*

$$\Sigma_n \vdash a_n = x_n + y_n i \tag{1.8}$$

*Here $x_n, y_n \in \mathbb{R}$. The **ω-rule of QED** is that the possibility $P(\mathcal{E})$ that the event $\mathcal{E}$ takes place is a function of the probability amplitudes a_n:*

$$\Sigma_\omega \vdash P(\mathcal{E}) = f(a_1, a_2, \ldots) = (\sum_{n=1}^{\infty} a_n)(\sum_{n=1}^{\infty} a_n^*) \tag{1.9}$$

where Σ_ω is the collection of identities of the a_n's and $a_n^* = x_n - y_n i$ is the complex conjugate of a_n.[26] ■

In general, the $p(n)$ premises Ψ_n^j in a set Σ_n are complicated, well-formed mathematical expressions that depend on the initial and final configurations of the microsystem, and the inference of the value of a_n from the set of premises Σ_n is a state-of-the-art computational procedure. A further discussion of QED is not required *hic et nunc*; the example below merely serves to illustrate Def. 1.1.6.

Example 1.1.7. In electron-electron scattering, we consider a microsystem that in its initial configuration is made up of two incoming electrons—one at A and one at B—and we consider the event $\mathcal{E}$ that one electron is detected at X and one at Y. Figs. 1.3 and 1.4 show three contributing Feynman diagrams; for the corresponding rules of QED we then have the following:

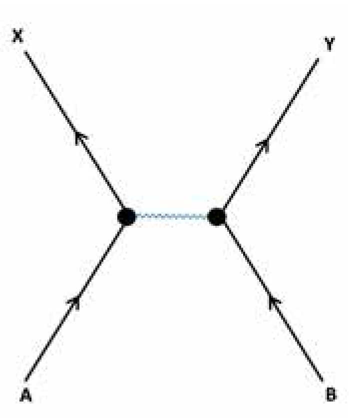
(i) rule 1 yields the probability amplitude a_1 for the Feynman diagram in Figure 1.3-(a);

(ii) rule 2 yields the probability amplitude a_2 for the Feynman diagram in Figure 1.3-(b);

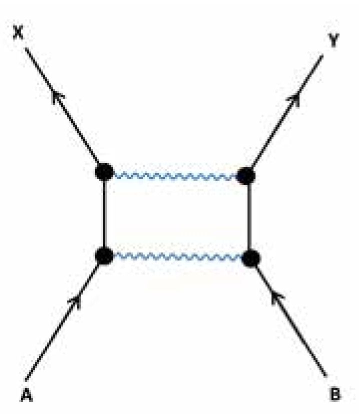
(iii) rule 3 yields the probability amplitude a_3 for the Feynman diagram in Figure 1.4;

(iv) the ω-rule yields the probability $P(\mathcal{E})$ that one electron is detected at X and one at Y.

It is emphasized that there are more contributing Feynman diagrams then the three shown in Figs. 1.3 and 1.4; the respective a_j's are included in the ω-rule in (iv) above. ■



(a) Diagram 1: two vertices



(b) Diagram 2: four vertices

Figure 1.3: Two contributing Feynman diagrams for electron-electron scattering; time is vertical. In Diagram (a) the electrons scatter after exchange of one photon; in Diagram (b) after exchange of two photons.

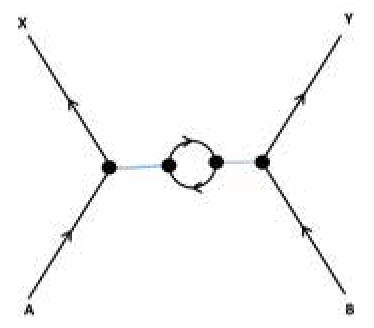


Figure 1.4: A third contributing Feynman diagram, with four vertices, for electron-electron scattering; time is vertical. The electrons scatter after exchange of a photon that has formed a virtual electron-positron pair.

The foundational problem of modern physics

Historically, the empirical successes of QED have led quantum physicists to apply the idea of an interaction theory as a set of computational rules formalized in the framework of quantum field theory to other interactions as well: this has led to the development of Quantum Chromodynamics (QCD) and Electroweak Theory (EW), which treat the strong and weak interactions and are structured like QED. For gravitation this approach has failed, which renders GR as the accepted theory of gravitation. The current state of affairs is then, thus, that modern physics does not provide a coherent answer to the fundamental questions of physics. It has been established that there are four types of fundamental interactions in nature (gravitational, electromagnetic, weak and strong), and for each of these interactions there is a theory available: the Standard Model (QED, QCD, and EW) can be applied to explain observations at microscopic scale involving the electromagnetic, strong or weak interaction, and GR can be applied to explain observations involving the gravitational interaction at macroscopic scale, where planets can be viewed as particles. But the point is that these interaction theories do not form a coherent whole, because the Standard Model and GR correspond with mutually exclusive world views.

The **foundational problem of modern physics** is then not just that there is no foundational theory that applies to all four fundamental interactions, but rather that *there cannot possibly be* a consistent, unitary theory that encompasses both GR and the modern quantum-physical interaction theories (QED, QCD, EW) as universally valid theories.

This foundational problem of modern physics leaves that precisely one of the following options is true:

(i) modern quantum physics is not universally valid, but GR is;

(ii) GR is not universally valid, but modern quantum physics is;

(iii) both modern quantum physics and GR are not universally valid.

Regarding modern quantum physics, there is no *empirical* ground to doubt its validity: the Standard Model has thus far never been contradicted by any experimental outcome. Moreover, the adjective 'Standard' in 'Standard Model' reflects the confidence of the modern physics community that the corresponding world view is basically correct. Consequently, although it may not be documented explicitly in black and white, any mainstream research program in modern physics does contain the negative heuristic that it is not interesting to doubt the fundamental correctness of quantum theory—that is, there is no mainstream research program aimed at new foundations that are outside the framework of quantum physics.

Regarding GR, there is also no *empirical* ground to doubt its validity: GR has thus far never been contradicted by any observation of any system in which gravity is predominant. However, the concept of continuous motion that is incorporated in GR is incompatible with the observed discreteness of the microcosmos (where gravity is overpowered by electromagnetism). In a hydrogen atom, for example, only discrete energy levels occur.[27] A transition from the ground state E_1 to the first excited state E_2 is thus a *discrete* transition: at any point in time *just before* the discrete transition the H-atom had energy E_1 with the electron in the 1^{st} shell, and at at any point in time *just after* the discrete transition the H-atom had energy E_2 with the electron in the 2^{nd} shell—at no point in time in a small interval $(t-\epsilon, t+\epsilon)$ around the time t at which the discrete transition took place did the H-atom have an intermediate energy E for which $E_1 < E < E_2$. This is *impossible* in a framework with continuous motion: in such a framework, the electron will have to undergo a continuous acceleration to get from the 1^{st} shell to the 2^{nd} shell, meaning that these intermediate energies E *will* be attained. Now a postulate of GR is that freely falling particles move on timelike geodesics of spacetime: this implies the assumption that there are continuously moving particles, and therefore GR's area of application cannot be extrapolated to include the microcosmos.

As a result, there is currently a variety of research programs addressing the foundational problem of physics—string theory, loop quantum gravity, causal set theory, emergent gravity, just to name a few. These contemporary research programs are mutually very different in their approach, but all are aimed at a replacement c.q. a successor of GR, such that all fundamental interactions can be described in the framework of quantum physics. However, despite the enormous effort, these research programs have failed to produce an advancement in the knowledge of the fundamental workings of the universe that has brought a solution to the foundational problem in physics any closer. The following quote by Immanuel Kant in the preface to *Critique of Pure Reason* (2^{nd} Ed., 1787) is then suddenly very interesting:

> "*If we find those who are engaged in metaphysical pursuits, unable to come to an understanding as to the method which they ought to follow; if we find them, after the most elaborate preparations, invariably brought to a stand before the goal is reached, and compelled to retrace their steps and strike into fresh paths, we may then feel quite sure that they are far from having attained to the certainty of scientific progress and may rather be said to be merely groping about in the dark.*"

Applying that to the present situation where those working on the foundational problem of physics are all working within the boundaries of the quantum paradigm, we find them unable to come to an understanding about which approach should be followed, and we find them time and time again publishing new approaches which **not only** have been developed *before* previously published approaches have reached their goal **but also** imply that the latter are *fundamentally mistaken*: we thus come to the grim conclusion that the modern physics community is very far from actually solving the foundational problem of physics and is merely groping about in the dark—in the dark corners of the quantum paradigm, that is.

That said, the purpose of this book is to present a radically different research program in theoretical physics, which—as we will see—corresponds to option (iii) on page 14. So, this is not yet another approach towards a complete quantum-theoretical foundation for physics: this approach goes 'out of the box'—and a thought experiment takes us there.

1.2 A thought experiment

If we would do an experiment in which we release a body of antimatter at a height h above the earth's surface with an initial velocity parallel to the earth's surface, then GR predicts that the height $h(t)$ of the body of antimatter as a function of time will be a downward curve like the one shown on Fig. 1.9-(a) on page 19. Namely, the Equivalence Principle underlying GR guarantees that the acceleration of a body in the earth's gravitational field is the same as the acceleration of an inertially moving body that would be observed by an observer accelerating "upwards" at a rate of $1g$.

This experiment has never been actually done. However, there are at least four sizeable experimental projects going on to establish the coupling of massive antiparticles with the gravitational field of the earth: three projects at CERN using antihydrogen, AEGIS, GBAR, and ALPHA, and the MAGE project at the Paul Scherrer Institute (PSI) using muonium.

The AEGIS experiment aims to determine the gravitational acceleration of antihydrogen $\overline{H}$ on earth by measuring the vertical displacement of a beam of $\overline{H}$ atoms with a Moiré deflectometer (AEGIS collaboration, 2008). The $\overline{H}$ atoms are essentially produced from a positronium (Ps) beam and antiprotons $\overline{p}$ according to $Ps + \overline{p} \rightarrow \overline{H} + e^-$. The beam of positronium is obtained by letting a beam of positrons, emitted by a ^{22}Na source, pass through a nanoporous insulator (such as SiO_2); this beam then interacts with trapped antiprotons $\overline{p}$, produced by the Antiproton Decelerator (AD) facility at CERN. See Fig. 1.5 for an illustration.

The GBAR experiment, on the other hand, aims to determine the gravitational acceleration of anti-hydrogen on earth by using $\overline{H}$ atoms that are initially at rest (GBAR collaboration, 2012). Ultracold $\overline{H}$ atoms are essentially produced by deionization and subsequent laser-cooling of trapped $\overline{H}^+$ ions. A beam of these $\overline{H}^+$ ions is produced by leading a beam of antiprotons from the AD through a positronium cloud, in which part of the positronium is excited by laser excitation: $\overline{H}^+$ is then obtained in a two-step process by the subsequent reactions $Ps + \overline{p} \rightarrow \overline{H} + e^-$ and $Ps^* + \overline{H} \rightarrow \overline{H}^+ + e^-$. The positronium cloud is produced, like in the AEGIS experiment, by leading a positron beam through a nanoporous insulator. The source of the positron beam, however, is an electron beam from a small linear accelerator that is lead through a layer of tungsten W. See Fig. 1.6 for an illustration.

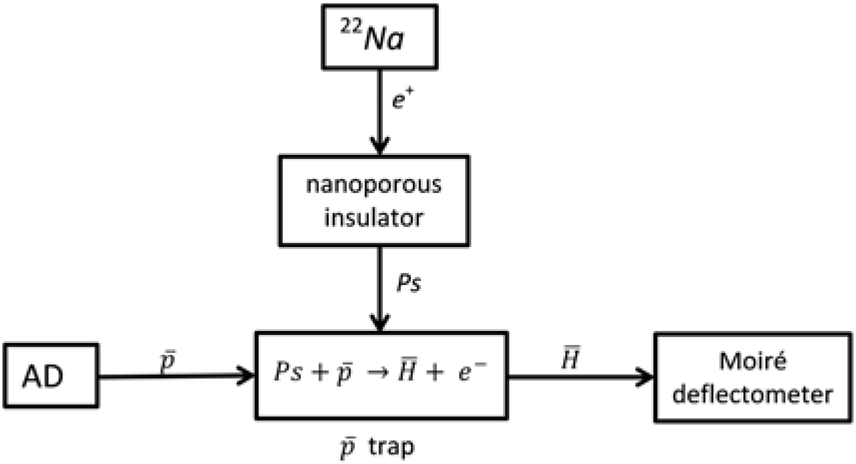


Figure 1.5: Schematic illustration of the AEGIS experiment. This reflects only the bare essence: details that others may find important are left out.

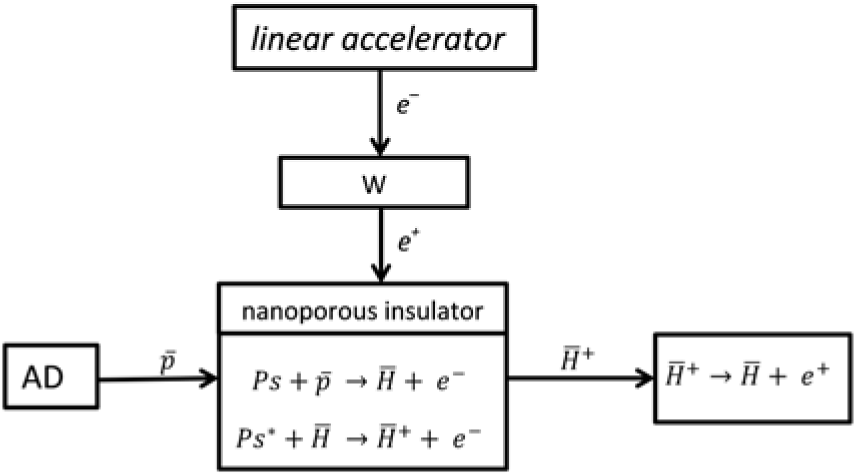


Figure 1.6: Schematic illustration of the GBAR experiment. This reflects only the bare essence: details that others may find important are left out.

Like the GBAR experiment, the ALPHA experiment also aims to determine the gravitational acceleration of antihydrogen on earth by using $\overline{H}$ atoms that are initially at rest (ALPHA collaboration, 2013). This time, however, the $\overline{H}$ atoms are produced by injecting cooled antiprotons from the AD into a positron plasma, obtained from trapping positrons emitted by a ^{22}Na source. $\overline{H}$ atoms are then trapped using an inhomogeneous magnetic field; the gravitational acceleration is then measured by measuring the time and position of annihilation events following a shutdown of the magnetic field. See Fig. 1.7 for an illustration. A first trial has yielded the result that the gravitational mass $\overline{m}_g$ of $\overline{H}$ must be in the range $-65\overline{m}_i < \overline{m}_g < 110\overline{m}_i$, where $\overline{m}_i$ is the inertial mass of $\overline{H}$.

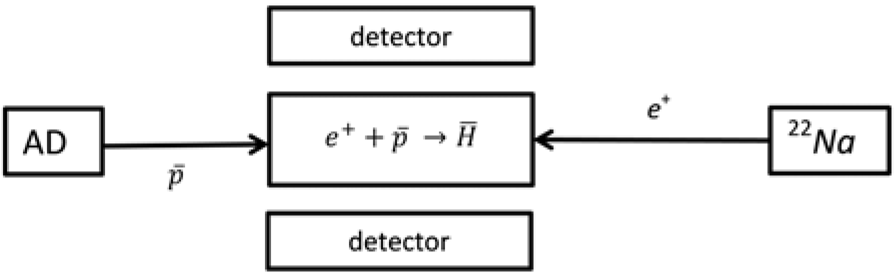


Figure 1.7: Schematic illustration of the ALPHA experiment. This reflects only the bare essence: details that others may find important are left out.

Last but not least, the MAGE collaboration aims to determine the gravitational acceleration of antimatter on earth by measuring the deflection of an initially horizontal, low-velocity muonium (μ^+e^-) beam (MAGE collaboration, 2018). The idea is that a virtually mono-energetic and divergence-free muonium beam is produced from an antimuon (μ^+) beam that is stopped in a superfluid helium film: μ^+e^- formed in the He phase is then expelled *vertically* due to the negative chemical affinity of μ^+e^- with He; the vertical μ^+e^- beam is deflected into horizontal direction by reflection off a 45°-inclined surface coated with superfluid He. The antimuon beam originates from a hadron collider, which produces a beam of positively charged pions (π^+): this automatically yields an antimuon beam due to the decay reaction $\pi^+ \rightarrow \mu^+ + \nu_\mu$. See Fig. 1.8 for an illustration.

That said, it is currently not the case that we already *know* that antimatter falls down on earth: there is, thus, nothing that withholds us from doing a thought experiment, in which a body of antimatter is released parallel to the

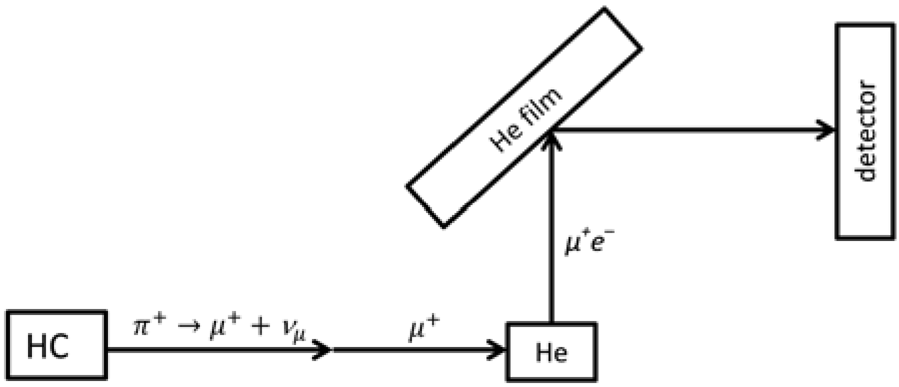


Figure 1.8: Schematic illustration of the MAGE experiment. This reflects only the bare essence: details that others may find important are left out.

earth's surface, but with the opposite outcome that its height as a function of time is an upward curve like the one shown in Fig. 1.9-(b).[28] This thought experiment is a perfectly valid scientific technique in theoretical physics for thinking through the consequences of repulsive gravity for our understanding of the fundamental workings of the universe.

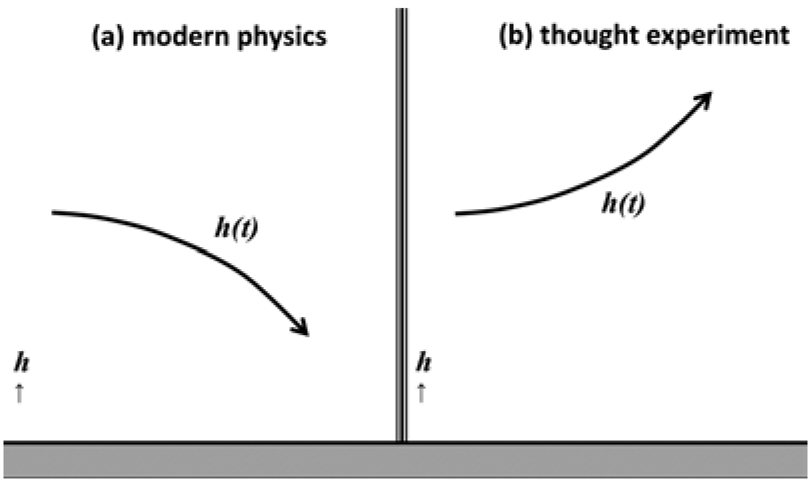


Figure 1.9: Illustration of the thought experiment. Figure (a) shows the height $h(t)$ of a body of antimatter above the earth's surface as a function of time, as predicted by modern physics (GR). Figure (b) shows the height $h(t)$ as a function of time as assumed in the thought experiment.

1.3 A criterion of truth

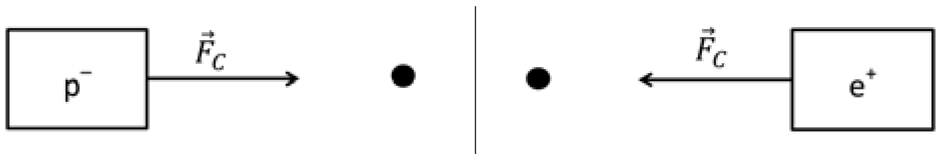
This section derives an important implication of the existence of a matter-antimatter repulsive gravity in terms of the classical concepts 'inertial mass' and 'gravitational mass'.

To start with, let's recall that *inertial mass* is the resistance of a body against a change in motion, as laid down in Newton's second law:

$$\vec{F}_{net} = m_i \cdot \vec{a} \tag{1.10}$$

Here the vector $\vec{F}_{net}$ represents the net force on a body, the number m_i its inertial mass and the vector $\vec{a}$ its acceleration; *inertial rest mass* m_0 is then the inertial mass of a body in rest, that is, that doesn't move relative to an observer.

Now it has already been established that antimatter has *positive* inertial rest mass: a negative inertial rest mass would, for example, be impossible to reconcile with the stability of antihydrogen observed by the ALPHA collaboration (2011), because the Coulomb force would then cause the antiproton and the positron to repel each other. See Fig. 1.10 for an illustration.



(a) Antiproton (b) Positron

Figure 1.10: Free-body diagrams of (a) the antiproton and (b) the positron in an antihydrogen atom. In both diagrams, the box represents the particle in question, and the black dot indicates the position of the other particle. So, both for the antiproton and for the positron the Coulomb force vector $\vec{F}_C$, represented by a black arrow, is directed *towards* the other particle because of the opposite electric charges. But if the inertial mass is *negative*, then the antiparticles will accelerate *away from* each other if we apply Eq. (1.10) with $\vec{F}_C = \vec{F}_{net}$: the acceleration vector $\vec{a}$ has then in both cases the opposite direction as the net force vector. This classical picture may not hold up to the last detail at subatomic level, but it clearly indicates that antihydrogen cannot be stable if antiparticles have negative inertial mass.

Gravitational mass, on the other hand, is the 'charge' of a body for the gravitational force as laid down in Newton's law of gravitation:

$$\vec{F}_{12} = G \cdot \frac{m_{g(1)} \cdot m_{g(2)}}{r^2} \cdot \vec{e}_{12} \tag{1.11}$$

Here the vector $\vec{F}_{12}$ represents the gravitational force on the first body exerted by the second body, the number G is a constant, the numbers $m_{g(1)}$ and $m_{g(2)}$ the gravitational mass of successively the first and the second body, the number r the distance between them, and the vector $\vec{e}_{12}$ is a unit vector from the position of the first body to that of the second.

To analyse repulsive gravity, consider a case in which a body of antimatter is initially at rest above the earth's surface, and in which the earth's gravitational force on that body of antimatter is the *only* force—so applying Eqs. (1.10) and (1.11) we have $\vec{F}_{12} = \vec{F}_{net}$. Since antimatter has *positive* inertial rest mass, an upwards-directed acceleration of the body of antimatter then means that the gravitational force vector $\vec{F}_{12}$ on the body of antimatter is directed *away from earth* in a free-body diagram. But that is only possible if the gravitational mass of the body of antimatter is *negative*: all other factors on the right hand side of Eq. (1.11) are namely *positive*, and the unit vector $\vec{e}_{12}$ is directed *towards* earth. See Fig. 1.11 for an illustration.

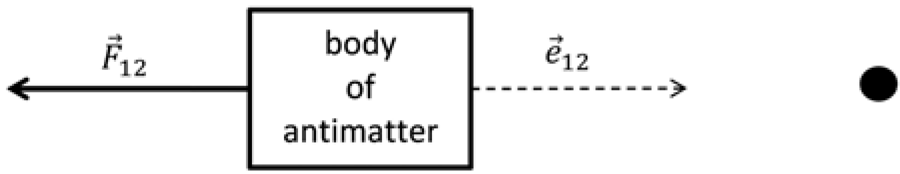


Figure 1.11: Free-body diagram for the body of antimatter. The dot on the right represents the position of earth, the square box the body of antimatter. The leftwards black arrow then represents the gravitational force $\vec{F}_{12}$ that earth exerts on the body of antimatter, and the rightwards dotted arrow represents the unit vector $\vec{e}_{12}$ occurring in Eq. (1.11). Then it has, thus, to be the case that $m_g < 0$ for massive antiparticles.

Thus speaking, a matter-antimatter gravitational repulsion being a fact of nature *necessarily implies* that the following conjunction holds for the observable properties gravitational mass $\overline{m}_g$ and inertial rest mass $\overline{m}_0$ of any massive antiparticle:

$$\overline{m}_0 > 0 \wedge \overline{m}_g < 0 \tag{1.12}$$

Note that this expression is model-free: it has been derived without any assumption on what antimatter *is*, and without taking a position on whether inertial mass and gravitational mass are *primary* or *secondary* properties as meant by John Locke, that is, whether these are observable properties that are also present in the thing in itself, or properties that are observable but not present in the thing in itself. In terms of *active* and *passive* gravitational mass as defined by Bondi—*active gravitational mass* is the mass that is the source the gravitational fields and *passive gravitational mass* is the mass on which the gravitational fields act (Bondi, 1957)—we have thus derived that the passive gravitational mass of antimatter is negative, but without making any statement about its active gravitational mass.

The above reasoning can also be found in a more condensed form in (Cabbolet, 2011b). Historically, the combination of positive inertial mass and negative gravitational mass has occurred in the literature since the late 1950's (Morrison and Gold, 1958; Bondi, 1957; Morrison, 1958); in their 1957 essay, Morrison and Gold were the first to conclude that antimatter must have this combination of properties in case of a matter-antimatter gravitational repulsion. In more recent times, also in the works of Hajdukovic (2011) and of Benoit-Lévy and Chardin (2012) it has been assumed that antimatter has the combination of properties of Eq. (1.12) in the context of a matter-antimatter gravitational repulsion.

What is important is that one should henceforth distinguish between *gravitational mass* and *inertial mass*. In the framework of Newton's theory we have $m_g = m_i = m_0$ for all particles, while in the framework of GR we have $m_g = m_i$ for all particles due the WEP (although we not generally have $m_i = m_0$ due to relativistic effects). So, one may have gotten used to thinking that these masses are the same, but in the context of a matter-antimatter repulsive gravity this is wrong thinking.[29]

1.4 Objections and replies

Objection 1.4.1. "*Berkeleyan idealism with regard to properties only is not the idealism of George Berkeley. Realism with regard to physical systems and idealism with regard to properties? Incoherent combination.*"—anonymous referee of journal that also covers philosophy of physics, rejecting in 2015 my conference paper (Cabbolet, 2015a). ■

Reply 1.4.2. The Berkeleyan idealism regarding properties, whose meaning is precisely stated in Th. 1.1.1, follows straight from the postulates of OQM by modus ponens. There is nothing incoherent about it: Th. 1.1.1 merely exposes a very strange feature of OQM. This shows that even the simplest of truths evokes emotional rejections based on strong feelings of dislike, when it yields some kind of criticism to a widely held belief. Note that this objection has been passed off as an objective evaluation of the quality of my paper. ■

Objection 1.4.3. "*[The] actually existing problems concerning the unification of quantum mechanics and general relativity remain untouched*".—Gerard 't Hooft on my 2007 concept-dissertation (2008c) ■

Objection 1.4.4. "*[It] has been tried to make clear that there exists an unsolved problem in theoretical physics: the formulation of a theory that unites quantum mechanics (QM) and general relativity (GR) in a broader theory. ... But upon reading a fundamental misunderstanding catches the eye. His exposition actually tries to show that Special Relativity (SR) and QM are incompatible. Which is not true.*".—Boudewijn Verhaar on my 2007 concept-dissertation (2008) ■

Reply 1.4.5. Verhaar's objection is a false assesment of my work. That said, what I see as the biggest problem is that any unification of GR and quantum physics is beforehand doomed to failure if the quantum physics imply the Berkelian idealism regarding properties (BIRP) discussed in Sect. 1.1—and that *is* the most common view. This BIRP poses, namely, a conceptual issue for the development of a quantum theory of gravitation. An important physical principle in this context is of course the principle of curvature as stated by GR: spacetime is curved **due to** the energy of objects (particles) as expressed by the Einstein field equations. The principle is backed up by empirical evidence, but if we want to develop a quantum theory of gravity and we want to recontextualize this physical principle in the framework of quantum theory, then we stumble on a problem. Namely, the spacetime of GR is not a substance, not an object: the fact that it has a metric doesn't make it an object—it is the void between the objects. That being said, it cannot be an individual in the quantum-theoretical ontology that has a wave-function. So we cannot speak of a 'metric operator' $\hat{g}$: the metric is not an observable property that a quantum 'has' (or can 'have'). So on the one hand, spacetime is itself not a quantum object that is subjected to this BIRP: therefore, at any spatiotemporal position $(\vec{x}, t)$ spacetime has a definite curvature regardless whether it is measured or not[30]. But on the other hand, the quanta that populate the universe do not 'have' a definite energy (or gravitational mass), which is supposed to be the cause of that curvature, unless the energy is measured: that is the BIRP—so no measurement, no cause of curvature. That's the problem: this is at the *conceptual level*, so one cannot "calculate" his way out of trouble. See Fig. 1.12 for an illustration.

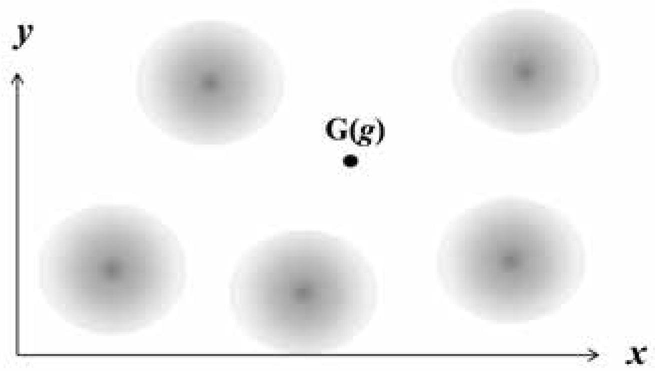


Figure 1.12: Illustration of the issue for quantum gravity. The picture shows a system of five quanta at a given time t. Horizontally the spatial $x-$axis, vertically the spatial $y-$axis; the $z-$axis is suppressed. The blurred spots represent the probability distributions of the quanta, with a darker tint indicating a higher probability of being found at that position. So at the spatiotemporal position indicated by the black dot, spacetime does have the property curvature with a definite value G regardless whether we make a measurement or not. But without measurement, the quanta do not 'have' a definite energy, which is supposed to be the cause of that curvature. Therefore, the principle of curvature cannot be recontextualized in the framework of OQM.

That said, this BIRP has potentially far-reaching implication for one of the hottest topics of theoretical research: the quantum physics of a black hole. The thing is, namely, that this BIRP *rules out* that the quantum state of the black hole can be anything else than an eigenstate of energy—for if the quantum state of the black hole would be a superposition of eigenstates of energy, then the black hole would not 'have' a definite energy, and consequently there would not be any curvature or event horizon.

Of course, one can approach the problem purely pragmatically and develop an equation by which the curvature emerges, for example, from expectation values of momenta of the quanta as expressed by

$$G^{\mu\nu} = k \cdot T(\langle p \rangle_1, \langle p \rangle_2, \langle p \rangle_3, \ldots)^{\mu\nu} \tag{1.13}$$

These field equations are mathematically well-defined, so one might think that this solves the problem. However, the expectation values $\langle p \rangle_j$ refer to expected outcomes of experiments: these are not properties that the quanta 'have' in absence of measurement. So this "solution" would be **conceptually incoherent**: it is not a solution at all. So, the problem concerning the unification of QM and GR is *conceptual* of nature. Consequently, it cannot possibly be solved by merely inventing new mathematics. ■

Objection 1.4.6. "*The formulation of quantum mechanics considered here is widely regarded as inadequate within the foundational literature, and the approach taken to quantum gravity appears misconceived.*"—referee of a philosophy journal, rejecting my conference paper (Cabbolet, 2015a) ■

Reply 1.4.7. Objection 1.4.6 is nothing but the bare denial of the two points that were put forward in the submitted paper, which had been presented at a conference on Planck-scale physics; this objection can be paraphrased by the following two negative claims about the submitted paper:

(i) it is false that orthodox QM entails a BIRP, as derived in Sect. 1.1;

(ii) it is false that a BIRP, if this would be entailed by orthodox QM, poses an issue for quantum gravity, as described in Reply 1.4.5.

As I will demonstrate below, both claims (i) and (ii) are false: the referee has responded in accordance with the response-in-an-outburst model on page li—he has merely blurted out whatever came first to mind without giving it a second thought.

As to the first claim (i) by the referee, we start by noting that the BIRP follows by modus ponens from two postulates of orthodox QM (plus a completeness argument). That means that to deny that the BIRP is a feature of orthodox QM, we either have to deny that orthodox QM is a complete theory, or we have to deny that the SPP (Post. 1.1.2) and the PP (Post. 1.1.3) are postulates of orthodox QM—note that these stem from the very founding fathers of QM, Von Neumann and Dirac.

Let us begin with the SPP, Post. 1.1.2: to deny that the SPP is true in the framework of orthodox QM means that we take the view that one of the following propositions can be true *in the framework of orthodox QM* for a one-component quantum system, an observable property X and the associated maximal operator $\hat{X}$ with eigenvalues $\{x_1, \ldots, x_n\}$:

(P1) a quantum system that's in the eigenstate $\mid x_j \rangle$ of the operator $\hat{X}$ does ***not*** have the property X with quantitative value x_j;

(P2) a quantum system that's ***not*** in the eigenstate $\mid x_j \rangle$ of the operator $\hat{X}$ does have the property X with quantitative value x_j.

As to the first of these, P1, orthodox QM predicts that the probability $P^{\mid \psi \rangle}(x_j)$ that the value of the property X of a quantum system in the state $\mid \psi \rangle$ will be measured to be x_j is

$$P^{\mid \psi \rangle}(x_j) = (\langle x_j \mid \psi \rangle)^2 \tag{1.14}$$

For a quantum system in the eigenstate $\mid x_j \rangle$, orthodox QM thus predicts that it is a certainty that the outcome of a measurement of the value of the property X will be x_j: Eq. (1.14) gives $P^{\mid x_j \rangle}(x_j) = 1$. Ergo, accepting proposition P1 is denying that a quantum system has the property X with quantitative value x_j when it is a certainty that the value of the property X will be measured to be x_j. This is absurd.

As to the second proposition, P2, this is saying that *even though* a quantum system is in an indeterminate state $\mid \psi \rangle$ that is a linear combination of multiple different eigenstates of the operator $\hat{X}$, it still *does have* the property X with quantitative value x_j . However, if the quantum system is in such an indeterminate state $\mid \psi \rangle = c_1 \cdot \mid x_1 \rangle + \ldots + c_n \cdot \mid x_n \rangle$, then the probability $P^{\mid \psi \rangle}(x_i)$ that the value of the property X will be measured to be $x_i \neq x_j$ will be nonzero for at least one value $x_i \neq x_j$. On the other hand, if a quantum system *actually* has property X with quantitative value x_j then the probability that another value $x_i \neq x_j$ will be measured is zero. This second position P2 thus corresponds with the view that the wave function ψ is an incomplete description of a quantum state. But the view of orthodox QM is that the wave function ψ ***is*** a complete description of a quantum state: therefore, this second proposition P2 cannot be true *in the framework of orthodox QM.* This demonstrates that the SPP cannot be denied.[31]

Proceeding, to deny that the PP is a postulate of orthodox QM is to deny that the wave function of a quantum system upon measurement collapses onto an eigenstate in the framework of orthodox QM. This is absurd—the collapse of the wave function upon measurement is one of the essential features of orthodox QM described by Von Neumann:

> "*We therefore have two fundamentally different types of interventions which can occur in a system S ... First, the arbitrary changes by measurements ... Second, the automatic changes which occur with passage of time.*"—Von Neumann (1955)

To see the ridiculousness of calling the PP "inadequate", imagine this referee assessing Von Neumann's original work for Springer in 1932:

> *Dear Dr. Von Neumann,*
> *I have read your work 'Mathematische Grundlagen der Quantenmechanik'. Unfortunately, your formulation of quantum mechanics is inadequate. Therefore, your work is rejected for publication by Springer.*

Just think about it. This demonstrates that the PP cannot be denied either. So, I consider it herewith proven that claim (i) by the referee is false.

As to the second claim (ii) by the referee, let's have a look at the Einstein Field equations as laid down in GR:

$$G^{\mu\nu} = k \cdot T^{\mu\nu} \tag{1.15}$$

This identifies the Einstein curvature tensor $[G^{\mu\nu}]$, which is a property of spacetime, with the product of a number k and the stress-energy tensor $[T^{\mu\nu}]$, which derives from properties of particles. Ergo, if these properties of particles are non-existent—in the sense that particles do not 'have' these properties due to the BIRP—then the stress-energy tensor vanishes: by Eq. (1.15) then also the Einstein curvature tensor vanishes. That's not a misconceived approach to quantum gravity: that's the mere establishment of a fact that derives from the meaning of the Einstein field equations and the BIRP entailed by orthodox QM. And that fact poses a problem for the development of a theory of quantum gravity: it means, namely, that there *cannot possibly be* a theory T that satisfies the first order conditions

$$T \vdash A_{QM} \tag{1.16}$$

$$T \vdash A_{GR} \tag{1.17}$$

for the axioms A_{QM} of orthodox QM and A_{GR} of GR translated in the language of T. That demonstrates that claim (ii) by the referee is false also: his referee report lacks substance to such a degree that it is at the level of pseudoskepticism—as I see it, this is scientific misconduct. ∎

Objection 1.4.8. "*Why this assumption of repulsive gravity? Why not developing a theory from the assumption that a distant planet is made of green cheese?* "—Hartmann (2007) ∎

Remark 1.4.9. By asking this question, Hartmann expressed doubt in the truthlikeness—i.e. the closeness to the truth—of the assumption of repulsive gravity. The question in itself is legit, but because of *the way things went* it came across to me as academic bullying, cf. page xxxii. To the defense of Hartmann: that may not have been his intention. Unfortunately, history cannot be changed. ∎

Reply 1.4.10. The assumption of repulsive gravity led *in my case* to what Descartes called a *clear and distinct idea* about the fundamental workings of the universe—that is, an idea about the fundamental workings of the universe that presents itself to the mind so clearly and distinctly that all grounds of doubt are excluded. So, I honestly believe in repulsive gravity. The assumption that a distant planet is made of green cheese, on the other hand, has never led to such an idea about the fundamental workings of the universe—of course we may postulate the existence of this green-cheese planet and we may endow it with properties that can explain observations, but still nobody believes in it. ∎

Objection 1.4.11. "*[Repulsive gravity] goes completely against all our physical knowledge and is clearly wrong*"—Krauss, in: (Van Nuffel and Luyckx, 2013) ■

Objection 1.4.12. "*Note that ... a statement about physics is just wrong. All evidence (theoretical and experimental) is that antiparticles are attracted by gravity in the same way as are particles.*"—anonymous referee of a journal in applied mathematics, commenting in 2006 about my submitted paper in which the EPT was still formalized as 'just' a first-order theory (cf. page xxxi) ■

Objection 1.4.13. "*Cabbolet has developed a number of abstract axioms, from which apparently deep thoughts emerge, but nowhere are these made explicit ... When he is being explicit, it is immediately obvious that his theory is false. He asserts, namely, that antimatter particles can fall upwards, which is absolutely impossible.*—'t Hooft, in: (Konings, 2008a)

Reply 1.4.14. These are three objections by elite physicists: all four use modern physics theories *beyond their established area of application* as a criterion of truth. This is wrong thinking: it is namely a basic principle of science that, as Feynman put it, "experiment is the sole judge of scientific truth" (2011). This raises the question as to whether they truly understand the concept of a thought experiment—they certainly didn't recognize one in my work. To their defense: the term wasn't explicitly mentioned in the (concept)-dissertation—I thought it was plain obvious, but that apparently was wrong thinking on my side. Interestingly, the philosophers who were heavily criticized for approving my dissertation actually did recognize a thought experiment in my work; see e.g. (De Swart, 2012). ■

Remark 1.4.15. Regarding Krauss, we should not dismiss the possibility that words have been put in his mouth: he has, namely, been interviewed by two members of the organized skeptical movement, Van Nuffel and Luyckx, who may have been out to have Krauss discredit my work. Anyway, I confronted Krauss with the fact that it is not yet known whether repulsive gravity is wrong. He replied as follows (personal communication, 2013):

> "*If I said it was clearly wrong, I overstated the case. I should have said it is very likely wrong.*"—Lawrence Krauss

This retraction, however, has never been published. All the general public sees is the claim by the scientific advisor to the president of the USA that my work is wrong—and they'll take him at his word. ■

Objection 1.4.16. "*I also object against the Elementary Process Theory* ***because*** *it makes a statement that by no means is supported by existing observations ... I'm referring to the statement that matter repulses antimatter instead of attracting it.*" (emphasis added)—condensed-matter expert, assessing my 2007 concept-dissertation for the LOWI ■

Reply 1.4.17. The above objection stems from the physicist's erroneous belief—he really has this belief, I talked with him in 2016—that new theories are derived from experimental data, which shows just how detached he is from the everyday practice in foundational research: these days one cannot open a physics journal without being confronted with these papers exploring ideas of spacetimes with ten or eleven dimensions, multiverses made up of multiple universes, or supersymmetry—none of which is supported by observations. ■

Objection 1.4.18. "*[Instead of proposing repulsive gravity] he could also have proposed that gravity may be caused by dancing devils (fallen angels!). Or he could have formulated his theory from the hypothesis that you can let the wand of your opponent fly upwards with the spell 'Expelliarmus'.*"—Nienhuys (2014) ■

Reply 1.4.19. These are false metaphors: considering repulsive gravity is neither the same as considering that gravity may be caused by dancing devils, nor the same as considering that you can let the wand of your opponent fly upwards with the spell 'Expelliarmus'. It is currently namely not known that the hypothesis of repulsive gravity is false, while the two other things mentioned by Nienhuys are known falsehoods. It is, thus, an outright fabrication by Nienhuys to state that these things are comparable.

From the controversy on my work I have compiled seven tell-tale signs of pseudoskepticism, which I have presented in my unpublished essay (Cabbolet, 2018d). The use of false metaphors is such a tell-tale sign: it is a clear indication that Nienhuys' writing has nothing to do with healthy scientific skepticism—he is merely out to publicly discredit my work by comparing it to known falsehoods. ■

Objection 1.4.20. "*The manuscript is an example of what the foundations of physics should 'not' be. A very heavy philosophical reasoning is applied to an approach that from the point of view of the foundations of physics is isolated and close to crackpot. You should as an editor not disturb serious scientists and send them this type of manuscripts and ask them to review.*"—Anonymous referee of a journal on foundational issues rejecting my unpublished paper "Meditations on First Principles Underlying an Assumed Matter-Antimatter Gravitational Repulsion: a Dialectic Essay" in 2013 ■

Reply 1.4.21. To get this straight: with "an approach that from the point of view of the foundations of physics is isolated and close to crackpot" this referee refers to hypothesizing repulsive gravity for the purpose of thinking through the consequences thereof for our understanding of the fundamental workings of the universe. An ad hominem attack is another tell-tale sign of pseudoskepticism: the use of the word 'crackpot' here indicates that it is a core belief of this referee that gravity is attraction only and that he has reacted emotionally to the fact that I challenge his core belief—what applies here is the response-in-an-outburst model on page li. ■

Objection 1.4.22. "*An important element in his reasoning is that 'antimatter in a gravitational field falls upwards'. Every physicist he ever met has tried to talk him out of this delusion. Without success.*"—'t Hooft (2015b) ■

Reply 1.4.23. First of all: just note the choice of words. Furthermore, the second sentence is a false statement of fact: it is not true that every physicist I ever met tried to talk me out of considering repulsive gravity. Some really did have the ability to suspend their disbelief. ■

Objection 1.4.24. "*Cabbolet thus assumes that antimatter has negative mass. That contradicts relativity theory and quantum mechanics, which both forbid negative masses. In itself that's not strange, but here the contradiction is taken as the starting point, and there is no hint that the problem [with the unification of GR and QM] lies at the gravitational interaction of antimatter.*—Van Joolingen (2011c) ■

Reply 1.4.25. To make this objection clear: Van Joolingen thinks that I started my research endeavor by merely asking "what if antimatter has negative mass?", and that I then decided to develop a theory from there. In a phone conversation I had with him he compared this to asking "what if there is a third fundamental electric charge?" and then developing a new theory from there. His objection is thus (i) that in general, new physics cannot be developed from blindly assuming a proposition that is forbidden by modern physics; and (ii) that the particular proposition that I have assumed is irrelevant for the unification of GR and QM.

While I agree with both points (i) and (ii) in the previous sentence, the crux is that Van Joolingen has the wrong idea of how I developed my theory and what the aim of it all is. First of all, the whole decision to develop a theory was *preceded* by a clear and distinct idea about the fundamental workings of the universe: from there I have *derived* that massive antiparticles must have positive inertial mass and negative gravitational mass, and from there I quickly found out that this clear and distinct idea cannot be consistently described in the frameworks of GR or quantum theory (see Ch. 2). Furthermore, my work should not be viewed as an attempt to unify GR and QM; rather, the EPT is a meant as a candidate for a unifying scheme that applies to all four fundamental interactions and the research program is aimed to (dis)prove that it is. See part IV for precise definitions. ■

Objection 1.4.26. "*Marcoen has said things that are impossible ... Nowadays you can make heavy anti-elements, but you have to decelerate them enormously and then you would have to try to establish whether they fall up ... It is very difficult to measure and* ***we all know the answer already***." (emphasis added)—'t Hooft in (Scheers, 2016) ■

Reply 1.4.27. Given the resistance I have experienced from the physics community, the emphasized statement—which, I believe, expresses the view of a significant part of the modern physics community—may gain some interest after a detection of repulsive gravity, because then it yields a quite explicit confirmation of the famous aphorism:

> *the biggest enemy of scientific inquiry is not ignorance, but the illusion of knowledge.*

Different versions of the aphorism have been used by others (e.g. Boorstin and—according to some—Hawking). It is closely related to the response-in-an-outburst model on page li. ■

Chapter 2

The destructive phase

> "*Cabbolet is simply one of these typical pseudoscientists. In Belgium they fell for it, but at a philosophy department not at a physics department. Telling.*"—Casper Hulshof, lecturer at Utrecht University, commenting on the news that I obtained my PhD in Belgium (2011).

2.1 Rejection of theories of modern physics

GR and ad-hoc modifications thereof

The basic idea underlying Einstein's GR is the equivalence principle, that is, the "complete physical equivalence of a gravitational field and a corresponding acceleration of the reference system" (Einstein, 1907). Let us have a closer look at this principle. Let U be a force-free environment and let Bob, an observer at rest in that environment, have fitted U with a rectangular coordinate system ξ^α. Consider now the inertial motion of a massive body in that environment in ξ^1-direction; the position $\xi^\alpha(\tau)$ of the massive body as a function of the proper time τ ticked off by a clock co-moving with the body then satisfies

$$\frac{d^2\xi^\alpha}{d\tau^2} = 0 \tag{2.1}$$

Now let Alice be an observer at rest in a box that accelerates uniformly at a rate $1g$ in ξ^2-direction in Bob's coordinate system, which is upwards for

Alice. After the massive body has entered the box, Alice sees it accelerating downwards at a rate $1g$; see Fig 2.1 for an illustration. The equivalence principle is then that the acceleration with rate $1g$ of the inertially moving massive body in the accelerated reference frame of Alice is equivalent to the acceleration at a rate $1g$ of a massive body in the earth's gravitational field in a non-accelerated reference frame.

Obviously, nothing will change if we replace the massive body by a massive body of antimatter: Alice, at rest in the uniformly accelerating box, will see the body of antimatter falling down in the same way as the massive body of ordinary matter, and by the equivalence principle there is thus no difference in the acceleration of matter and antimatter in a gravitational field. That is: according to the equivalence principle, both matter and antimatter will fall down on earth.

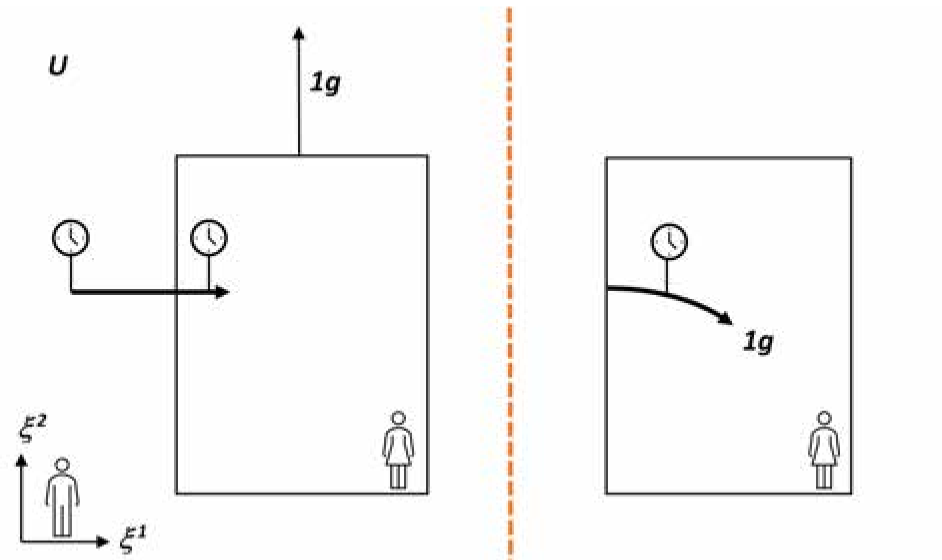


Figure 2.1: Illustration of Einstein's equivalence principle. To the left of the dotted line is the force free environment U; in the lower left corner Bob and the coordinate system are depicted. The straight horizontal arrow is the world line of the inertially moving massive body to which a clock is attached; the box is the uniformly accelerating box in which Alice is at rest—Alice is depicted as standing upright in the lower right corner of the box. To the right of the dotted line, the curved arrow in the box depicts the motion of the massive body as observed by Alice, who is at rest in the accelerating box.

Thinking this equivalence principle consequently through led Einstein to the idea that gravitation is nothing but motion on geodesics of a curved spacetime. This is an important postulate: GR consists of this postulate and the Einstein field equations

$$G^{\mu\nu} = k \cdot T^{\mu\nu} \tag{2.2}$$

that lay down how the curvature of spacetime relates to the spatial momenta and energies of the particles that are present in spacetime.

The thought experiment of Ch. 1, in which we assumed that massive antiparticles will be repulsed be the gravitational field of a body of ordinary matter, is incompatible with this equivalence principle. Obviously, if a massive body of antimatter and a massive body of ordinary matter move inertially next to each other in a force-free environment, then both will be observed as falling down by an observer at rest in a box accelerating "upwards" at a rate $1g$ as in Fig. 2.1. But if a matter-antimatter repulsive gravity is a fact of nature, then the acceleration of the bodies observed by the observer at rest in the accelerated frame is no longer equivalent to the acceleration of these bodies in a gravitational field of the earth, because the body of matter will accelerate *towards* earth at a rate $1g$ while the body of antimatter will accelerate *away from* earth at a rate $1g$.

Another way to state the equivalence principle is to say that inertial mass and gravitational mass are the same. This formulation of the principle, labeled the Weak Equivalence Principle (WEP), "is not a separate fact but is basic to the theory. Accordingly the ratio of inertial and passive gravitational masses is the same for all bodies" (Bondi, 1957). Thus speaking, in the framework of GR we get the following conjunction for the rest mass $\overline{m}_0$ and the (passive) gravitational mass $\overline{m}_g$ of a body of antimatter:

$$\overline{m}_0 > 0 \wedge \overline{m}_g > 0 \tag{2.3}$$

On account of the WEP, it is thus **absolutely impossible** from the perspective of GR that rest mass and gravitational mass of a body of antimatter have opposite signs. That is, GR is inconsistent with conjunction (1.12), the main implication of a matter-antimatter gravitational repulsion derived in Sect. 1.3.

In his 1637 book *Discourse de la Méthode*, Descartes gave the following criterion for theory rejection: if we have a reason for doubting a theory, then the theory should be rejected *in its entirety.* That said, no one will disagree with ‘t Hooft that repulsive gravity goes squarely against everything GR stands for, cf. page xxxvi: if we would detect repulsive gravity, we would therefore have a serious reason for doubting GR. So altogether, if we think through the consequences of a matter-antimatter repulsive gravity for our understanding of the fundamental workings for the universe, then the very first consequence is that GR then has to be rejected in its entirety.

In the Scripture it is written that “*no one puts new wine into old wineskins. For ... the wine and the skins would both be lost. New wine calls for new wineskins.*” (Mark 2:22). Applying that in the present context, that means repulsive gravity (new wine) calls for a new theory of gravity (new wineskins). However, two authors have nevertheless put the proverbial new wine in old wineskins: Santilli (1999) and Villata (2011) have both developed *ad hoc modifications* of GR that predict antimatter antigravity. Experimentally the two theories are indistinguishable, but Santilli has formulated his theory using what he calls *isodual mathematics.*[32] The principle of gravitation is that of GR: gravity is the deflection of a continuous particle trajectory due to the curvature of spacetime. But antimatter now “sees” an inverted spacetime, causing antigravity: as Santilli put it, “the trajectories we observe for antiparticles are the *projection* in our spacetime of the actual trajectories in isodual [i.e. inverted] space” (1999). And according to Villata, “all masses are and remain positive” (2011): in this framework, the passive gravitational mass $\overline{m}_g$ in conjunction (1.12) is thus a *secondary property* in Locke’s sense.

At an astronomic level where planets can be modeled as classical particles, these ad hoc modifications of GR are consistent with a matter-antimatter repulsive gravity. However, these ad hoc modifications of GR are *philosophically wrong.* That is, it is philosophically wrong to base the description of the fundamental workings of a matter-antimatter repulsive gravity on a principle of gravitation that has been developed from the assumption that gravity is attraction only: if a matter-antimatter repulsive gravity would turn out be a fact of nature, then the very principle on which its description by Santilli and Villata rests has *itself* been developed from a falsehood. So, although these ad hoc modifications of GR make predictions that at the macroscopic level may be consistent with observations if repulsive gravity were a fact of nature, it is ruled out that they teach us anything new about the fundamental workings of a matter-antimatter repulsive gravity.

That said, additional criticism has been given to Villata's method of theory development (Cabbolet, 2012; Cross, 2011). In a nutshell, Villata assumes CPT-symmetry and uses the operators for charge, parity and time inversion to transform the equation of motion of GR

$$\frac{\mathrm{d}^2\mathrm{x}^\lambda}{\mathrm{d}\tau^2} = -\frac{m_{(g)}}{m_{(i)}}\frac{\mathrm{d}\mathrm{x}^\mu}{\mathrm{d}\tau}\Gamma^\lambda_{\mu\nu}\frac{\mathrm{d}\mathrm{x}^\nu}{\mathrm{d}\tau} \tag{2.4}$$

into the equation

$$\frac{\mathrm{d}^2\mathrm{x}^\lambda}{\mathrm{d}\tau^2} = -\frac{-m_{(g)}}{m_{(i)}}\frac{\mathrm{d}\mathrm{x}^\mu}{\mathrm{d}\tau}\Gamma^\lambda_{\mu\nu}\frac{\mathrm{d}\mathrm{x}^\nu}{\mathrm{d}\tau} \tag{2.5}$$

which carries an additional minus sign, claiming that "antigravity appears as a prediction of general relativity when CPT is applied" (Villata, 2011). To this has been objected as follows:

> "*CPT-symmetry is a law at the metalevel that follows from the actual laws of physics at object level. In other words, from the theory of what gravitation actually is it should be clear at object level what the process of gravitational interaction for matter is and what the process of gravitational interaction for antimatter is, and from there it should follow at the metalevel that CPT-symmetry holds (or doesn't hold) between these processes. In theory development, it is one thing to assume a symmetry as a condition that has to be satisfied by a yet to be developed theory, but Villata puts the cart before the horse: he assumes CPT-symmetry and uses the operators C, T, and P* ***as if*** *these are applicable to derive the theory of what the process of gravitational interaction of antimatter is at object level from the theory of the corresponding process of matter. But these operators cannot be applied that way: this method of theory development is inadmissible.*"—Cabbolet (2012)

A similar argument is found in (Cross, 2011). Villata, who applied his modification of GR predicting matter-antimatter repulsive gravity mainly to explain the observed accelerated expansion of the universe, gave an interesting reply to the criticism:

> "*[Cabbolet] speaks of "cart before the horse" and "inadmissible method", and here he is partly right, in the sense that in his paper Villata is more concerned with scientific results and to give an intuitive and understandable view of the theory rather than to follow a rigorous and unassailable (but less effective) methodology.*"—Villata (2012)

That is, Villata has applied a purely pragmatic method of theory development to obtain a theory that allowed him to *get on with things* in the intended study: from the purely pragmatic point of view it is less important that the obtained theory may not hold up outside the intended area of application. There is nothing against this pragmatic method—Amelino-Camelia even advocated the view that theoretical physicists in general should settle for a purely pragmatic job execution (2015)—as long as it is clear that the area of application of Villata's theory cannot be extended to include the microcosmos. (The latter also holds for Santilli's theory.)

The Standard Model

The Standard Model entails CPT-symmetry, which implies the view that the relation between the properties of a matter particle and those of its antimatter counterpart is described by C-inversion. Kellerbauer *et al.* stated that

> "*the problem of the gravitational interaction of antimatter is completely independent from the question of matter-antimatter symmetry (CPT), as CPT-invariance merely dictates the equality of the inertial masses of particle and antiparticle pairs, but places no restriction on the gravitational masses.*"—AEGIS collaboration (2008)

But that is not true, for if we view CPT-invariance as a *correct* feature of the Standard Model, then we implicitly take the position that the relation between the properties of a matter particle and those of its antimatter counterpart is *correctly* described by C-inversion, which leaves gravitational mass untouched (and since quantum theory is about *observable* properties, this is about *passive* gravitational mass). So contrary to the statement by Kellerbauer *et al.*, the Standard Model dictates that the inertial rest masses m_0 and $\overline{m}_0$ and the gravitational masses m_g and $\overline{m}_g$ of a particle and its antimatter counterpart are related according to

$$\overline{m}_0 = C(m_0) = m_0 > 0 \wedge \overline{m}_g = C(m_g) = m_g > 0 \tag{2.6}$$

On account of C-inversion, it is thus **absolutely impossible** from the perspective of the Standard Model that rest mass and gravitational mass of an antimatter particle have opposite signs. That is, just like GR, the Standard Model is inconsistent with conjunction (1.12), the main implication of a matter-antimatter gravitational repulsion derived in Sect. 1.3. A detection of repulsive gravity would, thus, give a reason to doubt the Standard Model. So, if we think matter-antimatter repulsive gravity consequently through and apply Descartes' criterion for theory rejection, then a second consequence is that the Standard Model then has to be rejected in its entirety.

One might believe that the inconsistency of the Standard Model with repulsive gravity is easily resolved by modifying C-inversion to include gravitational mass inversion. We would, then, have the following relation between rest masses m_0 and $\overline{m}_0$ and the gravitational masses m_g and $\overline{m}_g$ of a particle and its antimatter counterpart:

$$\overline{m}_0 = C(m_0) = m_0 > 0 \wedge \overline{m}_g = C(m_g) = -m_g < 0 \tag{2.7}$$

That, however, is wrong thinking. Namely, from a set Σ_{SM} of premises from the Standard Model and Eq. (2.7) it *inevitably* follows that the *Eötvos parameter* of Beryllium and Titanium $\eta_{_{Be-Ti}}$ should be 10^{-6}:

$$\Sigma_{SM}, \text{Eq. (2.7)} \vdash \eta_{_{Be-Ti}} = 10^{-6} \tag{2.8}$$

This might be called *forcing in physics*: we assume that the particles making up Be and Ti have the property of Eq. (2.7), we assume they have all the properties that they should have according to the Standard Model, and that forces the property η_{Be-Ti} to have the value 10^{-6}. However, experimentally it has already been established that η_{Be-Ti} is much smaller (Wagner et al., 2012):

$$\eta_{Be-Ti} \lesssim 10^{-13} \tag{2.9}$$

By modus tollens, it thus follows from Eqs. (2.8) and (2.9) that the conjunction of Σ_{SM} and Eq. (2.7) cannot be true. From the perspective of the Standard Model Σ_{QM} is true, so then the premise Eq. (2.7) cannot be true: this is Schiff's argument against repulsive gravity, originally published in (1959). But if repulsive gravity exists, then Eq. (2.7) would have to be true, which leaves that Σ_{SM} is then false. In other words, the Standard Model is *fundamentally incompatible* with repulsive gravity.

That said, below it is shown how we can get to Eq. (2.8); this is taken from (Cabbolet, 2014b). To start with, the Eötvos parameter of Beryllium and Titanium is defined in terms of the observable free-fall accelerations a_{Be} and a_{Ti} of Be and Ti atoms; this can be expressed in terms of inertial mass M_i and gravitational mass M_g of the atoms:

$$\eta_{Be-Ti} = \frac{a_{Be} - a_{Ti}}{(a_{Be} + a_{Ti})/2} = \frac{(M_g/M_i)_{Be} - (M_g/M_i)_{Ti}}{((M_g/M_i)_{Be} + (M_g/M_i)_{Ti})/2} \tag{2.10}$$

The idea is that virtual electron-positron pairs inside the atom will give *different* contributions to the inertial mass and to the gravitational mass if the WEP does *not* hold for antimatter. However, since the ratio ${}^{M_g}/_{M_i}$ will still be very close to 1 for both Be and Ti, the denominator at the right-hand side of (2.10) will be approximately 1, so we get

$$\eta_{Be-Ti} = \left(\frac{M_g}{M_i}\right)_{Be} - \left(\frac{M_g}{M_i}\right)_{Ti} \tag{2.11}$$

In (Alves et al., 2009), the QED corrections (E_{Loop}) to the electrostatic self-energy of Beryllium and Titanium nuclei have been calculated to first order in perturbation theory. It was established that the difference in the fractional contribution of E_{loop} to the inertial masses M_i of Be and Ti atoms is approximately 10^{-6}:

$$\left(\frac{E_{loop}}{M_i}\right)_{Be} - \left(\frac{E_{loop}}{M_i}\right)_{Ti} \approx 10^{-6} \tag{2.12}$$

The leading term in the calculation of E_{loop} by Alves *et al.* is an effect of the presence of virtual electron-positron pairs: Eq. (2.12) thus means that the fractional contribution of virtual pairs to the inertial mass of the atom is different for Be and Ti. We now set the gravitational mass of an atom equal to its inertial mass minus a fraction of E_{Loop}:

$$M_g = M_i - \alpha \cdot E_{Loop} \tag{2.13}$$

Note that $\alpha = 0$ if the WEP holds: the virtual pairs then contribute equally to gravitational mass and inertial mass. But now we assume that the WEP doesn't hold: instead, we assume that Eq. (2.7) holds. Regardless of what gravitation then actually *is*, virtual electron-positron pairs inside an atom would then contribute to its inertial mass, but **not** to its gravitational mass: the factor α in Eq. (2.13) would then thus be 1. So, we then have

$$E_{Loop} = M_i - M_g \tag{2.14}$$

for both Be and Ti atoms. Substituting Eq. (2.14) in eq. (2.12) and taking the absolute value gives the following value for the Eötvos parameter:

$$\eta_{Be-Ti} \approx 10^{-6} \tag{2.15}$$

This is thus a *concrete prediction* of QED extended with the assumption (2.7); a similar prediction can be made on the basis of QCD when considering virtual quark-antiquark pairs inside the nuclei (Alves et al., 2009). These predictions contradict the experimental finding given by Eq. (2.9).

Since the assumption that virtual pairs exist is at the heart of prediction (2.15), we cannot but conclude that a detection of repulsive gravity—which falsifies this prediction—would mean that there is no such thing as a virtual pair. Physicists, however, have commented that they cannot believe that virtual pairs don't exist because of the Lamb-Retherford experiment (1947): it is apparently widely believed that the existence of virtual pairs has been confirmed by the "observation" (as physicist call it) of the Lamb shift. This belief, however, is **false**. The Lamb shift, namely, is not a *physical* shift, such as the frequency shift that is observable due to the Doppler effect, but a *theoretical* shift, that is, a difference between theoretical predictions:

what we have is that on the one hand QED predicts a *difference in energy* between the $2s_{1/2}$ and $2p_{1/2}$ states of hydrogen, while on the other hand Dirac theory predicts that there is <u>*no*</u> *difference in energy* between these states. Consequently, there is no such thing as an "observation" of the Lamb shift: there is only the fact that the 1947 experiment by Lamb and Retherford confirms the predictions of QED and falsifies the predictions of Dirac theory. This fact doesn't rule out that virtual pairs don't exist:

> *a detection of repulsive gravity means that the process represented by the Feynman diagram in Fig. 2.2 does not take place in reality: consequently, there has to be a theory T that reproduces the experimental data **without** assuming virtual pairs.*

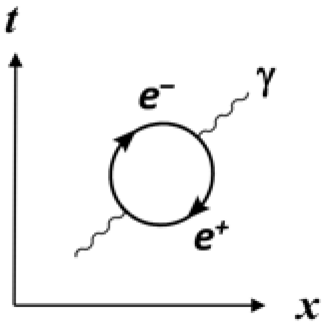


Figure 2.2: Feynman diagram for virtual electron/positron pair production; time is vertical.

So, a detection of repulsive gravity renders the belief that virtual pairs do exist, which is a core belief of a significant segment (if not the overwhelming majority) of the physics community, obsolete. That may indicate the enormity of the consequences of a detection of repulsive gravity for physics.[33]

2.2 Destruction of pseudoknowledge in physics

Direct and indirect observation

Even when existing interaction theories have to be rejected in case repulsive gravity is detected, one might still say that *independent of these interaction theories* a vast body of existential knowledge—i.e. knowledge that this or that exists (Cheyne, 1998)—has been developed from observations. So, any new physics will have to conform to the existing body of knowledge about particles that exist in the physical world. This section, however, shows that the body of existential knowledge is substantially less than currently believed because of a gratuitous use of the term “observation” by physicists.

As a starting point we assume that what henceforth will referred to as the ‘Kantian picture of observation’ is basically correct: there is a material outside world, to which Kant in his 1781 book *Critique of Pure Reason* referred as the ‘noumenal world’, and observation then produces a mental image of that outside world, to which Kant referred as the ‘phenomenal world’.[34] See Fig. 2.3 for an illustration. Note that we are not required to accept Kantian epistemology about the limits of knowledge about the outside world: we only accept this Kantian picture of observation as the meaning underlying the term as established by historical developments in philosophy and science.

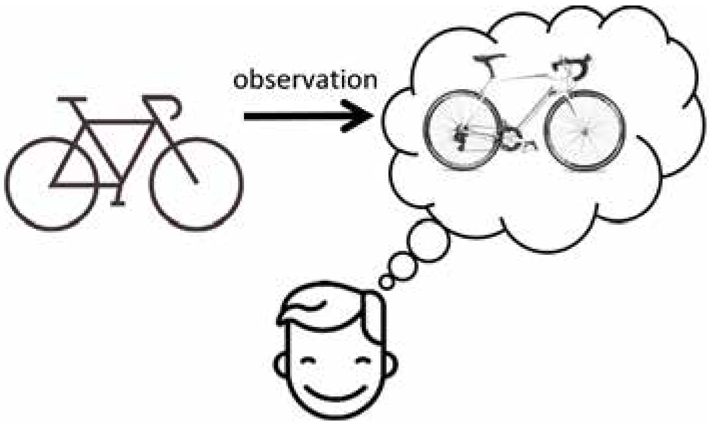


Figure 2.3: Illustration of the Kantian picture of observation. The drawing of a bicycle on the left depicts a bicycle in the outside world. The photograph of a bicycle on the right within the cloud represents the mental image of the bicycle that is produced by observation.

Historically, this Kantian picture has been denied by George Berkeley, who in his 1710 book *A Treatise Concerning the Principles of Human Knowledge* famously advocated the view that there is no such thing as a material outside world.[35] However, although Berkeley’s idealism is self-consistent, it is nowadays considered implausible to such a degree that if you reduce any thesis to Berkeleyan idealism, you can claim to have an argument against that thesis by *reductio ad absurdum*.

That said, these days there are philosophers who in their (confidential) reactions to my work have expressed a view entailing that this Kantian picture is outdated, and that we have to embrace new, more modern ideas about observation to keep up with the latest developments in science and technology. But contrary to Berkeley's idealism, that is *bad philosophy*: observation is and remains, namely, an *act of the senses*—so, in the tradition of Locke's *Abuse of Words* (the tenth chapter in Book III of *An Essay Concerning Human Understanding*, 1689) here the position is taken that one should not use the word 'observation' in a way that changes the criteria or meaning underlying the term. Van Fraassen was right when he put it as follows: 'observation' means observation-by-us, the epistemic community (1980)—this is consistent with the Kantian picture of observation. So, with technology we can greatly enhance c.q. extend the scope of the input of our senses, but observation remains a human thing.[36] See Fig. 2.4 for an illustration of how the Kantian picture of observation applies to outcomes of measurements on the system inside the Large Hadron Collider (LHC).

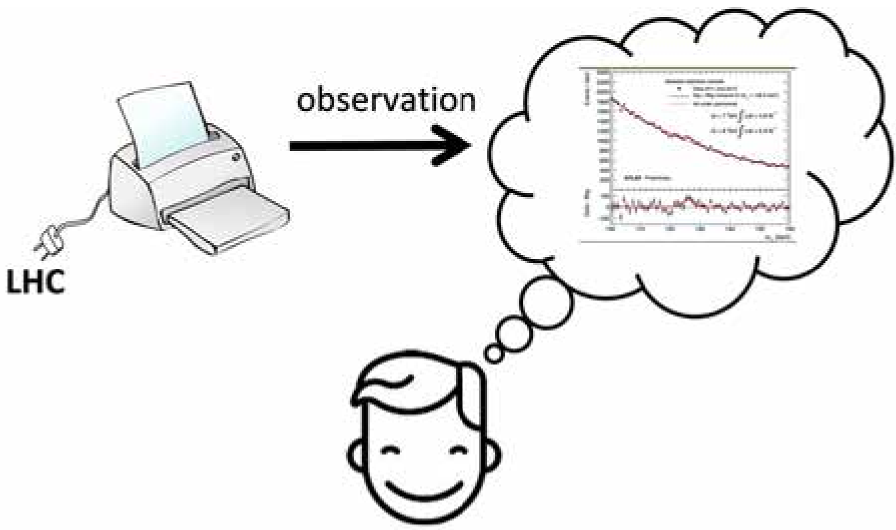


Figure 2.4: The Kantian picture of observation applied to an outcome of measurements on the system inside the LHC. The drawing of a printer on the left depicts a printer (in the outside world) that is connected to the LHC as indicated. The mental image depicted on the right is thus produced by observation of the diphoton mass spectrum, measured during the hunt for the Higgs boson: the output of the printer is the input of the senses!

Proceeding, we can now distinguish between *direct* observation and *indirect* observation using the definitions given by Fox (2009), which are consistent with the Kantian picture of observation:

Definition 2.2.1. *An object is* ***directly observed*** *if it is perceived as an individual within broader acquaintance.*[37] *The observation does not depend upon any physically-caused phenomenon.*[38] ■

Definition 2.2.2. *An object is* ***indirectly observed*** *if the physical phenomenon created by the object is observed directly. The indirectly observed object has to retain its individuality.* ■

It is emphasized that Def. 2.2.1 is about an *epistemologically* direct observation. E.g. when we directly observe a bicycle as shown in Fig. 2.3, then of course from the *physical* point of view the photons emitted from the bicycle are the input of our senses. But *epistemologically*, there is nothing in between us and the bicycle—it is *directly* observed because what one obtains is a mental image of the bicycle.

Furthermore—as also noted by Fox—Def. 2.2.2 implies that indirect observation requires knowledge of the cause of the directly observed phenomenon. For example, we already *know* that airplanes exist, and we already *know* that airplanes cause a vapor trail, and *therefore* we can call an observation of a vapor trail an indirect observation of an airplane. With some stretch of the imagination, we can then call the observation of the diphoton mass spectrum as shown in Fig. 2.4 an indirect observation of an excess of photon pairs with a mass of ± 125.6 GeV: namely, we already *know* that photons exists and we already *know* that these cause a signal in the measurement device.

Existential pseudoknowledge

Having discussed the established meaning that underlies the term 'observation', let's turn to the claims in the physics literature that ultrashort-lived unstable particles with an expected lifetime less than 10^{-20} second, postulated by the Standard Model c.q. in the framework of the Standard Model, have been "observed".[39] An example is the claim that the Higgs boson, dubbed the "God particle" by Leon Lederman (1993), has been observed at the LHC. Chronologically, at a press conference at CERN in 2012 where

Figure 2.5: Slide shown at a press conference at CERN in July 2012. Source: CERN document server.

the preliminary results of the hunt on the Higgs boson were presented, first the claim was made that "we have observed a new boson with a mass of 125.3 ± 0.6 GeV at 4.9σ significance"; see Fig. 2.5. This claim was repeated in two papers in *Physics Letters B*: in these papers, "observation of a new boson" and "observation of a new particle" was claimed right in the titles (CMS Collaboration, 2012; ATLAS Collaboration, 2012). These claims were followed by the claim that the new boson is indeed the Higgs boson (CERN press release, 2013). The leading journals *Science* and *Nature* hailed the discovery of the Higgs boson as the "Breakthrough of the Year" (Cho, 2012) and "the biggest particle-physics discovery in a generation" (Chalmers, 2012). In addition, the 2013 Nobel prize for physics was awarded to Peter Higgs and François Englert "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle".

It is then important to realize that the use of the word 'observation' (sometimes replaced by 'discovery', meaning 'first-time observation') is the key aspect of these papers: it is *therefore* that the existence of these ultrashort-lived unstable particles is widely believed to be confirmed. In particular the Higgs claim has had an impact on the physics community no less than a proof of God's existence would have had on the religious community. This impact is quantified in the thousands of references in the peer-reviewed literature to the "observation" c.q. "discovery" of the Higgs boson—as Sean Caroll put it: "only the most curmudgeonly will not believe that they have found it" (Heilprin and Borenstein, 2012). But it's not just that: the above-cited choice of words by the Nobel prize committee indicates that it is widely believed among physicists that not merely the existence of the Higgs boson has been experimentally confirmed by now, but also the whole Higgs mechanism of 'giving mass' to other particles.

That said, the method by which physicists reach the conclusion that the sought-after ultrashort-lived unstable particle has been "observed" is the same in all cases. Experimentally, each decay mode of the ultrashort-lived unstable particle is tested separately: the obtained data are then subjected to a statistical analysis, by which one tests the hypothesis 'predicted-decay-products-exist' versus the hypothesis 'no-predicted-decay-product'. E.g. in the hunt for the Higgs boson, the diphoton mass spectrum shown in Fig. 2.6 was obtained in the experimental work on the decay mode $H \to \gamma\gamma$: after statistical analysis, one accepts the hypothesis 'the 125 GeV photon pairs predicted by Higgs decay exist', and rejects the hypothesis 'the predicted 125 GeV photon pairs do not exist'. The statistical analysis thus rules out that the observed phenomenon (the obtained diphoton mass spectrum) has any other cause than the presence of (an excess of) photon pairs with a combined energy of 125 GeV in the system under observation; we may give these photon pairs a *theory-laden description* as the decay products

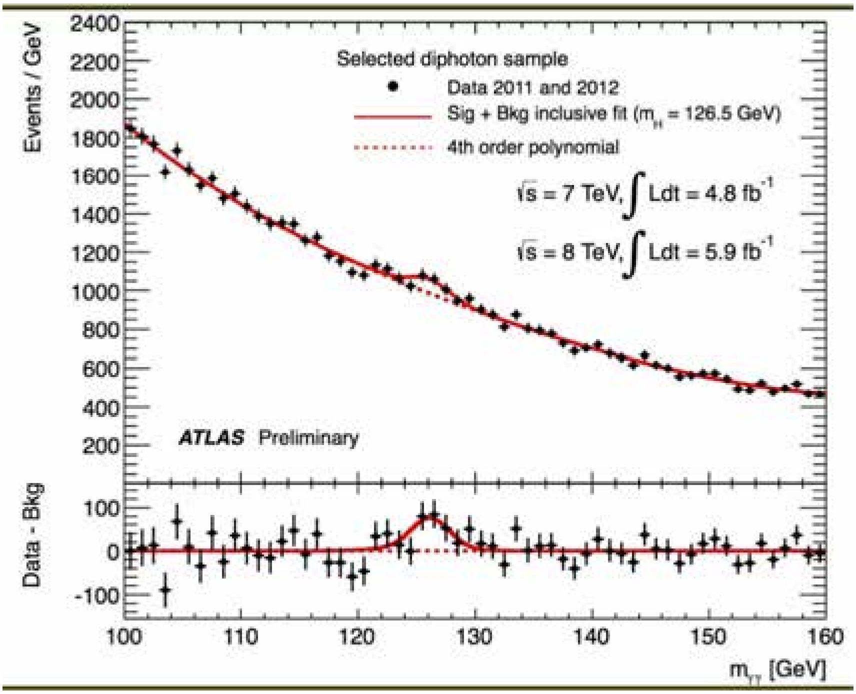


Figure 2.6: Diphoton mass spectrum obtained in the hunt for the Higgs boson. The lower curve with the peak at around 125 GeV is obtained from the upper one by substraction. Source: CERN Document Server.

of the sought-after Higgs boson, but we have to realize that we then have *tacitly assumed* (i) that, prior to these photon pairs, Higgs bosons existed in the system under observation and (ii) that these have decayed to these photon pairs—in other words: we have to realize that our conclusion that the obtained diphoton mass spectrum has been caused by the presence of these photon pairs *by no means* automatically implies that these photons, prior to interacting with the measurement device, came into existence due to the decay of a Higgs boson! Proceeding, if all goes well the conjunction of accepted hypotheses obtained from the analyses yields the *intermediate conclusion* that the predicted decay products of the ultrashort-lived unstable particle have been observed with a significance of 5σ—this observation is then an indirect observation as in Def. 2.2.2. None of this is questioned: the calculations involved in deriving testable predictions, the experimental work itself and the statistical analyses of the experimentally obtained data are all state-of-the-art. But the problematic step comes thereafter: from this intermediate conclusion physicists reach the *final conclusion* that the ultrashort-lived unstable particle *itself* has been observed by applying the following convention in particle physics, which will henceforth be called the '5σ-convention':[40]

> *the observation of an ultrashort-lived unstable particle can be claimed if the condition is satisfied that its predicted decay products have been observed with a significance of* 5σ.

The analytically skilled philosopher immediately recognizes that this 5σ-convention is a variant of "*obviously the observed particles are the decay products of the ultrashort-lived unstable particle; therefore the ultrashort-lived unstable particle exists*", which is a circular reasoning of the type 'A because of B, and B because of A'. Namely, first the particles that have been observed indirectly by measurements on the system inside the particle accelerator are given a theory-laden description: this is saying that the observed particles are the decay products of the ultrashort-lived unstable particle *because* prior to the measurement the ultrashort-lived unstable particle existed in the system under observation—this is 'A because of B'. Then the conclusion is drawn that the ultrashort-lived unstable particle exists *because* the observed particles are the decay products of the ultrashort-lived unstable particle—this is 'B because of A'. The circularity is obvious.

That aside, below it will be shown that when this 5σ-convention is applied, a *pure reasoning* is passed off as an *observation*—two primitive notions at the very basis of science that since long have been established to be fundamentally different, e.g. by the now historical works of Bacon, Descartes, Hobbes, Hume, Locke and the likes thereof. So, applying this 5σ-convention yields a wrong use of primitive notions of science—it yields a *category mistake*, which has nothing to do with measurement or calculation, but which *overstates* results. To show that what physicists call an "observation" of an ultrashort-lived unstable particle is not an observation at all, below it will be proved that the condition laid down in the 5σ-convention is *insufficient* for an observational claim regarding an ultrashort-lived unstable particle. That can be done by a standard method. The logical form of the 5σ-convention is, namely, that of an implication

$$S \Rightarrow C \tag{2.16}$$

where the proposition letter 'C' stands for the desired conclusion that the observation of the ultrashort-lived unstable particle X can be claimed, and 'S' for the (allegedly) sufficient condition for that claim, being that the predicted decay products have been observed with a significance of 5σ. To prove that the condition S is *insufficient*, it suffices to prove implications

$$C \Rightarrow N \tag{2.17}$$

$$S \Rightarrow \neg N \tag{2.18}$$

for some proposition N: Eq. (2.17) means that N is a necessary condition for C, and Eq. (2.18) means that this necessary condition N is not satisfied when S is satisfied—that proves that the allegedly sufficient condition S is *insufficient*, and thus that the 5σ-convention is *inadequate*.

We first identify a necessary condition for an observational claim. The crux is then that the term 'observation' refers to an *act of the senses*. Consequently, the following implication is true:

> ***if*** *it can be claimed that X has been observed,* ***then*** *it's necessarily true that X exists, that is,* ***then*** *the real world can only be a world in which X exists, and not one in which X doesn't exist*

This implication will henceforth be called 'the major': Eq. (2.17) expresses its logical form, with the proposition letter 'N' standing for 'it is necessarily true that X exists'—this is, thus, a necessary condition for any observational claim. (This major also holds for observations of other things than ultrashort-lived unstable particles.)

It can be proven by *reductio ad absurdum* that this indeed is a necessary condition. Suppose that we deny the major: that would be admitting to the possibility that we can claim that X has been observed, while X does not exist. That is patently absurd. In a similar vein, Kant argued that we must realize that if we perceive a phenomenon, there must be a thing in itself whose appearance we perceive; "[f]or, otherwise, we should require to affirm the existence of an appearance, without something that appears—which would be absurd" (preface to the 2nd edition of *Critique of Pure reason*, 1787). That proves that the denial of the above major leads to an absurdity: the major can, thus, **not** be denied—those who nevertheless deny the major are cordially invited on an expedition to spot a unicorn: if existence of a thing is not needed for its observation, we might spot one.

Proceeding, we now prove that the necessary condition for an observational claim identified above is not satisfied when the allegedly sufficient claim of the 5σ-convention is satisfied. In other words, we now prove that the following implication, henceforth to be called 'the minor', is true:

> ***if*** *the predicted decay products of the ultrashort-lived unstable particle X have been observed with a significance of 5σ,* ***then*** *it is not necessarily true that X exists—that is,* ***then*** *the real world can be a world in which X exists, but also one in which X does not exist*

Eq. (2.18) thus expresses the logical form of this minor. So, suppose that we have observed what can be described as the predicted decay products of the ultrashort-lived unstable particle X, with a significance of 5σ. We then have to admit the simple truths (i) that X itself has never been the sensum, i.e. the thing being sensed, in an *act of the senses*, and (ii) that the existence of X is not *logically* implied by the empirical data. So, we are left with inference to the best explanation (IBE), which is an *act of pure reasoning*: the *only* conclusion that we can draw is that the existence of the ultrashort-lived unstable particle X is the best explanation for the empirical data. But that means that it is not necessarily true that the ultrashort-lived unstable particle X exists: the empirical data by themselves, namely, admit *both* a real world in which the observed particles exist and X exists, *and* a real world in which the observed particles exist but X does not exist. We may *reason* that the first possibility is *currently* the best explanation of the empirical data, but—regardless of how much we *want* this to be true—by no means does this *exclude* the second possibility. To illustrate this with an example, consider the case of the Higgs boson. This has the essential property P that it 'gives mass' to other particles. But this property P is not reflected in its decay products: from merely observing the decay products, it cannot be logically concluded that the source is an ultrashort-lived unstable particle X **with** the property P—the decay products may also have originated from a particle X' that has the same decay reactions as the Higgs boson but **not** the property P. So, *even though* the existence of the Higgs boson is the best explanation now, the empirical data by themselves still admit the possibility that it does not exist. Concluding, even though the allegedly sufficient claim of the 5σ-convention is satisfied, we are forced to admit that it is not necessarily true that the ultrashort-lived unstable particle X exists. That proves the minor—it is emphasized that this minor obtains from an analysis of the mere concept of IBE.

It is important to realize that we engage in circular reasoning if we deny the minor—to deny the minor is to hold the view, expressed by the conjunction $S \wedge N$, that an observation of the predicted decay products of the ultrashort-lived unstable particle X goes hand in hand with the presence of the ultrashort-lived unstable particle X in the system under observation. What we have is that the analysis of the experimental data reveals that (an excess of) certain particles with certain properties must have been present in the system under observation, but the crux is that the analysis in itself doesn't reveal anything else: we may give the result a theory-laden description as an observation of the predicted decay products of the ultrashort-lived unstable particle X, but it remains to be proven that the existence of the ultrashort-lived unstable particle X is the *cause* of their presence. So, if we take the position expressed by the conjunction $S \wedge N$, then we have tacitly assumed what has to be proven: we have, then, engaged in circular reasoning. So, the minor cannot be denied.

Using standard propositional logic, the inevitable conclusion that can be drawn from the major and the minor is then the following implication:

> ***if*** *the predicted decay products of the ultrashort-lived unstable particle X have been observed with a significance of* 5σ*,* ***then*** *it cannot be claimed that X has been observed*

The logical form of this conclusion is then expressed by the implication

$$S \Rightarrow \neg C \tag{2.19}$$

in which the proposition letters 'S' and 'C' have the same meaning as above; it follows straight from Eqs. (2.17) and (2.18). That establishes as a fact that the 5σ-convention is *inadequate*—the allegedly sufficient condition S is *insufficient* for an observational claim. So, by applying the 5σ-convention a category mistake is made: what has actually been done is that the existence of X has been inferred on the basis of IBE, which is an *act of pure reasoning*, but this is (wrongly) passed off as an observation of X—that is, as an inference of the existence of X on the basis of an *act of the senses.* The crux is that X has never been the 'sensum' in an act of the senses!

Based on the fact that the post-World War II physics community has gradually replaced the traditional notion of *truth* by *general consensus* (Prugovecki, 1993), one might argue that the necessary condition to claim an observation of an ultrashort-lived unstable particle is satisfied when there is *general consensus* about the existence of that ultrashort-lived unstable particle. So, one might argue that it is necessarily true that Higgs bosons exist **because** the general consensus is that Higgs bosons exist. However, one ought to realize that history provides numerous counterexamples to the idea that 'there is general consensus that S' implies 'it is necessarily true that S': this idea should thus be rejected. In other words: it should be realized that reaching general consensus about the existence of Higgs bosons does **not** warrant the conclusion that it is therefore necessarily true that these bosons exist!

One may ask: how can we *then* prove the existence of ultrashort-lived unstable particles? The answer is then: (absent divine intervention) we can't—proving the existence of ultrashort-lived unstable particles is *beyond* the limit of the scientific method. These particles are neither directly nor indirectly observable—note that their trajectory is much smaller than the size of an atom—and besides observation there is no experimental method to prove their existence. So, the criterion laid down in the 5σ-convention is *necessary* for an observational claim, but there is nothing we can add to make it *sufficient*. Existential propositions concerning ultrashort-lived unstable particles remain, thus, always an object of *existential belief*—a belief in the truth of an existential proposition (Armstrong, 1973).

Obviously, the direct implication of the inadequacy of the 5σ-convention is that *all* published observational claims concerning ultrashort-lived unstable particles have to be dismissed as overstatements. In fact, these claims should be *retracted*, because the use of the word 'observation' is misleading: it suggests that the existence of the ultrashort-lived unstable particles in question is necessarily true, but that is not the case as shown above. Examples of such particles and corresponding observational claims are given in table 2.2; the list is not exhaustive but the point is that none of these particles can be said to have been "observed".

particle	**lifetime**	**observational claim**
Higgs boson*	$1.56 \cdot 10^{-22}$	(ATLAS Collaboration, 2012) (CMS Collaboration, 2012) (CERN press release, 2013)
$W^{\pm}$ bosons*	$3 \cdot 10^{-25}$	(CERN press release, 1983a)
Z^0 boson*	$3 \cdot 10^{-25}$	(CERN press release, 1983b,c)
Υ meson	$1.21 \cdot 10^{-20}$	(E288 Collaboration, 1977)
J/Ψ meson*	$1.56 \cdot 10^{-22}$	(Aubert, J. J. *et al.*, 1974)
Ω_b^-	$1.13 \cdot 10^{-12}$	(DØ Collaboration, 2008)
$Z(4430)^-$	?	(LHCb Collaboration, 2014)

Table 2.1: examples of unstable particles that are claimed to have been observed on the basis of the 5σ convention; an asterisk in the first column marks cases where the observational claim led to a Nobel prize award. It is true that the Ω_b^- baryon has a lifetime longer than 10^{-20} s and that the tetraquark $Z(4430)^-$ has an unknown lifetime, but both observational claims are based on the 5σ-convention.

Further implications are far more general and can be stated in the form of two incompleteness theorems for physics. These concern the *completeness* and the *correctness* of a physical theory, two notions that were introduced as important for the evaluation of the success of a physical theory: a theory is *complete* if and only if (i) every element in the physical world has a counterpart in the theory, and (ii) every element in the physical world, predicted with certainty by the theory, indeed exists; a theory is *correct* if and only if all its predictions are true (Einstein et al., 1935).

Theorem 2.2.3. *No experiments can prove* ***completeness*** *of a physical theory predicting the existence of ultrashort-lived unstable particles.* ■

Theorem 2.2.4. *No experiments can prove* ***correctness*** *of a physical theory predicting the existence of ultrashort-lived unstable particles.* ■

Proof: To prove completeness, one has to prove that the particles predicted by the theory exist. But as demonstrated above, the existence of ultrashort-lived unstable particles cannot be proven by observation nor by any other experiment—**regardless of the research effort**. Hence a theory predicting such particles cannot be proven to be complete by experimental physical research. Likewise, to prove correctness one has to prove that the predictions of the theory are true. But a prediction that an ultrashort-lived unstable particle has this or that (expectation value of) position cannot be proven to be true by any experiment. Hence, a theory predicting such particles cannot be proven to be correct by experimental physical research. Q.E.D.

Consequently, all we can do with physical theories that predict ultrashort-lived unstable particles is testing their *empirical adequacy*. This notion has been defined by Van Fraassen: a theory is *empirically adequate* if and only if all observations—past, present *and future*—in its area of application can be described as predictions of the theory (1980). So this is a somewhat weaker notion than correctness as defined in the EPR-paper: correctness implies empirical adequacy, but the converse is not necessarily true. What is important then is that the fact that the ultrashort-lived unstable particles postulated by the Standard Model are fundamentally unobservable does not render the empirical adequacy of the Standard Model any less.

Concluding, this section has proven that if particles that be described theory-ladenly as the predicted decay products of an ultrashort-lived unstable particle postulated by the Standard Model have been observed with a significance of 5σ, then that provides a justification for a belief in the existence of that ultrashort-lived unstable particle—this is an existential belief on the basis of IBE—but **not** a justification for a claim that this ultrashort-lived unstable particle *itself* has been observed: the 5σ-convention, on which claims that ultrashort-lived unstable particles have been "observed" are based, is <u>inadequate</u> because its criterion is <u>insufficient</u>. The validity of this conclusion depends on nothing else than on the validity of two premises: the only way to disprove the present conclusion is, thus, to prove that one of its premises is incorrect. But clear reasons have been given why the premises cannot be denied.

Furthermore, this is not a word game: the inadequateness of the 5σ-convention has far reaching implications, not the least of which is that currently a body of existential pseudoknowledge exists—that is, a body of existential statements that are falsely believed to be existential knowledge (e.g. 'Higgs bosons exists'). This body of pseudoknowledge will have to be destructed by *retracting* all observational claims based on the 5σ-convention because these are *overstatements*. Inferring the existence of an ultrashort-lived unstable particle X on the basis of IBE is, namely, *much weaker* than inferring the existence of X on the basis of an act of the senses: in the latter case it necessarily true that X exists in the system under observation, but in the former case it isn't. And *because of* this non-equivalence, none of the ultrashort-lived unstable particles postulated by the Standard Model can be claimed to have been observed—at best it can be claimed in each case that the predictions of the Standard Model (including the ultrashort-lived unstable particle X) have been confirmed, which is a substantially different claim. Ergo, the empirical support for the Standard Model of particle physics is *significantly less* than currently thought!

The present argument is strictly limited to observational claims concerning ultrashort-lived unstable particles: by no means is this intended to be applied to observational claims concerning things, living or lifeless, that can be directly observed such as cows and bicycles. The necessary condition for an observational claim is namely satisfied in case of a direct observation: the second premise of the present argument, as expressed by Eq. (2.18), then doesn't apply because it is the object itself that is observed, not its decay products. However, the physics literature contains many more observational claims that in fact are category mistakes in which the *observation of a thing* and the *inference of the existence of a thing based on IBE* have been confused; a recent example is the claimed observation of a gravitational wave (LIGO and Virgo Collaborations, 2016), which led to the award of the 2017 Nobel prize in physics. The recommendation is therefore to reassess observational claims in the physics literature.

On a more general note, the final conclusion is that this section has demonstrated the importance of analytical philosophy for elementary particle physics: the papers claiming observations of ultrashort-lived unstable particles have had such an enormous impact *precisely because* of the use of the word 'observation', but the present section has demonstrated that this use is not justified. So, as a physicist one may—rightfully—consider philosophical contemplations to be irrelevant when doing calculations or when performing experiments, but it is plain wrong to think that philosophy is irrelevant for physics altogether—which is the prevailing view among physicists. That said, Hawking recently claimed that "philosophy is dead" (2010); a correct reply is then: *no it isn't, but the Higgs claim is*—a proof of the existence of the God particle is just as elusive as a proof of the existence of God the Creator.

2.3 Objections and replies

The previous critical section has integrated the argument against the 5σ-convention in my paper (Cabbolet, 2018a) and the argument against the 5σ-convention in the unpublished conference paper (Cabbolet, 2015c) into a coherent whole. Both papers have received several rejections. Prior to publication in *Mod. Phys. Lett. A*, a number of peer-reviewed journals rejected the same criticism, which is to say that they refused to publish that the 5σ-convention is *by itself* insufficient for an observational claim. Likewise, *all* journals to which the conference paper had been submitted rejected it for publication, which is to say that they refused to publish the finding that the 5σ-convention is inconsistent with definitions of observations in the philosophical literature and the implications thereof such as Ths. 2.2.3 and 2.2.4. This section treats a selection of received objections.

Objection 2.3.1. "*Dear Dr. Cabbolet, the abstract of your paper promises to deliver a fatal blow to claims of detection of short-lived particles at research institutions like CERN. Even though the likelihood that your claim is true is non-zero, it is also not exactly high. Nevertheless I requested a neutral reviewer (not from any research institution like CERN or such) to evaluate your paper.* ***I have the highest confidence in the expertise, judgement, and objectivity of this reviewer.*** *My decision to reject your paper, based on the report, is final.*" (emphasis added)—editor of a recognized open-access mega journal, rejecting the same argument against the 5σ-convention as published in (Cabbolet, 2018a). ■

Reply 2.3.2. In his 1670 book *Tractatus theologico-politicus*, Spinoza described how disputes were settled in the first Hebrew commonwealth. Summarizing, the essence is that a dispute would eventually end up at the commander-in-chief. The commander-in-chief could then consult the High Priest, who was then assumed to give a comment about the dispute in the name of God. Nobody had the right to doubt the oracle of the High Priest, and only the commander-in-chief had the right to interpret this. That way, disputes were settled. But in time, doubt began to arise: people began to suspect that the High Priest no longer acted in the name of God, but rather in his own self-interest—according to Spinoza, this was a factor that led to the downfall of that first Hebrew commonwealth.

Now fast forward two millennia, and the process to decide on publication of a journal paper still resembles the above ancient process to settle a dispute. After all, a request to publish a paper ends up at a journal editor. The editor can then consult one or more referees, each of whom is assumed to give objective comments about the submission from the perspective of science, that is, from the perspective of truth-finding. **And as perfectly illustrated by the above statement (in bold) by the editor**, the subsequent comments by the referee(s) are not ever doubted: the editor has the *inalienable* right to treat these comment as objective facts about the submission and to base his decision thereon—'inalienable' here means that in case of a negative decision, the editor has the right to maintain his decision *even after* the author(s) of the submission have proved to him that the referee comments are outright fabrications—and that way a decision about the submission is reached. (The same also holds for the process to decide on allocation of research grants.) What I have against this process to decide on journal publication (or grant allocation) is that it gives rise to the same problem that plagued the ancient process for settling a dispute: just like the issue in ancient times was that the High Priest acted in his own self-interest rather than in the name of God, the issue now is that a referee, as a rule, acts in the interest of a few (which may be limited to his own self-interest) rather than in the general interest of truth-finding. That is to say: even when a referee passes off outright fabrications as "facts" that impair a manuscript as predicted by the response-in-an-outburst model on page li, these fabrications will be treated as facts about the submission even in the face of conclusive evidence to the contrary. That was the case here also: the editor reached his decision based on a referee report that was at crackpot level, and maintained that decision after having received a rebuttal *showing him* that the referee comments are at the level of pseudoskepticism (see below). ■

Objection 2.3.3. "*Let me call a 'super-skeptic' a person ... who (e.g.) would object to the statement that 'I see the moon' because I really only see moonlight and cannot be sure where this light comes from and even whether the moon exists. While the objections put forward by this super-skeptic are correct, they are not good reasons for rejecting the statements. Now the difference between the author of the manuscript and the super-skeptic is only gradual. The author emphasizes the question whether it is 'necessarily true' that the Higgs boson exists. Of course, it is not, and everyone knows that; we are just overwhelmingly confident. And that seems like a reasonable basis for claiming that the Higgs boson exists. Likewise, the author is correct when saying that an inference to the best explanation is involved; but everyone knows that. And if we are confident that the Higgs boson is the actual cause of the observed decay products, then we can be confident that we have indirectly observed the Higgs boson just like we are confident that we actually see the moon when seeing moonlight. ... In sum, I don't have the impression that this manuscript teaches physicists anything new, or that it improves our ways of doing science. The criticism that it raises against statements by physicists seems to me exaggerated and not useful. No convincing example is given of dangers coming from statements about having observed the Higgs boson. I recommend against publication.*"—referee of the mega journal meant in Obj. 2.3.1, rejecting the same argument against the 5σ-convention as published in (Cabbolet, 2018a) ■

Reply 2.3.4. This objection is at the level of pseudoskepticism, which is immediately evident from several tell-tale signs.

First of all, the referee uses an ad hominem argument. Make no mistake: by comparing me to a 'super-skeptic' he essentially argues that the paper should be rejected *because* it is written by someone with a super-skeptical attitude—which is obviously ridiculous, since a 'super-skeptic' is one who is skeptical that the moon has been observed. However, this ad hominem argument applies a false metaphor: by stating that I'm comparable to a 'super-skeptic' the referee tacitly assumes that doubting the claim that the Higgs boson has been observed is comparable to doubting a claim that the moon has been observed. This metaphor is false, because when someone claims to have observed the moon, the mental image produced by an act of the claimant's senses is actually an image of the moon; but when someone claims to have observed an ultrashort-lived unstable particle, it is not at all the case that a mental image of the particle has been produced by an act of the claimant's senses! Both the use of false metaphors and the use of ad hominem arguments are tell-tale signs of pseudoskepticism (Cabbolet, 2018d): the above objection has thus not been written with truth-finding in mind.

Secondly, the referee admits to the premises, i.e. the major and the minor as formally expressed by Eqs. (2.17) and (2.18), but denies the conclusion as formally expressed by Eq. (2.19), which follows directly from Eqs. (2.17) and (2.18) by a well-known rule of logic, by stating that in practice an indirect observation of the Higgs boson can be claimed because "we"—whoever that is—are confident that the observed excess of photons is caused by Higgs bosons. In essence the referee argues here that the two premises are true *in theory*, but *in practice* one can nevertheless claim that the ultrashort-lived unstable particles have been observed. This is dishonest trick #33 described by Schopenhauer in *The Art of Being Right* (1831): that settles that this is a fallacious argument, which is in contradiction with basic principles of science.

What he fails to understand is this: if you have merely inferred that the ultrashort-lived unstable particle X exists because it is the best explanation for the observations, then you cannot pass that off as an observation of the ultrashort-lived unstable particle X *regardless of the degree of confidence* *that you have that these particles are the cause of the observed phenomenon.* By the same token, it cannot be claimed that on the photo in Fig. 2.7 below we "observe" government complicity in the 9/11 atrocities, *regardless of one's degree of confidence that government complicity is the actual cause of the straight cut of the column.* In both cases, a reasoning is passed off as an observation. So only by lowering the standard of quality required for contributions to the scientific discourse we can allow the claim that a Higgs boson has been "observed"—but then we will also have to allow the claim that government complicity in the 9/11 atrocities has been "observed"! ■

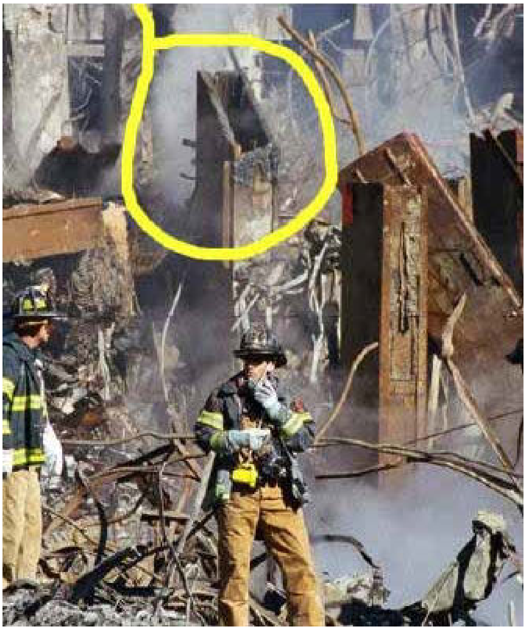


Figure 2.7: Photograph taken after collapse of the WTC towers. Enclosed in the yellow circle is a column with a straight cut. Source: public domain.

Remark 2.3.5. The foregoing two objections—the journal editor objecting to the paper *because* the referee objects to it, and the referee in question objecting to the paper in accordance with the response-in-an-outburst model on page li *because* it questions one of his core beliefs—have been treated in detail because together they stand model for the way my criticism of the observational claims regarding ultrashort-lived unstable particles has been kept out of the peer-reviewed literature for years in a row. So when in the remainder of this section an objection to my work is addressed, it must be kept in mind that in real life this objection has been treated as a "fact" that impairs the submitted manuscript. ■

Objection 2.3.6. "*The author questions the improper use of the word observation and, with it, the solidity of the standard model (SM) of particle physics itself. As the author says, the point raised is mainly semantic. The consideration that the word observation is improperly used is indeed quite reasonable. On the other hand, questioning the SM solidity based on it is not very justified in the paper. The paper itself has no real physics result to support this strong claim. The work is limited to an exercise of (classical) logic that seem to ignore the essence of quantum mechanics and the logic that goes with its most accepted interpretation. I don't see why this paper should be published on a physics journal, since it contains no physics result.*"—anonymous referee of a tier-1 physics journal, rejecting the same paper later published as (Cabbolet, 2018a) ■

Reply 2.3.7. This objection is not of the 'high quality' that the journal boasts about on its website. The referee—a physicist—failed to notice that the submitted paper does not question the solidity of the Standard Model (SM): it only questions the claims that the ultrashort-lived unstable particle, postulated by the SM, have been *observed*—note that this has noting to do whatsoever with interpretations of QM. So, with this objection the referee makes a *diversion*. This is dishonest trick #29 described by Schopenhauer in his 1831 book *The Art of Being Right*:

> "*you can make a* ***diversion****—that is, you can suddenly begin to talk of something else, as though it had a bearing on the matter in dispute, and afforded an argument against your opponent. ... [I]t is a piece of impudence if it has nothing to do with the case, and is only brought in by way of attacking your opponent.*"

Furthermore, the point is that *physicists* are the ones who have falsely claimed observations, and therefore criticism about these claims has to be addressed at *physicists*—hence my submission to a physics journal in which such criticism is visible. ■

Objection 2.3.8. "*The observation (in the HEP meaning of the word) comes from a hypothesis test as formulated by Neyman and Pearson. It consist of testing the H_1 hypothesis (a new resonance exists with such and such characteristics) against the null hypothesis H_0 (no new resonance exist and the final state I observe is the result of pure random combinatoric)...*

The word observation is [thus] used to imply the fact that the probability that the null hypothesis (no new resonance) reproduces the observed pattern in data is smaller than a pre-agreed threshold (the famous 5σ). While this seems to have nothing to do with an observation in its commonly accepted meaning, I am sure that the author sees how convenient it is to just misuse this word rather than saying 'we determined that the null hypothesis H_0 is discarded in favour of the H_1 hypothesis at a confidence level of 5σ'."— second and final argument of the anonymous referee of Obj. 2.3.6 ■

Reply 2.3.9. First of all, Neyman and Pearson wrote a purely mathematical paper on hypothesis testing (1933). It is simply not true that "observation" in high energy physics comes from that paper: no one else but the modern physics community has begun to use the term 'observation' for the outcome of statistical analyses of data.

That said, the referee is mistaken with his formulation of the hypotheses H_0 and H_1: each decay mode is analyzed separately, and by each such analysis one tests a hypothesis H_1 'predicted-decay-product-exist' versus a hypothesis H_0 'no-predicted-decay-product'. E.g. with the obtained diphoton mass spectrum of Fig. 2.6 one accepts the hypothesis 'the 125 GeV photon pairs predicted by Higgs decay exist', and rejects the hypothesis 'the predicted 125 GeV photon pairs do not exist': this is, thus, **not** a matter of testing 'Higgs bosons exist' versus 'no Higgs boson exist'! The conjunction of accepted hypotheses obtained from the analyses yields *at best* the theory-laden conclusion that the predicted decay products of the ultrashort-lived unstable particle have been observed with a significance of 5σ: the whole point of Sect. 2.2 is thus that this **cannot** be called an "observation" of a new state!

Neither this objection nor the previous one actually addresses the arguments brought in against the 5σ-convention: the present objection is merely a matter of simply reiterating what is being questioned, *as if* that somehow is an argument against the criticism. ■

Remark 2.3.10. Note that the referee plays down misuse of the term 'observation' by physicists as something convenient. For comparison, I have proven (see Ch. 5) that a recontextualization of physical principles of orthodox QM in the language of the Elementary Process Theory (EPT) is inconsistent with the axioms of the EPT. And I am sure that everyone sees how convenient it is to just say that I have disproved orthodox QM, rather than having to say the entire previous sentence. That said, it is not difficult to imagine how furiously the same referee—or any other physicist, for that matter—would react if I would claim in national newspapers that I have "disproved" orthodox QM. ■

Objection 2.3.11. "*The paper is not suited for publication in [our journal]. It is an epistemological treatise on the cognizability of shortlived particles such as the Higgs boson.*"—Editor in Chief of a tier-1 physics journal, rejecting the same argument later published in (Cabbolet, 2018a) ■

Reply 2.3.12. The assessment, that this is a mere epistemological treatise on the cognizability of short-lived particles, is more or less correct. That, however, does not make the criticism any less true. As stated in Reply 2.3.9, the point is that *physicists* are the ones who have used the term 'observation' wrongfully, and therefore the critical discussion about that word use has to be held *with physicists.* ■

Objection 2.3.13. "*We do not question the validity of your discussion on the use of the term 'observation' in recent high particle physics literature. It is indeed an interesting philosophical discussion that could be extended to any scientific experiment that is governed by statistics. However, because your manuscript does not report results from the physical sciences, I am afraid it falls somewhat outside the scope of [our journal].*"—Chief Editor of a tier-1 physics journal, rejecting the same paper later published as (Cabbolet, 2018a) ■

Objection 2.3.14. "*We do not question the validity of your points against the use of the term 'observation' in the recent scientific literature. However, I am afraid we are not persuaded that your findings represent a sufficiently striking advance to justify publication in [our journal].*"—Associate Editor of a top journal in physics, rejecting the same paper later published as (Cabbolet, 2018a) ■

Objection 2.3.15. "*I regret that we do not feel that your work matches our criteria for further consideration, even though we appreciate that your discussion of the interpretation of past results in experimental particle physics may be stimulating to others pondering similar questions.*"—Associate Editor of a top general scientific journal, rejecting the same paper later published as (Cabbolet, 2018a) ■

Objection 2.3.16. "*I'm sorry to tell you that the Editor has decided to reject your paper without inviting a resubmission ... We read this paper with interest but feel that it does not mark enough of an advance to merit being taken further.*"—Editorial Assistant of a top philosophy journal, rejecting the same paper later published as (Cabbolet, 2018a) ■

Reply 2.3.17. None of these journals is obliged to publish any of my submitted papers. That said, what we can infer is that the reason for rejection is the *message itself*, rather than a *lack of quality of the message*: the submitted paper, namely, hadn't been subjected to peer review (i.e. an objective evaluation of its quality). This indicates that we have entered an era in which criticism of 'Big Physics' has become (virtually) impossible.■

Objection 2.3.18. "*The paper has a lot of errors. Prominent is one crucial to the reasoning of the author. Conceptual analysis at best gets the author the necessity of If X is observed then X exists. ... In no way does it follow that if something is observed that thing then necessarily exists. Most of the author's (strange) polemics against physicists turns on this fallacy.*"—anonymous referee of a top philosophy journal, rejecting a previous version of (Cabbolet, 2018a) ■

Reply 2.3.19. In the previous version of (Cabbolet, 2018a) to which this objection refers, the major premise was 'if X has been observed, then it's necessarily true that X exists', instead of 'if *it can be claimed that* X has been observed, then it's necessarily true that X exists' (which is the major on page 49). In both cases the major has the propositional-logical form of Eq. (2.17), and in both versions of the paper the logical form of the argument against the 5σ-convention is the same, but to the defense of the referee one can maintain forever that the above two wordings of the major premise are not the same. That said, the objection of the referee is thus that the first of these two wordings makes an improper use of the term 'necessarily true', which has a precise meaning in modal logic. The reply is thus that *even **if** this objection is true*, it can be met by the addition of a mere five words, because the second of these two wordings is certainly consistent with the use of the term "necessarily true'. In the remainder of this reply I'll prove that the major premise as given on page 49 holds in a suitable frame for modal proposition logic: this proves that the objection could have been met by a minor revision of the manuscript.

The suitable frame for modal propositional logic consists of a formal language $\mathcal{L}$, a set of possible worlds W, an accessibility relation R, and a real-world meaning that is represented by Kripke possible worlds semantics. The formal language $\mathcal{L}$ consists of a vocabulary and a syntax. In addition, the formalism has an interpretation.

Definition 2.3.20. *The **vocabulary** of $\mathcal{L}$ consists of:*

(i) the atomic propositions '$\mathcal{O}X$', '$\mathcal{O}\delta_X$', '$\mathcal{E}X$', '$\mathcal{E}\delta_X$', with

- *'$\mathcal{O}X$' meaning 'the ultrashort-lived unstable particle X has been observed';*
- *'$\mathcal{O}\delta_X$' meaning 'particles have been observed that can be described theory-ladenly as the decay products of X';*
- *'$\mathcal{E}X$' meaning 'the ultrashort-lived unstable particle X exists in the system under observation';*
- *'$\mathcal{O}\delta_X$' meaning 'particles exist in the system under observation that can be described theory-ladenly as the decay products of X';*

(ii) the modifier '$\rhd$', used in front of an atomic proposition, meaning 'it can be claimed that';

(iii) the standard modalities '$\Box$', and '$\Diamond$', used in front of a proposition, meaning 'it is necessarily true that' and 'it is possible that';

(iv) the standard connectives '$\neg$', '$\Rightarrow$', '$\wedge$', '$\vee$', and '$\Leftrightarrow$'.

■

Definition 2.3.21. *The **syntax** of $\mathcal{L}$ is then just the standard syntax for modal propositional logic, with the additional clause that if Ψ is an <u>atomic</u> proposition, then $\rhd\Psi$ is also a formula—so $\rhd \rhd \Psi$ is <u>not</u> a well-formed formula in $\mathcal{L}$!* ■

The **set of possible worlds** has precisely seventeen elements:

$$W = \{w_0, w_1, w_2, \ldots, w_{16}\} \tag{2.20}$$

The possible world $w_0 \in W$ represents the 'epistemic world', a social construct built by (modal) propositions about the real world; the other possible worlds $w_j \in W$ represent possible real worlds. The motivation for distinguishing an *epistemic world* from *possible real worlds* is that an observation is an event in the *real world*, while an observational claim is a statement in the *epistemic world*. We could also call w_0 the 'international scientific discussion forum', but let's stick to *epistemic world*.

Proceeding, if a (modal) proposition Ψ is true in a possible world w_j then this is denoted by

$$\models_{w_j} \Psi \tag{2.21}$$

As said, acts of observation take place in the real world, not in the epistemic world w_0. Likewise, a (physical) thing doesn't exist in the epistemic world: it exists in the real world. Ergo,

$$\models_{w_0} \neg\mathcal{O}X \tag{2.22}$$

$$\models_{w_0} \neg\mathcal{O}\delta_X \tag{2.23}$$

$$\models_{w_0} \neg\mathcal{E}X \tag{2.24}$$

$$\models_{w_0} \neg\mathcal{E}\delta_X \tag{2.25}$$

The possible real worlds $w_j \neq w_0$ are then distinguished by the validity of the atomic propositions in w_j:

$$\models_{w_1} \mathcal{O}X \wedge \mathcal{O}\delta_X \wedge \mathcal{E}X \wedge \mathcal{E}\delta_X \tag{2.26}$$

$$\models_{w_2} \mathcal{O}X \wedge \mathcal{O}\delta_X \wedge \neg\mathcal{E}X \wedge \neg\mathcal{E}\delta_X \tag{2.27}$$

$$\models_{w_3} \neg\mathcal{O}X \wedge \neg\mathcal{O}\delta_X \wedge \mathcal{E}X \wedge \mathcal{E}\delta_X \tag{2.28}$$

$$\models_{w_4} \neg\mathcal{O}X \wedge \neg\mathcal{O}\delta_X \wedge \neg\mathcal{E}X \wedge \neg\mathcal{E}\delta_X \tag{2.29}$$

etc. (there are just 16 possibilities for the four atomic propositions of Def. 2.3.20).

The **accessibility relation** R is *irreflexive* and has domain $\{w_0\} \subset W$:

$$\forall w \in W : \neg wRw \tag{2.30}$$

$$\forall w, w' \in W : wRw' \Rightarrow w = w_0 \tag{2.31}$$

So, *if* a possible world $w' \in W$ is accessible from a possible world $w \in W$, *then* $w = w_0$. That means thus that the epistemic world w_0 is *inaccessible* from any possible real world, and that no possible real world $w' \neq w_0$ can be accessed from any possible real world $w \neq w_0$:

$$\forall w \neq w_0 : \neg w R w_0 \tag{2.32}$$

$$\forall w, w' \neq w_0 : w \neq w' \Rightarrow \neg w R w' \tag{2.33}$$

The accessibility of the possible worlds w_j from w_0 is determined by the modal propositions that are true in w_0 and by (standard) Kripke possible world semantics. For the present frame for modal propositional logic, these are then as follows:

(i) If $\models_{w_0} \Box\Psi$, then Ψ is true in every—and at least one—possible world $w \in W$ accessible from w_0, and vice versa; a possible world $w' \in W$ in which $\neg\Psi$ is true is then inaccessible from w_0.

(ii) If $\models_{w_0} \Diamond\Phi$, then Φ is true in at least one possible world $w \in W$ that is accessible from w_0, and vice versa.

Definition 2.3.22. *The* ***real-world meaning*** *represented by the above semantics is the following:*

(i) if $\models_{w_0} \Box\Psi$, then the real world can only be a world in which Ψ is true;

(ii) if $\models_{w_0} \Diamond\Phi$, then the real world can be a world in which Φ is true.

■

Now that we have defined our framework for modal propositional logic, we can *precisely* express the major (as on page 49, with X standing for the ultrashort-lived unstable particle X) in our newly defined language $\mathcal{L}$:

$$\models_{w_0} \ \rhd \mathcal{O}X \Rightarrow \Box \mathcal{E}X \tag{2.34}$$

Eq. (2.34) is a more refined formal expression of the major than Eq. (2.17); its real-world meaning is illustrated by Fig 2.8. This shows that the major on page 49 does not make improper use of the term 'necessarily true': to the contrary, it has a very precise meaning. This proves that Objection 2.3.18 could have been met by the addition of a mere five words to the manuscript. ■

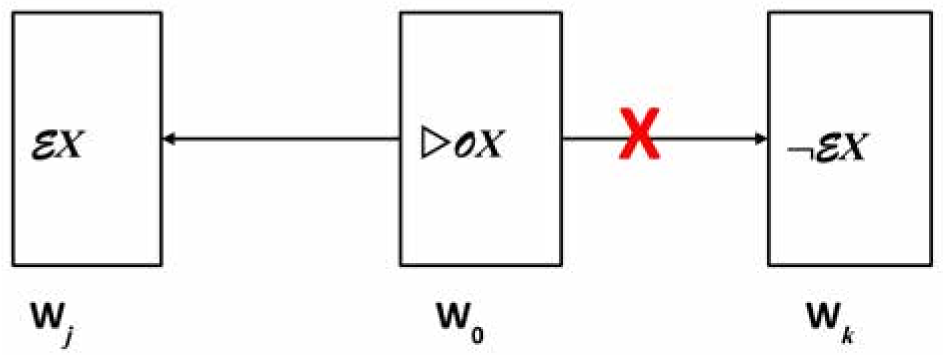


Figure 2.8: Illustration of the real-world meaning of Eq. (2.34). Suppose we have that Eq. (2.34) is valid. If we then have that the observation of the ultrashort-lived unstable particle X can be claimed, that is, if we then have that $\rhd\mathcal{O}X$ is true in the epistemic world w_0 as depicted by the square in the middle, then only possible real worlds $w_j \in W$ in which $\mathcal{E}X$ is true are accessible, as depicted by the arrow to the left and the square on the left. Possible real worlds $w_k \in W$ in which $\mathcal{E}X$ is false are then inaccessible, as depicted by the square on the right and the arrow to the right with the red cross. So, if we then have that the observation of the ultrashort-lived unstable particle X can be claimed, then the real world can only be a world in which X exists, and not one in which X doesn't exist.

Remark 2.3.23. The *denial* of the major in its general formulation, as discussed on page 50, yields the negation of Eq. (2.34) with X interpretable as any thing:

$$\models_{w_0} \ \rhd\mathcal{O}X \wedge \Diamond\neg\mathcal{E}X \tag{2.35}$$

Taking this view is admitting that it can be claimed that a thing X has been observed while it is possible that X does not exist. And that is admitting to the possibility of the Kantian picture of the observation of a unicorn, shown in Fig. 2.9, which is absurd. ■

Remark 2.3.24. As to the modal propositions in w_0, the modality '$\overline{\Diamond}$', to be read as 'it is at best possible that', is hereby defined as follows:

$$\models_{w_0} \overline{\Diamond}\Phi \Leftrightarrow \Diamond\Phi \wedge \Diamond\neg\Phi \tag{2.36}$$

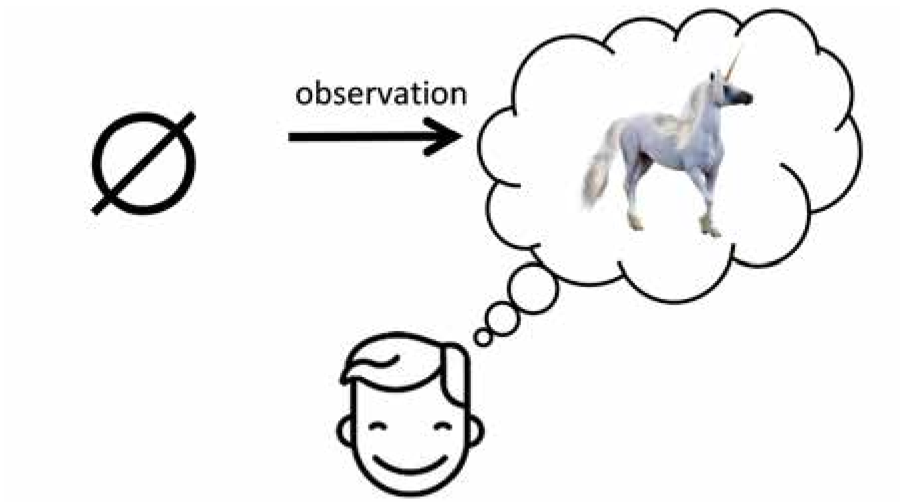


Figure 2.9: Kantian picture of the observation of a unicorn. The outside world is one in which the set of all existing unicorns is the empty set, represented by the empty-set symbol on the left. Observation produces a mental image of a unicorn. We thus have $\models_{w_0} \; \triangleright\mathcal{O}U$ (with U standing for the unicorn) and $\models_{w_j} \; \neg\mathcal{E}U$ for a possible real world w_j that is accessible from the epistemic world w_0. This is patently absurd.

We can then formalize the minor as stated on page 50 in the language $\mathcal{L}$:

$$\models_{w_0} \; \triangleright\mathcal{O}\delta_X \Rightarrow \overline{\Diamond}\mathcal{E}X \tag{2.37}$$

As a side note, this implies

$$\models_{w_0} \; \triangleright\mathcal{O}\delta_X \Rightarrow \neg\Box\mathcal{E}X \tag{2.38}$$

which is a more refined expression than Eq. (2.18). Furthermore, if we have accepted the general form of the major on page 49 (with X standing for any thing) then of course we also have

$$\models_{w_0} \; \triangleright\mathcal{O}\delta_X \Rightarrow \Box\mathcal{E}\delta_X \tag{2.39}$$

The real world meaning expressed by Eq. (2.37) is illustrated by Fig. 2.10.

Obviously, if the major holds in the form of Eqs. (2.34) and (2.39), and

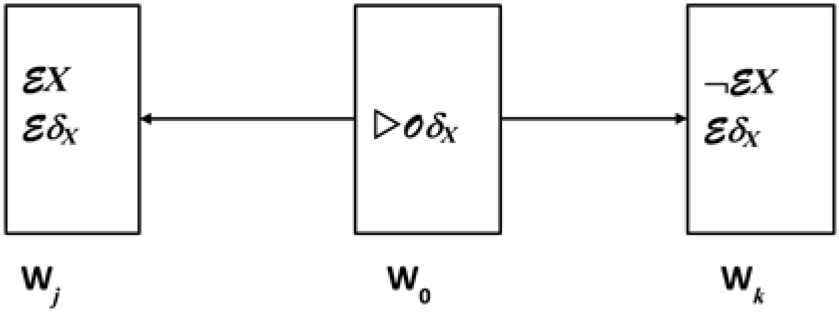


Figure 2.10: Illustration of the real-world meaning of Eq. (2.37). Suppose we have that Eqs. (2.39) and (2.37) are valid; and suppose we have that the observation can be claimed of particles that can be described as the decay products of the ultrashort-lived unstable particle X. We then have that $\rhd\mathcal{O}\delta_X$ is true in the epistemic world w_0 as depicted by the square in the middle. Then not only possible real worlds $w_j \in W$ in which $\mathcal{E}X$ and $\mathcal{E}\delta_X$ are true are accessible, as depicted by the arrow to the left and the square on the left, but also possible real worlds $w_k \in W$ in which $\neg\mathcal{E}X$ and $\mathcal{E}\delta_X$ are true, as depicted by the arrow to the right and the square on the right. That is, then the real world can be a world in which X exists, but also a world in which X does not exist.

the minor holds in the form of Eq. (2.37), then the 5σ-convention

$$\models_{w_0} \ \rhd\mathcal{O}\delta_X \Rightarrow \rhd\mathcal{O}X \tag{2.40}$$

does **not** hold (by the same argument as in Sect. 2.2). So if we want the 5σ-convention (2.40) to hold, the following is *at least* required:

$$\models_{w_0} \ \rhd\mathcal{O}\delta_X \Rightarrow \Box\mathcal{E}X \tag{2.41}$$

This is, arguably, the position of most physicists. However, it can easily be laid bare that this denial of the minor, as discussed in Sect. 2.2, amounts to a circular reasoning. To reject the minor (2.37) and to accept Eq. (2.41) instead is to take *a priori* the position that the possible real worlds w_k in Fig. 2.10 are inaccessible from w_0, leaving that only the possible real worlds w_j in Fig. 2.10 are accessible from w_0. That means that it is *beforehand* assumed that $\mathcal{E}X$ is true in the real world. But that is what we want to prove with the experiment. So this is a clear-cut case of *petitio principii*—assuming what has to be proven. ■

Remark 2.3.25. Since the possible real worlds $w_j \neq w_0$ are not in the domain of the accessibility relation R, modal propositions are *meaningless* in a possible real world. To formalize that in the present frame for modal propositional logic, we can introduce expressions

$$\not\models\!\!\!\!/_{w_j} \Psi \tag{2.42}$$

which have to be read as 'Ψ is meaningless in w_j'—the symbol '$\not\models\!\!\!\!/_{w_j}$' thus captures that the w_j's are not in the domain of the accessibility relation R. The Bochvar theory of meaninglessness applies:

(i) if $\not\models\!\!\!\!/_{w_j} \Phi$, then $\not\models\!\!\!\!/_{w_j} \neg\Phi$;

(ii) if $\not\models\!\!\!\!/_{w_j} \Phi$, then $\not\models\!\!\!\!/_{w_j} \Upsilon \Rightarrow \Phi$ for any formula Υ;

etc., see Bochvar (1939). Ergo, a formula is meaningless in w_j when a subformula is meaningless. That said, for any atomic proposition Ψ of Def. 2.3.20 we have

$$\forall w_j \neq w_0 : \not\models\!\!\!\!/_{w_j} \Diamond\Psi \tag{2.43}$$

$$\forall w_j \neq w_0 : \not\models\!\!\!\!/_{w_j} \Box\Psi \tag{2.44}$$

Note that Eq. (2.43) is different from $\models_{w_j} \neg\Diamond\Psi$: the latter, namely, implies $\models_{w_j} \Box\neg\Psi$, and because we have $\Box\Theta \Rightarrow \Diamond\Theta$ in the present frame (see Reply 2.3.19) that gives $\models_{w_j} \Diamond\neg\Psi$. But that would mean that there is at least one $w_k \in W$ with w_jRw_k with $\models_{w_k} \neg\Psi$. But there is no $w_k \in W$ such that w_jRw_k, so that is not true. Ergo, $\not\models\!\!\!\!/_{w_j} \Diamond\Psi$ is not the same as $\models_{w_j} \neg\Diamond\Psi$. A similar reasoning holds for expression (2.44).

Furthermore, claims are propositions in the epistemic world w_0 only, so we have

$$\forall w_j \neq w_0 : \not\models\!\!\!\!/_{w_j} \neg \rhd \Psi \tag{2.45}$$

In other words: propositions of the form 'it can be claimed that Ψ' are meaningless in any possible real world w_j. The point is that a claim can be *communicated* by a physical signal in the real world, e.g. words in a printed issue of a journal (which an ant also sees), but the communicated *meaning* of the signal (which an ant doesn't get), i.e. the actual claim , only 'lives' in the epistemic world. ■

Objection 2.3.26. "*The editors of the Journal have given careful consideration to this paper, and, I'm sorry to say, have decided not to accept it for publication.*"—Editor of a journal specializing in applications of logic to philosophy, rejecting **within 24 hours** a previous version of (Cabbolet, 2018a), in which the argument against the 5σ-convention was presented in the frame for modal logic defined above in Reply 2.3.19 and Rems. 2.3.23, 2.3.24, and 2.3.25 ■

Reply 2.3.27. The journal is the number one forum for applications of logic (including modal logic) to philosophical issues. The editorial rejection—in particular the time frame within it was given—is strange, but usually the simplest explanation for a phenomenon is true. Here the simplest explanation is that this was a so-called name-based rejection—i.e. a rejection of a submitted paper based on the name of the author—because the editor is from Dutch and remembers me from the controversy surrounding my work in the Netherlands (see page xxix ff.). He will deny that, but fact of the matter remains that this is the simplest explanation. ■

Objection 2.3.28. "*The role of logic in this paper is not of sufficient interest for considering this paper for publication in [our journal].*"—anonymous editor of a tier-1 logic journal, rejecting the previous version of (Cabbolet, 2018a) mentioned in Objection 2.3.26 ■

Reply 2.3.29. The website of the journal states that the scope of its published papers covers all the philosophical subjects provided they make use of formal logical methods. That condition was satisfied by the submitted paper, so I don't believe a single word of what the editor wrote: the real reason for rejection was something entirely else. ■

Objection 2.3.30. "*I am sorry to tell you that the editors have decided not to publish your paper in the journal.*"—manager of a tier-1 philosophy journal, rejecting the previous version of (Cabbolet, 2018a) mentioned in Objection 2.3.26 ■

Objection 2.3.31. "*This is a revised version of the paper that we rejected in 2016 [see Objection 2.3.87]. We do not consider updated versions of rejected papers again for publication.*"—associate editor of a tier-1 philosophy journal, rejecting the previous version of (Cabbolet, 2018a) mentioned in Objection 2.3.26 (which is a completely different paper than the conference paper (Cabbolet, 2015c) to which he refers) ■

Objection 2.3.32. "*I regret to inform you that the editors had to conclude that this work is not suitable for publication in [our journal]. This manuscript is more appropriate for consideration by a philosophy journal.*"—editor of a physics journal focussing on conceptual issues (which I believed to include issues with the concept of observation in physics), rejecting the previous version of (Cabbolet, 2018a) mentioned in Objection 2.3.26 ∎

Objection 2.3.33. "*We regret that as the subject of your study is beyond the scope of the journal we cannot consider it for publication.*"—Deputy Editor of an open-access mega journal, rejecting the previous version of (Cabbolet, 2018a) mentioned in Objection 2.3.26 ∎

Objection 2.3.34. "*You critically analyze the inferences of physical properties on the basis of statistical methods relying on the use of the standard deviation. You come to the conclusion that experimental results cannot be claimed to be (and called) 'observations'. Your analysis can be useful in the area of philosophy ... but falls outside the scope of [our journal].*"—Editor of an open-access mega journal in physics, rejecting the previous version of (Cabbolet, 2018a) mentioned in Objection 2.3.26 ∎

Reply 2.3.35. Of course, none of these journals is obliged to publish any submitted paper. But my question is what these journals are actually worth in the grand scheme of things when they flat-out refuse to offer a forum for well-founded criticism of the claims by Big Physics? Haven't we arrived at the end of an era of journal-based publication? ∎

Objection 2.3.36. "*What the author has indeed shown is the stunning infertility of analytic philosophy for science that results from the far-reaching neglect shown by contemporary epistemologists for philosophy of science. For instance, Franklin (Shifting Standards) has shown that the* 5σ*-convention is embedded into a plethora of strategies to establish the significance of a new particle signature against the background of known physics. Physicists are well aware of these methods and the problems of statistical analysis (see the papers by physicists included in a recent special issue of this journal). The author however seems not to care. It is either IBE respectively consensus or an epistemologically palatable and scientifically unreachable concept of observation—which probably refers to chairs, tables, and motor vehicles or even only to directly perceived blots of blue and red (pick your favorite* *foundationalism). I assume that the same logical machinery could also be used against mass points, electromagnetic field strength, and nano-particles in shaving foam. Epistemologists might love the paper; as a philosopher of science I must recommend rejection.*"—referee of a tier-1 philosophy journal, rejecting the previous version of (Cabbolet, 2018a) mentioned in Obj. 2.3.26

Reply 2.3.37. This rant is an example of what peer review is supposed to be **not**: the referee—we may speculate that it is Franklin himself, but we can't claim that—barks at the paper but does not address a single one of the arguments against the 5σ-convention provided in the submitted paper. This has nothing to do with an objective evaluation of the scientific quality of a submitted paper: this is abusing the peer-review report to express one's dislike of criticism of one's own belief in accordance with the response-in-an-outburst model on page li. ■

Objection 2.3.38. "*The paper does not offer sound reasoning and therefore cannot be accepted for publication. ... The author deploys extensive machinery of propositional logic. It remains unclear, however, what is being achieved by this. The conclusion extracted—that the observation of alleged decay products of an object A formally does not prove the existence of object A—seems fairly self-evident. The author may consider, however, that even the observation of tables and chairs must—from a physicist's perspective—be understood in terms of a contingent causal chain, involving, among others, light rays. In this light, the observation of a physical table does not follow logically from observational data either. To follow the author's advice and acknowledge the observation of an object only if the existence of the given object can be logically deduced from the data thus would imply not to acknowledge the existence of any objects at all..*"—second anonymous referee of the tier-1 philosophy journal, rejecting the previous version of (Cabbolet, 2018a) mentioned in Obj. 2.3.26 ■

Reply 2.3.39. Together with Objection 2.3.36 this shows that a high ranking of a journal does not exclude that the standard of peer review is the lowest of the lowest: like the previous one, this objection too has absolutely nothing to do with objectively evaluating the scientific quality of a submitted paper. The referee does not even make an attempt to actually address the arguments against the 5σ-convention provided in the submitted paper.

Make no mistake: his statement "it remains unclear ... by this." gives away that he has not even tried to understand the submitted paper, because if he would have done so he would have understood that the achievement of the paper is that the untenability of the 5σ-convention in particle physics, on which all these observational claims regarding ultrashort-lived unstable particles are based, has been proven from two premises, which have been formalized in a frame for modal propositional logic to avoid any misunderstanding about the meaning of 'necessarily true'. Moreover, the whole part from "The author may consider ..." on is really arm-chair philosophy. The referee is completely mistaken with his conclusion that the arguments against the 5σ-convention provided in the submitted paper would render it impossible to develop any existential knowledge at all. If we *directly* observe an object, e.g. a bicycle as in Fig. 2.3, then this is an *epistemologically direct* observation: the mental image produced by the act of the senses is then an image **of that object**: of course we can then conclude that the real world can only be a world in which the object exists—the causal chain to which the referee refers is *irrelevant*. The point here is that the minor of the present argumentation (see page 50) does <u>not</u> apply to cases of direct observation—the difference is thus that this mental image of the object is always absent when the object is an ultrashort-lived unstable particle postulated by the Standard Model. ■

Objection 2.3.40. "*The paper claims that it is false that certain ultrashort lived particles have been observed. The core of the argument consists in the claim that what has been observed is logically compatible with the non-existence of the particles in question. This is correct. But the argument could be made much more simply without the help of the logical machinery invoked in the paper and strikes us as philosophically not sufficiently deep point to warrant publication. Yes, high energy physicists use the term 'observation' in a misleading way in this context. But otherwise the paper only makes the familiar point that even the best and most compelling experimental evidence cannot strictly prove a theory.*"—Editors-in-Chief of a tier-1 journal in philosophy of science, rejecting of the previous version of (Cabbolet, 2018a) mentioned in Obj. 2.3.26 ■

Reply 2.3.41. This objection was helpful in the sense that it made me decide to present the argument against the 5σ-convention *without* its formalization in the frame for modal propositional logic: this led to the publication in *Mod. Phys. Lett. A*. For the rest, see Reply 2.3.35. ■

Objection 2.3.42. "*Because your manuscript was not given a high priority rating during the initial screening process, we have decided not to send your paper for further in-depth review.*"—Editor of an open-access mega journal, rejecting the previous version of (Cabbolet, 2018a) mentioned in Obj. 2.3.18 ■

Objection 2.3.43. "*In light of the appropriateness of your manuscript for our journal, your manuscript has been denied publication.*"—editor of an open-access mega journal, rejecting the previous version of (Cabbolet, 2018a) mentioned in Obj. 2.3.18 ■

Objection 2.3.44. "*Because your manuscript was not given a sufficiently high priority rating during the initial screening process, we have decided not to proceed to in-depth review.*"—Editor of a top journal, rejecting the previous version of (Cabbolet, 2018a) mentioned in Obj. 2.3.18 ■

Objection 2.3.45. "*I do not think this paper is matched with this journal because the subject is scientific philosophy. I recommend the author to resubmit this to a journal of the field.*"—anonymous board member a tier-1 physics journal, rejecting the previous version of (Cabbolet, 2018a) mentioned in Obj. 2.3.18 ■

Objection 2.3.46. "*I am certainly sympathetic for your philosophical and logical arguments concerning the use of the term 'observation'. E.g. I fully agree to your conclusion that the best way to describe these findings is indeed that the LHC measurements confirm the Standard Model. Without being able to discuss these issues with you in more detail, it is still our opinion that your manuscript cannot be considered for [our journal]. Rather it could be submitted to a journal in the area of science philosophy, logic or even science policy.*"—Editor-in-Chief of a tier-1 physics journal, rejecting the previous version of (Cabbolet, 2018a) mentioned in Obj. 2.3.18 ■

Objection 2.3.47. "*Dear Dr. Cabbolet, ... We have considered your manuscript. We do not think that it is suitable for publication in [our journal].*"—Managing of a high-impact open-access physics journal, rejecting the previous version of (Cabbolet, 2018a) mentioned in Obj. 2.3.18 ■

Objection 2.3.48. "*Dear Dr. Cabbolet, ... The review process is now completed, and I regret to inform you that your manuscript has not been accepted for publication in the journal.*"—Editorial Assistant of a tier-1 philosophy journal, communicating the editorial rejection of the previous version of (Cabbolet, 2018a) mentioned in Obj. 2.3.18 ■

Objection 2.3.49. "*Dear Dr. Cabbolet, ... Thank you for sending us your paper. We regret that it cannot be accepted for publication in our journal.*"—Administrator of a top philosophy journal, communicating the editorial rejection of the previous version of (Cabbolet, 2018a) mentioned in Obj. 2.3.18 ■

Objection 2.3.50. "*Dear Dr. Cabbolet, ... Thank you for sending us your paper. We regret that it cannot be accepted for publication in our journal.*"—Administrator of (another) top philosophy journal, communicating the editorial rejection of the previous version of (Cabbolet, 2018a) mentioned in Obj. 2.3.18 ■

Objection 2.3.51. "*Dear Dr. Cabbolet, ... The Editors have considered [your paper] and, I am sorry to say, it has not been accepted for publication. ... The Editors have not indicated any encouragement for a resubmission.*"—Managing Editor of (yet another) top philosophy journal, communicating the editorial rejection of the previous version of (Cabbolet, 2018a) mentioned in Obj. 2.3.18 ■

Objection 2.3.52. "*Dear Dr. Marcoen Cabbolet, The editors have given careful consideration to your manuscript and, I'm sorry to say, have decided not to accept it for publication in the [our journal]. We realize that it's unsatisfying to receive only a report of the decision, without any of the underlying rationale.*"—Editorial Manager of again a top philosophy journal, communicating the editorial rejection of the previous version of (Cabbolet, 2018a) mentioned in Obj. 2.3.18 ■

Reply 2.3.53. The last four objections (2.3.49 to 2.3.52) are by the top philosophy journals. To the last eleven objections above, Reply 2.3.35 applies. ■

Objection 2.3.54. "*The main point being made in this manuscript seems to be that the fallacy of affirmation of the consequent tends to be regularly committed in the physics literature (I would add, not only in particle* *physics). This is hardly a novel point nor one unknown to practicing physicists (see e.g. Leggett and Vural,* J. Phys. Chem B ***117****, 12966, 2013), and I think the paper is unlikely to be of much interest to either the physics or the philosophy of science community.*"—anonymous member of the Editorial Board of a tier-1 general journal, rejecting the previous version of (Cabbolet, 2018a) mentioned in Obj. 2.3.26 ■

Reply 2.3.55. This is a wrong assessment: it is **not at all** the point of the paper that the fallacy of affirmation of the consequent tends to be regularly committed in the physics literature. Instead, the point is that the 5σ-convention in particle physics is *by itself* insufficient for an observational claim regarding an ultrashort-lived unstable particle. ■

Objection 2.3.56. "*The statement that a new boson has been observed is in essence based on the comparison of the probabilities for the two hypotheses that the measured diphoton mass spectrum is only due to know processes ('background') or to background plus the production of a new particle (here a boson). If the probability for background plus 'new particle' hypothesis is very significantly larger than the background only hypothesis the convention is to call this an observation of a new state decaying in the particular decay channel (here gamma-gamma). ... This is a perfectly valid statistical procedure and should not be confused with potentially different definitions of 'observation' in other fields.* "—editor of a tier-1 physics journal, rejecting the conference paper (Cabbolet, 2015c) ■

Objection 2.3.57. "*I think the author has misinterpreted what physicists mean when they say something has been observed. ... I believe most physicists use the term 'observation' of a new phenomenon or signal to mean that there is significant evidence against the non-existence of the signal, usually in the context of a statistical test. This is the basis of the 5σ statement; it quantifies the outcome of a test of the no-signal hypothesis.*"—referee of a tier-1 physics journal, rejecting the conference paper (Cabbolet, 2015c) ■

Reply 2.3.58. Obj. 2.3.56 and Obj. 2.3.57 are both wrong with regard to the formulations of the hypotheses: this objection has already been treated in Reply 2.3.9. The reply I received from the editor meant in Obj. 2.3.56 was 'helpful' in the sense that I decided to show that the 5σ-convention is *by itself* inadequate for an observational claim—as opposed to showing that it contradicts definitions of 'observation' in the philosophical literature. ■

Remark 2.3.59. As to the time line, after my talk at the 7th conference of the Dutch-Flemish Association for Analytic Philosophy in January 2015 I first tried to publish the conference paper (Cabbolet, 2015c). I persisted therein—see below for some more objections to it—until I received Objection 2.3.56. I considered his view, that the 5σ-convention should not be confused with definitions of 'observation' in philosophy, to be a valid objection, although it remains of course true that the 5σ-convention is inconsistent with the definitions by Van Fraassen and Fox. That led to the version of (Cabbolet, 2018a) mentioned in Objection 2.3.18: I tried to publish that argument against the 5σ-convention until I received Objection 2.3.18 : that made me decide to present the argument in a suitable frame for modal propositional logic to avoid confusion about the term 'necessarily true'. I then tried to publish that rather technical version of the finally published argument until I received Objection 2.3.40. That made me decide to present the argument in its form as finally published in *Mod. Phys. Lett. A*, so without the frame for modal propositional logic. ■

Objection 2.3.60. "*Physicists are using models and test these models. Nothing of the measurements contradicts the 'Standard Model' Higgs model, in contrary more and more of its facets are confirmed. But physicists keep also open for other possibilities. We have rules according to which a model is accepted and interpreted. You may question them, but these are 'rules' according to which we communicate our findings and we understand the limitations of those rules.*"—editor of a tier-1 physics journal, rejecting the conference paper (Cabbolet, 2015c) ■

Reply 2.3.61. With this objection, which I received after having sent a rebuttal of Objection 2.3.57, the editor merely reiterates that the 5σ-convention is the rule that physicists use to communicate their findings, *as if* that somehow means that this rule is infallible c.q. beyond criticism. For me, this objection is the very negation of a scientific discussion, and an example of intolerance towards any view other than one's own. ■

Objection 2.3.62. "*[Huh, what?] No Higgs, no quarks, no atoms??? ... This is simply naive and bad philosophy ... A golden opportunity for every physicist who wants to show how irrelevant and pompous philosophy is.*"—anonymous referee of a journal in philosophy of science, rejecting the conference paper (Cabbolet, 2015c) ■

Reply 2.3.63. To pass this off as a peer-review report is nothing but scientific misconduct. The referee—obviously a physicist—failed to notice that the submitted paper does not question that ultrashort-lived unstable particles *exist*: it only questions the claims that ultrashort-lived unstable particles have been *observed*. This indicates that not even an attempt has been made to adhere to the principle of carefulness. The above reply is yet another example of an objection that can perfectly be explained with the response-in-an-outburst model on page li. ■

Objection 2.3.64. "*The author does not understand the basics of Higgs physics.*"—second argument of the referee who came up with Obj. 2.3.62■

Reply 2.3.65. This is dishonest trick #16 described in Schopenhauer's *The Art of Being Right*: the ad hominem argument. And not only that: the referee has made this claim up from thin air, because the submitted paper contained no section on Higgs physics—so, he doesn't know whether or not I understand it. Apart from that, the referee has used this as an argument to reject my paper on unobservability of the Higgs boson. We are then getting dangerously close to the position that only very intelligent people, who can understand Higgs physics, can "see" an observation of the Higgs boson in the outcome of the experiments—the parallel to the fairy tale about the emperor's cloths is obvious. ■

Objection 2.3.66. "*The author ... claims with an arrogant sentiment that particle physics is all wrong. The attitude is not appropriate for a scientific audience.* "—anonymous referee of a journal focussing on foundational issues in science, rejecting the conference paper (Cabbolet, 2015c) ■

Reply 2.3.67. The quality of the analysis is not really better than that in Objection 2.3.62: nowhere in the paper is it claimed that particle physics is all wrong. The analytical skills of the referee are not at the level he thinks they are. ■

Objection 2.3.68. "*There is no direct observation of an object. The example of the airplane is horrible because what we observe are the photons reflected by it.*"—second referee of the same journal as meant in Obj. 2.3.66 ■

Reply 2.3.69. The referee simply denies the definition: that's not an argument, that is just contradiction (as Monty Python put it). As was also stated in the submitted paper, Def. 2.2.1 is about *epistemologically* direct observation: regardless of the fact that e.g. a bicycle is observed *by means of* photons, fact of the matter is that a direct observation of a bicycle produces a mental image of a bicycle as illustrated by Fig. 2.3. There is nothing more to it: that is a direct observation. ■

Objection 2.3.70. "*Our editorial staff has assessed your submission, and we have concerns about the grammar, usage, and overall readability of the manuscript. We therefore request that you revise the text to fix the grammatical errors and improve the overall readability of the text before we send it for review.*"—co-worker op an open-access mega journal, inviting the resubmission of the conference paper (Cabbolet, 2015c) after copyediting■

Reply 2.3.71. Many of my opponents have reacted in an emotional outburst to my unorthodox or critical papers, but not so this mega journal: this is calculated strategic action. I'll try to explain. Objection 2.3.70 is an excerpt of a longer revise-and-resubmit letter, in which the mega journal first declared that the submitted paper was essentially unintelligible and then recommended an editing service (which was mentioned by name) to me for copyediting. So, I had a Dutch friend of mine copy edit the manuscript, and I then resubmitted the revised version (which was virtually flawless). However, the mega journal came with the same objection: "We have carefully examined your manuscript following our recent request for copyediting, and unfortunately still feel that the quality of the language is not at an adequate standard for peer review." And again, they recommended the same editing service. I then replied to them that I believed that they had a little scam going on by duping foreign authors into using the services of that editing service. I received no response from the mega journal. However, my friend (the one who copy edited the paper) was willing to pay the fee for the editing service, just to see where this was going. So, I had the paper copy-edited by the editing service. The result was interesting: apart from the fact that the copyediting was done by someone with Russian first and last names (probably a student), and apart from the fact that erroneous suggestions to replace technical terms gave away that the copy editor was not familiar with the jargon, the whole copyediting boiled down to trivial suggestions to replace words by their synonyms. E.g. it was suggested to change "the main implications" into "the major implications", to change "the modern physicist's stance" into "the stance of the modern physicist", to change "the significance has to be 5σ" into "the significance must be 5σ", and trivial things like that—*literally* the **only** nontrivial suggestion was to change "the importance of [this] for particle physics" into "the importance of [this] to particle physics". I then submitted the copy-edited manuscript to the mega journal. Within a few days I receive the following rejection:

> "*I regret we have decided that your manuscript is not suitable for publication by [our journal]. [Our journal] has been specifically designed for the publication of the results of primary scientific research in any applied discipline; it is not suitable for purely theoretical research. In this case we feel that your submission falls too far into this category to justify inclusion in [our journal].*"

I'm telling you: they knew that already when I submitted the paper for the first time. This is a scam: their initial statement that the submitted manuscript was unintelligible is a deliberate lie. ■

Objection 2.3.72. "*We find this article more appropriate for a philosophy journal or for one on the conceptual foundations of physics, rather than for [our journal]*"—Journal Manager of a tier-1 physics journal, communicating the editorial rejection of the conference paper (Cabbolet, 2015c) ■

Objection 2.3.73. "*I have read your paper with interest but regret that this work is not appropriate for presentation in [our journal]. Please consider submitting your work to a regular journal specializing in the foundations of physics or particle physics.*"—Editor of a tier-1 physics journal, rejecting the conference paper (Cabbolet, 2015c) ■

Objection 2.3.74. "*The paper does not present rigorous scientific arguments. The methodology is not compatible with the standards of [our journal].*"—Editorial Board Member of an open-access mega journal, rejecting the conference paper (Cabbolet, 2015c) ■

Objection 2.3.75. "*We regret to inform you that, after due consideration, your paper has been deemed unsuitable for publication in [our journal] by the Editorial Board.*"—anonymous coworker of the editorial office of a tier-1 physics journal, rejecting the conference paper (Cabbolet, 2015c) ■

Objection 2.3.76. "*Dear Dr Cabbolet, ... we regret that we are unable to conclude that the work provides the sort of firm advance in general understanding that would warrant publication in [our journal].*"—Senior Editor of a top physics journal, rejecting the conference paper (Cabbolet, 2015c) ■

Objection 2.3.77. "*Because your manuscript was not given a high priority rating during the initial screening process, we have decided not to proceed to in-depth review. The overall view is that the scope and focus of your paper make it more appropriate for a more specialized journal.*"—Editor of a top general scientific journal, rejecting the conference paper (Cabbolet, 2015c) ■

Objection 2.3.78. "*Dear Dr Cabbolet, ... we do not believe that [your paper] represents a development of sufficient scientific impact to warrant publication in [our journal]. These editorial judgements are based on such considerations as the degree of advance provided, the breadth of potential interest to researchers and timeliness.* "—Physical Sciences Editor of another top general scientific journal, rejecting the conference paper (Cabbolet, 2015c) ■

Reply 2.3.79. To these latter seven objections, Reply 2.3.35 applies. ■

Remark 2.3.80. In between the conference paper and the version submitted to *Australas. J. Philos.* (cf. Rem. 2.3.59) I developed a version of the argument against the 5σ-convention that used the so-called JTB-definition of knowledge. In a nutshell, the argument was that if you observe a thing X, then you 'know' that X exists; but if you observe what can be described as the decay products of an ultrashort-lived unstable particle X, then you still don't 'know' that X exists; therefore, if you have observed decay products of X, you still haven't observed X—this is the negation of the 5σ-convention. Attempting to publish this version of the argument against the 5σ-convention led to vicious replies by referees, as well as some rather strange comments. Some of these will be treated below. ■

Objection 2.3.81. "*The main argument now is that existential knowledge regarding ultrashort-lived particles is unavailable, because it has to be based on an inference to the best explanation (IBE) and IBE is unable to generate existential knowledge. This argument is based on a mixture of conceptual* *confusion and ignorance of almost the complete debate on IBE in philosophy of science.*"—anonymous referee of a tier-1 philosophy journal, rejecting the prior version of (Cabbolet, 2018a) of Rem. 2.3.80 ■

Reply 2.3.82. By denying the second premise mentioned in Rem. 2.3.80, this referee holds that we 'know' that an ultrashort-lived unstable particle X exists upon an observation of what can be described as the decay products of X. This is bad philosophy, based on overgeneralized conclusions that emerged from an excessively narrow philosophical debate on 'knowledge' in an abstract sense—i.e., as a topic on its own, apart from specific instances of knowledge. Even if there are cases (e.g. in the macroscopic world) where IBE generates existential knowledge it is simply not true that IBE generates existential knowledge *in every case*. In particular this is not true in the cases at hand concerning ultrashort-lived unstable particles. The statement "we 'know' that an ultrashort-lived unstable particle X exists c.q. existed in the system under observation upon an observation of the decay products of X" is, namely a circular reasoning (*petitio principii*). The crux is that the observed particles are given a theory-laden description as 'the decay products of the ultrashort-lived unstable particle X'. But by giving the observed particles this theory-laden description, it has been tacitly assumed (i) that prior to the observation, the ultrashort-lived unstable particle X was present in the system under observation and (ii) that prior to observation, that existing ultrashort-lived unstable particle X has decayed into the observed particles. Therefore, the conclusion that we 'know' that the ultrashort-lived unstable particle X exists c.q. existed in the system under observation has been tacitly assumed. This is similar to the circular reasoning involved in calling an observation of what can be described as the decay products of an ultrashort-lived unstable particle X an indirect observation of X: as mentioned on page 45, an indirect observation presupposes prior knowledge of the cause of the observed phenomenon. So, existential knowledge of a postulated particle X derives *solely* from an observation of X, and that's it. ■

Objection 2.3.83. "*Observational claims can be justified even though the implied existential beliefs may turn out to be false.*"—anonymous referee of a philosophy journal, rejecting the prior version of (Cabbolet, 2018a) of Rem. 2.3.80 ■

Reply 2.3.84. If an existential belief is false, then the thing believed to exist does not exist. Therefore, this objection implies that it is the view of this referee that we can claim to have observed a thing even though that thing may not exist. This is precisely the negation of major, discussed on page 49 ff. So, I wish this referee happy unicorn hunting! ■

Objection 2.3.85. "*It seems like the work of the philosopher here is better served in educating philosophers about how these experiments [i.e. experiments aimed at proving the existence of ultrashort-lived unstable particles] actually work, rather than demanding that the particle physics community change their usage of the word 'observation'.*"—referee of a tier-1 journal in philosophy of science, rejecting the prior version of (Cabbolet, 2018a) of Rem. 2.3.80 ■

Reply 2.3.86. This reeks of a so-called *courtier's reply*: as I see it, this referee takes the position that a philosopher lacks the necessary background to criticize claims by physicists in any way. But even apart from the fact that I'm not a pure philosopher—I rather see myself as an interdisciplinist—it remains unclear how this invalidates the arguments provided in the paper against the observational claims by physicists. ■

Objection 2.3.87. "*In the paper it is argued that the 'observations of ultrashort-lived unstable particles cannot be claimed' and that as such 'such observational claims in the literature have to be dismissed as overstatements'. I disagree with these statements. Therefore I recommend the paper be rejected. The crucial part in the argument ... is true for any observation. ... Maybe our observations are tricking us. Maybe the cows we see are just fluctuations. Or maybe we are just brains in the vat, with experiences of cows but without cows actually existing. So the reasoning of the author applies to any observation; strictly speaking it never shows the existence of anything. ... For example, we also don't directly observe the cow. It is the light that is reflected from the cow that we see.*"—anonymous referee of a tier-1 philosophy journal, rejecting the prior version of (Cabbolet, 2018a) of Rem. 2.3.80 ■

Reply 2.3.88. This is nothing but yet another example of arm-chair philosophy. The fact that in the paper the position is taken that we still don't 'know' that the ultrashort-lived unstable particle X exists if we have observed what can be described as the decay products of X , does absolutely not imply that <u>also</u> the position is taken that we cannot even 'know' that a thing exists if we have observed it *directly*: in the latter case, namely, we have a mental image of the thing which is absent in the former case. So the referee is mistaken with his claim that the argument against the 5σ-convention applies to any observational claim. And he is mistaken again in his claim that cows aren't directly observable: we do obtain a mental image of the cow. See also Objections 2.3.36, 2.3.38, and 2.3.66. ■

Objection 2.3.89. "*The author ... tries to convince the reader that it is incorrect to claim an observation of an ultrashort lived particle based on the sole study of its decay products. ... His main objection seems to be in the fact that if the significance is larger than predefined value it is not usually quoted and the statement without it can be identified as 'existential preposition' [sic] as the Author calls it. ... Both theoreticians and experimentalist working in high-energy physics do understand this issue and just omit significance level for brevity. Moreover, the author argues that due to short life-time ($< 10^{-20}$ s) and the finiteness of the speed of light it is impossible to detect the particle in a bubble chamber. First of all, a track in a bubble chamber is still an indirect observation. And what is more important, the author does not take time-dilation into account. Indeed, in the particle rest frame the distance is tiny. Nevertheless, it can travel a long path in the laboratory frame, if it is produced with large enough velocity (high energy). As a consequence, it can, in principle, be 'directly' detected via track (displaced decay vertex) in a detector. Due to the above-mentioned issues, I am not able to recommended the manuscript for publication in the [our journal] in any form.*"—anonymous referee of a physics journal focussing at conceptual issues (which I believed to include issues with the concept of observation in physics), rejecting of the prior version of (Cabbolet, 2018a) of Rem. 2.3.80 ■

Reply 2.3.90. This referee report lacks substance to such a degree that the term pseudoskepticism applies. As a first argument against my paper, he "refutes" what he believes is my main objection. But unfortunately for him, he has wrongly paraphrased my main objection: this indicates that he has barely understood the paper and is responding in accordance with the response-in-an-outburst model on page li. His second argument, that ultrashort-lived unstable particles can in fact be observable if their energy is high enough, is another fine example of arm-chair philosophy. None of what the referee babbles has been the case in the actual experiments that led to the observational claims which I criticized in the paper. ■

Objection 2.3.91. "*Although the content of the paper may be logically correct, I believe it would have essentially no impact on the physics community if published in its present form. Whilst it is true that particles with lifetimes of order* 10^{-23} *sec cannot travel detectable distances, I doubt there are any working physicists who consider that this raises any doubt about their existence. This reviewer believes that the paper would have to be entirely rewritten if it was to be of significant interest to the physics community. This reviewer sees two major changes as being required. First, the discussion of ultrashort-lived particles should be based on the ultrashort-lived particles that were originally observed in the 1950s and 1960s by Fermi, Alvarez and others. ... Secondly, if one wishes to question the Standard Model or any part of it on philosophical grounds, there are more suitable questions than ultrashort-lived particles in the opinion of this reviewer.*"—second anonymous referee of the same journal as in Obj. 2.3.89 ■

Reply 2.3.92. Apart from the fact that this referee, with his statement "Whilst it is true that particles with lifetimes of order 10^{-23} sec cannot travel detectable distances" directly contradicts the other referee of *Found. Phys.*, cf. Objection 2.3.89, his two suggestions demonstrate a lack of understanding of the submitted paper. First of all, my criticism is addressed at *all* these claims that ultrashort-lived particles have been observed: this is about the convention that these claims can be made. So, the first change that the referee suggests is irrelevant for the point of the paper. Second, the aim here is not to question the Standard Model: the aim is purely to question that these ultrashort-lived unstable particles have been "observed", cf. Reply 2.3.63. ■

Objection 2.3.93. "*This paper is an essay about the differences between physicists and philosophers understanding of the word 'observation'. ... There might be a case for a much shortened essay focusing on the author's key point ... in a collection of philosophical essays rather than physics journal. This paper is not suitable for publication in [our journal].*"—third anonymous referee of the same journal as in Obj. 2.3.89 ■

Objection 2.3.94. "*With regret, I must inform you that the Editors have decided that your manuscript cannot be accepted for publication in [our journal].*"—anonymous coworker of a tier-1 philosphy journal, communicating the editorial rejection of the prior version of (Cabbolet, 2018a) of Rem. 2.3.80 ■

Objection 2.3.95. "*We regret to inform you that the editors have decided not to select your paper for publication in the [our journal]. Unfortunately, the editors find it impossible to detail [the] reasons; they trust that you will understand.*"—Editorial Assistant of a top philosophy journal, rejecting the prior version of (Cabbolet, 2018a) of Rem. 2.3.80 ■

Reply 2.3.96. To these latter three objections, Reply 2.3.35 applies. ■

Remark 2.3.97. Some objections have been received that I will not dignify with a reply. Nevertheless, I want to display them in this section to lay bare the standard of discussion in science and philosophy as it is behind closed doors. ■

Objection 2.3.98. "*This paper is not fit for publication in a philosophy journal. It's discussion of philosophical literature is very sparse, superficial, and dated. It makes some outrageous claims ... and doesn't seem to be familiar with some very basic philosophical concepts*"—anonymous referee of the same journal as in Obj. 2.3.36, rejecting the conference paper (Cabbolet, 2015c) ■

Objection 2.3.99. "*The paper crudely misunderstands the practice of physics, makes no effort to interpret the physicists' use of the terms 'observation' and 'particle' in detail, and ignores relevant philosophical literature. ... Meaning is use, and the physicists use the concepts of 'observation' and 'particle' in another way than most philosophers. What is indirectly observed is a new kind of particle, or unstable quantum state of a given mass, and what is directly observed is the corresponding resonance. The further conclusions of the paper are not justified [and] the paper does also not shed any light on the question of whether theories aim at truth or are just empirically adequate.*"—second anonymous referee of the same journal as in Obj. 2.3.36, rejecting the conference paper (Cabbolet, 2015c) ■

Objection 2.3.100. "*The text is plagued with inaccurate information and biased opinions that fail to count as arguments. To my mind, such opinions* *erode the academic tenor of the work presented and of the journal that publishes such works.*"—second anonymous referee of the same journal as in Obj. 2.3.66, rejecting the conference paper (Cabbolet, 2015c) ■

Objection 2.3.101. "*The author's analysis is completely out of touch with scientific practice ... The author proposes his argument as completely new and revolutionary, and even calls for a kind of revolution in science. But in fact something like his argument and variations of it are well-known ... So the physicist who complained about the irrelevance of this kind of philosophy [see Objection 2.3.62, which was discussed in the submitted paper] appears to be right.*"—Co-Editor of a tier-1 philosohy journal, rejecting the prior version of (Cabbolet, 2018a) of Rem. 2.3.80 ■

Objection 2.3.102. "*While the problem that the author takes up is interesting and appropriate for [our journal], the nature and quality of the argument are not.*"—anonymous referee of a top journal in philosophy of science, rejecting the prior version of (Cabbolet, 2018a) of Rem. 2.3.80 (without providing any arguments) ■

Objection 2.3.103. "*While the paper is scientifically informed, it is extremely philosophically naive and unsophisticated. It makes philosophically trivial points, and errs in the interpretation of basic philosophical notions.*"—second anonymous referee of the same journal as in Obj. 2.3.83, rejecting the prior version of (Cabbolet, 2018a) of Rem. 2.3.80 ■

Remark 2.3.104. When the conference paper (Cabbolet, 2015c) was still under development, I discussed the matter with a physicist from CERN whom I held (and still hold) in high regard. His reply was as follows:

> "*While I understand—I believe—the point you are making, I do not agree with it. Whether a resonance is short lived or not, it is always indirectly observed through its decay products. Perhaps we are in disagreement about semantics, but the stance of physicists is that if you observe the decay products, you observe the thing that has decayed. For a physicist, to claim that you accept the observation of a photon in your detector but to deny that these photons stem from a resonance if their invariant mass distribution follows exactly that of a resonance is* ***perverse*** *... The enhanced signal at 126 GeV in the photon-photon invariant*

> *mass distribution stems from something. If this something did not exist, there would be no enhancement. The observation of the enhancement* ***is*** *the observation of the thing.*" (emphasis added)

This describes a belief widely held amongst members of the physics community. So every physicist who in his capacity as a journal referee got to review one of the versions of my criticism on observational claims regarding ultrashort-lived unstable particles, has been confronted with criticism of one of his own core beliefs. So to the defense of all those who passed off the pseudoskeptic objections to my criticism discussed in this section, I can imagine that they have let themselves be led by their emotions—resulting in a response in accordance with the response-in-an-outburst model on page li. But I consider it unacceptable: for me, one of the things that distinguishes a professional scientist from a layman is that a professional scientist should be able to look beyond a first emotional reaction to a new piece of information—if that ability is not there, the analytical skills are still underdeveloped. ■

Chapter 3

The constructive phase

> “*For me, the fact that the theory [the EPT, MC] dissents from research programs in quantum field theory, string theory or GR is not the decisive argument for the rejection of the PhD thesis. However, the theory is written in a formalism that is highly unusual, and that is the invention of the author.*”—Jos Uffink, (then) associate professor at Utrecht University, expressing his support for the decision to cancel my PhD graduation (2008)

3.1 A new principle of gravitation in words

In Ch. 1 we have developed the *thesis*

> **if** antimatter is repulsed by the gravitational field of ordinary matter, **then** Eq. (1.12) holds for all massive antiparticles

by means of a Cartesian analysis of the hypothesis on gravitational repulsion, that is, an analysis of that hypothesis in smallest possible terms (*in casu* the classical concepts ‘inertial mass’ and ‘gravitational mass’). In Ch. 2 we have developed the *antithesis*

> in the frameworks of GR and the Standard Model, Eq. (1.12) is **false** for all massive antiparticles

by showing (i) that Eq. (1.12) contradicts the WEP of GR, and (ii) that Eq. (1.12) contradicts the C-inversion of the Standard Model. Now both thesis and antithesis are *true*. So, if it turns out that repulsive gravity doesn't exist the thesis still remains true, although it isn't relevant for physics then. And if it turns out that repulsive gravity does exist, the antithesis remains true: given that we cannot simply modify GR or the Standard Model to solve inconsistencies with repulsive gravity (Sect. 2.1), it is then clear beforehand that *something big* has to go if we want to identify the fundamental principles that would have to be in place for a matter-antimatter repulsive gravity to be a fact of nature. In the present research program that *something big* is not just Einstein's idea that gravity can be reduced to motion on geodesics of a curved spacetime: gravity is a true interaction, but the idea that interactions between massive systems take place by exchanging mediating particles, which is at the heart of the Standard Model, is abandoned as well.

That being said, the constructive phase starts off with the following *synthesis*, which leaves the truth of thesis and antithesis untouched:

> under the condition that a body of antimatter is repulsed by the gravitational field of a body of ordinary matter, the principle of gravitation is **incompatible** with the frameworks of GR and the Standard Model and can be expressed in words as follows:
>
> (i) the smallest possible massive systems (electrons, positrons, free nucleons, atomic nuclei, ...) go through a cycle of ground state, transition state, and excited state in each individual process in which a gravitational interaction takes place between such a system and its environment;
>
> (ii) a ground state is a *normal particle state* that exists only at one instant of time, at which the system has a definite position and momentum;
>
> (iii) a transition state is a *wave state* with a short lifetime, during which the system has a constant velocity and absorbs energy from its environment;
>
> (iv) an excited state is an *excited particle state* that immediately decays into the next ground state and a radiation packet, whereby the system receives an impulse that depends on the nature of the system and the gravitational field in its environment and that comes to expression in a difference between the momenta of consecutive ground states.

Let's illustrate this principle with an example. Suppose that an observer $\mathcal{O}$ is at rest on the earth's surface; let the positive z-axis of $\mathcal{O}$'s reference frame point in the direction of increasing height above the earth's surface. Now consider a system made up of one free nucleon in an environment where gravitation is predominant, satisfying the following conditions:

- at time $t = t_0$ the system with inertial rest mass $m_0 > 0$ is in a ground state at position $z = z_0$ with momentum $p_0^z > 0$;
- at times $t \in (t_0, t_0 + \Delta t_0)$ the system is in a transition state, to which can be associated a constant velocity $v_0 = p_0/m_0$ away from earth;
- at time $t = t_1 = t_0 + \Delta t_0$ the system gets in an excited state, which immediately falls back to the next ground state at position $z = z_1 = z_0 + \Delta z_0 = z_0 + v_0 \cdot \Delta t_0$ with momentum p_1^z by emitting a photon with momentum $\Delta p_0 = p_0^z - p_1^z$.

The energy $E = \Delta p_0 \cdot c$ of the photon (with c being the speed of light) has been absorbed when the system was in its transition state. We will get back to this in more detail in Part III and Part IV. What is important for now is that the momentum of the emitted photon—this corresponds to the impulse that the system receives—depends on the gravitational mass of the system, which is *positive* for ordinary matter and *negative* for antimatter. The process then repeats: in this way, the nucleon evolving in time receives a series of impulses due to gravitational interactions with its environment. If we then look at the constant velocities v_n of the subsequent transition states and the height differences $\Delta z_n = z_{n+1} - z_n$ between the positions of subsequent ground states, then the idea is the following:

(i) if the nucleon concerns *ordinary matter*, then it accelerates *towards* earth: $v_0, v_1, v_2, \ldots$ and $\Delta z_0, \Delta z_1, \Delta z_2, \ldots$ are then *decreasing* arrays;

(ii) if the nucleon concerns *antimatter*, then it accelerates *away from* earth: $v_0, v_1, v_2, \ldots$ and $\Delta z_0, \Delta z_1, \Delta z_2, \ldots$ are then *increasing* arrays.

Once a sequence of positions has been determined experimentally, the data can be fitted with a continuous curve in a position vs. time diagram; acceleration, inertial mass and gravitational mass can then be calculated using Eqs. (1.10) and (1.11), and Eq. (1.12) then obtains for antimatter.

Having argued that the principle of gravity as stated on p. 92 is consistent with the thesis developed in Ch. 1, let us now convince ourselves that this principle indeed lies outside the frameworks of GR and the Standard Model. First of all, in the framework of GR a massive system of particles of ordinary matter and a massive system of antiparticles do not interact differently with the gravitational field in their environment on account of the equivalence principle: instead, any gravitational acceleration of a massive system is purely due to the geometry of spacetime—this is *independent* of the nature of the component(s) of the system, contrary to what has been stated in clause (iv) on p. 92. That establishes that 'our' principle of gravitation lies outside the framework of GR.

Secondly, in the framework of the Standard Model the basic idea is that interactions between massive systems take place by exchanging mediating particles. The synthesis on p. 92, however, entails the rejection of this whole idea: interactions are between a massive system and its environment—a system absorbs energy from its environment while it is in a transition state, but it does not absorb an incoming discrete particle as part of the interaction. That means that here the position is taken that the processes considered in QED—for example the process for electron-electron scattering represented by the Feynman diagram in Fig. 3.1—do **not** take place in reality. Instead of exchanging mediating particles, nearby massive systems go through cycles of ground state, transition state, and excited state: each system gradually absorbs energy from its environment while it is in a transition state, and at once emits energy into the environment when it falls back from an excited state to the next ground state.

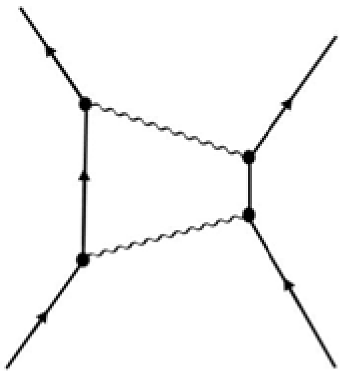


Figure 3.1: Feynman diagram with four vertices for electron-electron scattering; time is vertical. The electrons scatter by the exchange of two photons.

Having established that we have formulated a principle of gravity that lies outside the frameworks of GR and the Standard Model, we can ask ourselves the question whether someone else has already proposed the very same idea earlier. Historically, "the idea that accelerated motion consists of discrete changes in velocity during equal time intervals can be traced back to Galileo and to Isaac Beeckman" (Nauenberg, 2018). According to Beeckman, the attractive force of the earth moves an object by pulling "with small jerks" (Van Berkel, 2013). However,

> "*Beeckman started from the idea that a stone falls under the influence of a discontinuously working force, which he labeled 'the attraction of the earth' (tractio Terrae) or 'attractive force' (vis attractiva). Naturally this is ... not a force of attraction working at a distance. Beeckman's natural philosophy has no place for such a force. Beeckman used the terms only as a common expression for a force whereby the particles of ether, coming from world space and continually striking the Earth and colliding with all earthly objects, are actually responsible for the motion of falling bodies. It would have been more precise if he had not spoken of 'attractive force' but rather of 'collision force of ether particles'. 'Weight,' he would later write emphatically, 'that is to say the downward movement of objects towards the Earth, arises from the collision of igniculi, which go from the surrounding atmosphere towards the center of the Earth'.*"—Van Berkel (2013)

So, although Beeckman's view of gravitation and the present principle of gravitation share the common denominator that the gravitational acceleration of a massive system comes about by discrete impulses, these are radically different views: in Beeckma's view a massive system does not undergo internal state transitions as in the present view, and in addition the impulses that accelerate a smallest possible massive system are in the present view due to a true interaction of the massive system with the surrounding gravitational field—and not due to collisions with particles as in Beeckman's view. Galileo, on the other hand, stated that

> "*a motion is said to be uniformly accelerated when starting from rest, it acquires, during equal time intervals, equal increments of speed.*"—Galileo (1954)

However, Galileo has focussed on the kinematics: he hasn't developed a theory of the process by which these increments of speed happen—massive systems do not undergo internal state transitions in the work of Galileo. In addition, Galileo has assumed that the time intervals between subsequent increments of speed are all identical: in the present view, the duration of a process of alternation may be subject to relativistic effects and may depend on the strength of the surrounding gravitational field.

That said, also Newton considered discrete processes (Nauenberg, 2018). More precisely, in the proof of proposition I (Kepler's law) of Book 1 of his *Principia*, he considered discrete orbits of heavenly bodies that were subjected to impulses separated by equal time intervals δt: if we would apply that consideration to the motion of an object falling in the earth's gravitational field, it would be compatible with the present principle of gravity since the velocity between two impulses remain constant due to Newton's first law of motion. However, apart from the fact that the above comment on equal time intervals again applies, after this initial consideration Newton let the time interval δt between impulses go to zero and the number n of impulses during any finite time interval to infinity: the biggest difference with Newton's idea of accelerated motion is thus that the present idea *forbids* that the time interval δt between impulses becomes less than the duration of one individual process of interaction (say, a Planck time). That is, here discrete processes are considered to be fundamental, while Newton considered these only as an approximation of continuous processes.

In more recent times an idea compatible with the present principle of gravitation has been suggested by Van Dantzig, who wrote:

> "*... matter could be considered as discontinuous in time as well as in space. Let us see to what consequences this would lead. Using the usual illustration in spacetime, a particle would not be represented by a curve (worldline) but by a sequence of world-points, which will be called 'flashes'.*"—(Van Dantzig, 1937).

However, this '*more or less vague suggestion*' by Van Dantzig (as he called it himself) has never been developed further into a mathematically formulated theory of physics. In addition, none of these historical figures has contemplated the idea that there are two different kinds of massive systems that interact oppositely with the gravitational fields in their environment.

Summarizing, there have been great minds in the past who have pondered on the idea that the acceleration of a massive body in a gravitational field comes about by discrete impulses (changes of momentum). Nevertheless, we reach the conclusion that 'our' principle of gravity is a fundamentally new idea in physics: there are no known physics in the framework of which 'our' principle of gravity can be described.

Proceeding with the constructive phase, we are thus interested in an exact, mathematical formulation of 'our' principle of gravitation—its formulation in words on p. 92 has to be seen as a preliminary formulation that we can use as a heuristic. And if we do just that, then we can immediately see from clause (i) of the preliminary formulation that an exact formulation of this principle of gravitation requires a foundational framework for physics in which a smallest possible massive system goes through cycles of ground state, transition state, and excited state. In other words: our principle of gravitation is underlain by a collection of "first principles" that are process-physical of nature, describing in mathematical language *precisely how* a smallest possible massive system evolves in time—once we have that collection of first principles at our disposal, we can develop an exact description of a process of gravitational interaction in which 'our' principle of gravity comes to expression. But it is important to understand that such process-physical first principles have nothing whatsoever to do with a Lagrangian. So, en route to a mathematical formulation of principles underlying repulsive gravity, we do away with the methodological straitjacket imposed by a widely accepted maxim that has been put into words by Leonard Susskind as follows:

> "*Physicists usually think of the Lagrangian as given, and whenever a new law of physics is speculated about, it's never speculated about by giving the laws of motion. You speculate about what the form of the action is.*"—Susskind (2011)

> "*These days when a physicist is interested in trying out new laws of physics, the usual pattern is to write down the Lagrangian and then from that derive the equations.*"—Susskind (2011)

That is to say, we agree with Feyerabend (1975) that there are no universal methodological rules in the search for the fundamental laws of physics, and we abandon the whole idea that new laws of physics **have to be** formulated in terms of a Lagrangian. Instead, we take the position that physical reality is best understood in terms of elementary processes; historically, the Greek philosopher Heraclitus of Ephesus ($\pm 550 - 480$ B.C.) was the first known to hold the view that reality is best understood as a process. This entails the view that the most fundamental theory of physics is a *process theory*, rather than an *interaction theory*.

The first step towards the sought-after process-physical first principles is to arrive at a description of the envisaged building blocks of the universe that participate in the elementary processes. For that matter, it is necessary to reject the classical concept of a particle, defined as a body whose size is negligible compared to its motion, as *inapplicable* for the description of a particle state of a smallest possible massive system. Consider, for example, a proton, which has an established size—its 'charge radius'—with an order of magnitude of 10^{-15} m (Antognini *et al.* 2013). Suppose, then, that by one cycle from a ground state to the next one, a proton moves a fraction of a Planck distance, with an order of magnitude of 10^{-35} m. One can then hardly maintain that the size of the object is negligible compared to its (stepwise) motion! See Fig. 3.2 for an illustration.

In addition, it is also necessary to reject the concept of a quantum state from orthodox QM as *inapplicable* for the description of the transition states of the smallest possible massive systems: the quantum states do not 'have' a definite momentum, nor do they spontaneously collapse, i.e. transform into, a particle state with a definite position. Ghiradi, Remini and Weber have developed a modified quantum theory, which has the additional feature that quantum states are subjected to spontaneous localization processes at random times (Ghirardi et al., 1986). Although this extra postulate yields an ontology in which quantum states at discrete times have a definite position in absence of observation, it is rejected as an ad hoc assumption: the elementary processes by which the smallest possible massive systems evolve in time are more complex than the localization processes in GRW quantum theory. E.g. in the present framework a decelerating electron can emit Bremsstrahlung at every time in turns into a particle state: this emission does not take place every time a quantum state collapses into an eigenstate of position in GRW quantum theory. David Bohm has developed another interpretation of QM (1952a; 1952b). This Bohmian QM entails

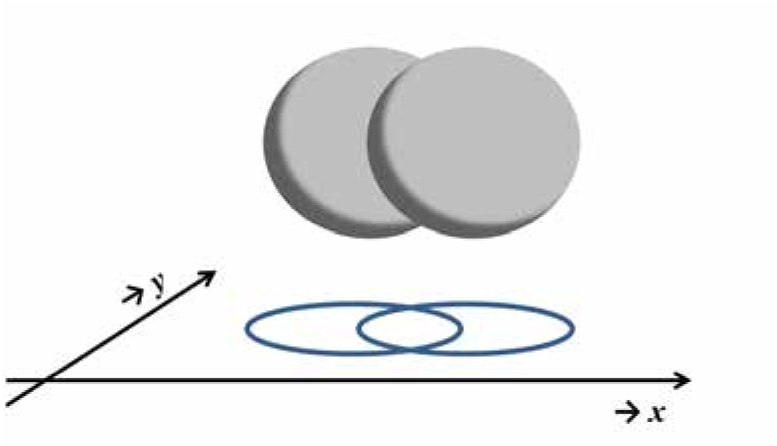


Figure 3.2: Illustration of the inapplicability of the classical concept of a particle at supersmall level. The two balls represent two subsequent ground states of a proton "hovering" over an xy-plane. The two intersecting blue ovals represent circles that are projections onto that xy-plane of the spatial extensions of these ground states. Now consider a scale, whereby the diameter of the circles is of the size of our galaxy—so not of our *solar system*, but of our *galaxy.* Stepwise motion of a proton at Planck scale then corresponds to a distance between the centers of the circles of approximately 1 m. The size of the particle is then not negligible compared to its motion!

that particles move on continuous trajectories accompanied by pilot waves that guide their motion: such a pilot wave *coexists* with a particle, but it's rather something external to it. The present principle of gravity, however, entails a radically different ontology: the transition states occurring in the elementary processes by which a smallest possible massive system evolves in time are states *of the system*, not states *external to the system.* Therefore, the transition states in the cycles of ground state, transition state, and excited state cannot be described as Bohmian pilot waves—Bohmian QM is therefore rejected as *inapplicable* to the universe at supersmall scale.

Summarizing, the individual building blocks of the universe that participate in the elementary processes cannot be described in the framework of classical mechanics, nor in the framework of orthodox QM, nor in the framework of Bohmian QM, nor in the framework of GRW QM: new ontological concepts for physics will have to be introduced. That is the topic of the next section.

3.2 Four-dimensionalistic concepts for physics

Looking forward, the EPT as formulated in Ch. 5 is an extremely simple theory. Its simplicity, however, is deceptive: even apart from its degree of abstractness, the EPT is namely formulated in terms of *designators* that refer to *four-dimensionalistic objects*—here the adjective 'four-dimensionalistic' means *related to four dimensionalism*, i.e. the doctrine that objects have temporal parts.[41] To understand the EPT it is therefore not only necessary to understand the concept of a designator: it is also necessary to understand that the objects that the formalism refers to are four-dimensionalistic—that is even the crux for understanding the EPT. This has not been emphasized in the three papers in *Annalen der Physik* (Cabbolet, 2010, 2011a, 2016a) nor in the dissertation (Cabbolet, 2011b), and that omission might have been the reason that the EPT has not led to much understanding, if any, in the physics community. Viewing the world in terms of four-dimensionalistic objects is counterintuitive to most who are not familiar with it, as the following quote by Antony Galton illustrates:

> "*The four-dimensionalist view is probably coherent ... but you have to make many adjustments to ordinary language, or at least to how it is understood, to talk coherently about it. This is not always appreciated, and I have the impression that many people who are drawn to four-dimensionalism are not fully aware of just what a wrenching disruption to our everyday world-view it entails.*"—Galton (2016)

We can say that there are two pairs of glasses through which we can look at the world: *three-dimensionalist glasses* and *four-dimensionalist glasses.* If we look through three-dimensionalist glasses, we see the outside world in terms of *continuants.* If we look through four-dimensionalist glasses, we see the outside world in terms of *occurrents.* The difference will be explained below, but the point is that the EPT has been developed looking through four-dimensionalist glasses: this yields the simplest expressions for the most fundamental laws of physics.

Let us start with the introduction of the basic theoretical terms 'continuant' and 'occurrent': understanding the difference between them is key to understanding the EPT. The definitions below have been distilled from the philosophical literature, (Sider, 1997; Steward, 2015; Galton, 2016), but it is emphasized that the theory of relativity has not been taken into account. That is to say: the definitions below reflect the essence, but we have to keep in mind that consistency with relativity may require minor revisions, e.g. using proper time.

Definition 3.2.1 (Continuant).
*A **continuant** is an object that continuously exists throughout an extended period of time but that is wholly, i.e. in its entirety, present at any point in time at which it exists.* ■

A modern physicist intuitively views the world in terms of elementary particles and interactions: these elementary particles (electrons, photons, neutrinos, etc.) are all continuants. E.g. an electron is an object that continuously exists throughout an extended period of time, and if we think of an electron at a time t then we intuitively think of the electron as being present in its entirety at that time t—it is not the case that only a part of the electron is present at that time t while another part of the electron has been left behind at an earlier time $t' < t$.

Another example of a continuant is a physical system in non-relativistic classical physics: it is a portion of matter that exists continuously throughout a period of time, while all of the system is present at any point in that period of time. The system may be subject to change throughout that period of time: the state of the system, which we can model for example by the distribution of mass over space, may change from time to time, but these are then different states of one and the same system.

The notion of an occurrent, on the other hand, stands in sharp contrast to the notion of a continuant. As a rule, a modern physicist is not familiar with viewing the world as being made up of occurrents, and it will therefore be counterintuitive to do so—nevertheless, that's what we are going to do.

Definition 3.2.2 (Occurrent).
*An **occurrent** is an object that has a time span and that is not wholly present at a proper subset of its time span.* ■

An example of an occurrent in physics is the life of a free neutron: it has a time span that begins with the creation of the neutron by e.g. the spontaneous fission of a ${}^{252}_{98}$Cf-nucleus and ends with the decay of the neutron to a proton, an electron and a neutrino, but the life of the neutron is not in its entirety present in the first half of its time span. Importantly, it is not the case that the notion of change does not apply to occurrents: if we look at a single occurrent, then change is a difference between its *temporal parts.* Here a temporal part of an occurrent is defined as follows:

Definition 3.2.3 (Temporal part).
Given an occurrent with a time span, the ***temporal part*** *of the occurrent at a point in time in its time span is the part of the occurrent that exists at that point in time.* ■

With a temporal part we thus always mean an *instantaneous* temporal part: we will use the term 'segment' for a part of an occurrent that exists within an extended part of its time span. That said, let's illustrate the difference between an occurrent and a continuant by modeling the life of a neutron in the framework of classical mechanics, assuming that its time span is an open interval $(t_0, t_1) \subset \mathbb{R}$ and assuming that the state of its temporal part at a time $t \in (t_0, t_1)$ can be represented by a real function $f_t : \mathbb{R}^3 \to \mathbb{R}$ given by

$$f_t : \begin{cases} (x, y, z) \mapsto \rho & \Leftrightarrow \quad (x, y, z) \in \overline{B}_R(X(t)) \\ (x, y, z) \mapsto 0 & \Leftrightarrow \quad (x, y, z) \notin \overline{B}_R(X(t)) \end{cases} \tag{3.1}$$

where ρ is the mass density and $\overline{B}_R(X(t))$ is the closed ball centered at $X(t)$ with radius R. The occurrent, *in casu* the life of the neutron, is then represented by a real function F on spacetime $\mathbb{R} \times \mathbb{R}^3$ given by

$$F : \begin{cases} (t, x, y, z) \mapsto f_t(x, y, z) & \Leftrightarrow \quad t \in (t_0, t_1) \\ (t, x, y, z) \mapsto 0 & \Leftrightarrow \quad t \notin (t_0, t_1) \end{cases} \tag{3.2}$$

Equivalently, we can view this occurrent as the four-dimensional object that has been traced out by a continuant, *in casu* a neutron, that continuously existed throughout the time interval (t_0, t_1). The state of that neutron at a time $t \in (t_0, t_1)$ is then represented by the function f_t of Eq. (3.1). So generally speaking, we can view the state of a temporal part of *the life of a neutron* (an occurrent) at a point in time as the state of *a physical system made up of a single neutron* (a continuant)—the states of two different temporal parts can then be viewed as different states of one and the same physical system. See Fig. 3.3 for an illustration where $X(t)$ is constant.

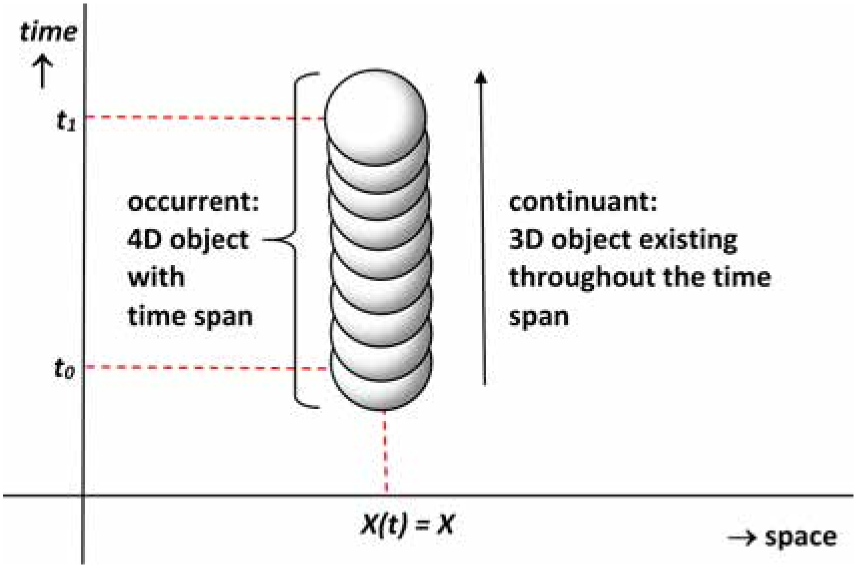


Figure 3.3: Illustration of the notion of an occurrent vs. the notion of a continuant by considering the life of a neutron at rest, assuming a neutron can be modeled in the framework of classical mechanics as a spinless, spatially extended particle. The vertical axis represents the time dimension, the horizontal axis represents 3D space. The nine overlapping balls represent nine temporal parts of the occurrent (which is the life of the neutron) at nine different times in its time span (t_0, t_1). The occurrent is the whole 4D object with time span (t_0, t_1). The state of a temporal part at a time $t \in (t_0, t_1)$ is the state of a neutron at a position $X(t)$ which does not depend on time, so $X(t) = X$ for all $t \in (t_0, t_1)$. The occurrent can then equivalently be viewed as the 4D object that has been traced out by a neutron at rest (which is a continuant that in this case is a 3D object) that exists throughout the time interval (t_0, t_1).

Phase quanta

With these definitions in place, let us have a look at a general overview of the EPT. Recall that the EPT is a collection of process-physical first principles, which describe the elementary processes by which a smallest possible massive system goes through cycles of ground state, transition state, and excited state. In the world view of the EPT, however, the notion of a physical system does not occur: the world view of the EPT is not one of *elementary particles* and the *interactions* between them, but one of *atomic occurrents* and the *transitions* between them—here the adjective ‘atomic’ is used in the sense of ‘forming a single unit’. In fact, we can view the EPT as an *ontology for physics*, and as such we can divide its axioms in two categories:

(i) Axioms about things that *exist* in the outside world.
The things that exist are all made up of atomic occurrents, and these can be divided in two categories:

(a) atomic occurrents whose time span is a degenerate interval;

(b) atomic occurrents whose time span is a non-degenerate interval.

(A degenerate interval is a single point in time.) To this is attached a notion of completeness: no other things exist than those meant above.

(ii) Axioms about things that *happen* in the outside world.
The things that happen can also be divided in two categories:

(a) discrete transitions, by which one atomic occurrent ceases to exist and another one comes into existence;

(b) continuous transitions, by which one atomic occurrent gradually transforms into another one.

To this is also attached a notion of completeness: no other things happen than those meant above.

This ontology yields a picture of the *universe at supersmall scale*, which we will interpret later on as the Planck scale. As it turns out, we need only one axiom that explicitly states the existence of a thing: that other things exist can then be derived from that one existential axiom and the axioms about things that happen. Below we proceed with the constructive phase by introducing the things that exist in the universe of the EPT.

Let’s start from Feynman’s view that a positron is an electron travelling backwards in time (1949). A similar view is incorporated in the present framework of the EPT:

- the entire universe is a four-dimensional object that consists of a (four-dimensional) world and a (four-dimensional) antiworld;
- *the life of an electron in the world* (an occurrent) is in opposite time direction *the life of a positron in the antiworld* (also an occurrent).

Focussing at the (four-dimensional) world, we can distinguish two phases: a *condensed matter field* and a *heterogenous vacuum*. Each of these two phases can be viewed as being made up of atomic occurrents. We have then arrived at a new general physical concept: the *phase quantum*. As to the etymology, the noun 'phase quantum' is a compound noun in which the word 'phase' in its sense of a distinctive component of the (four-dimensional) world is combined with the word 'quantum' in its sense as the smallest possible amount of something. So, what the name aims to capture is that a 'phase quantum ' is an atomic occurrent that is a smallest possible, individually existing amount of one of the above two distinctive components of the (four-dimensional) world.[42] We then have the following:

(i) the atomic occurrents that make up the condensed matter field are phase quanta, whose time span is degenerate, i.e. a single point in time, and whose spatial part at that point in time is bounded;

(ii) the atomic occurrents that make up the heterogenous vacuum are phase quanta, whose time span is an extended period.

It follows from (i) that the condensed matter field is *discontinuous* in both time and space: the phase quanta that make up this field are particlelike. See Fig. 3.4 for an illustration.

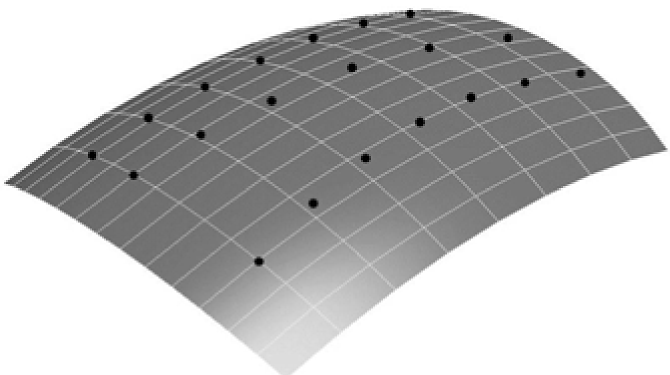


Figure 3.4: Illustration of the two phases of the four-dimensional world. The condensed matter field is depicted as a collection of black dots that represent particlelike phase quanta. The heterogenous vacuum is depicted as a curved surface that is fixed with some coordinate system. (For this figure, an image of a surface by Ali Ismail was used as a source.)

As an occurrent, a phase quantum has temporal parts and the idea is that a temporal part of a phase quantum is an object in which an amount of energy c.q. temporal momentum is distributed over a spatial extension. And just like in orthodox QM a quantum state is represented mathematically by a wave function ψ with norm $\|\psi\| = 1$, the idea here is that the state of a temporal part of a phase quantum at a point in time t is represented mathematically by an object that models the state as an amount of energy distributed over a spatial extension. Such a mathematical object can then be *heuristically characterized* as an object φ for which

$$\varphi = k \cdot E \cdot \psi \cdot \chi \tag{3.3}$$

where E is a real number that corresponds to the energy content of the temporal part of the phase quantum, χ is a characteristic function on spacetime whose support represents the spatial extension of the temporal part of the phase quantum at the time t, ψ is a function that represents the distribution of the energy over the spatial extension at the time t, and k a normalization constant ensuring that $\|\varphi\| = E$ at the time t. But we have to realize that at this point the functions ψ and χ are undefined—just as their domains.

Having introduced the basic notions, we can proceed with a description of the *kinds of phase quanta* that have existence in the physical world. These are the following:

- extended particlelike phase quanta
- nonextended particlelike phase quanta
- nonlocal wavelike phase quanta
- local wavelike phase quanta
- spatial phase quanta

Below these will be treated *conceptually* rather than *mathematically*. Assuming special-relativistic conditions, that is, assuming that all observers are inertial observers and that the reference frame of an inertial observer (IRF) is Minkowski space $(\mathbb{R}^{1,3}, \eta)$, we will look though four-dimensionalist glasses at the principle of gravitation on p. 92, and list the defining characteristics of the various phase quanta for an observer $\mathcal{O}$.

The first kind of phase quantum to be treated is the *extended particlelike phase quantum*. For any observer $\mathcal{O}$,

(i) its spatiotemporal extension has only one temporal part, meaning that it lies in a hyperplane of simultaneity $\{t\} \times \mathbb{R}^3 \subset \mathbb{R}^{1,3}$ for some point of time $t \in \mathbb{R}$;

(ii) its spatial extension is bounded, meaning that there is a smallest possible 3D closed ball $\{t\} \times \overline{B}_r(X) \subset \mathbb{R}^{1,3}$ with center $(t, X) \in \{t\} \times \mathbb{R}^3$ and radius $r > 0$ that encloses its spatial extension;

(iii) the form of energy distributed over its spatial extension is gravitational mass.

Any two coexisting extended particlelike phase quanta #1 and #2 satisfy the **separation axiom**: for the smallest possible 3D closed balls $\{t\} \times \overline{B}_1$ and $\{t\} \times \overline{B}_2$ covering the spatial extensions of the phase quanta #1 and #2 there are then open environments U_1, U_2 in spacetime $\mathbb{R}^{1,3}$ such that

$$\{t\} \times \overline{B}_j \subset U_j \tag{3.4}$$

$$U_1 \cap U_2 = \emptyset \tag{3.5}$$

That being said, the link to clause (i) of our principle of gravitation on p. 92 is that an extended particlelike phase quantum can be viewed as a smallest possible massive system (e.g. an electron, positron, free nucleon, atomic nucleus) in a ground state.

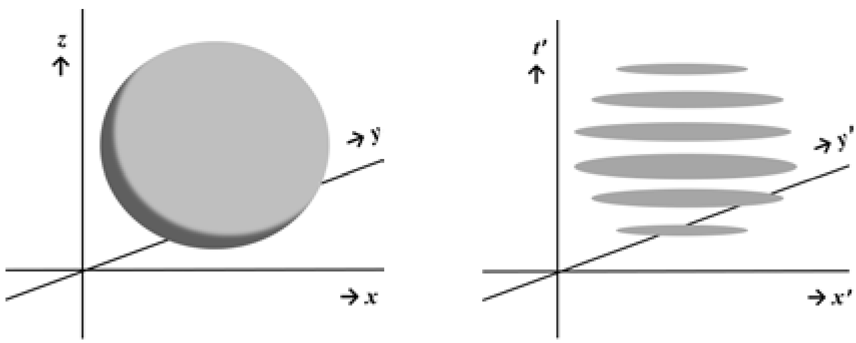
Remark 3.2.4 (Radius of an electron)**.**
So, in this framework an electron has a (tiny) radius, which can be called its mass radius. The literature, however, makes the following statement on the topic, which is prominently displayed on Wikipedia:

> "*any attempt to gain conceptual insights by considering the electron as anything other than a point particle are ill-conceived and counter-pedagogic.*"—L.J. Curtis (2003)

This, however, is an unfair generalization. It is true that the attempt to describe the electron as a mechanically spinning spherical body *in the framework of classical mechanics* has failed: the reason for failure is that on the one hand the electron then must have a minimum radius, called the 'classical electron radius', while on the other hand tangential velocities greater than the speed of light occur when the electron has this radius. That by itself, however, does absolutely not imply that the present attempt to endow the electron with a mass radius is beforehand doomed to failure too: notions from classical mechanics, namely, do **not** apply to the present universe at supersmall scale! First of all, the extended particlelike phase quantum exists only at a single point in time: if we would endow it with an intrinsic angular spin momentum, then that does not imply that an infinitesimal piece of the phase quantum has traveled a spatial distance ds in an infinitesimal time span dt such that $\frac{ds}{dt}$ exceeds the speed of light—there is no such "motion" since a particlelike phase quantum simply doesn't have an extended time span with a magnitude Δt for which $\Delta t \geq dt$! Secondly, in classical mechanics 'charge' is a primitive notion, and in the spinning sphere model of the electron it is assumed to be uniformly distributed over the sphere. In the present framework, however, charge may be a derived notion that emerges from a succession of states—it is then not something that at any one point in time is "distributed" over the spatial extension of the extended particlelike phase quantum. Thirdly, in the spinning sphere model the electron continuously radiates an electromagnetic field, whereas in the present framework an electron goes through cycles of ground state, transition state, and excited states, and only emits electromagnetic radiation at discrete times—there simply is no continuous process of emission of radiation! ■

Remark 3.2.5 (Erroneous thinking, I)**.**
The creation of an extended particlelike phase quantum is a *single event.* We then have to be very careful not to apply intuitive ideas that are incorporated in classical mechanical to the supersmall scale. It is wrong thinking if we treat the different points in the spatial extension as being created at separate "events". Suppose we have two inertial observers $\mathcal{O}$ and $\mathcal{O}'$, and suppose that observer $\mathcal{O}'$ moves with 75% of light speed in the z-direction in the IRF of observer $\mathcal{O}$: there is then a Lorentz transformation Λ that transforms the coordinates (t, x, y, z) of an event in the IRF of $\mathcal{O}$ to the coordinates (t', x', y', z') in the IRF of $\mathcal{O}'$. Now let the spatial extension of some extended particlelike phase quantum be represented by a 3D closed ball $\{t_1\} \times \overline{B}_{r_1}(X_1) \subset \{t_1\} \times \mathbb{R}^3$ in the IRF of $\mathcal{O}$. If we then apply the corresponding Lorentz transformation Λ to the closed ball

$\{t_1\} \times \overline{B}_{r_1}(X_1) \subset \{t_1\} \times \mathbb{R}^3$, then the spatial extension of the extended particlelike phase quantum becomes a collection of "discs" spread out in time in the coordinate system of $\mathcal{O}'$, see Fig. 3.5. We might therefore be tempted to think that the creation of the extended particlelike phase quantum is *spread out in time* for $\mathcal{O}'$, which stands in sharp contrast to the assumption that it had been created *at once* in the IRF of $\mathcal{O}$. The error here is in thinking that we can 'zoom in' ad infinitum and treat such an ultimate constituent at supersmall scale as an object whose infinitesimal constituents are created at separate events. Instead, this has to be treated as a single event: if an extended particlelike phase quantum is created *at once* in the IRF of an observer $\mathcal{O}$, then that same extended particlelike phase quantum is also created *at once* in the IRF of another observer $\mathcal{O}'$. So, the spatiotemporal position (t_1, X_1) of the center of the spatial extension in the IRF of $\mathcal{O}$ corresponds to a spatiotemporal position $(t_1', X_1') = \Lambda(t_1, X_1)$ in the IRF of $\mathcal{O}'$, and the spatial extension of the extended particlelike phase quantum is then a closed ball $\{t_1'\} \times \overline{B}_{r_1'}(X_1')$ in the hyperplane of simultaneity $\{t_1'\} \times \mathbb{R}^3$ of the IRF of $\mathcal{O}'$. ■



(a) closed ball in the RF of $\mathcal{O}$ (b) image under Λ in the RF of $\mathcal{O}'$

Figure 3.5: Illustration of the Lorentz transformation of the spatial extension of a closed ball into a collection of discs spread out over time. The xyz-diagram (a) shows a closed ball; this represents the spatial extension at a time t_1 of an extended particlelike phase quantum in the coordinate system of observer $\mathcal{O}$. The $x'y't'$-diagram (b) shows (part of) the image of that closed ball in the coordinate system of observer $\mathcal{O}'$ under a Lorentz transformation Λ: as $\mathcal{O}'$ moves with 75% of light speed in the z-direction in the IRF of observer $\mathcal{O}$, the z-axis of the IRF of $\mathcal{O}$ lies tilted in the $t'z'$-plane of the IRF of $\mathcal{O}'$, so that the closed ball becomes a collection of discs spread out in time; some of these discs are depicted.

Remark 3.2.6 (Erroneous thinking, II).
We are also applying intuitive ideas wrongly if we say that the principle of locality—this is the principle that an object can not instantly exert influence at a distance—is violated if the extended particlelike phase quantum gets its (bounded) spatial extension instantly. The creation of the phase quantum is, namely, a single event *at supersmall scale*: there are no observers at a yet smaller "super-supersmall" scale, such that one observer can position himself at the center of the spatial extension and another one can position himself at the surface of the spatial extension, and such that they can use the creation of the extended particlelike phase quantum as a superluminal signal. That is to say: a signal exchange requires at least two individual processes (one for emitting the signal, one for receiving), but processes at a scale smaller than the supersmall scale, which are required for using the event by which an extended particlelike phase quantum is created as a superluminal signal, are *nonexistent*—that is, the processes at supersmall scale, by which the smallest possible massive systems go through cycles of ground state, transition state, and excited state, are *elementary*. So, the principle of locality is not violated if an extended particlelike phase quantum gets its spatial extension instantly. ■

Proceeding, the second kind of phase quantum to be considered is the *nonlocal wavelike phase quantum*. A **temporarily co-moving observer** is then an observer for whom the spatial velocity associated to a given nonlocal wavelike phase quantum is zero, cf. p. 92; the IRF of a temporarily co-moving observer is a **proper IRF** for a given nonlocal wavelike phase quantum. That being said, for any observer $\mathcal{O}$,

(i) there is a time span (t_1, t_2) in the IRF of $\mathcal{O}$ such that the spatiotemporal extension of a given nonlocal wavelike phase quantum is the union (i.e., the sum set) of the family of spatiotemporal extensions W_i of its *proper temporal parts* indexed in (t_1, t_2), i.e. the union $\bigcup\{W_i\}_{i\in(t_1,t_2)}$;

(ii) there is a Lorentz transformation Λ and a hyperplane of simultaneity $\{t\} \times \mathbb{R}^3$ in a proper IRF, such that $W_i = \Lambda[\{t\} \times \mathbb{R}^3]$ for the spatiotemporal extension W_i of a proper temporal part;

(iii) the form of energy distributed over the spatiotemporal extension W_i of a proper temporal part of a given nonlocal wavelike phase quantum is gravitational mass.

The link to clause (i) of our principle of gravitation on p. 92 is that a proper temporal part of a nonlocal wavelike phase quantum can be viewed as a smallest possible massive system in a transition state.

Remark 3.2.7. As to the necessity of the spatial extension of a nonlocal wavelike phase quantum, it is important to realize that one shouldn't be too parochial by viewing physics as a branch of natural science of that is entirely isolated from all other branches of natural science and from philosophy. Particularly interesting in this context is Whitehead's view that any ontology that does not explain thinking is an inadequate ontology (Cobb Jr., 1990): it is from this view that the necessity of the spatial extension arises. This will be treated in detail in Ch. 7 in part III; for now it suffices to understand that a nonlocal wavelike phase quantum *necessarily* has a spatial extension for human observers to have a free will. ■

Remark 3.2.8. If we look at a nonlocal wavelike phase quantum that has been created at a time $t = t_1$ in a proper frame of reference, then we see that the proper temporal part at a point in time $t_1 + dt > t_1$, which comes arbitrarily shortly after t_1, has a spatial extension that includes points with an arbitrarily large spatial distance r between them, so that r/dt can take any value. The idea is that a temporal part of a nonlocal wavelike phase quantum instantly "senses" the state of the vacuum at every point in its spatial extension in a proper IRF. So, such an object violates the principle of locality: hence the adjective 'nonlocal' in the name of the phase quantum.
■

The third kind of phase quantum to be treated is the *nonextended particlelike phase quantum*. For any observer $\mathcal{O}$,

(i) its spatiotemporal extension W consists of simultaneous isolated points, meaning that there is a time t in the IRF of $\mathcal{O}$ and a counting number $n > 0$ such that $W = \{(t, X_1), \ldots, (t, X_n)\} \subset \{t\} \times \mathbb{R}^3 \subset \mathbb{R}^{1,3}$;

(ii) the form of energy distributed over the isolated points is gravitational mass.

The link to clause (i) of our principle of gravitation on p. 92 is that a nonextended particlelike phase quantum can be viewed as a smallest possible massive system in an excited state.

Remark 3.2.9 (Necessity of existence).
Let's go back to the idea that accelerated motion of a smallest possible massive system consists of discrete changes in its velocity, which under non-relativistic conditions are evenly spaced in time, and let's again assume that these discrete changes in velocity come about by emitting a photon. We have to take into consideration that when a photon is emitted, it is emitted *from a certain position*: it is then not possible that the photon is emitted when the system is in a spatially extended transition state, because a photon may then be emitted from any position of the spatial extension. Consider, for example, an observer who sees a car approaching, and assume that the smallest possible massive system that form the car emit photons when they are in a spatially extended transition state. The photons that are instrumental for the perception of the head lights of the approaching car may then originate from positions located outside the trajectory of that car (which is a tube). But that is absurd: it would lead to strange situations in everyday traffic—it would not even be effectively realizable. That establishes that a smallest possible massive system does not emit a photon when it is in a transition state: there is then no other possibility that it does so when it is in a particle state. However, then we get the situation that *immediately after* the emission of a photon a new particle state remains with less energy: the emission of photons thus inevitably involves two *different* particle states. In the language of atomic occurrents, the only possible option is then that there are two different kinds of particlelike phase quanta: nonextended and extended ones. ■

The fourth kind of phase quantum to be treated is the *local wavelike phase quantum*. For any observer $\mathcal{O}$,

(i) there is a spatiotemporal position $(t, X) \in \mathbb{R}^{1,3}$ in the IRF of $\mathcal{O}$ such that the spatiotemporal extension of a given local wavelike phase quantum lies on the future light cone of (t, X);

(ii) in each temporal part, energy is distributed over its spatial extension.

The link to clause (i) of our principle of gravitation on p. 92 is that the life of an emitted photon is a (possibly only) constituent of a local wavelike phase quantum. The point (t, X) from clause (i) is then the point from where the photon has been emitted.

Remark 3.2.10 (Raison d'être of the photon)**.**
Let's once more go back to the idea that accelerated motion of a smallest possible massive system consists of discrete changes in its velocity, which under non-relativistic conditions are evenly spaced in time. Such a discrete change in velocity, which happens instantaneously, goes inevitably hand in hand with an impulse, that is, with a change in momentum: if there is such a thing as a law of conservation of momentum, then there is no other possibility than that the change in momentum corresponds to the momentum of an emitted photon. Even stronger: there is then no other possibility than that the impulse is *caused* by the emission of a photon. ■

Remark 3.2.11 (No antiphotons)**.**
It has to be understood that a photon in this framework is an entirely different kind of matter than a massive system: a photon does not go through cycles of ground state, transition state, and excited state, and has no gravitational mass. There is no such thing as a photon being attracted by the gravitational field of a massive body: the observation by Dyson *et al.* 1920 that photons are deflected by the gravitational field of the sun is merely a refutation of the idea that the world line of a photon has no curvature—we'll get back to this in Ch. 10. Furthermore, there is no such thing as an "antiphoton": massive systems of matter and massive systems of antimatter emit the same photons—it is thus not the case that a massive system of antimatter emits a *different kind* of photons. This latter view has been proposed by both Santilli (1999) and Villata (2012), but they were forced into this position by their assumption that antimatter existing in our time-direction exists in an inverted spacetime. ■

Last but not least, the fifth kind of phase quantum to be treated is the *spatial phase quantum*. For any observer $\mathcal{O}$,

(i) there is a spatiotemporal position $(t, X) \in \mathbb{R}^{1,3}$ in the IRF of $\mathcal{O}$ such that the spatiotemporal extension of a given spatial phase quantum lies in the interior of the future light cone $L^+_{(t,X)}$ of (t, X);

(ii) a temporal part at a time $\tau > t$ is a constituent of the space in the hyperplane of simultaneity $\{\tau\} \times \mathbb{R}^3$ enclosed by $L^+_{(t,X)}$, that is, a constituent of the space int $L^+_{(t,X)} \cap \{\tau\} \times \mathbb{R}^3$.[43]

The link to clause (i) of our principle of gravitation on p. 92 is that the spaciousness of the environment of the system is due to spatial phase quanta.

Remark 3.2.12. The existence of spatial phase quanta lies at the basis of the observable difference in speed between photons and the smallest possible massive systems. Recall from p. 105 that the four-dimensional world consists of two phases: a condensed matter field and a heterogenous vacuum. The idea is then that the heterogenous vacuum itself consists of two homogenous (four-dimensional) phases: the first phase is made up of the nonlocal wavelike phase quanta and the spatial phase quanta, the second phase is made up of the local wavelike phase quanta. Photons live in that second phase, and do not interact with the first phase: therefore photons move at maximum speed on straight lines c.q. geodesics. The smallest possible massive systems, on the other hand, alternate between a particle state and transition state: these transition states live in that first phase and interact with it, resulting in a lower speed—this holds equally well for electrons, positrons, free nucleons, etc. See Fig. 3.6 for an illustration by means of a metaphor with birds and flying fish; the metaphor is an oversimplification but reflects the principle idea.[44] ■

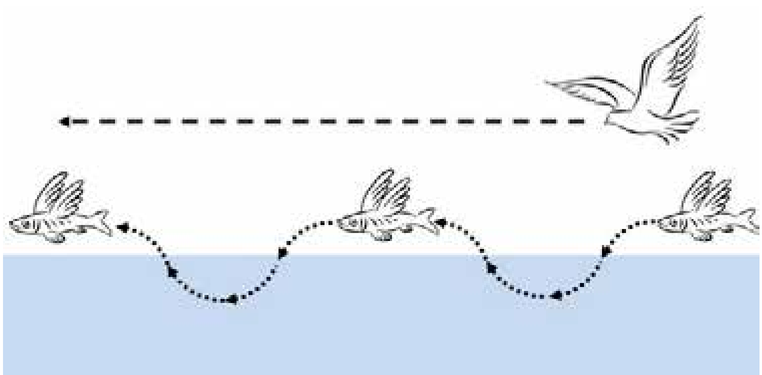


Figure 3.6: Metaphor illustrating the difference in speed between photons and massive bodies. A bird flies over the sea: it does not interact with the water, and can continuously fly at high speed. A flying fish, on the other hand, is alternately above and under water: while under water there is interaction with the water, slowing the fish down—it cannot keep up with the bird. In this metaphor, the sea represents the phase of the heterogeneous vacuum made up of the spatial and nonlocal wave phase quanta, the bird represents a photon, and the flying fish a massive system (under water in a transition state, above water in a particle state). Once more: this metaphor is not correct in all aspects, it merely illustrates the basic idea.

Monads

Proceeding, we are also interested in a notion of property that applies to our atomic occurrents (phase quanta), such that the state of a temporal part of the phase quantum translates to the state of a system with properties. That brings us to the concept of a monad:

Definition 3.2.13 (Monad).
*A **monad** is an immaterial bundle of invariant properties.* ■

The next concept of a monadic occurrent links these invariant properties to material objects:

Definition 3.2.14 (Monadic occurrent).
*A **monadic occurrent** is an occurrent that carries a monad, so that the invariant properties of that monad are primary properties that are present in its temporal parts.* ■

Here the term 'primary property' is used in the sense meant by John Locke as an observable property that is present in the object itself, as opposed to a secondary property, which is an observable property that is not present in the object itself (like color). The idea is then that for simple cases a monadic occurrent is a succession of an extended particlelike phase quantum and a nonlocal wavelike phase quantum: viewing the states of its temporal parts as states of a massive system, the properties of the system then derive from the invariant properties of the monad carried by the temporal parts of the monadic occurrent.

Let us now turn to the invariant properties of a monad. In the first place there is the *characteristic number of normality* $c_{\rm n}$, which is just a number that has the value $+1$ or -1: if $c_{\rm n} = +1$ then a temporal part of the monadic occurrent is made up of ordinary matter, and if $c_{\rm n} = -1$ then a temporal part of the monadic occurrent is made up of antimatter. Consider, for example, the case that the states of the temporal parts of a given monadic occurrent can be viewed as states of a massive system made up of a single electron: the monadic occurrent under consideration then carries a monad containing a characteristic number of normality $c_{\rm n} = 1$. If, on the other hand, that system would have been made up of a positron, then we would have had $c_{\rm n} = -1$. Note that the characteristic number of normality here coincides with the lepton number of the Standard Model.

Secondly, there is the *rest mass spectrum*, which is a function s from a countable set of numbers, to be interpreted as *degrees of evolution*, to the nonnegative reals. As to the degrees of evolution, the observable process of evolution that goes on in the physical world is nothing but an aggregation of the elementary processes by which the smallest possible massive systems go through cycles of ground state, transition state, and excited state; the ground states, which can be identified with states of extended particlelike phase quanta, are separated in space and time, hence countable, and can therefore be indexed by integer degrees of evolution:

(i) there is precisely one ground state of an initial massive system at the degree of evolution $n = 0$;

(ii) *if* there are $z(n)$ ground states of massive systems at the degree of evolution n, *then* $z(n)$ elementary processes take place from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution, yielding $\omega(n+1)$ ground states of massive systems at the degree of evolution $n+1$.

So, all elementary process involve an observer-invariant unit jump in degrees of evolution, but note that we have not assumed that all processes have the same *duration*. Furthermore, due to elementary processes in which nuclear reactions (creation, annihilation, fission, fusion, decay, etc.) take place, it is not necessarily so that $\omega(n+1) = z(n)$. That being said, the rest mass spectrum of a monad is a function s that maps every degree of evolution n to a *predetermined* inertial rest mass $s(n) \geq 0$. The idea is that for a (non-annihilating) massive system made up of one indivisible component, the inertial rest mass of its ground states is positive and predetermined by the rest mass spectrum. The gravitational rest mass of the system in its ground state then derives from the invariant properties of the monad carried by the corresponding monadic occurrent: the gravitational rest mass m_g^0 is the product of the (dimensionless) characteristic number of normality c_{n} and an inertial rest mass $s(x) > 0$ predetermined by the rest mass spectrum s. In S.I. units,

$$m_g^0 = c_{\text{n}} \cdot s(x)\ [kg] \tag{3.6}$$

Note that this is negative for antimatter. Treating electrons, free protons, free neutrons, and their antimatter counterparts as indivisible—we ignore a composition of quarks—we can then distinguish six kinds of basic monads by their invariant properties: see Table 3.1 below.

monad	$\boldsymbol{s}$	$\boldsymbol{c_{\mathrm{n}}}$	$\boldsymbol{L}$	$\boldsymbol{B}$
electronic	s_e	1	1	
protonic	s_p	1		1
neutronic	s_n	1		1
positronic	s_e	-1	-1	
antiprotonic	s_p	-1		-1
antineutronic	s_n	-1		-1

Table 3.1: Six basic monads by their properties. The first column displays the name of the monad, the second column the rest mass spectrum. Here s_e, s_p, and s_n stand respectively for the electronic, protonic, and neutronic rest mass spectrum. The third column displays the characteristic number of normality c_{n}. The fourth and fifth column display the lepton number L c.q. the baryon number B assigned to the corresponding particles in modern physics.

Proceeding, we may treat *electric charge* as a primary property: it is then included in the invariant bundle of invariant properties that forms a monad. In that case, the rest mass spectrum is a constant function: for an electronic or positronic monad, the rest mass spectrum s_e displayed in Table 3.1 is then simply the constant function that maps every degree of evolution x to the inertial rest mass $m_e = 9.1 \cdot 10^{-31}$ $[kg]$ of an electron:

$$s_e : x \mapsto m_e \tag{3.7}$$

The rest mass spectrum s_e can then be modeled by the constant m_e, and electronic and positronic monads can then be modeled as sets M_{e^-} and M_{e^+}:

$$\mathrm{M}_{e^-} = \{m_e, +1, Q_e\} \tag{3.8}$$

$$\mathrm{M}_{e^+} = \{m_e, -1, -Q_e\} \tag{3.9}$$

where the number ± 1 is the characteristic number of normality and Q_e the electric charge of the electron. The temporal parts of a monadic occurrent that carries an electronic/positronic monad can then be viewed as states of a system made up an electron/positron with the corresponding inertial rest mass and electric charge. A system made up of a free nucleon (proton, antiproton, neutron, or antineutron) can be treated likewise if we view the free nucleon as an indivisible unit.

However, with the above definitions in place we can introduce a speculative idea about the nature of electric charge, which reduces the number of primitive concepts by one. We can define an **emergent charge** q as the loss of gravitational rest mass, and we can relate q to the electric charge Q by a constant factor; in S.I. units we have

$$c_{\mathrm{n}} \cdot s(x+1) = c_{\mathrm{n}} \cdot s(x) - q \ [kg] \tag{3.10}$$

$$Q = k \cdot q \ [C] \tag{3.11}$$

We then arrive at the idea that electric charge is a *secondary property* as meant by John Locke, i.e. an observable property that is not present in the thing itself. This view on electric charge yields the following picture:

(i) for an electron, the electric charge -1 means that it has an increasingly positive gravitational rest mass;

(ii) for a proton, the electric charge $+1$ means that it has an decreasingly positive gravitational rest mass;

(iii) for a positron, the electric charge $+1$ means that it has an increasingly negative gravitational rest mass;

(iv) for an antiproton, the electric charge -1 means that it has an decreasingly negative gravitational rest mass;

(v) for a neutron or antineutron, the electric charge 0 means that it has a constant gravitational rest mass.

Modeling electronic and positronic monads as sets, we then obtain

$$\mathrm{M}_{e^-} = \{s_e, +1\} \tag{3.12}$$

$$\mathrm{M}_{e^+} = \{s_e, -1\} \tag{3.13}$$

instead of Eqs. (3.8) and (3.9); the electric charges Q_e and $-Q_e$ then follow from Eqs. (3.10) and (3.11). In later chapters we will occasionally refer to this approach to electric charge.

Matter quanta

Having introduced phase quanta and properties, we're not there yet with regard to the ontology. We have to consider, namely, that per degree of evolution n the total number $z(n)$ of extended particlelike phase quanta may vary due to elementary processes in which nuclear reactions (fission, fusion, decay, creation, annihilation, radioactivity, etc.) take place. If you think that consequently through from the perspective of our assumption that the smallest possible massive systems go through cycles of ground state, transition state, and excited state, then there is no other option for the description of elementary processes than to introduce new terminology in the language of physics for objects that in four-dimensionalistic terminology can be viewed as *subatomic occurrents.*

The first kind of subatomic occurrent that needs to be added to the ontology for the EPT is the *extended particlelike matter quantum.*[45] For any observer $\mathcal{O}$,

(i) an extended particlelike matter quantum is a spatial part of an extended particlelike phase quantum;

(ii) the union of the spatiotemporal extensions of the matter quanta constituting an extended particlelike phase quantum existing at a point in time t in the IRF of $\mathcal{O}$ does not form a disconnected subset of the hyperplane of simultaneity $\{t\} \times \mathbb{R}^3$—that is, for any extended particlelike phase quantum made up of $n > 1$ extended particlelike matter quanta existing at a time t in the IRF of $\mathcal{O}$, there are no n closed 3D balls $\{t\} \times \overline{B}_{r_1}(X_1), \ldots, \{t\} \times \overline{B}_{r_n}(X_n)$ in the hyperplane of simultaneity $\{t\} \times \mathbb{R}^3$ such that

$$\forall i \forall j : i \neq j \Leftrightarrow \overline{B}_{r_i}(X_i) \cap \overline{B}_{r_j}(X_j) = \emptyset \tag{3.14}$$

and such that the j^{th} closed 3D ball $\overline{B}_{r_j}(X_j)$ encloses the spatiotemporal extension of the j^{th} of the matter quanta;

(iii) an extended particlelike matter quantum carries a monad.

This sounds rather abstract, so let us illustrate it with an example. Consider the case that a given extended particlelike phase quantum can be viewed as a system made up of a deuterium nucleus ${}^2_1H$ that finds itself in a ground state. The ${}^2_1H$ nucleus consists of two bound nucleons, a proton and a neutron: each of these bound nucleons then corresponds to an extended particlelike matter quantum. So, in this case the extended particlelike phase quantum is made up of two extended particlelike matter quanta. None of the bound nucleons can be viewed as an atomic nucleus by itself: likewise, none of those matter quanta forms an extended particlelike phase quantum by itself—the idea is that these matter quanta do not satisfy the separation axiom of extended particlelike phase quanta. Furthermore, the proton and the neutron in the ${}^2_1H$ nucleus have of course different properties. In the present ontology, each of the two matter quanta carries a monad: this covers the difference in properties.

The second kind of subatomic occurrent that needs to be added to the ontology for the EPT is the *nonextended particlelike matter quantum.* For any observer $\mathcal{O}$,

(i) a nonextended particlelike matter quantum is a spatial part of a nonextended particlelike phase quantum;

(ii) its spatiotemporal extension is an isolated point in the IRF of $\mathcal{O}$;

(iii) a nonextended particlelike matter quantum carries a monad.

The general idea is that the smallest possible massive systems go through cycles of ground state, transition state, and excited state: consequently, a nonextended particlelike matter quantum, which can be viewed as a subcomponent of a smallest possible massive system in an excited state, spontaneously transforms by a discrete transition into an extended particlelike matter quantum, which can be viewed as a subcomponent of that smallest possible massive system in the next ground state. Since the excited state of a proton cannot transform spontaneously in a ground state of a neutron, the two consecutive matter quanta carry *the same monad.* That way, a smallest possible massive system keeps having the same set of invariant properties upon a transition from an excited state to a ground state.

This concludes the ontology for the EPT as far as it concerns the things that exist *in the world.* What remains to be treated is the *antiworld*—recall from p. 104 that the life of an electron in our world in opposite time direction is the life of a positron in the antiworld.

The antiworld

The general idea is that the universe consists of world and antiworld, and that a fundamental building block of the universe consists of an atomic occurrent in the world and a conjugated atomic occurrent in the antiworld, whereby the latter is what would be observed of that building block by a (hypothetical) observer living in opposite time-direction. Below the conjugated phase quantum in the antiworld will be treated for extended particlelike and nonlocal wavelike phase quanta: the treatment is again *conceptual* rather than *mathematical*, but that way it is clear how the other conjugated phase quanta in the antiworld have to be viewed.

So, consider an extended particlelike phase quantum that exists in the world, and let its state in the IRF of an observer $\mathcal{O}$ be represented by a function φ on $\mathbb{R}^{1,3}$. Now let's compare the *sea of extended particlelike phase quanta in the world in which 'our' extended particlelike phase quantum has just appeared* with the *sea of extended particlelike phase quanta in the world in which 'our' extended particlelike phase quantum has not yet appeared.* Let these two seas be represented by functions S^+ and S^- on $\mathbb{R}^{1,3}$, which can be viewed as sums of functions that represent the states of the extended particlelike phase quanta in the sea. For the function φ representing the state of 'our' extended particlelike phase quantum we thus have

$$\varphi = S^+ - S^- \tag{3.15}$$

So because 'our' extended particlelike phase quantum appears in the sea of extended particlelike phase quanta in the world, the latter changes from S^- to S^+. If we now *ex post facto* look back into the past, then 'our' extended particlelike phase quantum disappears from the sea of extended particlelike phase quanta in the world, so that the latter changes from S^+ to S^-. What we then have is that the disappearance of an extended particlelike phase quantum from the sea of extended particlelike phase quanta in the world corresponds to the appearance of the conjugated extended particlelike phase quantum in the sea of extended particlelike phase quanta in the antiworld. The state of the conjugated extended particlelike phase quantum in the antiworld can then be represented by a function $\overline{\varphi}$ on $\mathbb{R}^{1,3}$ for which

$$\overline{\varphi}(t, x, y, z) = -\varphi(t, x, y, z) \tag{3.16}$$

We have to understand, however, that this is not a state in the world observed by $\mathcal{O}$: it is true that the function $\overline{\varphi}$ has $\mathbb{R}^{1,3}$ as its domain, and it is true that for every point (t, X) in the IRF of $\mathcal{O}$ there is a point (t', X') in the domain of the function $\overline{\varphi}$ such that (t, X) and (t', X') are physically the same point, but it has to be taken that the function $\overline{\varphi}$ represents a state in the antiworld where the passing of time goes *in opposite direction* compared to the passing of time in the IRF of $\mathcal{O}$, and as such $\overline{\varphi}$ represents a ground state of a system that is only observable by a (hypothetical) observer that exists in that opposite time-direction.

Proceeding, let's now consider a nonlocal wavelike phase quantum that exists in the world, let it have a time span (t_1, t_2) in the IRF of a momentarily co-moving observer $\mathcal{O}$, and let it be modeled mathematically by a function $\varphi_{(t_1,t_2)}$ on $\mathbb{R}^{1,3}$ that represents the states of its successive proper temporal parts in this proper IRF. Furthermore, let, for an intermediate time $t_i \in (t_1, t_2)$, the function $\overline{\varphi}_{(t_i,t_2)}$ on $\mathbb{R}^{1,3}$ likewise model the segment of the conjugated nonlocal wavelike phase quantum in the antiworld with time span (t_i, t_2). For any (t, x, y, z) in the support of $\overline{\varphi}_{(t_i,t_2)}$ we then have

$$\overline{\varphi}_{(t_i,t_2)} : (t, x, y, z) \mapsto -\varphi_{(t_1,t_2)}(t, x, y, z) \tag{3.17}$$

Let the function $\varphi_{(t_1,t_i]}$ likewise model the segment of the nonlocal wavelike phase quantum in the world with time span $(t_1, t_i]$. The relation between these segments in world and antiworld is then given by

$$\varphi_{(t_1,t_i]} = \varphi_{(t_1,t_2)} + \overline{\varphi}_{(t_i,t_2)} \tag{3.18}$$

So if we look back in time after the time span (t_1, t_2) of the nonlocal wavelike phase quantum in the world has passed, and we let t_i run <u>backwards</u> in time from t_2 to t_1, then Eq. (3.18) shows that the disappearance of proper temporal parts of the nonlocal wavelike phase quantum in the world corresponds to the appearance of proper temporal parts of the conjugated nonlocal wavelike phase quantum in the antiworld. The conjugated nonlocal wavelike phase quantum in the antiworld is then modeled by the function $\overline{\varphi}_{(t_1,t_2)}$, but as before it has to be understood that this object is not observable by our observer $\mathcal{O}$: the function $\overline{\varphi}_{(t_1,t_2)}$ represents a state in the antiworld, where the passing of time goes in opposite direction compared to the passing of time in the IRF of $\mathcal{O}$.

3.3 Elements of a new formal language for physics

Recall that what we are after are the most general expressions that exactly represent what happens in the elementary processes by which the smallest possible massive systems go through cycles of ground state, transition state, and excited state. The first step is to let the terms be *designators* (Dutch: *aanduidingen*) of physical things instead of *representations.* Past experience has shown that the concept of a designator is notoriously hard to understand for physicists, so some elaboration is in place.

In non-relativistic QM, the wave function ψ is a *representation* of a quantum state. Mathematically, ψ is an element of the space $L_2(X)$ of square integrable functions from position space X to the complex numbers $\mathbb{C}$ with norm $\|\psi\| = 1$; once you know the wave function of a microsystem, e.g. an electron, then you can calculate the expectation values $\langle x \rangle$ and $\langle p \rangle$ of its position and momentum, respectively. Likewise, in Newtonian mechanics a vector $\overrightarrow{F}$ is a *representation* of a force. Mathematically, $\overrightarrow{F}$ is an element of $\mathbb{R}^3$; once you know the force on a body with mass m you can calculate its acceleration $\overrightarrow{a}$ according to Newton's second law $\overrightarrow{F} = m \cdot \overrightarrow{a}$. A Social Security Number (SSN), on the other hand, is a *designator* of a unique individual: once you know the SSN of an individual, you still do not know what the position of the individual is, nor do you know his or her momentum—the SSN refers to a unique individual but it is **not** a representation of the physical state of that individual. That said, for our purposes a designator has to be a *formal object*, i.e. a thing in the mathematical universe, that refers to a unique *material object*, i.e. a (postulated) thing in the physical universe. The formal objects are abstract constants: each such constant has (c.q. is represented by) a symbol, and each such symbol $\mathfrak{S}$ comes with a formal axiom

$$\exists \alpha : \alpha = \mathfrak{S} \tag{3.19}$$

saying that there is a thing α in the mathematical universe such that α is identical to $\mathfrak{S}$.[46] In the framework of ZF set theory, for example, all things in the mathematical universe are sets: the formal object $\mathfrak{S}$ in Eq. (3.19) is then a set whose elements are not specified. And that's it: it must therefore be clear from the *typography* of the designator to which unique material object it refers.

So now let us focus at a suitable typography. First and foremost we then have to take into consideration that the universe consists of world and antiworld: a component of this universe is simultaneously an occurrent in the world and a conjugated occurrent in the antiworld, cf. Sect. 3.2. So, a suitable designator of such a component is of the form of a 2×1 matrix $\begin{bmatrix} \mathfrak{S} \\ \overline{\mathfrak{S}} \end{bmatrix}$ of which the upper entry $\mathfrak{S}$ **always** refers to an occurrent in the world and the lower entry $\overline{\mathfrak{S}}$ **always** to the conjugated occurrent in the antiworld. Such a designator $\begin{bmatrix} \mathfrak{S} \\ \overline{\mathfrak{S}} \end{bmatrix}$ comes, thus, with a formal axiom of the type of Eq. (3.19) for both entries of the matrix, and with a formal definition of a 2×1 matrix as a thing in the mathematical universe. For example, in the framework of ZF, a $m \times n$ matrix can be formalized as the graph of a function on the set $\{\langle i, j\rangle \ : \ i \in \{1, \ldots, m\}, j \in \{1, \ldots, n\}\}$ of two-tuples; we then get

$$\begin{bmatrix} \mathfrak{S} \\ \overline{\mathfrak{S}} \end{bmatrix} := \{\langle\langle 1, 1\rangle, \mathfrak{S}\rangle, \langle\langle 2, 1\rangle, \overline{\mathfrak{S}}\rangle\} \tag{3.20}$$

Proceeding, for a suitable typography of a designator $\mathfrak{S}$ referring to a material object in the outside world, we have to consider that we have developed three concepts in the foregoing Sects. 3.1 and 3.2:

(i) the phase quantum: an atomic occurrent of which there are five kinds;

(ii) the matter quantum: a spatial part of a (particlelike) phase quantum;

(iii) the monadic occurrent: a composite occurrent that carries a set of invariant properties (a monad).

It has to be understood that each individual of each type of material object has to have its own designator. Luckily, finding a suitable typography does not pose much of a problem. Recall from Sect. 3.2 that the observable process of evolution is an aggregation of elementary processes, each of which is a process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution for some integer n—its *initial degree of evolution*—that can be described in terms of atomic occurrents (phase quanta) and the transitions between them. So, for any observer, the *perceived* process of evolution is a succession of mental images of states, each of which is a superposition of states of temporal parts of phase quanta, each of which has its origin in one elementary process. The duration of elementary processes is not necessarily the same, so any two processes that are ongoing at a time t in the reference frame of an observer may have a different initial degree of evolution. But for any n in the set of all initial degrees of evolution, there are a finite number $z(n)$ of elementary processes with that initial degree of evolution. And therefore, a number k from the section $I_{z(n)} = \{1, 2, \ldots, z(n)\}$ of positive integers can be assigned to each of the elementary processes with initial degree of evolution n: we are thus interested in a scheme of basic principles that are formulated mathematically as *generalized expressions* of the form

$$\forall n \forall k \in I_{z(n)} \Psi \tag{3.21}$$

such that the scheme gives a process-physically complete description of what happens in *all* these elementary processes. That said, the idea is now that in each elementary process, precisely one individual of every type of phase quantum is created and/or destroyed. So, starting with designators for phase quanta existing in the world, a suitable designator $\mathfrak{S}$ of a phase quantum that exists in the outside world (and not in the antiworld) is therefore of the form ${}^{\alpha}\varphi_k^x$ where

(i) the Greek letter 'φ' indicates that the designated material object is a phase quantum;

(ii) the left superscript 'α' stands for either EP, NP, LW, NW, or S, indicating the type of phase quantum designated (extended particlelike, nonextended particlelike, local wavelike, nonlocal wavelike, spatial);

(iii) the right superscript 'x' stands for one of the numbers n or $n + 1$, indicating the degree of evolution at which the phase quantum in question has been created;

(iv) the right subscript 'k' is the counting number from the set $I_{z(n)}$ assigned to that process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution in which the phase quantum in question has been created.

Concerning clause (iii), the relation between the degree of evolution x at which an individual of that type is created and the initial degree of evolution n of the process in which that individual is created is fixed for every type of phase quantum. For example, when the left superscript 'α' is 'EP', then $x = n$; so, the designator ${}^{EP}\varphi_k^n$ refers to *the extended particlelike phase quantum created at the* n^{th} *degree of evolution in the* k^{th} *process from the* n^{th} *to the* $(n+1)^{\text{th}}$ *degree of evolution.* That's quite a mouthful, but it is *exact*: there is only one material object that fits this description. As to clause (iv), different observers may assign a different number $k \in S_{z(n)}$ to a given elementary process with initial degree of evolution n. The point is that the value of k assigned by an observer to an elementary process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution is not important for the description of what happens during that process: maintaining the same value throughout one such process is both necessary and sufficient—that is, for any two designators ${}^{\alpha(1)}\varphi_{k(1)}^{x(1)}$ and ${}^{\alpha(2)}\varphi_{k(2)}^{x(2)}$ that refer to phase quanta created in one and the same process, the value of the right subscripts $k(1)$ and $k(2)$ has to be the same, as in $k(1) = k(2)$. Now that we have suitable designators for phase quanta in the world, we can apply the following rule for the conjugated phase quanta in the antiworld: if the designator ${}^{\alpha}\varphi_k^x$ refers to a phase quantum in the world, then the designator ${}^{\alpha}\overline{\varphi}_k^x$ refers to the conjugated phase quantum in the antiworld. Thus speaking, a 2×1 matrix $\begin{bmatrix} {}^{\alpha}\varphi_k^x \\ {}^{\alpha}\overline{\varphi}_k^x \end{bmatrix}$ designates a component of the universe, that consists of a phase quantum in the world and the conjugated phase quantum in the antiworld, cf. Eq. (3.20).

Proceeding, what's required next is a suitable typography for designators referring to *monadic occurrents*—a temporal part of a monadic occurrent carrying an electronic monad can be viewed as an electron, a temporal part of a monadic occurrent carrying an protonic monad as a proton, etc. A suitable designator $\mathfrak{S}$ for a monadic occurrent in the world (and not in the antiworld) is then of the form $\psi_{\mathfrak{m}_j}^n$ where

(i) the letter 'ψ' indicates that the designated material object is a monadic occurrent;

(ii) the right subscript '$\mathfrak{m}_j$' refers to the bundle of invariant properties (the monad) carried by the monadic occurrent;

(iii) the right superscript 'n' indicates that the monad $\mathfrak{m}_j$ is carried from the degree of evolution n to the next;

Thus speaking, the designator $\psi_{\mathfrak{m}_j}^n$ refers to *the monadic occurrent carrying* *the set of properties* $\mathfrak{m}_j$ *from the* n^{th} *to the* $(n+1)^{\text{th}}$ *degree of evolution.* Again that's quite a mouthful, but this designator is also *exact.* As to clause (ii), different observers may assign a different number j to a monad $\mathfrak{m}_j$. The point is that the value of j assigned by an observer to a monad is not important: it is merely the case that maintaining the same value for consecutive monadic occurrents carrying one and the same monad is both necessary and sufficient. That is, for any two designators $\psi^n_{\mathfrak{m}_{j(1)}}$ and $\psi^{n+1}_{\mathfrak{m}_{j(2)}}$ that refer to consecutive monadic occurrents carrying one and the same monad, the value of the right subscripts $\mathfrak{m}_{j(1)}$ and $\mathfrak{m}_{j(2)}$ has to be the same, as in $j(1) = j(2)$: we then have that if a temporal part of $\psi^n_{\mathfrak{m}_{j(1)}}$ can be viewed e.g. as an electron, then a temporal part of $\psi^n_{\mathfrak{m}_{j(2)}}$ is *that very same* electron. Now that we have suitable designators for monadic occurrents in the world, we can apply the following rule for the conjugated objects in the antiworld: if the designator $\psi^n_{\mathfrak{m}_j}$ refers to a monadic occurrent in the world, then the designator $\overline{\psi}^n_{\overline{\mathfrak{m}}_j}$ refers to the conjugated material object in the antiworld—it carries the set of properties $\overline{\mathfrak{m}}_j$ in opposite time-direction. Thus speaking, a 2×1-matrix $\begin{bmatrix} \psi^n_{\mathfrak{m}_j} \\ \overline{\psi}^n_{\overline{\mathfrak{m}}_j} \end{bmatrix}$ designates a component of the universe, that consists of a monadic occurrent carrying a monad in the world and the conjugated monadic occurrent in the antiworld.

Last but not least, what remains to be treated is a suitable typography for designators referring to particlelike matter quanta remains. The idea is that every monadic occurrent that carries a given monad is *preceded* by a nonextended particlelike matter quantum that carries that monad, so that the latter is *succeeded* by the first temporal part of the monadic occurrent, which is an extended particlelike matter quantum carrying the monad in question. That said, a suitable designator $\mathfrak{S}$ of a matter quantum that exists in the world (and not in the antiworld) is of the form ${}^{\alpha}\mu^n_{\mathfrak{m}_j}$ where

(i) the letter 'μ' indicates that the symbol designates a matter quantum;

(ii) the left superscript 'α' indicates the type of matter quantum designated, with 'α' standing for either 'NP' of 'EP';

(iii) the right subscript '$\mathfrak{m}_j$' refers to a monad;

(iv) the right superscript 'n' refers to the degree of evolution at which the matter quantum in question has been created.

So, the designator ${}^{EP}\mu^n_{\mathfrak{m}_j}$ refers to *the extended particlelike matter quantum carrying the monad* $\mathfrak{m}_j$ *at the* n^{th} *degree of evolution in the world.* And the designator ${}^{NP}\mu^{n+1}_{\mathfrak{m}_j}$ refers to *the nonextended particlelike matter quantum carrying the monad* $\mathfrak{m}_j$ *at the* $(n+1)^{\text{th}}$ *degree of evolution in the world.* Once more this is quite a mouthful, but it is also once more exact.

Now that we have suitable designators for particlelike matter quanta in the world, we can apply the following rule for the conjugated matter quanta in the antiworld: if the designator ${}^{\alpha}\mu^x_{\mathfrak{m}_j}$ refers to a matter quantum in the world, then the designator ${}^{\alpha}\overline{\mu}^x_{\overline{\mathfrak{m}}_j}$ refers to the conjugated matter quantum in the antiworld. Thus speaking, a 2×1-matrix $\begin{bmatrix} {}^{\alpha}\mu^x_{\mathfrak{m}_j} \\ {}^{\alpha}\overline{\mu}^x_{\overline{\mathfrak{m}}_j} \end{bmatrix}$ designates a component of the universe, that consists of a matter quantum in the world and the conjugated matter quantum in the antiworld.

Now that we have discussed the basic terms of a new formal language for physics, next up are the atomic expressions of the language: we herewith depart from the widely assumed but unfounded idea that the formal expressions of the most fundamental workings of the universe have to be *equations.* In the language of mathematics, an equation is an atomic expression of the type $t_1 = t_2$. However, the language of mathematics contains also $\in$-*relations*, which are atomic expressions of the type $t_1 \in t_2$. The process-physical principles of the EPT are largely built with $\in$-*relations.*

The first atomic expression involves the atemporal *existence predicate* $\mathbb{E}$. We can define expressions with this unary predicate formally in the language of mathematics by the following postulate of meaning:

$$\mathbb{E}\begin{bmatrix} \mathfrak{S} \\ \overline{\mathfrak{S}} \end{bmatrix} \Leftrightarrow \begin{bmatrix} \mathfrak{S} \\ \overline{\mathfrak{S}} \end{bmatrix} \in R_1 \tag{3.22}$$

where $\begin{bmatrix} \mathfrak{S} \\ \overline{\mathfrak{S}} \end{bmatrix}$ stands for a designator of a component of the universe that consists of a constitutent of the world and the conjugated constituent of the antiworld, and R_1 is a unary relation on the set of all components of the universe. That way, we have defined the atomic expression on the left hand side of Eq. (3.22) as an $\in$-relation. The meaning of such an expression is that the component of the universe designated by $\begin{bmatrix} \mathfrak{S} \\ \overline{\mathfrak{S}} \end{bmatrix}$ exists.

The remaining two atomic expressions of the new formal language can be defined in the language of mathematics by the following postulates of meaning, which make use of a *binary relation* R_2 and a *ternary relation* R_3 on the set of all components of the universe:

$$\begin{bmatrix} \mathfrak{S}_1 \\ \overline{\mathfrak{S}}_1 \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} \mathfrak{S}_2 \\ \overline{\mathfrak{S}}_2 \end{bmatrix} \Leftrightarrow \langle \begin{bmatrix} \mathfrak{S}_1 \\ \overline{\mathfrak{S}}_1 \end{bmatrix}, \begin{bmatrix} \mathfrak{S}_2 \\ \overline{\mathfrak{S}}_2 \end{bmatrix} \rangle \in R_2 \tag{3.23}$$

$$\begin{bmatrix} \mathfrak{S}_1 \\ \overline{\mathfrak{S}}_1 \end{bmatrix} : \begin{bmatrix} \mathfrak{S}_2 \\ \overline{\mathfrak{S}}_2 \end{bmatrix} \begin{matrix} \dashrightarrow \\ \dashleftarrow \end{matrix} \begin{bmatrix} \mathfrak{S}_3 \\ \overline{\mathfrak{S}}_3 \end{bmatrix} \Leftrightarrow \langle \begin{bmatrix} \mathfrak{S}_1 \\ \overline{\mathfrak{S}}_1 \end{bmatrix}, \begin{bmatrix} \mathfrak{S}_2 \\ \overline{\mathfrak{S}}_2 \end{bmatrix}, \begin{bmatrix} \mathfrak{S}_3 \\ \overline{\mathfrak{S}}_3 \end{bmatrix} \rangle \in R_3 \tag{3.24}$$

That way, we have defined the atomic expressions on the left hand sides of Eqs. (3.23) and (3.24) as $\in$-relations in mathematical language. As to their meaning, the atomic expression in Eq. (3.23) means that the component $\begin{bmatrix} \mathfrak{S}_1 \\ \overline{\mathfrak{S}}_1 \end{bmatrix}$ is in equilibrium with the component $\begin{bmatrix} \mathfrak{S}_2 \\ \overline{\mathfrak{S}}_2 \end{bmatrix}$, which is to say that in the world a discrete transition $\mathfrak{S}_1 \rightarrow \mathfrak{S}_2$ takes place by which the occurrent $\mathfrak{S}_1$ ceases to exist and the occurrent $\mathfrak{S}_2$ comes into existence, while in the antiworld the discrete transition $\overline{\mathfrak{S}}_2 \rightarrow \overline{\mathfrak{S}}_1$ takes place. And the atomic expression in Eq. (3.24) means that the component $\begin{bmatrix} \mathfrak{S}_1 \\ \overline{\mathfrak{S}}_1 \end{bmatrix}$ mediates an equilibrium between the component $\begin{bmatrix} \mathfrak{S}_2 \\ \overline{\mathfrak{S}}_2 \end{bmatrix}$ and the component $\begin{bmatrix} \mathfrak{S}_3 \\ \overline{\mathfrak{S}}_3 \end{bmatrix}$, which is to say that in the world the occurrent $\mathfrak{S}_1$ effects that the occurrent $\mathfrak{S}_2$ is succeeded by the occurrent $\mathfrak{S}_3$, while in the antiworld the occurrent $\overline{\mathfrak{S}}_1$ effects that the occurrent $\overline{\mathfrak{S}}_3$ is succeeded by the occurrent $\overline{\mathfrak{S}}_2$.

The above three atomic expressions are excellently suited for the description of the sought-after process-physical principles, which will be presented in Part III. The supersmall scale is not experimentally accessible, so these process-physical principles are not directly testable. However, with the help of auxiliary hypotheses in the form of a model of the EPT, testable predictions can nevertheless be derived. Namely, if we know the state in which we have prepared a massive system, then the EPT—supplemented with a model—can predict the state of the massive system at a later point in time after a (large) number of elementary processes have taken place: *that* is testable. We will get back to this in more detail in part IV.

3.4 The development of the EPT, philosophically

The development of the EPT included a search for first principles: this certainly falls under *speculative philosophy*, defined by Whitehead as an endeavor to develop a coherent, logical, necessary system of ideas in terms of which every element of our experience can be interpreted (1978). Under this denominator, the method by which the search for first principles has been carried out is the so-called *Hegelian dialectic*: concretely, that means that the EPT has been developed by means of a finite number of cycles consisting of *thesis*, *antithesis* and *synthesis*. In each cycle, the thesis is a proposition about the outside world, and the antithesis lays bare a problem with that proposition by criticizing it from a theoretical or experimental perspective. The synthesis is then a new proposition that solves the problem: this new proposition is then the thesis in a new dialectic cycle. It is undoable to give an exhaustive treatment of all these dialectic cycles, but the first one has been completely described; the first thesis, antithesis, and synthesis are explicitly written out on pages 91-92. During these dialectic cycles assistance, mainly assistance by putting forward antitheses, has been provided by Sergey Sannikov. All antitheses were based on established foundational theories or on established experimental results.

Furthermore, during this search for first principles, the four rules of René Descartes for the development of true knowledge, which he described in part II of his *Discours de la Méthode*, were adhered to as guidelines:

- do not accept anything for true which is not presented to the mind so clearly and distinctly that all grounds of doubt are excluded;
- analyse the difficulty under examination and divide it into parts if necessary;
- starting with the objects the simplest to know, ascend step by step to the knowledge of the more complex;
- be so complete and general that it is sure that nothing is omitted.

Concretely, the clear and distinct idea about the fundamental workings of the universe was accepted as true; the central aspect of this clear and distinct idea, repulsive gravity, has been analyzed in terms of inertial mass and gravitational mass; the atomic building blocks of the outside world are phase quanta, and every perceivable object is a superposition of temporal parts of phase quanta; the EPT is complete and general in the sense that in the framework of the EPT there are assumed to be no other processes in the universe. Moreover, three phases can be identified in the development of the EPT:

(i) a foundational phase in which a starting point for true knowledge is formulated on the basis of an analysis of a clear and distinct idea;

(ii) a destructive phase in which existing knowledge is rejected on the basis of contradiction with that starting point for true knowledge;

(iii) a constructive phase in which the system is extended to completeness.

In his *Meditations on First Philosophy*, René Descartes goes through the same three phases for the development of his system, but in a different order: for Descartes, his “cogito ergo sum” was the only truth that remained *after* radically doubting existing knowledge, while in the present research project the criterion of truth, Eq. (1.12), was formulated *before* existing theories were doubted.

At the end of the constructive phase, when the theory had already taken shape, the axiomatic method was applied. In the present case this means that primitive notions were formalized in mathematical language but without reference to any concrete mathematical structure, that derived notions were defined in terms of primitive notions using a monoid structure, that axioms were formulated as well-formed formulas in mathematical language using the newly defined formalism, and that interpretation rules were defined which translate the formal axioms into statements about physical reality. As a result, the whole construct forms an axiomatic system, or a ‘closed system’ as meant by Heisenberg (2007). Guidance has been provided by Harrie de Swart.

It is important to realize, however, that although *the search for first principles* falls under speculative philosophy, the *result of that search*—the EPT, that is—transcends the borders of pure philosophy for two reasons: firstly, because the EPT is experimentally testable, and secondly, because the EPT is formalized in mathematical language—as Cobb put it: “the dominant form of philosophy in the English-language world ... assumes that meaningful communication can only occur in *ordinary* language. ”

3.5 Objections and replies

Objection 3.5.1. "***Marcoen Cabbolet ... has been unable to sell his research to several physics groups, so that he went looking for a promotor in a different area: philosophy.*** *...* ***His PhD graduation was originally planned in Tilburg, but a co-promotor prevented it because of the bad quality.*** *After that he went to the TU/e and this university approved his dissertation.* ***Probably he has sold his dissertation there as mathematical and philosophical research so that he could easily obtain a PhD.*** *Marcoen is not a theoretical physicist or a mathematical physicist* ***and has had no education in this direction.*** *He is also no genius.* ***His knowledge of quantum mechanics is the same as that of any other graduate in chemistry: mainly knowledge of the applications of quantum mechanics****.*" (emphasis added)—Anonymous coworker of Utrecht University, commenting as 'Lezer69' about my then unpublished 2007 concept-dissertation (2008) ■

Reply 3.5.2. To begin with, the statements in bold are outright fabrications that this anonymous critic has passed off as "facts" about me, my work and my intentions—*as if* he is intimately familiar with the situation. And make no mistake: with these comments he is trying to win over the readership of widely read forums for his preconceived opinion that I'm a crackpot who doesn't know the first thing about physics. And not just that: his statement that I "sold" my dissertation as mathematical and philosophical research "to easily obtain a PhD" is nothing but a thinly veiled accusation of intentional deceit. This anonymous critic signed his comments by "someone who read the dissertation", but in another unrelated forum post he gave away that he was from Utrecht; since 't Hooft at the time had one of the few available copies of my unpublished work, this anonymous critic is thus either 't Hooft himself or one of his close colleagues.[47]

But the real problem is that *he feels good about it*, cf. the response-in-an-outburst model on page li: you can count on it that he has been bragging about it to his colleagues in the university canteen. And even though his colleagues now know that he has been passing off outright fabrications as "facts", they will do not one iota about it—no outcry, no nothing. They will even refuse to disclose his identity. If science is to go to the next level, this behavior will have to be eradicated root and branch from academia.■

Objection 3.5.3. *"At elementary level—according to Cabbolet—you have extended particles, point-shaped particles, local waves, global waves, and space. This sounds only a tad more sciencey than the five elements of Chinese astrology."—Nienhuys (2015)* ■

Reply 3.5.4. At elementary level—according to Newton—every action has an equal and opposite reaction. This sounds only a tad more sciencey than the yin and yang in Chinese philosophy. At elementary level—according to Schroedinger—a particle has a wave function. This sounds only a tad more sciencey than the New Age concept of a body having an 'energy field'. At elementary level—according to Gell Mann—every baryon consists of three quarks. This sounds only a tad more sciencey than the belief in numerology that a number reoccurs in separate events. Furthermore, Nienhuys has failed to understand that various phase quanta are *occurrents*, not *continuants*. Altogether this shows that the above objection is nothing but an expression of Nienhuys' dislike of my work. He never read Feynman:

> "*if we have a set of 'strange ideas', ..., whether we **like** them or do **not** like them is an irrelevant question. The only relevant question is whether the ideas are consistent with what is found experimentally.*" (original emphasis)—Feynman (2011), p. 16-3.

Nienhuys is Secretary of the Dutch organized skeptical movement *Skepsis*, and is editor of their journal *Skepter*: it is telling that the leadership of the organized skeptical movement is ignorant of the fact that there is no relation between *personal dislike of a theory* and *consistency of the theory with experiment*—make no mistake, Nienhuys and, unfortunately, many others believe that the feeling of dislike that they experience when reading my theory is a clear tell-tale sign that the theory is false, i.e., is inconsistent with the outcomes of experiments. ■

Objection 3.5.5. "*he talks about a 'phase quantum' for quantum mechanics, but it remains unclear how that notion has been derived and what it means physically.*"—'t Hooft (2008c) ■

Reply 3.5.6. It is false that the 'phase quantum' is a quantum-mechanical object. However, although I doubt 't Hooft's scientific integrity, I do not doubt his intelligence: Objection 3.5.5 should therefore be viewed as a valid objection against the description of the physical meaning of the phase quantum. The present edition is intended to meet that objection. ■

Objection 3.5.7. "*But they found the interpretation of the formalism absurd!* "—Dennis Dieks about the cancelation of my PhD graduation at the TU/e in 2008 (personal communication, 2016) ■

Reply 3.5.8. This has to be viewed as the objection that the entire material presented in this chapter has already been established to be absurd. This indicates that Dieks believes (i) that during the reevaluation of the dissertation (p. xxix ff.) the formalism as well as its physical interpretation has been thoroughly studied, and (ii) that the two physicists among the referees (Verhaar and Dieks' close friend 't Hooft) have established that the interpretation of the formalism is absurd. But that is not true. 't Hooft and Verhaar merely reacted emotionally to my hypothesis of repulsive gravity. They barely looked at the formalism and misunderstood its interpretation completely: they failed to understand that it was interpreted in terms of occurrents (as opposed to continuants). Cf. Objection 3.5.5. ■

Objection 3.5.9. "*There are plenty of occasions where physicists have developed new mathematics, but in the end things like numbers, arrays, lines, and sets thereof have always been sufficient to define those new mathematics. Cabbolet, on the other hand, wants to have notations that designate the things themselves, not coordinates or so. ... Furthermore, he thinks that notations for the 'things in themselves' cannot be numbers or vectors.*"—Nienhuys (2015) ■

Reply 3.5.10. The objection here is thus that the terms of the formalism designate things instead of properties (like coordinates) **and** that these terms are abstract sets instead of numbers or vectors. This objection can be dismissed as an expression of dislike of the formalism—it has nothing to do with objective criticism.

As an aside, the opening statement is a falsehood. E.g. the Russian physicist Vladimir Fock has developed the new mathematical notion of what is now called 'Fock space', but neither numbers, nor arrays, lines or sets thereof are sufficient to define Fock space—it is defined in terms of Hilbert spaces. So, Nienhuys is less knowledgeable about the topic than he thinks he is. That being said, he puts forward the next statement "Cabbolet ... so" *as if* it is a bad thing that notations designate things and not properties. He thus completely ignores that in QM a wave function also represents a thing and not the properties of the thing. So again, Nienhuys is less knowledgeable on the topic than he thinks he is. And last but not least, the final statement of the above objection is an outright fabrication: although I *do* think that notations for the 'things in themselves' cannot be numbers—that would be going back to Pythagorean physics—I *do not* think that notations for the 'things in themselves' cannot be vectors. See Part IV where states of the 'things in themselves' are modeled by vectors (although these are functions, not arrays of numbers as in classical mechanics). ■

Objection 3.5.11. "*The [Elementary Process Theory] is axiomatic, i.e. not based on observations but on a body of mathematical axioms. This method of theory development is completely alien to the natural sciences. The mathematical formulation of laws of physics follows from observations ... On the basis of the method alone I object against a PhD graduation in the natural sciences on the basis of this dissertation.*"—condensed matter physicist, reviewing my 2007 concept-dissertation for the LOWI ■

Reply 3.5.12. First of all, it is simply not true that a physical theory being axiomatic means that it is based on mathematical axioms and not based on observations: it only means that the theory is expressed as a collection of *physical* axioms—these may be presented as formulas in mathematical language together with interpretation rules, but in general these physical axioms are not *mathematical* axioms. E.g. Newton's theory is axiomatic and based on observations, but not based on mathematical axioms—the three laws of Newton are not axioms of mathematics!

That being said, this objection implies the position that new theories of physics are to be derived from observations. This is completely false: new theories in physics are seldom developed from observations. For comparison, consider the case that a referee for JHEP would have commented as follows to Verlinde's paper on emergent gravity (2011):

> *Dear Dr. Verlinde,*
> *the mathematical formulation of laws of physics follows from observations. So on the basis of the method alone I object against your emergent gravity. I therefore reject your paper.*

Just imagine it. All in all, this shows that expertise in condensed matter physics does **absolute not** automatically imply familiarity with methods of theory development in physics (such as the thought experiment) or expertise in the foundations. ■

Objection 3.5.13. "*Cabbolet has applied techniques that ... in my opinion are inadmissible in a scientific publication*"—'t Hooft (Hardeman, 2008) ■

Reply 3.5.14. This is a false statement of fact by 't Hooft, which he passed off in the public media as a genuine conclusion of a serious investigation into the quality of my work. The thought experiment described in Sect. 1.2 is a perfectly valid technique in theoretical physics, and so is the analysis of the thought experiment in Sect. 1.3—the same holds for other techniques used to develop the EPT. Of course one is free to believe that this approach doesn't lead to progress in physics, but despite the above allegation to the contrary by 't Hooft the techniques in themselves are correct. ■

Remark 3.5.15. When I wrote the 2007 concept-dissertation—the only source of my work that 't Hooft had seen in 2008—I held the view that it is not important for a physical theory *how* it has been developed: its merit lies in its correspondence to reality, which can be gauged by testing the theory according to a scientific method. And in this era of glorification of calculation I didn't exactly stand alone with this view, as for example the authors of GRW quantum theory demonstrate:

> "*[A]ll microscopic systems are subjected to localizaton processes with an appropriate frequency. We do not consider here the problem of the physical origin of these localizations for microscopic systems ... but we simply postulate that they occur.*"—Ghirardi, Rimini, and Weber (1986)

So, in the 2007 concept-dissertation I had devoted little to no space on *how* my theory, the EPT, had been developed: I mentioned that the axiomatic method was applied, but that wasn't meant to imply that the axiomatic method was applied *ab ovo*. That is to say, the above two objections are about the method c.q. techniques of theory development, yet both objectors have no idea what they are talking about—they could not have known which method c.q. techniques I had applied from reading the 2007 concept-dissertation, nor did they ever ask me.

That said, in between the affair at the TU/e and the PhD graduation in Brussels I changed my mind and embraced the view that an important aspect of a theory is *how* it has been developed.[48] In particular, I do not believe that true progress in our understanding of the fundamental workings of the universe can be made by merely developing new mathematics and giving these a physical interpretation—as I see it, this method yields at best *cleverly invented poetry* (cf. 2 Peter 1:16). ■

Objection 3.5.16. "*light is also matter, but indistinguishable from the corresponding antimatter, and yet light falls down. Cabbolet did not know that.*"—'t Hooft in (Botte, 2014) ■

Objection 3.5.17. "*As far as I know, Cabbolet knew nothing about the existence of all these particles that are their own antiparticle. 't Hooft had to teach him that.*"—Nienhuys (2014) ■

Objection 3.5.18. "*In 2009 Cabbolet learned from Gerard 't Hooft that photons are their own antiparticles.*"—Nienhuys (2015) ■

Reply 3.5.19. It is an outright fabrication by 't Hooft, which has been uncritically parroted twice by Nienhuys, that I didn't know that photons are their own antiparticle according to the Standard Model, yet are measurably deflected by the gravitational field of a large enough body (such as the sun). Fact of the matter is that this was literally the first thing that came up back in 1997 in my investigation into repulsive gravity. In Sect 3.2 it is mentioned that in the present framework, photons are a different kind of matter than e.g. protons and electrons. ■

Objection 3.5.20. "*I would say that 'deep speculative character' is not exactly a recommendation for a dissertation*"—Hajo Reijers (2013), commenting on Van Bendegem's remark in (Konings, 2013) that for him the deep speculative character was a valuable aspect of my 2011 dissertation■

Reply 3.5.21. This shows you how clueless my opponents can be: Van Bendegem used the adjective 'speculative' in its philosophical sense, meaning that he has used the adjective with a different meaning than it has in everyday language. Reijers, professor of Department of Mathematics and Computer Science at the TU/e, didn't know this distinction. To elaborate: in philosophy, the term 'speculative philosophy' refers to the endeavor to frame a coherent, logical, necessary system of ideas in terms of which every element of our experience can be interpreted (Whitehead, 1978). This endeavor includes a search for first principles, which was an essential part of my PhD project—the idea is thus that all perceptible physical things are superpositions of (temporal parts of) phase quanta. See also Sect. 3.4. ■

Objection 3.5.22. "*And so in practice it turns out that it is unthinkable that someone in the Netherlands can really contribute to the discussion on these branches of physics [i.e. the foundations, quantum physics, relativity; MC] without intensively communicating with all research groups in the Netherlands (Amsterdam, Utrecht, Leiden, Groningen) that are active in this area. This author has only had one mentor, who is unknown among physicists.*"—'t Hooft on my 2007 concept-dissertation (2008b) ■

Reply 3.5.23. What 't Hooft meant to say here is that there are two (more) reasons for the rejection of my entire work:

(i) my entire work has to be rejected *because* I am Dutch and my theory has not been developed in cooperation with Dutch research groups;

(ii) my entire work has to be rejected *because* I had only one mentor and that one mentor is not well-known amongst physicists.

Let's treat this as an objection against the entire material presented in this chapter.

As to (i), I agree with 't Hooft it is unthinkable that one can contribute to the discussion on the foundations of physics without having intensively communicated with researchers active in the field. But I reject the limitation that these researchers have to be affiliated to a university in the same country. In particular, researchers in the Netherlands do not have a monopoly on knowledge about the foundations of quantum physics and relativity: as a Dutchman, one may discuss these foundations equally well with researchers abroad—which is what I did.

As to (ii), the claim by 't Hooft that I has only one mentor is false. I had three: Sannikov, De Swart, and (later) Van Bendegem—their combined areas of competence covered the foundations of modern physics, the foundations of mathematics, and analytical philosophy. But even if the claim were true, the rule still is that a PhD graduate has only one mentor. E.g. 't Hooft himself had only one mentor. Furthermore, the merit of a dissertation is hardly a function of the degree of fame of the PhD advisor. In particular, the fact that Sannikov was unknown doesn't detract from the fact that he was competent in the foundations of standard quantum physics and relativity.

This shows that Objection 3.5.22 is not a valid objection against the material presented in this chapter—or any other part of my work. ■

Part II

Axiomatic introduction of the EPT

Chapter 4

Mathematical foundation

"*An unbelievable crackpot PhD graduation*"—Wouter van Joolingen, professor of science and mathematics education, commenting on the news that I obtained a PhD in Belgium (2011a)

4.1 General introduction

Purpose of a mathematical foundation

Recall from Sect. 3.3 (i) that for every material object postulated to exist in the physical universe, there is an abstract constant in the formal language of the EPT that uniquely refers to that material object, and (ii) that any such constant $\mathfrak{S}$ comes with a mathematical axiom given by Eq. (3.19), that is, given by

$$\exists \alpha : \alpha = \mathfrak{S} \tag{3.19}$$

To spell it out, this reads: "there is a thing α in the mathematical universe such that α is identical to the formal object represented by the symbol $\mathfrak{S}$". This 'mathematical universe' is then made up of the things that satisfy the axioms of the mathematical foundation of the EPT. Thus speaking, the purpose of taking this or that theory as the mathematical foundation of the EPT is in the first place to give meaning to the formal axioms expressed by Eq. (3.19): an abstract constant of the EPT then stands for a further unspecified thing in the corresponding mathematical universe.

Furthermore, we want to be able to "do mathematics" in the framework of the EPT. That is the second purpose of taking this or that theory as the mathematical foundation of the EPT. More precisely, the axiomatic system containing the foundational theory provides the mathematical-logical framework for proofs and inferences in the framework of the EPT. So, once the EPT has a mathematical foundation, we can use its mathematical axioms, its logical axioms, and its inference rules in the framework of the EPT. And that means that we then can *do mathematics* in the framework of the EPT in the same way as we *do mathematics* in the framework of its mathematical foundation. The motivation for a choice of mathematical foundation then largely lies in the area of pure mathematics: given that the EPT has a finite universe—that is, given that the language of the EPT has a finite number of abstract constants that uniquely refer to things that are postulated to exist in the physical universe—a change from one mathematical foundation to another mathematical foundation might have no consequences for the physics in the framework of the EPT.

It is emphasized, however, that we could also go for a formalization of the EPT *without* a mathematical foundation. That is, a formalization of the EPT as 'just' a first-order theory, as opposed to a formalization within the framework of a mathematical foundation, is also possible. The formal axioms given by Eq. (3.19) are then removed: we don't make any assumptions at all about the constants of the EPT—as De Swart put it, they might as well be chocolate letters then. Such a strictly first-order formalization is *just as rigorous*, but it is important to understand that this severely limits the things we can do with the theory. Without a mathematical foundation, we cannot make use of the notion of a set or a function, because these do not exist in bare first-order logic: they have to be introduced by a collection of axioms. But such a collection of axioms is a mathematical foundation, since these axioms are not a part of bare first-order logic. So without any mathematical foundation, we cannot construct subsets, cartesian products, powersets, pair sets, sum sets, unions, disjoint unions, intersections, graphs, function spaces, choice functions, images or inverse images under a function, etc.: any proof or inference that requires any of these notions is then out of the window. This shows that a formalization of the EPT within the framework of a mathematical foundation is to be preferred over a formalization as 'just' a first-order theory.

Motivation for the choice of mathematical foundation

In the 19$^{\text{th}}$ century, Georg Cantor's paper "*Über eine Eigenschaft des Inbegriffs aller reellen algebraischen Zahlen*" (1874) marked the beginning of the development of set theory; Cantor honestly believed that it was communicated to him by God (Dauben, 1993). Cantor's set theory met fierce resistance from his contemporaries, but Hilbert defended the idea:

> "*No one shall be able to expel us from the paradise that Cantor has created for us.*"—(Hilbert, 1926)

That said, after Russell identified an inconsistency in a formalization of Cantor's idea by Frege, Ernst Zermelo proposed a new axiomatic set theory (1908). The implementation of improvements suggested independently by Skolem and Fraenkel led to Zermelo-Fraenkel set theory: this is without a doubt the most widely accepted foundational theory for mathematics. Let us, in accordance with common convention, use ZFC to denote the full theory, ZF for the full theory minus the axiom of choice (AC), and let us use ZF(C) in statements that are to hold for both ZF and ZFC; we could, thus, take ZF or ZFC as the mathematical foundation for the EPT:

- Eq. (3.19) then means that an abstract constant $\mathfrak{S}$ in the language of the EPT stands for a set whose elements are not specified, where a set is a thing that satisfies the axioms of ZF(C);
- the axiomatic system of ZF(C) then provides the mathematical-logical framework for proofs and inferences in the framework of the EPT.

But we are not going to do that: ZF(C) has two features that we may call 'unwanted' or 'pathological'. In a sentence, these are:

(i) the number of axioms of ZF(C) is infinite, as a result of which ZF(C) cannot be written down explicitly;

(ii) a corollary of the downward Löwenheim-Skolem theorem Loewenheim (1915); Skolem (1922) is that ZF(C) has a countable model (if it has a model at all), so that we have to swallow that there is a model of ZF(C) in which the powerset of the natural numbers is countable.

But let's be more specific, starting with the infinite axiomatization of ZF(C). One might have the impression that ZF(C) has just eight or nine axioms—that's eight for ZF, and nine for ZFC which includes AC. This impression, however, is false. The crux is that ZF(C) contains two *axiom schemata*, which are sometimes colloquially referred to as 'axioms': each axiom schema consists of infinitely many axioms. The first of these is the *separation axiom schema*, usually abbreviated by SEP. A standard formulation of SEP is the following:

$$\forall X \exists Y \forall z (z \in Y \Leftrightarrow z \in X \wedge \Phi) \tag{4.1}$$

This means: for any set X there is a set Y, such that any z is an element of Y if and only if z is an element of X and Φ is true. With such an axiom, we can construct a subset Y of X. The thing is, however, that Φ is a *metavariable*: it is a variable that stands for any well-formed formula not open in X. So in fact, we have a separation axiom for every suitable well-formed formula that we substitute for Φ in Eq. (4.1). Using the constant $\emptyset$ of the language of ZF and using set-builder notation to abbreviate well-formed formulas in the language of ZF, it is very easy to think of infinite sequences of separation axioms. For example, the following formulas are all separation axioms of ZF:

$$\forall X \exists Y \forall z (z \in Y \Leftrightarrow z \in X \wedge z = \emptyset)$$
$$\forall X \exists Y \forall z (z \in Y \Leftrightarrow z \in X \wedge z = \{\emptyset, \{\emptyset\}\})$$
$$\forall X \exists Y \forall z (z \in Y \Leftrightarrow z \in X \wedge z = \{\emptyset, \{\emptyset, \{\emptyset\}\}\})$$

and so forth: this sequence of formulas is infinite.

The second axiom schema of ZF(C) is the *replacement axiom schema*, which is usually abbreviated by the acronym REP. A standard formulation of REP is the following:

$$\forall x \exists ! y \Phi(x, y) \Rightarrow \forall X \exists Y \forall y (y \in Y \Leftrightarrow \exists x \in X(\Phi(x, y))) \tag{4.2}$$

This means: if for every set x there is a unique set y such that the relation $\Phi(x, y)$ is true, then for any set X there is a set Y made up of all the elements y for which there is an element x in X such that the relation $\Phi(x, y)$ is true. Again, Φ is a *metavariable* but now it stands for any well-formed functional relation. So in fact, we have a replacement axiom for every well-formed functional relation that we substitute for Φ in Eq. (4.2).

For example, the following formulas are all replacement axioms of ZF:

$$\forall x \exists ! y(y = \{x, \emptyset\}) \Rightarrow \forall X \exists Y \forall y(y \in Y \Leftrightarrow \exists x \in X(y = \{x, \emptyset\}))$$
$$\forall x \exists ! y(y = \{x, \{\emptyset\}\}) \Rightarrow \forall X \exists Y \forall y(y \in Y \Leftrightarrow \exists x \in X(y = \{x, \{\emptyset\}\}))$$
$$\forall x \exists ! y(y = \{x, \{\{\emptyset\}\}\}) \Rightarrow \forall X \exists Y \forall y(y \in Y \Leftrightarrow \exists x \in X(y = \{x, \{\{\emptyset\}\}\}))$$

and so forth: this is an infinite sequence of formulas. And with a little creativity, one can come up with many more examples of infinite sequences of replacement axioms of ZF(C). While the above examples of separation axioms c.q. replacement axioms may not be very interesting, they nevertheless demonstrate that ZF(C) is infinitely axiomatized. As a consequence, ZF(C) cannot ever be written down explicitly—that's our first pathological feature of ZF(C).

Now let's turn to the corollary of the downward Löwenheim-Skolem theorem that if ZF(C) has a model, it has a countable model—of all people, Zermelo himself considered this a pathological feature of the theory (Ebbinghaus, 2007). This countable model, let's call it 'M', consists of a universe $|M|$, which is a countable family of sets $m_1, m_2, m_3, \ldots$ such that for every axiom A of ZF(C), its translation A^* in the language of the model M is valid in M. That is, we have

$$\models_M A^* \tag{4.3}$$

for the translation A^* of any axiom A of ZF(C) in the language of M. Elaborating, the countable universe $|M|$ contains *at least* the following sets:

(i) the natural numbers $0, 1, 2, \ldots$ defined as sets;

(ii) the countable set of natural numbers $\mathbb{N} = \{0, 1, 2, \ldots\}$;

(iii) countably many subsets $S_1, S_2, S_3, \ldots$ of the set $\mathbb{N}$;

(iv) a countable set $K = \{S_1, S_2, S_3, \ldots\}$, made up of the subsets S_j of $\mathbb{N}$.

Now the powerset axiom of ZF(C), usually abbreviated POW, is the following:

$$\forall X \exists Y \forall z(z \in Y \Leftrightarrow z \subset X) \tag{4.4}$$

This means: for any set X there is a set Y made up of the subsets of X. The set Y is then usually denoted by $Y = \mathcal{P}(X)$. But in our model M, this translates as: for any set X in $|M|$ there is a set Y in $|M|$ made up of all the subsets of X in $|M|$. As a result, we have

$$\models_M K = \mathcal{P}(\mathbb{N}) \tag{4.5}$$

So, in our model M the powerset of the natural numbers is a countable set. Intuitively we think that the powerset of $\mathbb{N}$ is uncountable and contains subsets of $\mathbb{N}$ other than the S_j's in the universe $|M|$ of the model M. But the crux is that these "other" subsets of $\mathbb{N}$ are not in $|M|$. Löwenheim and Skolem have proven that the existence of such a model M is an inevitable consequence of the standard first-order axiomatization of ZF. This is a famous result in the foundations of mathematics, and one that is completely counterintuitive to boot. The proof is not constructive, that is, there exists no specification of how the set K can be constructed, but nevertheless we have to swallow that ZF(C) has a model M in which a countable set K is the powerset of the natural numbers. This is the second pathological feature of ZF(C).

The purpose of this chapter is to present the axioms one has to accept such that the axioms of ZF can be derived from the new axioms—we omit a discussion of AC—but such that these two pathological features are *both* removed. The collection of these new axioms is thus a finite collection of well-formed formulas of finite length. We might jokingly refer to this collection of axioms with the acronym 'FANTOMAS' (<u>F</u>initely <u>A</u>xiomatized <u>N</u>on-classical <u>T</u>heory <u>O</u>f <u>M</u>appings <u>A</u>nd <u>S</u>ets) as an allude to the hilarious movies with Louis de Funès, but we are not going to do that: we will henceforth refer to it with the symbol $\mathfrak{T}$ (a Gothic 'T').

Importantly, we thus choose $\mathfrak{T}$ over of ZF as the mathematical foundation for the EPT, which means that the axiomatic system containing $\mathfrak{T}$ provides the mathematical-logical framework for proofs and inferences in the framework of the EPT.[49] But it is emphasized that the fact that $\mathfrak{T}$ lacks the pathological features of ZF is *irrelevant* for the physics: it is not the case that the choice for $\mathfrak{T}$ enables us to formalize physics that would unformalizable in the framework of ZF.

Related works

We will not review every idea ever published in set theory *hic et nunc*, but it is true that at least one set theory that can be finitely axiomatized has already been suggested, namely Von Neumann-Gödel-Bernays set theory (NGB). NGB is provably a mere conservative extension of ZF, and as such "it seems to be no stronger than ZF" (Mendelson, 1997). However, NGB shares the second of the two aforementioned unwanted features with ZF. In that regard, Von Neumann has been quoted stating

> "*At present we can do no more than note that we have one more reason here to entertain reservations about set theory and that for the time being no way of rehabilitating this theory is known.*"—(Van Dalen and Ebbinghaus, 2000)

That shows that Von Neumann too considered the countable model a pathological feature. That being said, a finite theory in the same language as ZF (without extra objects) and *as strong as* ZF has already in the 1950's been proved impossible by Montague (1957). This result is a landmark in the historical development of the foundations of mathematics: even though it may not be stated anywhere explicitly, it has ever since become accepted that there is no standard solution to "our" problem identified in the beginning. That is, the general consensus is that it is impossible to develop a foundational theory for mathematics in standard first-order language that lacks both pathological features of ZF—all the more so because the downward Löwenheim-Skolem theorem pertains to standard first-order theories in general. It is therefore not surprising that this is not an active research field: those working in the foundations of mathematics are well aware of "our" problem, but ongoing research in set theory focusses at other topics such as, for example, large cardinals, forcing, and inner models—see e.g. Bagaria et al. (2019); Gitman et al. (2020); Barton et al. (2020) for some recent works. That being said, the finitely axiomatized theory $\mathfrak{T}$ that we present here is a *non-standard solution* to "our" problem: it entails a rather drastic departure from the language, ontology, and logic of ZF. Earlier a radical departure has already been suggested by Lawvere, who formulated a theory of the category of sets: here the $\in$-relation has been defined in terms of the primitive notions of category theory, that is, in terms of mappings, domains and codomains (1964). The present theory

$\mathfrak{T}$, however, is more of a "marriage"—by lack of a better term—between set theory and category theory: the $\in$-relation is maintained as an atomic expression, while the notion of a category is built in as the main structural element. So regarding the philosophical position on the status of category theory, here neither Lawvere's position is taken, that category theory provides the foundation for mathematics (1966), nor Mayberry's position that category theory requires set theory as a foundation (1994), nor Landry's position that category theory provides (all of) the language for mathematics Landry (1999): instead, the present position is that category theory is *incorporated* in the foundations.

Informal overview of the main result

Category theory being incorporated in the foundations entails a departure from Cantor's paradise, in the sense that the universe of (mathematical) discourse is not Cantor's paradise of sets, but a category:

Definition 4.1.1. *The* ***universe of discourse*** *is a category consisting of*

(i) a proper class of objects, each of which is a ***set****;*

(ii) a proper class of arrows, each of which is a ***function****.*

This category will henceforth be referred to with the letter $\mathscr{C}$. ■

As to the meaning of the term 'universe of discourse' in Def. 4.1.1, the following quote from a standard textbook is interesting (Gamut, 1991):

> "*Instead of having to say 'the entities to which the predicates might in principle apply', we can make things easier for ourselves by collectively calling these entities the 'universe of discourse'.*"

So, a theory *without* a universe of discourse is nothing but a scheme of meaningless strings of symbols, which are its axioms; an inference rule is then nothing but a rule by which (other) meaningless strings of symbols can be "deduced" from those axioms. Such a notion of 'theory' might be acceptable from the perspective of a formalist view, but here the position is taken that theories c.q. strings of symbols without meaning are *not interesting*. So, to the present theory $\mathfrak{T}$ is associated a Platonic universe of discourse—*in casu*: $\mathscr{C}$—which we can think of as being made up of the things that satisfy the axioms of $\mathfrak{T}$. But that does not mean that for every thing in the universe of discourse a constant needs to be included in the formal language: the vocabulary contains only countably many constants. But $\mathfrak{T}$ has been formulated with an *intended model* in mind: its universe is then a "Platonic imitation" of the universe of discourse. Below we briefly elaborate on the universe of discourse using set-builder notation: strictly speaking this is not a part of the formal language, but given its status as a widely used tool for the description of sets it is suitable for an *informal* introductory exposition that one can hold in the back of one's mind.

For starters, the primitive notion of a set is, of course, that it is an object made up of elements: a thing α being an element of a set S is formalized by an irreducible $\in$-relation, that is, by an atomic expression of the form $\alpha \in S$. The binary predicate '$\in$' is part of the language for $\mathfrak{T}$: there is no need to express it in the language of category theory, since that does not yield a simplification. (Hence the language of the present theory is not reduced to the language of category theory.) In ZF we then have the adage 'everything is a set', meaning that if we have $x \in y$, then x is a set too. Here, however, that adage remains valid in this proper class of objects only to the extent that all the *objects* are sets—the adage does not hold for all elements of all sets. That is, we will assume that every object of the category is either the empty set or an object that contains elements, but an element of an object—if any—can either be the empty set, or again an object made up of elements, or a function: a function is then <u>not</u> a set. A number of constructive set-theoretical axioms then describe in terms of the $\in$-relation which sets there are *at least* in this proper class of sets; these axioms are very simple theorems of ZF that hardly need any elaboration.

As to the notion of a function, in the framework of ZF a function is *identified* with its graph. However, as hinted at above, here we reject that set-theoretical reduction. First of all, functions are *objects sui generis*. If we use simple symbols like X and Y for sets, then a composite symbol f_X—to be pronounced "f-on-X"—can be used for a function on X: in the intended model, a function is a thing f_X where f stands for the graph of the function and X for its domain. To give an example, let the numbers 0 and 1 be defined as sets, e.g. by $0 := \emptyset$ and $1 := \{\emptyset\}$, and let, for sets x and y, a two-tuple $\langle x, y\rangle$ be defined as a set, e.g. by $\langle x, y\rangle := \{x, \{x, y\}\}$; then the composite symbol $\{\langle 0, 1\rangle, \langle 1, 0\rangle\}_{\{0,1\}}$ refers to the function on the set $\{0,1\}$ whose graph is the set $\{\langle 0,1\rangle, \langle 1,0\rangle\}$. However, we have $f_X \neq Y$ for any function on any domain X and for any set Y, so

$$\{\langle 0,1\rangle, \langle 1,0\rangle\}_{\{0,1\}} \neq \{\langle 0,1\rangle, \langle 1,0\rangle\} \tag{4.6}$$

That is to say, the function $\{\langle 0,1\rangle, \langle 1,0\rangle\}_{\{0,1\}}$ is not identical to its graph $\{\langle 0,1\rangle, \langle 1,0\rangle\}$—nor, in fact, to any other set Y. At this point one might be inclined to think that the whole idea of functions on a set as objects sui generis is superfluous, and should be eliminated in favor of the idea that functions are identified with their graphs (which are sets). That, however, has already been tried in an earlier stage of this investigation: it turned out to lead to unsolvable difficulties with the interpretation of the formalism, cf. (Cabbolet, 2014a). The crux is that the main constructive axiom of the theory—here a *constructive axiom* is an axiom that, when certain things are given (e.g. one or two sets or a set and a predicate), states the existence of a uniquely determined other thing (Bernays, 1968)—'produces' things referred to by a symbol F_X: one gets into unsolvable difficulties if one tries to interpret these things as sets.

But functions are not only different things than sets. Contrary to a set, a function in addition *has* a domain and a codomain—both are sets—and it also *does something*: namely, it maps every element in its domain to an element in its codomain. This first aspect, that a function 'has' a domain and a codomain, can be expressed in the language of category theory: an atomic formula $f_X : Y \twoheadrightarrow Z$ expresses that the function f_X has domain Y and codomain Z. In accordance with existing convention, the two-headed arrow '$\twoheadrightarrow$' expresses that f_X is a surjection: the codomain is *always* the set of the images of the elements of the domain under f_X. Since such an expression $f_X : Y \twoheadrightarrow Z$ is irreducible in the present framework, it requires some function-theoretical axioms to specify when such an atomic formula is true and when not. For example, for the function $\{\langle 0,1\rangle, \langle 1,0\rangle\}_{\{0,1\}}$ discussed above we have

$$\{\langle 0,1\rangle, \langle 1,0\rangle\}_{\{0,1\}} : \{0,1\} \twoheadrightarrow \{0,1\} \tag{4.7}$$

while other expressions $\{\langle 0,1\rangle, \langle 1,0\rangle\}_{\{0,1\}} : Y \twoheadrightarrow Z$ are false. Again, at this point one might be inclined to think that these expression $f_X : Y \twoheadrightarrow Z$ are superfluous, because the notation f_X already indicates that X is the domain of f_X. The crux, however, is that these expressions are *essential* to get to a finite axiomatization: we may, then, have the opinion that it is obvious from the notation f_X that X is the domain of f_X, but only an expression $f_X : X \twoheadrightarrow Z$ expresses this fact—it is, thus, an axiom of the theory that $f_X : Y \twoheadrightarrow Z$ is only true if $Y = X$.

The second aspect, that for any set X any function f_X 'maps' an element y of its domain to an element z of its codomain is expressed by another atomic formula $f_X : y \mapsto z$. In the framework of ZF this is just a notation for $\langle y, z\rangle \in f_X$, but in the present framework this is also an irreducible expression: therefore, it requires some more function-theoretical axioms to specify when such an atomic formula is true and when not. The idea, however, is this: **given** a set X and a function f_X, precisely one expression $f_X : y \mapsto z$ is true for each element y in the domain of f_X. E.g. we have

$$\{\langle 0, 1\rangle, \langle 1, 0\rangle\}_{\{0,1\}} : 0 \mapsto 1 \tag{4.8}$$

$$\{\langle 0, 1\rangle, \langle 1, 0\rangle\}_{\{0,1\}} : 1 \mapsto 0 \tag{4.9}$$

for the above function $\{\langle 0, 1\rangle, \langle 1, 0\rangle\}_{\{0,1\}}$.

All the above can be expressed with a dozen and a half very simple axioms—these can, in fact, all be reformulated in the framework of ZF. The present axiomatic scheme does, however, contain 'new mathematics' in the form of the second axiom of a pair of constructive, function-theoretical axioms. The first one is again very simple, and merely states that given any two singletons $X = \{x\}$ and $Y = \{y\}$, there exists an 'ur-function' that maps the one element x of X to the one element y of Y. An ur-function is thus a function with a singleton domain and a singleton codomain. The above function $\{\langle 0, 1\rangle, \langle 1, 0\rangle\}_{\{0,1\}}$ is thus not an ur-function, but the function referred to by the symbol $\{\langle 0, 1\rangle\}_{\{0\}}$ is: we have

$$\{\langle 0, 1\rangle\}_{\{0\}} : \{0\} \twoheadrightarrow \{1\} \tag{4.10}$$

$$\{\langle 0, 1\rangle\}_{\{0\}} : 0 \mapsto 1 \tag{4.11}$$

That said, the second of the pair of constructive, function-theoretical axioms is a new mathematical principle: it states that given any family of ur-functions $f_{\{j\}}$ indexed in a set Z, there exists a sum function F_Z such that the sum function maps an element j of Z to the same image as the corresponding ur-function $f_{\{j\}}$. The formulation of this principle requires, however, a new nonstandard concept that can be called a 'multiple quantifier'. This new concept can be explained as follows. Suppose we have defined the natural numbers $0, 1, 2, \ldots$ as sets, suppose the singletons $\{0\}, \{1\}, \{2\}, \ldots$ exist as well, and suppose we also have the set of natural numbers $\omega = \{0, 1, 2, \ldots\}$. We can, then, consider variables $f_{\{0\}}, f_{\{1\}}, f_{\{2\}}, \ldots$ ranging over all ur-functions on a singleton of a natural number as indicated by the subscript—so, $f_{\{0\}}$ is a variable that ranges over all ur-functions on the singleton of 0. In the standard first-order language of ZF we have the possibility to quantify over all ur-functions on a singleton $\{a\}$ by using a quantifier $\forall f_{\{a\}}$, and we have the possibility to use any finite number of such quantifiers in a sentence. E.g. we can have a formula

$$\forall f_{\{0\}} \forall f_{\{1\}} \forall f_{\{2\}} \Psi \tag{4.12}$$

meaning: for all ur-functions on $\{0\}$ and for all ur-functions on $\{1\}$ and for all ur-functions on $\{2\}$, Ψ. We can then introduce a new notation by the following postulate of meaning:

$$(\forall f_{\{j\}})_{j \in \{0,1,2\}} \Psi \Leftrightarrow \forall f_{\{0\}} \forall f_{\{1\}} \forall f_{\{2\}} \Psi \tag{4.13}$$

This new formula can be read as: for any family of ur-functions indexed in $\{0, 1, 2\}$, Ψ. So $(\forall f_{\{i\}})_{i \in \{0,1,2\}}$ is then a multiple quantifier that, in this case, is equivalent to three quantifiers in standard first-order language. The next step is now that we lift the restriction that a multiple quantifier has to be equivalent to a finite number of standard quantifiers: with that step we enter into nonstandard territory. In the nonstandard language of $\mathfrak{T}$ we can consider a formula like

$$(\forall f_{\{i\}})_{i \in \omega} \Psi \tag{4.14}$$

The multiple quantifier is equivalent to infinitely many standard quantifiers $\forall f_{\{0\}}, \forall f_{\{1\}}, \forall f_{\{2\}}, \ldots$ in this case. But in the present framework the constant ω in formula (4.14) can be replaced by *any* constant, yielding nonstandard multiple quantifiers equivalent to an uncountably infinite number of standard quantifiers.

To yield meaningful theorems, the subformula Ψ of formula (4.14) has to be open in infinitely many variables $f_{\{0\}}, f_{\{1\}}, f_{\{2\}}, \ldots$, each of which ranges over all ur-functions on a singleton of a natural number. This is achieved by placing a *conjunctive operator* $\bigwedge_{i\in\omega}$ in front of a formula $\Psi(f_{\{i\}})$ that is open in a composite variable $f_{\{i\}}$, yielding an expression

$$\bigwedge\nolimits_{i\in\omega}\Psi(f_{\{i\}}) \tag{4.15}$$

Syntactically this is a formula of finite length, but *semantically* it is the infinitary conjunction of the formulas $\Psi(f_{\{0\}}), \Psi(f_{\{1\}}), \Psi(f_{\{2\}}), \ldots$. Together with the multiple quantifier from formula (4.14) it yields a *sentence* $(\forall f_{\{i\}})_{i\in\omega}\bigwedge_{i\in\omega}\Psi(f_{\{i\}})$: semantically it contains a bound occurrence of the variables $f_{\{0\}}, f_{\{1\}}, f_{\{2\}}, \ldots$. The nonstandard 'sum function axiom' constructed with these formal language elements is so powerful that it allows to derive the infinite schemes SEP and REP of ZF from just a finite number of axioms.

That said, the literature already contains a plethora of so-called *infinitary logics*; see (Bell, 2016) for a short, general overview. In the framework of such an infinitary logic, one typically can form infinitary conjunctions of *any* collection Σ of standard first-order formulas indexed by some set S. So, if $\Sigma = \{\phi_j \mid j \in S\}$ is such a collection of formulas, then a formula $\bigwedge\Sigma$ stands for $\wedge_{j\in S}\phi_j$, which resembles formula (4.15). That way, one can, for example, form the conjunction of all the formulas of the SEP scheme of ZF: that yields a finite axiomatization of set theory. However, such an infinitary conjunction cannot be written down explicitly: the string of symbols '$\wedge_{j\in S}\phi_j$' is an informal abbreviation that is not part of the formal language—that is, it is not a well-formed formula. In the present case, however, we are only interested in well-formed formulas of finite length, which can be written down explicitly. This is achieved by building restrictions in the definition of the syntax, so that a conjunctive operator like $\bigwedge_{x\in\omega}$ forms a well-formed formula *only if* it is put in front of an atomic expression of the type $f_{\{x\}} : x \mapsto t(x)$ where both $f_{\{x\}}$ and $t(x)$ are terms with an occurrence of the same variable x that occurs in the conjunctive operator: that way typographically finite expressions obtain that semantically are infinitary conjunctions. So, the language for our theory $\mathfrak{T}$ is much more narrowly defined than the language of (overly?) general infinitary logics.

That brings us to the next point, which is to discuss the (possible) practical use of the new finite theory $\mathfrak{T}$ as a foundational theory for mathematics. The practical usefulness of the scheme lies therein that it (i) provides an easy way to construct sets, and (ii) that categories like **Top**, **Mon**, **Grp**, etc, which are subjects of study in category theory, can be viewed as subcategories of the category of sets and functions of Def. 4.1.1, thus providing a new approach to the foundational problem identified in (Cabbolet, 2015b). While that latter point (ii) hardly needs elaboration, the former (i) does. The crux is that one can use the theorem of $\mathfrak{T}$ that given any set X, we can construct a new function on X by giving a function prescription. So, this is a philosophical nuance: in ZF one constructs a new object with the $\in$-relation, but in the present framework one can construct a new function f_X not with the $\in$-relation, but by simply defining which expressions $f_X : y \mapsto z$ are true for the elements y in the domain. On account of the sum function axiom, it is then a guarantee that the function f_X exists. So, given any set X one can simply give a defining function prescription

$$f_X : y \overset{\text{def}}{\longmapsto} \imath z \Phi(y, z) \tag{4.16}$$

where the iota-term $\imath z\Phi(y, z)$ denotes the unique thing z for which the functional relation $\Phi(y, z)$ holds: f_X is then guaranteed to exist, and so are its graph and its image set—giving a function prescription *is* constructing a set. The nonstandard axiom, which may be cumbersome to use directly, stays thus in the background: one uses the main theorem of $\mathfrak{T}$.

What remains to be discussed is that $\mathfrak{T}$, as mentioned in the first paragraph, entails the axioms of ZF and does not have a countable model. As to the first-mentioned property, it will be proven that the infinite axiom schemes SEP and REP of ZF, translated in the formal language of $\mathfrak{T}$, can be derived from the finitely axiomatized theory $\mathfrak{T}$: that provides an argument for considering $\mathfrak{T}$ to be *not weaker* than ZF. Secondly, even though the language of $\mathfrak{T}$ has only countably many constants, it will be shown that the validity of the nonstandard sum function axiom in a model $\mathcal{M}$ of $\mathfrak{T}$ has the consequence that the downward Löwenheim-Skolem theorem does not hold: if $\mathfrak{T}$ has a model $\mathcal{M}$, then $\mathcal{M}$ is not countable. This is a significant result that does not hold in the framework of ZF: it provides, therefore, an argument for considering $\mathfrak{T}$ to be *stronger* than ZF.

4.2 Axiomatic introduction of $\mathfrak{T}$

Formal language, standard part

First of all a remark. In standard first-order logic, the term 'quantifier' refers *both* to the logical symbols '$\forall$' and '$\exists$' *and* to combinations like $\forall x$, $\exists y$ consisting of such a symbol and a variable. While that may be unproblematic in standard logic, here the logical symbols '$\forall$' and '$\exists$' are applied in *different* kinds of quantifiers. Therefore, to avoid confusion we will refer to the symbol '$\forall$' with the term 'universal quantification symbol', and to the symbol '$\exists$' with the term 'existential quantification symbol'.

Definition 4.2.1. *The* ***vocabulary*** *of the language $L_{\mathfrak{T}}$ of $\mathfrak{T}$ consists of the following:*

(i) the constants $\emptyset$ and $\boldsymbol{\omega}$, to be interpreted as the empty set and the first infinite ordinal;

(ii) the constant $1_{\emptyset}$, to be interpreted as the inactive function;

(iii) simple variables $x, X, y, Y, \ldots$ ranging over sets;

(iv) for any constant $\hat{\mathbf{X}}$ referring to an individual set, composite symbols $f_{\hat{\mathbf{X}}}, g_{\hat{\mathbf{X}}}, \ldots$ with an occurrence of the constant $\hat{\mathbf{X}}$ as the subscript are simple variables ranging over functions on that set $\hat{\mathbf{X}}$;

(v) for any variable X ranging over sets, composite symbols $f_X, g_X, \ldots$ with an occurrence of the variable X as the subscript are composite variables ranging over functions on a set X;

(vi) simple variables $\alpha, \beta, \ldots$ ranging over all things (sets and functions);

(vii) the two binary predicates '$\in$' and '$=$', and the two ternary predicates '$(.) : (.) \twoheadrightarrow (.)$' and '$(.) : (.) \mapsto (.)$';

(viii) the logical connectives of first-order logic $\neg, \wedge, \vee, \Rightarrow, \Leftrightarrow$;

(ix) the universal and existential quantification symbols $\forall, \exists$;

(x) the brackets '(' and ')'.

■

Remark 4.2.2. To distinguish between the theory $\mathfrak{T}$ and its intended model, boldface symbols with a hat like $\hat{\mathbf{X}}$, $\hat{\boldsymbol{\alpha}}$, etc. will be used to denote constants in the vocabulary of the theory $\mathfrak{T}$, while underlined boldface symbols like $\underline{\mathbf{X}}$, $\underline{\boldsymbol{\alpha}}$, etc., will be used to denote individuals in the intended model of $\mathfrak{T}$. ■

Definition 4.2.3. *The* ***syntax*** *of the language $L_{\mathfrak{T}}$ is defined by the following clauses:*

(i) if t is a constant or a simple variable, then t is a term;

(ii) if t_1 and t_2 are terms, then $t_1 = t_2$ and $t_1 \in t_2$ are atomic formulas;

(iii) if t_1, t_2, and t_3 are terms, then $t_1 : t_2 \twoheadrightarrow t_3$ and $t_1 : t_2 \mapsto t_3$ are atomic formulas;

(iv) if Φ and Ψ are formulas, then $\neg\Phi$, $(\Phi \wedge \Psi)$, $(\Phi \vee \Psi)$, $(\Phi \Rightarrow \Psi)$, $(\Phi \Leftrightarrow \Psi)$ are formulas;

(v) if Ψ is a formula and t a simple variable ranging over sets, over all things, or over functions on a constant set, then $\forall t\Psi$ and $\exists t\Psi$ are formulas;

(vi) if X and $f_{\hat{\mathbf{X}}}$ are simple variables ranging respectively over sets and over functions on the set $\hat{\mathbf{X}}$, f_X a composite variable with an occurrence of X as the subscript, and Ψ a formula with an occurrence of a quantifier $\forall f_{\hat{\mathbf{X}}}$ or $\exists f_{\hat{\mathbf{X}}}$ but with no occurrence of X, then $\forall X[X\backslash\hat{\mathbf{X}}]\Psi$ and $\exists X[X\backslash\hat{\mathbf{X}}]\Psi$ are formulas.

■

Remark 4.2.4. Regarding clause (vi) of Def. 4.2.3, $[u\backslash t]\Psi$ is the formula obtained from Ψ by replacing t everywhere by u. This definition will be used throughout this paper. Note that if Ψ is a formula with an occurrence of the simple variable $f_{\hat{\mathbf{X}}}$, then $[X\backslash\hat{\mathbf{X}}]\Psi$ is a formula with an occurrence of the composite variable f_X. ■

Definition 4.2.5. *The language $L_{\mathfrak{T}}$ contains the following special language elements:*

(i) if t is a simple variable ranging over sets, over all things, or over functions on a constant set, then $\forall t$ and $\exists t$ are ***quantifiers with a simple variable****;*

(ii) if f_X is a composite variable, then $\forall f_X$ and $\exists f_X$ are a ***quantifiers with a composite variable****.*

A sequence like $\forall X \forall f_X$ can be called a ***double quantifier****.* ■

The scope of a quantifier is defined as usual: note that a quantifier with a composite variable can only occur in the scope of a quantifier with a simple variable. A free occurrence and a bounded occurrence of a simple variable is also defined as usual; these notions can be simply defined for formulas with a composite variable.

Definition 4.2.6. *Let f_X be a composite variable with an occurrence of the simple variable X; then*

(i) an occurrence of f_X in a formula Ψ is ***free*** *if that occurrence is neither in the scope of a quantifier with the composite variable f_X nor in the scope of a quantifier with the simple variable X;*

(ii) an occurrence of f_X in a formula Ψ is ***bounded*** *if that occurrence is in the scope of a quantifier with the composite variable f_X.*

A ***sentence*** *is a formula with no free variables—simple or composite. A formula is* ***open*** *in a variable if there is a free occurrence of that variable. A formula that is open in a composite variable f_X is also open in the simple variable X.* ■

Definition 4.2.7. *The* ***semantics*** *of any sentence without a quantifier with a composite variable is as usual. Furthermore,*

(i) a sentence $\forall X \Psi$ with an occurrence of a quantifier $\forall f_X$ or $\exists f_X$ with the composite variable f_X is valid in a model $\mathcal{M}$ if and only if for every assignment g that assigns an individual set $g(X) = \underline{\mathbf{X}}$ in $\mathcal{M}$ as a value to the variable X, the sentence $[\underline{\mathbf{X}} \backslash X]\Psi$ is valid in $\mathcal{M}$;

(ii) a sentence $\exists X \Psi$ with an occurrence of a quantifier $\forall f_X$ or $\exists f_X$ with the composite variable f_X is valid in a model $\mathcal{M}$ if and only if for at least one assignment g that assigns an individual set $g(X) = \underline{\mathbf{X}}$ in $\mathcal{M}$ as a value to the variable X, the sentence $[\underline{\mathbf{X}} \backslash X]\Psi$ is valid in $\mathcal{M}$;

The sentences $[\underline{\mathbf{X}} \backslash X]\Psi$ obtained in clauses (i) and (ii) are sentences without a quantifier with a composite variable, hence with usual semantics. ■

Standard set-theoretic axioms

We now proceed with the introduction of the 'standard' first-order axioms of $\mathfrak{T}$: first the set-theoretical axioms, then the function-theoretical axioms. Due to the simplicity of these axioms, comments are kept to a bare minimum. Thereafter, the language $L_{\mathfrak{T}}$ will be extended to enable the formulation of the nonstandard axiom.

Axiom 4.2.8 (Extensionality Axiom for Sets, EXT)**.** *Two sets X and Y are identical if they have the same things (sets or functions) as elements.*

$$\forall X \forall Y (X = Y \Leftrightarrow \forall \alpha(\alpha \in X \Leftrightarrow \alpha \in Y)) \tag{4.17}$$

Axiom 4.2.9. *For any set X, any function f_X, and any set Y, the function f_X is not identical to the set Y:*

$$\forall X \forall f_X \forall Y (f_X \neq Y) \tag{4.18}$$

Axiom 4.2.10. *A set X has no domain or codomain, nor does it map any thing to an image:*

$$\forall X \forall \alpha \forall \beta (X : \alpha \not\twoheadrightarrow \beta \wedge X : \alpha \not\mapsto \beta) \tag{4.19}$$

■

These latter two axioms establish that sets are different from functions on a set, and do not have the properties of functions on a set.

Axiom 4.2.11 (Empty Set Axiom, EMPTY)**.** *There exists a set X, designated by the constant $\emptyset$, that has no elements.*

$$\exists X (X = \emptyset \wedge \forall \alpha (\alpha \notin X)) \tag{4.20}$$

Axiom 4.2.12 (Axiom of Pairing, PAIR)**.** *For every thing α and every thing β there exists a set X that has precisely the things α and β as its elements.*

$$\forall \alpha \forall \beta \exists X \forall \gamma (\gamma \in X \Leftrightarrow \gamma = \alpha \vee \gamma = \beta) \tag{4.21}$$

■

Remark 4.2.13. Using set-builder notation, the empty set can be interpreted as the individual $\{\}$ in the intended model. Furthermore, given individual things $\underline{\boldsymbol{\alpha}}$ and $\underline{\boldsymbol{\beta}}$ in the universe of the intended model, the pair set of $\underline{\boldsymbol{\alpha}}$ and $\underline{\boldsymbol{\beta}}$ can then be identified with the individual $\{\underline{\boldsymbol{\alpha}}, \underline{\boldsymbol{\beta}}\}$. Note that this is a singleton if $\underline{\boldsymbol{\alpha}} = \underline{\boldsymbol{\beta}}$. ■

Definition 4.2.14 (Extension of vocabulary of $L_{\mathfrak{T}}$)**.**
If t is a term, then $(t)^+$ is a term, to be called "the singleton of t"—which may be written as t^+ if no confusion arises. In particular, if α is a variable ranging over all things and x a variable ranging over all sets, then α^+ is a variable ranging over all singletons and x^+ a variable ranging over all singletons of sets. We thus have

$$\forall\alpha\forall\beta(\beta = \alpha^+ \Leftrightarrow \exists X(\beta = X \wedge \forall\gamma(\gamma \in X \Leftrightarrow \gamma = \alpha))) \tag{4.22}$$

Likewise for x^+. ■

Notation 4.2.15. On account of Def. 4.2.14, the language $L_{\mathfrak{T}}$ contains the constants $\emptyset^+, \emptyset^{++}, \emptyset^{+++}, \ldots$ Therefore, we can introduce the (finite) **Zermelo ordinals** at this point as a notation for these singletons:

$$\begin{cases} 0 := \emptyset \\ 1 := \emptyset^+ \\ 2 := \emptyset^{++} \\ \vdots \end{cases} \tag{4.23}$$

According to the literature, the idea stems from unpublished work by Zermelo in 1916 (Levy, 1979). ■

Axiom 4.2.16 (Sum Set Axiom, SUM)**.** *For every set X there exists a set Y made up of the elements of the elements of X.*

$$\forall X\exists Y\forall\alpha(\alpha \in Y \Leftrightarrow \exists Z(Z \in X \wedge \alpha \in Z)) \tag{4.24}$$

■

Remark 4.2.17. Given an individual set $\underline{\mathbf{X}}$ in the universe of the intended model, the sum set of $\underline{\mathbf{X}}$ can be denoted by the symbol $\bigcup\underline{\mathbf{X}}$ and, using set-builder notation, be identified with the individual $\{\alpha \mid \exists Z \in \underline{\mathbf{X}}(\alpha \in Z)\}$. ■

Axiom 4.2.18 (Powerset Axiom, POW)**.** *For every set X there is a set Y made up of the subsets of X.*

$$\forall X \exists Y \forall \alpha(\alpha \in Y \Leftrightarrow \exists Z(Z \subset X \wedge \alpha = Z)) \tag{4.25}$$

■

Remark 4.2.19. Given an individual set $\underline{\mathbf{X}}$ in the universe of the intended model, the powerset of $\underline{\mathbf{X}}$ can be denoted by the symbol $\mathcal{P}(\underline{\mathbf{X}})$ and, using set-builder notation, be identified with the individual $\{x \mid x \subset \underline{\mathbf{X}}\}$. ■

Axiom 4.2.20 (Infinite Ordinal Axiom, INF)**.** *The infinite ordinal $\boldsymbol{\omega}$ is the set of all finite Zermelo ordinals.*

$$0 \in \boldsymbol{\omega} \wedge \forall \alpha(\alpha \in \boldsymbol{\omega} \Rightarrow \alpha^+ \in \boldsymbol{\omega}) \wedge \forall \beta \in \boldsymbol{\omega}(\nexists \gamma \in \boldsymbol{\omega}(\beta = \gamma^+) \Leftrightarrow \beta = \emptyset)) \tag{4.26}$$

■

Remark 4.2.21. The set $\boldsymbol{\omega}$ in INF is uniquely determined. In the intended model, the set $\boldsymbol{\omega}$ can be denoted by the symbol $\mathbb{N}$ and, using set-builder notation, be identified with the individual $\mathbb{N} := \{\ \{\}, \{\{\}\}, \{\{\{\}\}\}, \ldots\}$. ■

Axiom 4.2.22 (Axiom of Regularity, REG)**.** *Every nonempty set X contains an element α that has no elements in common with X.*

$$\forall X \neq \emptyset \exists \alpha(\alpha \in X \wedge \forall \beta(\beta \in \alpha \Rightarrow \beta \notin X)) \tag{4.27}$$

■

Definition 4.2.23. *For any things α and β, the* ***two-tuple*** *$\langle \alpha, \beta \rangle$ is the pair set of α and the pair set of α and β; using the iota-operator we get*

$$\langle \alpha, \beta \rangle := \imath x(\forall \gamma(\gamma \in x \Leftrightarrow \gamma = \alpha \vee \exists Z(\gamma = Z \wedge \forall \eta(\eta \in Z \Leftrightarrow \eta = \alpha \vee \eta = \beta))) \tag{4.28}$$

■

A simple corollary of Def. 4.2.23 is that for any things α and β, the two-tuple $\langle \alpha, \beta \rangle$ always exists. There is, thus, no danger of nonsensical terms involved in the use of the iota-operator in Def. 4.2.23.

Remark 4.2.24. Given individual things $\underline{\boldsymbol{\alpha}}$ and $\underline{\boldsymbol{\beta}}$ in the universe of the intended model, the two-tuple $\langle\underline{\boldsymbol{\alpha}},\underline{\boldsymbol{\beta}}\rangle$ can, using set-builder notation, be identified with the individual $\{\underline{\boldsymbol{\alpha}},\{\underline{\boldsymbol{\alpha}},\underline{\boldsymbol{\beta}}\}\}$. ■

Standard function-theoretic axioms

Axiom 4.2.25. *A function f_X on a set X has no elements:*

$$\forall X \forall f_X \forall \alpha(\alpha \notin f_X) \tag{4.29}$$

■

Remark 4.2.26. One might think that Ax. 4.2.25 destroys the uniqueness of the empty set. But that is not true. It is true that a function on a set X and the empty set share the property that they have no elements, but the empty set is the only **set** that has this property: Ax. 4.2.9 guarantees, namely, that a function on a set X is not a set! ■

Axiom 4.2.27 (General Function-Theoretical Axiom, GEN-F)**.** *For any nonempty set X, any function f_X has a set Y as domain and a set Z as codomain, and maps every element α in Y to a unique image β:*

$$\forall X \forall f_X(X \neq \emptyset \Rightarrow \exists Y \exists Z(f_X : Y \twoheadrightarrow Z \wedge \forall \alpha \in Y \exists! \beta(f_X : \alpha \mapsto \beta))) \tag{4.30}$$

Axiom 4.2.28. *For any set X, any function f_X has no other domain than the set X:*

$$\forall X \forall f_X \forall \alpha(\alpha \neq X \Rightarrow \forall \xi(f_X : \alpha \not\twoheadrightarrow \xi)) \tag{4.31}$$

Axiom 4.2.29. *For any set X, any function f_X does not take a thing outside X as argument:*

$$\forall X \forall f_X \forall \alpha \notin X \forall \beta(f_X : \alpha \not\mapsto \beta) \tag{4.32}$$

■

Remark 4.2.30. Ax. 4.2.27 dictates that for each $\alpha \in X$, precisely one expression $f_X : \alpha \mapsto \beta$ is true. This doesn't a priori exclude that such an expression can also be true for another thing α not in X. But by Ax. 4.2.29 this is excluded. ■

Axiom 4.2.31. *For any nonempty set X and any function f_X, the image set is the only codomain:*

$$\forall X \forall f_X (X \neq \emptyset \Rightarrow \tag{4.33}$$
$$\forall \beta (f_X : X \twoheadrightarrow \beta \Rightarrow \exists Z(\beta = Z \wedge \forall \gamma (\gamma \in Z \Leftrightarrow \exists \eta \in X(f_X : \eta \mapsto \gamma)))))$$

(This is the justification for the use of the two-headed arrow '$\twoheadrightarrow$', commonly used for surjections.) ■

Remark 4.2.32. Note that these first function-theoretical axioms already provide a tool to construct a set: if we can construct a new function f_X on a set X from existing functions (an axiom will be given further below), then these axioms guarantee the existence of a unique codomain made up of all the images of the elements of X under f_X. ■

Remark 4.2.33. Given an individual set $\underline{\mathbf{X}}$ and an individual function $\underline{\mathbf{f}_{\mathbf{X}}}$ in the universe of the intended model, this unique codomain can be denoted by a symbol $\underline{\mathbf{f}_{\mathbf{X}}}[\underline{\mathbf{X}}]$ or $\text{cod}(\underline{\mathbf{f}_{\mathbf{X}}})$, and, using set-builder notation, be identified with the individual $\{\beta \mid \exists \alpha \in \underline{\mathbf{X}}(\underline{\mathbf{f}_{\mathbf{X}}} : \alpha \mapsto \beta)\}$ in the universe of the intended model. Furthermore, given a thing $\underline{\boldsymbol{\alpha}}$ in $\underline{\mathbf{X}}$, its unique image under $\underline{\mathbf{f}_{\mathbf{X}}}$ can be denoted by the symbol $\underline{\mathbf{f}_{\mathbf{X}}}(\underline{\boldsymbol{\alpha}})$. ■

Notation 4.2.34. At this point we can introduce expressions $f_X : X \to Y$, to be read as "the function f-on-X is a function from the set X to the set Y", by the postulate of meaning

$$f_X : X \to Y \Leftrightarrow \exists Z(f_X : X \twoheadrightarrow Z \wedge Z \subset Y) \tag{4.34}$$

This provides a connection to existing mathematical practices. ■

Axiom 4.2.35 (Inverse Image Set Axiom, INV)**.** *For any nonempty set X and any function f_X with domain X and any co-domain Y, there is for any thing α a set $Z \subset X$ that contains precisely the elements of X that are mapped to α by f_X:*

$$\forall X \neq \emptyset \forall f_X \forall Y (f_X : X \twoheadrightarrow Y \Rightarrow \forall \beta \exists Z \forall \alpha (\alpha \in Z \Leftrightarrow \alpha \in X \wedge f_X : \alpha \mapsto \beta)) \tag{4.35}$$

■

Remark 4.2.36. Note that INV, in addition to GEN-F, also provides a tool to construct a set: if we have constructed a new function f_X with domain X from existing functions, then with this axiom guarantees that the inverse image set exists of any thing β in the codomain of f_X. ■

Remark 4.2.37. Given an individual set $\underline{\mathbf{X}}$, an individual function $\underline{\mathbf{f}}_{\underline{\mathbf{X}}}$, and an individual thing $\underline{\boldsymbol{\beta}}$ in the universe of the intended model, the unique inverse image set can be denoted by the symbol $\underline{\mathbf{f}}_{\underline{\mathbf{X}}}^{-1}(\underline{\boldsymbol{\beta}})$ and can, using set-builder notation, be identified with the individual $\{\alpha \mid \alpha \in \underline{\mathbf{X}} \wedge \underline{\mathbf{f}}_{\underline{\mathbf{X}}} : \alpha \mapsto \underline{\boldsymbol{\beta}}\}$ in the universe of the intended model. ■

Axiom 4.2.38 (Extensionality Axiom for Functions, EXT-F)**.** *For any set X and any function f_X, and for any set Y and any function g_Y, the function f_X and the function g_Y are identical if and only if their domains are identical and their images are identical for every argument:*

$$\forall X \forall f_X \forall Y \forall g_Y (f_X = g_Y \Leftrightarrow X = Y \wedge \forall \alpha \forall \beta (f_X : \alpha \mapsto \beta \Leftrightarrow g_Y : \alpha \mapsto \beta)) \tag{4.36}$$

■

Axiom 4.2.39 (Inactive Function Axiom, IN-F)**.** *There exists a function $f_\emptyset$, denoted by the constant $1_\emptyset$, which has the empty set as domain and codomain, and which doesn't map any argument to any image:*

$$\exists f_\emptyset (f_\emptyset = 1_\emptyset \wedge f_\emptyset : \emptyset \twoheadrightarrow \emptyset \wedge \forall \alpha \forall \beta (f_\emptyset : \alpha \not\mapsto \beta)) \tag{4.37}$$

■

Note that there can be no other functions on the empty set than the inactive function $1_\emptyset$, since the image set is always empty: the expression $f_\emptyset : \emptyset \twoheadrightarrow A$ cannot be true for any nonempty set A.

Axiom 4.2.40 (Ur-Function Axiom, UFA)**.** *For any things α and β there exists an ur-function f_{α^+} with domain α^+ and codomain β^+ that maps α to β:*

$$\forall \alpha \forall \beta \exists f_{\alpha^+} (f_{\alpha^+} : \alpha^+ \twoheadrightarrow \beta^+ \wedge f_{\alpha^+} : \alpha \mapsto \beta) \tag{4.38}$$

■

Remark 4.2.41. Given individual things $\underline{\boldsymbol{\alpha}}$ and $\underline{\boldsymbol{\beta}}$ in the universe of the intended model, the ur-function on $\{\underline{\boldsymbol{\alpha}}\}$ that maps $\underline{\boldsymbol{\alpha}}$ to $\underline{\boldsymbol{\beta}}$ can, using set-builder notation, be identified with the individual $\{\langle\underline{\boldsymbol{\alpha}}, \underline{\boldsymbol{\beta}}\rangle\}_{\{\underline{\boldsymbol{\alpha}}\}}$ in the universe of the intended model. Note that the graph of the ur-function is guaranteed to exist. ∎

Axiom 4.2.42 (Axiom of Regularity for Functions, REG-F)**.** *For any set X and any function f_X with any codomain Y, f_X does not take itself as argument or has itself as image:*

$$\forall X \forall f_X \forall Y (f_X : X \twoheadrightarrow Y \Rightarrow \forall \alpha (f_X : f_X \not\mapsto \alpha \wedge f_X : \alpha \not\mapsto f_X)) \tag{4.39}$$

∎

Remark 4.2.43. As to the first part, Wittgenstein already mentioned that a function cannot have itself as argument Wittgenstein (1922). The second part is to exclude the existence of pathological 'Siamese twin functions', e.g. the ur-functions f_X and h_Y given, using set-builder notation, by

$$f_X : \{h_Y\} \twoheadrightarrow \{f_X\}\ ,\ f_X : h_Y \mapsto f_X \tag{4.40}$$

$$h_Y : \{f_X\} \twoheadrightarrow \{h_Y\}\ ,\ h_Y : f_X \mapsto h_Y \tag{4.41}$$

We thus have $\mathrm{dom}(f_X) = X = \{h_Y\}$ and $\mathrm{dom}(h_Y) = Y = \{f_X\}$; if we substitute $\{h_Y\}$ for X and $\{f_X\}$ for Y, then we get 'infinite towers' as

$$X = \{h_Y\} = \{h_{\{f_X\}}\} = \{h_{\{f_{\{h_Y\}}\}}\} = \ldots \tag{4.42}$$

$$Y = \{f_X\} = \{f_{\{h_Y\}}\} = \{f_{\{h_{\{f_X\}}\}}\} = \ldots \tag{4.43}$$

These functions may not be constructible from the axioms, but they could exist a priori in the category of sets and functions: to avoid that we practice mathematical eugenics and prevent them from occurring with REG-F. See Fig. 4.1 for an illustration with a Venn diagram. The name 'Siamese twin functions' is derived from the name 'Siamese twin sets' for sets A and B satisfying $A \in B \wedge B \in A$, which can be found in (Muller, 2001). ∎

Herewith the standard part of $\mathfrak{T}$ has been introduced. Below we proceed with the nonstandard part, which requires an extension of both the vocabulary of the language $L_{\mathfrak{T}}$ of $\mathfrak{T}$ and of the definition of the syntax.

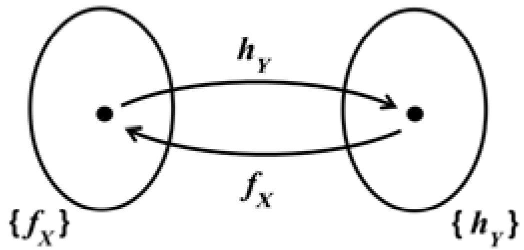


Figure 4.1: Venn diagram of the Siamese twin functions f_X and h_Y. The left oval together with the black point inside represents the singleton $\{f_X\}$; the right oval together with the black point inside represents the singleton $\{h_Y\}$. The upper arrow represents the mapping of f_X to h_Y by h_Y, the lower arrow the mapping of h_Y to f_X by f_X.

Nonstandard extension of the formal language

Definition 4.2.44. *The **vocabulary** of $L_{\mathfrak{T}}$ as given by Def. 4.2.1 is extended*

(i) with symbols '$\imath$', the iota-operator, *and '$\bigwedge$', the* conjunctor*;*

(ii) for any constant $\hat{\mathbf{X}}$ denoting a set, with enough composite symbols $\hat{\mathbf{f}}_{\alpha^+}$, $\hat{\mathbf{h}}_{\beta^+}$, ... such that each of these is a simple variable that ranges over a family of ur-functions indexed in $\hat{\mathbf{X}}$.

■

Definition 4.2.45. *The **syntax** of $L_{\mathfrak{T}}$ as given by Def. 4.2.3 is extended with the following clauses:*

(i) if $\hat{\mathbf{f}}_{\alpha^+}$ is a variable as in clause (ii) of Def. 4.2.44, then $\hat{\mathbf{f}}_{\alpha^+}$ is a term;

(ii) if t is a term and u_{t^+} is a composite term with an occurrence of t, and β is a variable ranging over all things, then $\imath\beta(u_{t^+} : t \mapsto \beta)$ is a iota-term denoting the image of t under the ur-function u_{t^+};

(iii) if $\hat{\mathbf{X}}$ is a constant designating a set, α a simple variable ranging over all things, and $\Psi(\alpha)$ an atomic formula of the type $t : t' \mapsto t''$ that is open in α, then $\bigwedge_{\alpha\in\hat{\mathbf{X}}} \Psi(\alpha)$ is a formula;

(iv) if Φ is a formula with a subformula $\bigwedge_{\alpha\in\hat{\mathbf{X}}} \Psi(\alpha)$ as in (iii), and f_{α^+} a composite variable ranging over ur-functions on the singleton of α, then $(\forall f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}\Phi$ and $(\exists f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}\Phi$ are formulas;

(v) *if X is a simple variable ranging over sets, and Υ a formula with no occurrence of X but with a subformula $(\forall f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}\Phi$ as in (iv), then $\forall X[X\backslash\hat{\mathbf{X}}]\Upsilon$ and $\exists X[X\backslash\hat{\mathbf{X}}]\Upsilon$ are formulas with a subformula $(\forall f_{\alpha^+})_{\alpha\in X}[X\backslash\hat{\mathbf{X}}]\Phi$.*

(vi) *if X is a simple variable ranging over sets, and Υ a formula with no occurrence of X but with a subformula $(\exists f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}\Phi$ as in (iv), then $\forall X[X\backslash\hat{\mathbf{X}}]\Upsilon$ and $\exists X[X\backslash\hat{\mathbf{X}}]\Upsilon$ are formulas with a subformula $(\exists f_{\alpha^+})_{\alpha\in X}[X\backslash\hat{\mathbf{X}}]\Phi$.*

■

Definition 4.2.46. *The following special language elements are added:*

(i) *if $\hat{\mathbf{X}}$ is a constant designating a set, X a simple variable ranging over sets, α a simple variable ranging over all things, f_{α^+} a composite variable ranging over ur-functions on α^+, then*

- $(\forall f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}$ *is a* ***multiple universal quantifier;***
- $(\exists f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}$ *is a* ***multiple existential quantifier;***
- $(\forall f_{\alpha^+})_{\alpha\in X}$ *in the scope of a quantifier $\forall X$ is a* ***universally generalized multiple universal quantifier;***
- $(\forall f_{\alpha^+})_{\alpha\in X}$ *in the scope of a quantifier $\exists X$ is an* ***existentially generalized multiple universal quantifier;***
- $(\exists f_{\alpha^+})_{\alpha\in X}$ *in the scope of a quantifier $\forall X$ is a* ***universally generalized multiple existential quantifier;***
- $(\exists f_{\alpha^+})_{\alpha\in X}$ *in the scope of a quantifier $\exists X$ is an* ***existentially generalized multiple existential quantifier;***

(ii) *if $\hat{\mathbf{X}}$ is a constant designating a set, X a simple variable ranging over sets, and α a simple variable ranging over all things, then*

- $\bigwedge_{\alpha\in\hat{\mathbf{X}}}$ *is a* ***conjunctive operator with constant range****, and*
- $\bigwedge_{\alpha\in X}$ *a* ***conjunctive operator with variable range****.*

■

Concerning the language elements in clause (i), if $\reflectbox{$\mathrm{K}$}$ and $\reflectbox{$\mathrm{K}$}'$ are existential or universal quantification symbols, then we can generally say that $(\reflectbox{$\mathrm{K}$} f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}$ is a **multiple quantifier**, and that $(\reflectbox{$\mathrm{K}$} f_{\alpha^+})_{\alpha\in X}$ in the scope of a quantifier $\reflectbox{$\mathrm{K}$}'X$ is a **generalized multiple quantifier**.

Definition 4.2.47. *If $\hat{\mathbf{X}}$ is a constant designating a set and $\bigwedge_{\alpha\in\hat{\mathbf{X}}}\Psi$ is a subformula of a formula Φ, then Ψ is the* ***scope of the conjunctive operator****; furthermore,*

(i) if there is an occurrence of a variable α and/or $\hat{\mathbf{f}}_{\alpha^+}$ in the scope of the conjunctive operator, then a formula $\bigwedge_{\alpha\in\hat{\mathbf{X}}}\Psi$ has a ***semantic occurrence*** *of each of the constants $\hat{\boldsymbol{\alpha}}$ over which the variable α ranges, and/or of each of the constant ur-functions $\hat{\mathbf{u}}_{\hat{\boldsymbol{\alpha}}^+}$ over which the variable $\hat{\mathbf{f}}_{\alpha^+}$ ranges—a subformula $\bigwedge_{\alpha\in\hat{\mathbf{X}}}\Psi$ has thus to be viewed as the conjunction of all the formulas $[\hat{\boldsymbol{\alpha}}\backslash\alpha][\hat{\mathbf{u}}_{\hat{\boldsymbol{\alpha}}^+}\backslash\hat{\mathbf{f}}_{\alpha^+}]\Psi$ (there is one such formula for each $\hat{\boldsymbol{\alpha}}\in\hat{\mathbf{X}}$).*

(ii) if there is an occurrence of a composite variable f_{α^+} in the scope of the conjunctive operator, then the subformula $\bigwedge_{\alpha\in\hat{\mathbf{X}}}\Psi(f_{\alpha^+})$ has a ***free semantic occurrence*** *of each of the simple variables $f_{\hat{\boldsymbol{\alpha}}^+}$ ranging over ur-functions on the singleton of $\hat{\boldsymbol{\alpha}}$ with $\hat{\boldsymbol{\alpha}}\in\hat{\mathbf{X}}$—the formula $\bigwedge_{\alpha\in\hat{\mathbf{X}}}\Psi(f_{\alpha^+})$ has thus to be viewed as the conjunction of all the formulas $[\hat{\boldsymbol{\alpha}}\backslash\alpha][f_{\hat{\boldsymbol{\alpha}}^+}\backslash f_{\alpha^+}]\Psi$.*

■

Definition 4.2.48. *If $\hat{\mathbf{X}}$ is a constant designating a set and if $(\forall f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}\Psi$ is a subformula of a formula Φ, then Ψ is the* ***scope of the multiple quantifier****; likewise for the scope of the generalized multiple quantifiers of Def. 4.2.46. If a formula Ψ has a free semantic occurrence of each of the simple variables $f_{\hat{\boldsymbol{\alpha}}^+}$ with a constant $\hat{\boldsymbol{\alpha}}\in\hat{\mathbf{X}}$, then a formula $(\forall f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}\Psi$ has a* ***bounded semantic occurrence*** *of each of the simple variables $f_{\hat{\boldsymbol{\alpha}}^+}$ with a constant $\hat{\boldsymbol{\alpha}}\in\hat{\mathbf{X}}$. A nonstandard formula Ψ without free occurrences of variables is a* ***sentence****. If X is a simple variable ranging over sets and Ψ is a sentence with an occurrence of a multiple quantifier $(\forall f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}$ and with no occurrence of X, then $\forall X[X\backslash\hat{\mathbf{X}}]\Psi$ and $\exists X[X\backslash\hat{\mathbf{X}}]\Psi$ are sentences with an occurrence of a generalized multiple quantifier $(\forall f_{\alpha^+})_{\alpha\in X}$.* ■

Remark 4.2.49. For the iota-terms of Def. 4.2.45 we have

$$\forall\alpha\forall f_{\alpha^+}\forall\gamma(\gamma=\imath\beta(f_{\alpha^+}:\alpha\mapsto\beta)\Leftrightarrow f_{\alpha^+}:\alpha\mapsto\gamma) \tag{4.44}$$

Note that upon assigning constant values to α and f_{α^+}, the iota-term $\imath\beta(f_{\alpha^+}:\alpha\mapsto\beta)$ always refers to an existing, unique thing: there is thus no danger of nonsensical terms involved in this use of the iota-operator. ■

Nonstandard axiom and inference rules

Axiom 4.2.50 (Sum Function Axiom, SUM-F)**.** *For any nonempty set X and for any family of ur-functions f_{α^+} indexed in X, there is a sum function F_X with a codomain Y such that the conjunction of all mappings by F_X of α to its image under the ur-function f_{α^+} holds for α ranging over X:*

$$\forall X \neq \emptyset (\forall f_{\alpha^+})_{\alpha \in X} \exists F_X \exists Y \left(F_X : X \twoheadrightarrow Y \wedge \bigwedge\nolimits_{\alpha \in X} F_X : \alpha \mapsto \imath\beta(f_{\alpha^+} : \alpha \mapsto \beta) \right) \tag{4.45}$$

■

With SUM-F, all non-logical axioms of the present nonstandard theory have been introduced. But still, rules of inference must be given to derive meaningful theorems from SUM-F. So, the rules of inference that follow have to be seen as part of the *logic*.

Inference Rule 4.2.51 (Nonstandard Universal Elimination)**.**

$$\forall X \Psi \left((\forall\!\!\!\!\forall f_{\alpha^+})_{\alpha \in X}, \bigwedge\nolimits_{\alpha \in X} \right) \vdash [\hat{\mathbf{X}} \backslash X]\Psi \qquad \text{for any constant } \hat{\mathbf{X}} \tag{4.46}$$

where $\Psi\left((\forall\!\!\!\!\forall f_{\alpha^+})_{\alpha \in X}, \bigwedge_{\alpha \in X}\right)$ is a formula with an occurrence of a generalized multiple quantifier and of a conjunctive operator with variable range, and where $[\hat{\mathbf{X}} \backslash X]\Psi$ is a formula with an occurrence of a multiple quantifier $(\forall\!\!\!\!\forall f_{\alpha^+})_{\alpha \in \hat{\mathbf{X}}}$ and of a conjunctive operator $\bigwedge_{\alpha \in \hat{\mathbf{X}}}$ with constant range. ■

Thus speaking, from SUM-F we can deduce a formula

$$(\forall f_{\alpha^+})_{\alpha \in \hat{\mathbf{X}}} \exists F_{\hat{\mathbf{X}}} \exists Y \left(F_{\hat{\mathbf{X}}} : \hat{\mathbf{X}} \twoheadrightarrow Y \wedge \bigwedge\nolimits_{\alpha \in \hat{\mathbf{X}}} F_{\hat{\mathbf{X}}} : \alpha \mapsto \imath\beta(f_{\alpha^+} : \alpha \mapsto \beta) \right) \tag{4.47}$$

for any constant $\hat{\mathbf{X}}$ designating a set.

Inference Rule 4.2.52 (Multiple Universal Elimination)**.**

$$(\forall f_{\alpha^+})_{\alpha \in \hat{\mathbf{X}}} \Phi(f_{\alpha^+}) \vdash [\hat{\mathbf{f}}_{\alpha^+} \backslash f_{\alpha^+}]\Phi \tag{4.48}$$

where $\Phi(f_{\alpha^+})$ is a formula with an occurrence of the same composite variable f_{α^+} that also occurs in the preceding multiple quantifier $(\forall f_{\alpha^+})_{\alpha \in \hat{\mathbf{X}}}$, and where $\hat{\mathbf{f}}_{\alpha^+}$ is a variable as meant in clause (ii) of Def. 4.2.44. ■

Thus speaking, from a sentence (4.47), which is an instance of SUM-F derived by inference rule 4.2.51, we can derive a formula

$$\exists F_{\hat{\mathbf{X}}} \exists Y \left(F_{\hat{\mathbf{X}}} : \hat{\mathbf{X}} \twoheadrightarrow Y \wedge \bigwedge_{\alpha \in \hat{\mathbf{X}}} F_{\hat{\mathbf{X}}} : \alpha \mapsto \imath\beta(\hat{\mathbf{f}}_{\alpha^+} : \alpha \mapsto \beta) \right) \tag{4.49}$$

for each variable $\hat{\mathbf{f}}_{\alpha^+}$ ranging over a family of ur-functions indexed in $\hat{\mathbf{X}}$. Note that the range of such a variable $\hat{\mathbf{f}}_{\alpha^+}$ is constructed by assigning to each of the simple variables $f_{\hat{\boldsymbol{\alpha}}^+}$ semantically occurring in formula (4.47) a constant value $\hat{\mathbf{u}}_{\hat{\boldsymbol{\alpha}}^+}$.

Inference Rule 4.2.53 (Nonstandard Rule-C).

$$\exists t \Phi \vdash [\hat{\mathbf{t}} \backslash t]\Phi \tag{4.50}$$

where t is a simple variable x ranging over sets or a simple variable $f_{\hat{\mathbf{X}}}$ ranging over functions on a constant set, and where $\hat{\mathbf{t}}$ is a constant in the range of t that does not occur in Φ but for which $[\hat{\mathbf{t}} \backslash t]\Phi$ holds. If Φ has an occurrence of a generalized multiple quantifier $(\mathcal{Y} f_{\alpha^+})_{\alpha \in t}$, then $[\hat{\mathbf{t}} \backslash t]\Phi$ has an occurrence of a multiple quantifier $(\mathcal{Y} f_{\alpha^+})_{\alpha \in \hat{\mathbf{t}}}$; if Φ has an occurrence of a conjunctive operator $\bigwedge_{\alpha \in t}$ with variable range, then $[\hat{\mathbf{t}} \backslash t]\Phi$ has an occurrence of a conjunctive operator $\bigwedge_{\alpha \in \hat{\mathbf{t}}}$ with constant range. ■

Thus speaking, from SUM-F we can deduce a formula

$$\exists Y (\hat{\mathbf{F}}_{\hat{\mathbf{X}}} : \hat{\mathbf{X}} \twoheadrightarrow Y) \wedge \bigwedge_{\alpha \in \hat{\mathbf{X}}} \hat{\mathbf{F}}_{\hat{\mathbf{X}}} : \alpha \mapsto \imath\beta(\hat{\mathbf{f}}_{\alpha^+} : \alpha \mapsto \beta) \tag{4.51}$$

which is a conjunction of a standard first-order formula and a nonstandard formula with an occurrence of the new constant $\hat{\mathbf{F}}_{\hat{\mathbf{X}}}$, designating the sum function on $\hat{\mathbf{X}}$, in the scope of a conjunctive operator. Of course, this conjunction $\Psi \wedge \Phi$ is true if and only if both its members are true. This requires one more inference rule.

Inference Rule 4.2.54 (Conjunctive Operator Elimination).

$$\bigwedge_{\alpha \in \hat{\mathbf{X}}} \Psi(\alpha) \vdash [\hat{\boldsymbol{\alpha}} \backslash \alpha]\Psi(\alpha) \tag{4.52}$$

where $\Psi(\alpha)$ is a formula of the type $t : t' \mapsto t''$ that is open in α, and $\hat{\boldsymbol{\alpha}}$ any constant designating an element of $\hat{\mathbf{X}}$. ■

Thus speaking, from the right member of the conjunction (4.51) we can derive an entire scheme, consisting of one standard first-order formula

$$\hat{\mathbf{F}}_{\hat{\mathbf{X}}} : \hat{\boldsymbol{\alpha}} \mapsto \imath\beta(\hat{\mathbf{u}}_{\hat{\boldsymbol{\alpha}}^+} : \hat{\boldsymbol{\alpha}} \mapsto \beta) \tag{4.53}$$

for each constant $\hat{\mathbf{u}}_{\hat{\boldsymbol{\alpha}}^+}$. It has thus to be taken that an infinitary conjunction $\bigwedge_{\alpha\in\hat{\mathbf{X}}} \hat{\mathbf{F}}_{\hat{\mathbf{X}}} : \alpha \mapsto \imath\beta(\hat{\mathbf{f}}_{\alpha^+} : \alpha \mapsto \beta)$ is true if and only if the sentences (4.53) derived by rule 4.2.54 are true for each constant $\hat{\mathbf{u}}_{\hat{\boldsymbol{\alpha}}^+}$ semantically occurring in Eq. (4.51).

Remark 4.2.55. Given an individual set $\underline{\mathbf{X}}$ and a variable $\underline{\mathbf{f}}_{\alpha^+}$ that ranges over a family of ur-functions indexed in $\underline{\mathbf{X}}$ in the universe of the intended model, the unique sum function $\underline{\mathbf{F}}_{\underline{\mathbf{X}}}$ for which

$$\bigwedge\nolimits_{\alpha\in\underline{\mathbf{X}}} \underline{\mathbf{F}}_{\underline{\mathbf{X}}} : \alpha \mapsto \imath\beta(\underline{\mathbf{f}}_{\alpha^+} : \alpha \mapsto \beta) \tag{4.54}$$

can, using set-builder notation, be identified with the individual

$$\underline{\mathbf{F}}_{\underline{\mathbf{X}}} = \{\langle\alpha,\beta\rangle \mid \alpha \in \underline{\mathbf{X}} \wedge \beta = \underline{\mathbf{f}}_{\alpha^+}(\alpha)\}_{\underline{\mathbf{X}}} \tag{4.55}$$

in the universe of the intended model. The graph of $\underline{\mathbf{F}}_{\underline{\mathbf{X}}}$, i.e. the set $\{\langle\alpha,\beta\rangle \mid \alpha \in \underline{\mathbf{X}} \wedge \beta = \underline{\mathbf{f}}_{\alpha}(\alpha)\}$ is certain to exist, see Th. 4.3.1 (next section). So constructing a sum function is a means to constructing a set. ■

Example 4.2.56. Consider the infinite ordinal $\boldsymbol{\omega}$ from Ax. 4.2.20: its elements are the finite ordinals 0, 1, 2, ... Applying Nonstandard Universal Elimination, we thus deduce from SUM-F that

$$(\forall f_{\alpha^+})_{\alpha\in\boldsymbol{\omega}} \exists F_{\boldsymbol{\omega}} \exists Y \left(F_{\boldsymbol{\omega}} : \boldsymbol{\omega} \twoheadrightarrow Y \wedge \bigwedge\nolimits_{\alpha\in\boldsymbol{\omega}} F_{\mathbb{B}} : \alpha \mapsto \imath\beta(f_{\{\alpha\}} : \alpha \mapsto \beta)\right) \tag{4.56}$$

On account of the ur-function axiom 4.2.40 we have

$$\forall x \in \boldsymbol{\omega} \exists f_{x^+}(f_{x^+} : x \mapsto x) \tag{4.57}$$

That is, for any finite ordinal x there is an ur-function on the singleton of x that maps x to itself. Let the variable $\hat{\mathbf{f}}^1_{\alpha^+}$ range over these identity ur-functions; applying Multiple Universal Elimination to the sentence (4.56) then yields a sentence

$$\exists F_{\boldsymbol{\omega}} \exists Y \left(F_{\boldsymbol{\omega}} : \boldsymbol{\omega} \twoheadrightarrow Y \wedge \bigwedge\nolimits_{\alpha \in \boldsymbol{\omega}} F_{\boldsymbol{\omega}} : \alpha \mapsto \imath\beta(\hat{\mathbf{f}}^1_{\alpha+} : \alpha \mapsto \beta) \right) \tag{4.58}$$

Introducing the new constant $1_{\boldsymbol{\omega}}$ by applying Rule-C to the sentence (4.58) and substituting $\imath\beta(\hat{\mathbf{f}}^1_{\alpha+} : \alpha \mapsto \beta) = \alpha$ then yields the conjunction

$$1_{\boldsymbol{\omega}} : \boldsymbol{\omega} \twoheadrightarrow \boldsymbol{\omega} \wedge \bigwedge\nolimits_{\alpha \in \boldsymbol{\omega}} 1_{\boldsymbol{\omega}} : \alpha \mapsto \alpha \tag{4.59}$$

By applying Conjunctive Operator Elimination to the right member of this conjunction (4.59), we obtain the countable scheme

$$\begin{cases} 1_{\boldsymbol{\omega}} : 0 \mapsto 0 \\ 1_{\boldsymbol{\omega}} : 1 \mapsto 1 \\ 1_{\boldsymbol{\omega}} : 2 \mapsto 2 \\ \quad \vdots \end{cases} \tag{4.60}$$

This example demonstrates, strictly within the language of $\mathfrak{T}$, how SUM-F and the inference rules can be used to construct the identity function on $\boldsymbol{\omega}$ from a family of ur-functions indexed in $\boldsymbol{\omega}$. ■

Summarizing, it has thus to be taken

(i) that SUM-F is a typographically finite sentence;

(ii) that an instance (4.47) of SUM-F, deduced by applying Nonstandard Universal Elimination, is a typographically finite sentence;

(iii) that a formula (4.49), deduced from an instance of SUM-F by applying Multiple Universal Elimination, is a typographically finite sentence;

(iv) that a conjunction (4.51), deduced by applying Rule-C to a sentence (4.49), is a typographically finite sentence.[50]

This concludes the axiomatic introduction of the nonstandard theory $\mathfrak{T}$. Since we are primarily interested in the theorems that can be derived from the axioms of $\mathfrak{T}$, no rules have been given for the introduction of (multiple) quantifiers or conjunctive operators. Below such rules are given for the sake of completeness, but these will not be discussed.

Inference Rule 4.2.57 (Conjunctive Operator Introduction).

$$\{[I(\alpha)\backslash\alpha]\Psi(\alpha)\}_{I(\alpha)\in\hat{\mathbf{X}}} \vdash \bigwedge\nolimits_{\alpha\in\hat{\mathbf{X}}}\Psi(\alpha) \tag{4.61}$$

where $\Psi(\alpha)$ is an atomic formula of the type $t : t' \mapsto t''$ that is open in α, and $\{[I(\alpha)\backslash\alpha]\Psi(\alpha)\}_{I(\alpha)\in\hat{\mathbf{X}}}$ is a possibly infinite collection of formulas, each of which is obtained by interpreting the variable α as a constant $I(\alpha) \in \hat{\mathbf{X}}$ and replacing α in $\Psi(\alpha)$ everywhere by $I(\alpha)$.[51] ■

Inference Rule 4.2.58 (Multiple Universal Introduction).

$$\Phi\left(\bigwedge\nolimits_{\alpha\in\hat{\mathbf{X}}}\Psi(\hat{\mathbf{f}}_{\alpha^+})\right) \vdash (\forall f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}[f_{\alpha^+}\backslash\hat{\mathbf{f}}_{\alpha^+}]\Phi \tag{4.62}$$

where $\Phi\left(\bigwedge_{\alpha\in\hat{\mathbf{X}}}\Psi(\hat{\mathbf{f}}_{\alpha^+})\right)$ denotes a formula Φ with a subformula $\bigwedge_{\alpha\in\hat{\mathbf{X}}}\Psi(\hat{\mathbf{f}}_{\alpha^+})$ (implying that Ψ is an atomic formula of the type $t : t' \mapsto t''$), and where the variable $\hat{\mathbf{f}}_{\alpha^+}$ ranges over an ***arbitrary*** *family of ur-functions indexed in $\hat{\mathbf{X}}$.* ■

Inference Rule 4.2.59 (Multiple Existential Introduction).

$$\Phi\left(\bigwedge\nolimits_{\alpha\in\hat{\mathbf{X}}}\Psi(\hat{\mathbf{f}}_{\alpha^+})\right) \vdash (\exists f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}[f_{\alpha^+}\backslash\hat{\mathbf{f}}_{\alpha^+}]\Phi \tag{4.63}$$

where $\Phi\left(\bigwedge_{\alpha\in\hat{\mathbf{X}}}\Psi(\hat{\mathbf{f}}_{\alpha^+})\right)$ denotes a formula Φ with a subformula $\bigwedge_{\alpha\in\hat{\mathbf{X}}}\Psi(\hat{\mathbf{f}}_{\alpha^+})$ (implying that Ψ is an atomic formula of the type $t : t' \mapsto t''$), and where the variable $\hat{\mathbf{f}}_{\alpha^+}$ ranges over a ***specific*** *family of ur-functions indexed in $\hat{\mathbf{X}}$.* ■

Remark 4.2.60. Nonstandard Universal Quantification and Nonstandard Existential Quantification, i.e. the rules

$$\Psi(\hat{\mathbf{X}}) \vdash \forall X[X\backslash\hat{\mathbf{X}}]\Psi \tag{4.64}$$

$$\Psi(\hat{\mathbf{X}}) \vdash \exists X[X\backslash\hat{\mathbf{X}}]\Psi \tag{4.65}$$

for a nonstandard formula Ψ with an occurrence of an **arbitrary** c.q. a **specific** constant $\hat{\mathbf{X}}$, are the same as in the standard case, but with the understanding that upon quantification a multiple quantifier $(\text{Ꝗ} f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}$ in Ψ becomes a generalized multiple quantifier $(\text{Ꝗ} f_{\alpha^+})_{\alpha\in X}$ in $[X\backslash\hat{\mathbf{X}}]\Psi$, and a conjunctive operator $\bigwedge_{\alpha\in\hat{\mathbf{X}}}$ with constant range in Ψ becomes a conjunctive operator $\bigwedge_{\alpha\in X}$ with variable range in $[X\backslash\hat{\mathbf{X}}]\Psi$. ■

4.3 Discussion

Theorems

Theorem 4.3.1 (Graph Theorem)**.**
For any set X and any function f_X with any codomain Y, there is a set Z that is precisely the graph of the function f_X—that is, there is a set Z whose elements are precisely the two-tuples $\langle \alpha, \beta \rangle$ made up of arguments and images of the function f_X. In a formula:

$$\begin{aligned} &\forall X \forall f_X \forall Y (f_X : X \twoheadrightarrow Y \Rightarrow \\ &\qquad \exists Z \forall \zeta (\zeta \in Z \Leftrightarrow \exists \alpha \exists \beta (\zeta = \langle \alpha, \beta \rangle \wedge f_X : \alpha \mapsto \beta)))) \end{aligned} \tag{4.66}$$

Proof: Let $\hat{\mathbf{X}}$ be an arbitrary set, and let the function $\hat{\mathbf{f}}_{\hat{\mathbf{X}}}$ be an arbitrary function on $\hat{\mathbf{X}}$. On account of GEN-F (Ax. 4.2.27), for any $\alpha \in X$ there is then precisely one β such that $\hat{\mathbf{f}}_{\hat{\mathbf{X}}} : \alpha \mapsto \beta$. Using Def. 4.2.23, there exists then for each $\alpha \in \hat{\mathbf{X}}$ a singleton $\langle \alpha, \beta \rangle^+$ such that $\hat{\mathbf{f}}_{\hat{\mathbf{X}}} : \alpha \mapsto \beta$. On account of the ur-function axiom (Ax. 4.2.40), there exists then also an ur-function $u_{\alpha^+} : \alpha^+ \twoheadrightarrow \langle \alpha, \beta \rangle^+$, $u_{\alpha^+} : \alpha \mapsto \langle \alpha, \beta \rangle$ for each $\alpha \in \hat{\mathbf{X}}$. Thus, on account of SUM-F there is a sum function $\hat{\mathbf{G}}_{\hat{\mathbf{X}}}$ with some codomain Z such that $\hat{\mathbf{G}}_{\hat{\mathbf{X}}}$ maps every $\alpha \in X$ precisely to the two-tuple $\langle \alpha, \beta \rangle$ for which $\hat{\mathbf{f}}_{\hat{\mathbf{X}}} : \alpha \mapsto \beta$. On account of GEN-F, the codomain Z of $\hat{\mathbf{G}}_{\hat{\mathbf{X}}}$ exists, and on account of Ax. 4.2.31 it is unique: this codomain is precisely the graph of $\hat{\mathbf{f}}_{\hat{\mathbf{X}}}$. Since $\hat{\mathbf{X}}$ and $\hat{\mathbf{f}}_{\hat{\mathbf{X}}}$ were arbitrary, the Graph Theorem follows from universal generalization. ■

Theorem 4.3.2 (Main Theorem)**.**
For any nonempty set X, if there is a functional relation $\Phi(\alpha, \beta)$ that relates every α in X to precisely one β, then there is a function F_X with some codomain Y that maps every $\eta \in X$ to precisely that $\xi \in Y$ for which $\Phi(\eta, \xi)$. In a formula, using the iota-operator:

$$\begin{aligned} &\forall X \neq \emptyset (\forall \alpha \in X \exists ! \beta \Phi(\alpha, \beta) \Rightarrow \\ &\qquad \exists F_X \exists Y (F_X : X \twoheadrightarrow Y \wedge \forall \eta \in X (F_X : \eta \mapsto \imath \xi \Phi(\eta, \xi)))) \end{aligned} \tag{4.67}$$

Proof: Let $\hat{\mathbf{X}}$ be an arbitrary nonempty set. Suppose then, that for every $\alpha \in \mathbf{X}$ we have precisely one β such that $\Phi(\alpha, \beta)$. On account of the ur-function axiom (Ax. 4.2.40), for an arbitrary constant $\hat{\boldsymbol{\alpha}} \in \hat{\mathbf{X}}$ there exists then also an ur-function $\hat{\mathbf{u}}_{\hat{\boldsymbol{\alpha}}^+}$ for which

$$\hat{\mathbf{u}}_{\hat{\boldsymbol{\alpha}}^+} : \hat{\boldsymbol{\alpha}} \mapsto \imath\beta\Phi(\hat{\boldsymbol{\alpha}}, \beta) \tag{4.68}$$

Let the variable $\hat{\mathbf{f}}_{\alpha^+}$ range over these ur-functions. We then deduce from SUM-F by applying Nonstandard Universal Elimination and subsequently Multiple Universal Elimination that

$$\exists F_{\hat{\mathbf{X}}} \exists Y \left(F_{\hat{\mathbf{X}}} : \hat{\mathbf{X}} \twoheadrightarrow Y \wedge \bigwedge\nolimits_{\alpha \in \hat{\mathbf{X}}} F_{\hat{\mathbf{X}}} : \alpha \mapsto \imath\beta(\hat{\mathbf{f}}_{\alpha^+} : \alpha \mapsto \beta) \right) \tag{4.69}$$

By subsequently applying Rule-C and Conjunctive Operator Elimination we then deduce the scheme

$$\hat{\mathbf{F}}_{\hat{\mathbf{X}}} : \hat{\boldsymbol{\alpha}} \mapsto \imath\beta\Phi(\hat{\boldsymbol{\alpha}}, \beta) \tag{4.70}$$

for the sum function $\hat{\mathbf{F}}_{\hat{\mathbf{X}}}$. Generalizing this scheme we obtain

$$\forall \eta \in \hat{\mathbf{X}}(\hat{\mathbf{F}}_{\hat{\mathbf{X}}} : \eta \mapsto \imath\xi\Phi(\eta, \xi))) \tag{4.71}$$

We thus obtain

$$\exists F_{\hat{\mathbf{X}}} \exists Y \left(F_{\hat{\mathbf{X}}} : \hat{\mathbf{X}} \twoheadrightarrow Y \wedge \forall \eta \in \hat{\mathbf{X}}(F_{\hat{\mathbf{X}}} : \eta \mapsto \imath\xi\Phi(\eta, \xi))) \right) \tag{4.72}$$

Since the functional relation was assumed, we get $\forall \alpha \in \hat{\mathbf{X}} \exists! \beta\Phi(\alpha, \beta) \Rightarrow \Psi$ where Ψ is formula (4.72). Since $\hat{\mathbf{X}}$ was an arbitrary nonempty set, we can quantify over nonempty sets. This gives precisely the requested formula (4.67). ■

Remark 4.3.3. Theorem 4.3.2 is an infinite scheme, with one formula for every functional relation Φ. The point is this: given a set X, on account of this theorem we can **construct** a function f_X by giving a function prescription—what we then actually do is defining an ur-function for every $\alpha \in X$; the function f_X then exists on account of SUM-F. And by constructing the function we construct its graph, which exists on account of Th. 4.3.1. Generally speaking, if we define an ur-function for each singleton $\alpha^+ \subset X$, then we do not yet have the graphs of these ur-functions in a set. But in the present framework, the set of these graphs is guaranteed to exist. Ergo, giving a function prescription *is* constructing a set! ■

Having derived the main theorems, we now prove that the infinite axiom schemes SEP and REP of ZF are a theorem (scheme) of our theory $\mathfrak{T}$.

Theorem 4.3.4 (Separation Schema).
$\forall X \exists Y \forall \alpha(\alpha \in Y \Leftrightarrow \alpha \in X \wedge \Phi(\alpha))$

Proof: Let $\hat{\mathbf{X}}$ be an arbitrary set and let Φ be an arbitrary unary relation on $\hat{\mathbf{X}}$. On account of the ur-function axiom (Ax. 4.2.40), for an arbitrary constant $\hat{\boldsymbol{\alpha}} \in \hat{\mathbf{X}}$ there exists then an ur-function $\hat{\mathbf{u}}_{\hat{\boldsymbol{\alpha}}^+}$ for which

$$\begin{cases} \hat{\mathbf{u}}_{\hat{\boldsymbol{\alpha}}^+} : \hat{\boldsymbol{\alpha}} \mapsto 1 \ \ if \ \Phi(\hat{\boldsymbol{\alpha}}) \\ \hat{\mathbf{u}}_{\hat{\boldsymbol{\alpha}}^+} : \hat{\boldsymbol{\alpha}} \mapsto 0 \ \ if \ \neg\Phi(\hat{\boldsymbol{\alpha}}) \end{cases} \tag{4.73}$$

Let the variable $\hat{\mathbf{f}}_{\eta^+}$ range over these ur-functions. On account of Th. 4.3.2 we then get

$$\exists F_{\hat{\mathbf{X}}} \forall \eta \in \hat{\mathbf{X}}(F_{\hat{\mathbf{X}}} : \eta \mapsto \imath\beta(\hat{\mathbf{f}}_{\eta^+} : \eta \mapsto \beta)) \tag{4.74}$$

Let this sum function be designated by the constant $\hat{\mathbf{F}}_{\hat{\mathbf{X}}}$. On account of INV (Ax. 4.2.35), the inverse image set $\hat{\mathbf{F}}_{\hat{\mathbf{X}}}^{-1}(1)$ exists: we then have $\forall \alpha(\alpha \in \hat{\mathbf{F}}_{\hat{\mathbf{X}}}^{-1}(1) \Leftrightarrow \alpha \in \hat{\mathbf{X}} \wedge \Phi(\alpha))$. Th. 4.3.4 then obtains from here by existential generalization and universal generalization. ■

Theorem 4.3.5 (Replacement Schema).
$\forall X(\forall \alpha \in X \exists! \beta \Phi(\alpha, \beta) \Rightarrow \exists Z \forall \gamma(\gamma \in Z \Leftrightarrow \exists \xi(\xi \in X \wedge \Phi(\xi, \gamma))))$

Proof: Let $\hat{\mathbf{X}}$ be an arbitrary set and let there for every $\alpha \in \hat{\mathbf{X}}$ be precisely one β such that $\Phi(\alpha, \beta)$. Then on account of Th. 4.3.2, a sum function $\hat{\mathbf{F}}_{\hat{\mathbf{X}}}$ exists for which

$$\forall \alpha \in X(\hat{\mathbf{F}}_{\hat{\mathbf{X}}} : \hat{\boldsymbol{\alpha}} \mapsto \imath\beta\Phi(\hat{\boldsymbol{\alpha}}, \beta)) \tag{4.75}$$

On account of Ax. 4.2.31, the codomain of $\hat{\mathbf{F}}_{\hat{\mathbf{X}}}$ is the image set; denoting this by $\hat{\mathbf{F}}_{\hat{\mathbf{X}}}[\hat{\mathbf{X}}]$ we then have

$$\forall \gamma(\gamma \in \hat{\mathbf{F}}_{\hat{\mathbf{X}}}[\hat{\mathbf{X}}] \Leftrightarrow \exists \xi(\xi \in X \wedge \Phi(\xi, \gamma))) \tag{4.76}$$

Since the functional relation Φ on the arbitrary set $\hat{\mathbf{X}}$ was assumed, this is implied by $\forall \alpha \in \hat{\mathbf{X}} \exists! \beta \Phi(\alpha, \beta)$. We write out this implication: Th. 4.3.5 then obtains by existential generalization and universal generalization. ■

These two theorems schemes prove that translations of the axioms of ZF in the language $L_{\mathfrak{T}}$ can be deduced from $\mathfrak{T}$. However, we have strictly speaking not yet proven that every result in the framework of ZF automatically translates to the present framework of $\mathfrak{T}$, because in ZF everything is a set while in the present framework sets may have elements (functions) that are not sets. A general proof thereof is left as a topic for further research.

Remark 4.3.6. Should further research on $\mathfrak{T}$ reveal unintended consequences that render it inconsistent or otherwise useless, there is still the possibility to remove SUM-F from $\mathfrak{T}$ add the above theorem schemes 4.3.4 and 4.3.5 as axioms to $\mathfrak{T}$. That still gives a theory $\mathfrak{T}_\infty$—although a standard one with infinitely many axioms (as indicated by the subscript ∞—that merges set theory and category theory into a single framework. ■

Model theory

Definition 4.3.7. *A* ***model*** $\mathcal{M}$ *of the present theory* $\mathfrak{T}$ *consists of the* ***universe*** $|\mathcal{M}|$ *of* $\mathcal{M}$*, which is a concrete category made up of a nonempty collection of objects (sets) and a nonempty collection of arrows (functions on sets), and the* ***language*** $L_{\mathcal{M}}$ *of* $\mathcal{M}$*, which is the language* $L_{\mathfrak{T}}$ *of* $\mathfrak{T}$ *extended with a constant for every object and for every arrow in* $|\mathcal{M}|$*, such that the axioms of* $\mathfrak{T}$ *are valid in* $\mathcal{M}$*.* ■

In standard first-order logic it is well defined what it means that a formula is 'valid' in a model M. This notion of validity translates to the framework of $\mathfrak{T}$ for all standard formulas. However, it remains to be established what it means that SUM-F and nonstandard consequences thereof are valid in a model $\mathcal{M}$ of $\mathfrak{T}$. Recall that symbols referring to individuals in $|\mathcal{M}|$ will be underlined to distinguish these individuals from constants of $\mathfrak{T}$.

Definition 4.3.8 (Semantics of nonstandard sentences)**.**

(i) a sentence $\forall X \neq \emptyset \Psi$ *with a nonstandard subformula* Ψ*, such as the sum function axiom, is* ***valid*** *in a model* $\mathcal{M}$ *of* $\mathfrak{T}$ *if and only if for every assignment g that assigns an individual nonempty set* $g(X) = \underline{\mathbf{X}}$ *in* $|\mathcal{M}|$ *as a value to the variable* X*,* $[\underline{\mathbf{X}}\backslash X]\Psi$ *is valid in* $\mathcal{M}$*;*

(ii) a sentence $(\forall f_{\alpha^+})_{\alpha \in \underline{\mathbf{X}}}\Phi$ *with an occurrence of an individual nonempty set* $\underline{\mathbf{X}}$ *of* $|\mathcal{M}|$*, such as an instance of SUM-F, is* ***valid*** *in a model*

$\mathcal{M}$ of $\mathfrak{T}$ if and only if for every 'team assignment' g that assigns an individual ur-function $g(f_{\underline{\boldsymbol{\alpha}}^+}) = \underline{\mathbf{u}}_{\underline{\boldsymbol{\alpha}}^+}$ in $|\mathcal{M}|$ as a value to each variable $f_{\underline{\boldsymbol{\alpha}}^+}$ semantically occurring in Φ, the sentence $[\underline{\mathbf{f}}^g_{\alpha^+} \backslash f_{\alpha^+}]\Phi$ with the variable $\underline{\mathbf{f}}^g_{\alpha^+}$ ranging over the family of ur-functions $(\underline{\mathbf{u}}_{\alpha^+})_{\alpha \in \underline{\mathbf{X}}}$ is valid in $\mathcal{M}$;

(iii) *a sentence $\exists t \Upsilon$ with an occurrence of a simple variable t ranging over sets or over functions on a set $\underline{\mathbf{X}}$ and with Υ being a nonstandard formula, such as the sentences that can be obtained by successively applying Nonstandard Universal Elimination and Multiple Universal Elimination to SUM-F, is **valid** in a model $\mathcal{M}$ of $\mathfrak{T}$ if and only if for at least one assignment g that assigns an individual function $g(t) = \underline{\mathbf{F}}_{\underline{\mathbf{X}}}$ or an individual nonempty set $g(t) = \underline{\mathbf{Y}}$ as value to the variable t, the sentence $[g(t)\backslash t]\Upsilon$ is valid in $\mathcal{M}$;*

(iv) *a sentence $\bigwedge_{\alpha \in \underline{\mathbf{X}}} \Psi(\underline{\mathbf{f}}_{\alpha^+}, \alpha)$ is **valid** in a model $\mathcal{M}$ of $\mathfrak{T}$ if and only if for every assignment g that assigns an individual ur-function $g(\underline{\mathbf{f}}_{\alpha^+}) = \underline{\mathbf{u}}_{\underline{\boldsymbol{\alpha}}^+}$ from the range $(\underline{\mathbf{u}}_{\alpha^+})_{\alpha \in \underline{\mathbf{X}}}$ of the variable $\underline{\mathbf{f}}_{\alpha^+}$ and an individual $\underline{\boldsymbol{\alpha}}$ as values to the variables $\underline{\mathbf{f}}_{\alpha^+}$ and α respectively, the sentence $[\underline{\boldsymbol{\alpha}}\backslash\alpha][\underline{\mathbf{u}}_{\underline{\boldsymbol{\alpha}}^+}\backslash\underline{\mathbf{f}}_{\alpha^+}]\Psi$ is valid in $\mathcal{M}$.*

This defines the validity of the nonstandard formulas that can be deduced from SUM-F in terms of the well-established validity of standard first-order formulas. ■

Proposition 4.3.9. *If $\mathfrak{T}$ has a model $\mathcal{M}$, then $\mathcal{M}$ is not countable.*

Proof: Suppose $\mathfrak{T}$ has a model $\mathcal{M}$, and $\mathcal{M}$ is countable. That means that there are only countably many subsets of $\mathbb{N} = \{0, 1, 2, \ldots\}$ in $\mathcal{M}$, and that the powerset $\mathcal{P}(\mathbb{N})$ in $\mathcal{M}$ contains those subsets: we thus assume that there are subsets of $\mathbb{N}$ that are "missing" in $\mathcal{M}$. Let $\underline{\mathbf{A}}$ be any subset of $\mathbb{N}$ that is **not** in $\mathcal{M}$, and let $\underline{\mathbf{h}} \in \underline{\mathbf{A}}$. All numbers $0, 1, 2, \ldots$ are in $\mathcal{M}$ (including $\underline{\mathbf{h}}$), so for an arbitrary number $\underline{\mathbf{n}} \in \mathbb{N}$ there is thus on account of the ur-function axiom (Ax. 4.2.40) an ur-function on $\{\underline{\mathbf{n}}\}$ that maps $\underline{\mathbf{n}}$ to $\underline{\mathbf{n}}$ and an ur-function on $\{\underline{\mathbf{n}}\}$ that maps $\underline{\mathbf{n}}$ to $\underline{\mathbf{h}}$. Since $\mathbb{N}$ is in $\mathcal{M}$, we get on account of SUM-F and Nonstandard Universal Elimination that

$$\models_{\mathcal{M}} (\forall f_{p^+})_{p \in \mathbb{N}} \exists F_{\mathbb{N}} \exists Y \left(F_{\mathbb{N}} : \mathbb{N} \twoheadrightarrow Y \wedge \bigwedge\nolimits_{p \in \mathbb{N}} F_{\mathbb{N}} : p \mapsto \imath q (f_{p^+} : p \mapsto q) \right) \tag{4.77}$$

Eq. (4.77) being valid in $\mathcal{M}$ means thus that for *any* team assignment g, there is a sum function $\underline{\mathbf{F}}^g_{\mathbb{N}}$ in $|\mathcal{M}|$ for which

$$\forall p \in \mathbb{N}(\underline{\mathbf{F}}^g_{\mathbb{N}} : p \mapsto \imath q(\underline{\mathbf{f}}^g_{p^+} : p \mapsto q)) \tag{4.78}$$

where the variable $\underline{\mathbf{f}}^g_{p^+}$ ranges over ur-functions $g(f_{0^+}), g(f_{1^+}), g(f_{2^+}), \ldots$ That said, the crux is that there is a team assignment g^* which assigns to the variables $f_{0^+}, f_{1^+}, f_{2^+}, \ldots$, the constants $g^*(f_{0^+}), g^*(f_{1^+}), g^*(f_{2^+}), \ldots$ such that for all $n \in \boldsymbol{\omega}$ we have

$$\begin{cases} g^*(f_{n^+}) : n \mapsto n & if\ n \in \underline{\mathbf{A}} \\ g^*(f_{n^+}) : n \mapsto \underline{\mathbf{h}} & if\ n \notin \underline{\mathbf{A}} \end{cases} \tag{4.79}$$

To see that, note that there is (i) at least one team assignment g such that $g(f_{0^+}) = \{\langle 0, 0\rangle\}_{\{0\}}$ so that $g(f_{0^+}) : 0 \mapsto 0$, and (ii) at least one team assignment g' such that $g'(f_{0^+}) = \{\langle 0, \underline{\mathbf{h}}\rangle\}_{\{0\}}$ so that $g'(f_{0^+}) : 0 \mapsto \underline{\mathbf{h}}$: it is therefore a certainty that there is at least one team assignment g^0 such that Eq. (4.79) is satisfied for $n = 0$. Now assume that there is a team assignment g^k such that Eq. (4.79) is satisfied for $n \in \{0, 1, \ldots, k\}$. There is, then, at least one team assignment g^k_{k+1} such that for $n \in \{0, 1, \ldots, k\}$ we have $g^k_{k+1}(f_{n^+}) = g^k(f_{n^+})$ and such that $g^k_{k+1}(f_{(k+1)^+}) = \{\langle k{+}1, k{+}1\rangle\}_{\{k+1\}}$ so that $g^k_{k+1}(f_{(k+1)^+}) : k + 1 \mapsto k + 1$, **and** there is then at least one team assignment $g^k_{\underline{\mathbf{h}}}$ such that for $n \in \{0, 1, \ldots, k\}$ we have $g^k_{\underline{\mathbf{h}}}(f_{n^+}) = g^k(f_{n^+})$ and such that $g^k_{\underline{\mathbf{h}}}(f_{(k+1)^+}) = \{\langle k{+}1, \underline{\mathbf{h}}\rangle\}_{\{k+1\}}$ so that $g^k_{\underline{\mathbf{h}}}(f_{(k+1)^+}) : k{+}1 \mapsto \underline{\mathbf{h}}$: it is then a certainty that there is at least one team assignment g^{k+1} such that Eq. (4.79) is satisfied for $n \in \{0, 1, \ldots, k + 1\}$. By induction, there is thus a team assignment g^* such that Eq. (4.79) is satisfied for all $n \in \boldsymbol{\omega}$. Ergo, there is a sum function $\underline{\mathbf{F}}^*_{\boldsymbol{\omega}}$ for which

$$\forall p \in \boldsymbol{\omega}(\underline{\mathbf{F}}^*_{\boldsymbol{\omega}} : p \mapsto g^*(f_{p^+})(p)) \tag{4.80}$$

But then we get $\underline{\mathbf{F}}^*_{\boldsymbol{\omega}}[\boldsymbol{\omega}] = \underline{\mathbf{A}}$, so $\underline{\mathbf{A}}$ is in $\mathcal{M}$, contrary to what was assumed. Ergo, if $\mathfrak{T}$ has a model, it is not countable. ■

Remark 4.3.10. Prop. 4.3.9 is a significant result that does not hold in ZF: given Ths. 4.3.4 and 4.3.5, this provides an argument for considering the present theory $\mathfrak{T}$ to be **stronger** than ZF. The crux here is that the nonstandard sentence (4.77), which is an instance of SUM-F, has to be valid in $\mathcal{M}$: the notion of validity of Def. 4.3.8 entails that there are uncountably many variables $\underline{\mathbf{f}}^g_{p+}$, ranging over a family of individual ur-functions indexed in $\mathbb{N}$, in the language of the model. As a result, the subsets of $\mathbb{N}$ that can be constructed within the model are non-denumerable—a model of $\mathfrak{T}$ in which Multiple Universal Elimination, inference rule 4.2.52, applies for at most countably many variables $\underline{\mathbf{f}}^g_{p+}$ is thus nonexisting. ■

Thus speaking, the Löwenheim-Skolem theorem does not apply because $\mathfrak{T}$ is a **nonstandard** first-order theory, meaning that it is not the case that $\mathfrak{T}$ can be reformulated as a standard first-order theory, nor that $\mathfrak{T}$ is a second order theory—this latter fact will be proven in the next proposition.

Proposition 4.3.11. *$\mathfrak{T}$ is not a second-order theory.*

Proof: Let's assume that $\mathfrak{T}$ is a second-order theory. That is, let's assume that the use of a multiple quantifier $(\forall f_{\{\alpha\}})_{\alpha\in\hat{\mathbf{X}}}$ amounts to second-order quantification. With such a multiple quantifier, we *de facto* quantify over all functional relations on the set $\hat{\mathbf{X}}$—note, however, that we do not quantify over all functional relations on the universe of sets! But this has an equivalent in ZF: if $\hat{\mathbf{X}}$ is a constant (a set), and $\hat{\mathbf{Y}}^{\hat{\mathbf{X}}}$ is the set of all functions from $\hat{\mathbf{X}}$ to a set $\hat{\mathbf{Y}}$, then with the quantifier $\forall B \forall f \in B^{\hat{\mathbf{X}}}$ in a sentence

$$\forall B \forall f \in B^{\hat{\mathbf{X}}} \Psi \tag{4.81}$$

we *de facto* quantify over all functional relations on the set $\hat{\mathbf{X}}$ too. Ergo, if $\mathfrak{T}$ is a second-order theory, then ZF is a second-order theory too. But ZF is a first-order theory, and not a second-order theory. So by modus tollens, $\mathfrak{T}$ is not a second-order theory. ■

As an additional heuristic argument, we can also directly compare second-order quantification and the present nonstandard first-order quantification with a multiple quantifier $(\forall f_{\{\alpha\}})_{\alpha\in\hat{\mathbf{X}}}$.

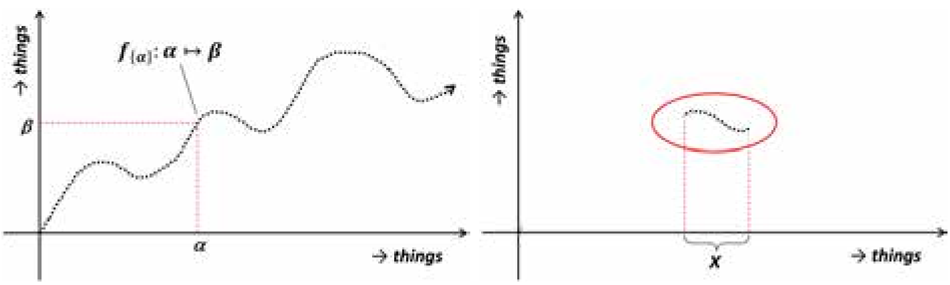
Let's first look at second-order quantification with a quantifier $\forall \Phi$ where the variable Φ ranges over functional relations. An arbitrary individual functional relation $\hat{\mathbf{\Phi}}$ has the entire proper class of things as its 'domain', so $\hat{\mathbf{\Phi}}$ corresponds to a proper class of ur-functions: for an arbitrary thing $\hat{\boldsymbol{\alpha}}$ there is a $\hat{\mathbf{\Phi}}$-related ur-function $\hat{\mathbf{u}}_{\hat{\boldsymbol{\alpha}}^+}$ for which $\hat{\mathbf{u}}_{\hat{\boldsymbol{\alpha}}^+} : \hat{\boldsymbol{\alpha}} \mapsto \imath\beta\hat{\mathbf{\Phi}}(\hat{\boldsymbol{\alpha}}, \beta)$. A quantifier $\forall \Phi$ is thus equivalent to a **proper class** of simple quantifiers $f_{\hat{\boldsymbol{\alpha}}^+}$ ranging over ur-functions on the singleton of a thing $\hat{\boldsymbol{\alpha}}$.

The universe of $\mathfrak{T}$, however, does not contain a set $\hat{\mathbf{U}}$ of all things (see Sect. 4.4), so there is no multiple quantifier $(\forall f_{\alpha^+})_{\alpha\in\hat{\mathbf{U}}}$ which would be equivalent to quantifier $\forall\Phi$: a multiple quantifier $(\forall f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}$ is **at most** equivalent to an *infinite set* of simple quantifiers $f_{\hat{\alpha}^+}$ and the degree of infinity is then bounded by the notion of a set. Thus speaking, since a set does not amount to a proper class, a multiple quantifier $(\forall f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}$ does not amount to second-order quantification. See Fig. 4.2 below for an illustration.

Axioms of category theory

Having shown that the axioms of ZF can be derived from $\mathfrak{T}$, recall that it has been assumed in Def. 4.1.1 that the universe of sets and functions is a category. In this section we prove that the axioms of category theory for the arrows indeed hold for the functions (which are the arrows of the present category). That means that we must prove the following:

(i) that domain and codomain of any function on any set are unique;



(a) 2^{nd} order (b) nonstandard 1^{st} order

Figure 4.2: Illustration of the heuristic argument. In both diagrams (a) and (b), all things in the universe of T are *for illustrative purposes* represented on the horizontal and vertical axes. In diagram (a), the dotted black line represents an arbitrary functional relation $\hat{\mathbf{\Phi}}$: each dot corresponds to a constant ur-function as indicated, so the dotted line is equivalent to a proper class of ur-functions. In diagram (b) it is indicated of which things on the horizontal axis the set $\hat{\mathbf{X}}$ is made up, and each of the black dots within the red oval corresponds to a constant ur-functions: the dotted line segment is thus equivalent to a set of ur-functions. So, a multiple quantifier $(\forall f_{\alpha^+})_{\alpha\in\hat{\mathbf{X}}}$ cannot be equivalent to a quantifier $\forall\Phi$.

(ii) that, given sets X and Y and functions f_X and g_Y with $Y = f_X[X]$, there is a function $h_X = g_Y \circ f_X$ such that h_X maps every $\alpha \in X$ to the image under g_Y of its image under f_X;

(iii) that for any set X there is a function 1_X such that $f_X \circ 1_X = f_X$ and $1_{f_X[X]} \circ f_X = f_X$ for any function f_X on X.

Ad(i): uniqueness of domain and codomain of a function f_X

This has already been proven in Sect. 4.2. GEN-F (Ax. 4.2.27) guarantees that for any set X, any function f_X has at least one domain and at least one codomain. Ax. 4.2.28 guarantees that no other thing (set or function) than X is a domain of f_X. And Ax. 4.2.31 guarantees that no other thing (set or function) than the image set $f_X[X]$ is a codomain of f_X. That proves uniqueness of domain and codomain.

Ad(ii): existence of the composite of two functions

Given a set X, a function f_X and a function g_Y with $Y = f_X[X]$, there is for every $\alpha \in X$ precisely one ur-function h_{α^+} such that

$$h_{\alpha^+} : \alpha \mapsto \imath\beta(g_Y : f_X(\alpha) \mapsto \beta) \tag{4.82}$$

So, there is a sum function H_X that maps each $\alpha \in X$ precisely to its image under the ur-function h_{α^+} for which $\imath\xi(h_{\alpha^+} : \alpha \mapsto \xi) = \imath\beta(g_Y : f_X(\alpha) \mapsto \beta)$. This sum function is precisely the composite $H_X = g_Y \circ f_X$. The proof that function composition is associative is omitted.

Ad(iii): existence of an identity function on any set X

On account of the ur-function axiom, for every thing α there is precisely one ur-function f_{α^+} for which

$$f_{\alpha^+} : \alpha \mapsto \alpha \tag{4.83}$$

For this ur-function f_{α^+} we thus have $\imath\beta(f_{\alpha^+} : \alpha \mapsto \beta) = \alpha$. Given a set X, we thus have on account of SUM-F that

$$\exists F_X \left(F_X : X \twoheadrightarrow X \wedge \bigwedge_{\alpha \in X} F_X : \alpha \mapsto \alpha \right) \tag{4.84}$$

There is thus a sum function F_X that maps every $\alpha \in X$ precisely to α. This sum function is the requested function 1_X. The proof that this sum function 1_X satisfies the properties that $g_X \circ 1_X = g_X$ and $1_{g_X[X]} \circ g_X = g_X$ for any function g_X on X, is omitted.

This shows that the axioms for a category hold for the proper class of functions.

Concerns regarding inconsistency

Proceeding, since $\mathfrak{T}$ is a nonstandard theory there is the obvious risk that $\mathfrak{T}$ is not (relatively) consistent. So let us address the main concerns regarding inconsistency, which are in particular that the existence of a set of all sets or a set of all functions can be derived from $\mathfrak{T}$.

Theorem 4.3.12. *REG (Ax. 4.2.22) excludes that a set of all sets exists. So, abbreviating Eq. (4.27) by 'REG' we have*

$$\text{REG } \Rightarrow \nexists U \forall X (X \in U)$$

Proof: Suppose the set of all sets $\hat{\mathbf{U}}$ exists. Then $\hat{\mathbf{U}}^+$ (the singleton of $\hat{\mathbf{U}}$) also exists. But $\hat{\mathbf{U}}^+$ has no elements that have no elements in common with $\hat{\mathbf{U}}^+$, because $\hat{\mathbf{U}} \in \hat{\mathbf{U}}$. This is inconsistent with REG. Ergo, if REG holds, then there is no set of all sets. ■

This excludes that a set of all sets exists *a priori*. That is, Th. 4.3.12 excludes that the category of sets and functions contains a set of all sets that is not constructible from the axioms. However, a concern regarding inconsistency of $\mathfrak{T}$ is that the set of all sets may be constructed from the axioms. This, however, seems not to be the case.

Conjecture 4.3.13. *In the category of sets and functions, a set of all sets cannot be constructed.*

Heuristic argument: SUM-F, the only constructive axiom of $\mathfrak{T}$ that is not a theorem of ZF, excludes that $\hat{\mathbf{U}}$ exists *by construction*. The crux is that one must *first* have constructed the set X *before* one can construct a sum function F_X: the set X is thus a regular set, and by applying SUM-F one cannot create a new set with a higher cardinality than the set X because the graph of F_X contains precisely one element for each element of X. The same for the image set $F_X[X]$: it cannot have a higher cardinality than X. Therefore, if ZF doesn't allow the construction of a set of all sets, then SUM-F doesn't allow the construction of a set $\hat{\mathbf{U}}$ of all sets. ■

Theorem 4.3.14. *REG-F (Ax. 4.2.42) excludes that a set of all functions exists. Abbreviating Eq. (4.39) by 'REG-F', we have*

$$\text{REG} - \text{F} \;\Rightarrow \nexists\Omega\forall X\forall f_X(f_X \in \Omega)$$

Proof: Suppose that we have a set $\hat{\mathbf{\Omega}}$ such that $\forall X\forall f_X(f_X \in \hat{\mathbf{\Omega}})$. Then on account of Th. 4.3.4 we can single out the subset $\hat{\mathbf{\Omega}}_1$ of *all* identity functions:

$$\forall\alpha(\alpha \in \hat{\mathbf{\Omega}}_1 \Leftrightarrow \alpha \in \hat{\mathbf{\Omega}} \wedge \exists X(\alpha = 1_X))$$

But since the axioms of category theory hold in the framework of $\mathfrak{T}$, then there also exists the identity function $1_{\hat{\mathbf{\Omega}}_1}$ for which

$$1_{\hat{\mathbf{\Omega}}_1} : \hat{\mathbf{\Omega}}_1 \twoheadrightarrow \hat{\mathbf{\Omega}}_1,\; 1_{\hat{\mathbf{\Omega}}_1} : 1_{\hat{\mathbf{\Omega}}_1} \mapsto 1_{\hat{\mathbf{\Omega}}_1}$$

This latter feature that $1_{\hat{\mathbf{\Omega}}_1}$ maps itself to itself contradicts the axiom of regularity for functions, REG-F (Ax.4.2.42). Ergo, REG-F excludes that there is a set $\hat{\mathbf{\Omega}}$ of all functions. ■

As with Th. 4.3.12, this excludes that a set of all functions exists *a priori*. A heuristic argument similar to that used for Conj. 4.3.13 yields the final conjecture:

Conjecture 4.3.15. *In the category of sets and functions, a set of all functions cannot be constructed.*

It is true that we have herewith argued that the category of sets and functions cannot contain a set of all sets nor a set of all functions, but it remains the case that further research may reveal that $\mathfrak{T}$ has unintended consequences which render it inconsistent.

4.4 Concluding remarks

Limitations of the present study

First of all, the syntax of the formal language for the theory $\mathfrak{T}$ has been defined in such a way that the axioms of $\mathfrak{T}$ are well-formed formulas. While this definition of the syntax has been checked for obvious mistakes, a limitation of the present study is that it has not been checked *exhaustively* for unintended consequences. That is, it may turn out that details of the present definition of the syntax require revision to avoid the situation that this or that "weird" formula becomes a well-formed formula.

As to the axioms of $\mathfrak{T}$, the axiom of regularity for functions, Axiom 4.2.42, has been formulated to rule out the existence of the pathological functions mentioned in its formulation. While the existence of certain other pathological objects, such as a set X and a function f_X for which $X = \{f_X\}$, is also ruled out as a corollary of this axiom, it cannot be excluded that a creative mind can come up with even more pathological objects that are not ruled out by the two axioms of regularity of $\mathfrak{T}$. That is, it may turn out that the axioms of regularity require revision to avoid the situation that $\mathfrak{T}$ has a model in which certain pathological objects exist a priori.

Furthermore, since $\mathfrak{T}$ is a non-classical theory there is the obvious risk that $\mathfrak{T}$ is not (relatively) consistent. While the theory $\mathfrak{T}$ has been checked for the most obvious concerns regarding inconsistency—we have argued that the category of sets and functions cannot contain a set of all sets nor a set of all functions—it has not been checked *exhaustively* for inconsistency. That is, further research may reveal that $\mathfrak{T}$ has unintended consequences which render it inconsistent. In such a case the approach would be to resolve the inconsistency by a revision of the axioms of $\mathfrak{T}$. However, if that fails, we still have the prospect of a fallback position: as outlined in Rem. 4.3.6, by removing the nonstandard part of $\mathfrak{T}$ and adding the schemes 4.3.4 and 4.3.5 as axioms, we obtain a theory $\mathfrak{T}_\infty$. This $\mathfrak{T}_\infty$ then still combines ideas from set theory and category theory in a single framework, while its universe of discourse can serve as an ontological basis for category theory. Since $\mathfrak{T}_\infty$ is a standard first-order theory, it seems safe to assume that it is relatively consistent. That is, it seems safe to assume that if ZF is consistent, then $\mathfrak{T}_\infty$ is consistent too—we leave the proof of relative consistency as a topic for further research.

A further limitation of this study is that the axiom of choice has been left out. We can easily express AC in the language $L_{\mathfrak{T}}$ as

$$\forall X \neq \emptyset(\Theta(X) \Rightarrow \exists f_X \forall Z \in X \forall \gamma(f_X : Z \mapsto \gamma \Rightarrow \gamma \in Z) \tag{4.85}$$

where $\Theta(X)$ stands for

$$\forall \alpha \in X \exists Y(\alpha = Y \wedge \exists \eta(\eta \in Y)) \wedge \forall U \in X \forall V \in X \; \nexists \beta(\beta \in U \wedge \beta \in V) \tag{4.86}$$

However, the question is whether this has to be added as an axiom or whether it can be derived as a theorem of $\mathfrak{T}$—we certainly have for any $Z \in X$ that there is an ur-function f_{Z^+} such that $\imath\xi(f_{Z^+} : Z \mapsto \xi) \in Z$. We leave this as a topic for further research.

Last but not least, another limitation of the present study is that the metamathematics of $\mathfrak{T}$ have not been studied. That is, it has not been investigated whether the present calculus has any of the various soundness and completeness properties. We leave this too as a topic for further research—(dis-)proving that these properties hold is a sizeable research project in itself.

Aesthetic counterarguments

On the other hand, the present theory $\mathfrak{T}$ gives immediately rise to at least three purely aesthetical arguments for rejection.

First of all, the universe of $\mathfrak{T}$ contains sets and functions, the latter being objects sui generis: this entails a departure from the adage 'everything is a set' that holds in the framework of ZF(C), and that will be enough to evoke feelings of dislike among mathematical monists who hold the position that set theory, in particular ZF(C), has to be the foundation for mathematics.

Secondly, although the universe of $\mathfrak{T}$ is a category, the formal language of $\mathfrak{T}$ contains $\in$-relations $t_1 \in t_2$ as atomic formulas: an $\in$-relation is, thus, not reduced to a mapping in the language of category theory, and that fact alone will be enough to evoke feelings of dislike among mathematical monists who hold the position that category theory has to be the foundation for mathematics.

Thirdly, the language of $\mathfrak{T}$ entails a rather drastic departure from standard first-order language: that will be enough to evoke feelings of dislike among those who attach a notion of beauty to the standard first-order language of ZF(C), or who consider that the language of category theory is *all of* the language of mathematics.

However, we dismiss these aesthetical objections as nonmathematical. Nevertheless, those who experience these feelings of dislike will nevertheless reject the theory $\mathfrak{T}$ *straightaway* as not suitable as a foundational theory for mathematics.

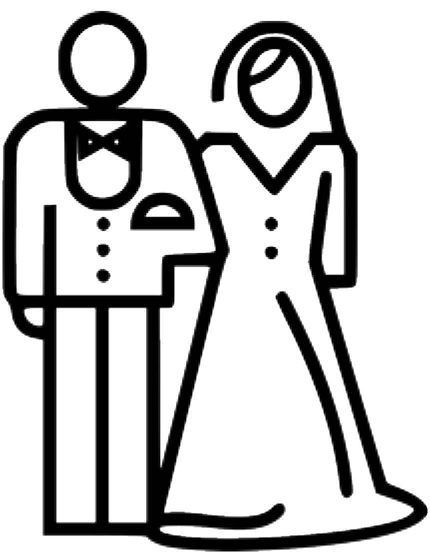
Main conclusions

The main conclusion is that the aim stated in the introduction has been achieved: a theory $\mathfrak{T}$, with a vocabulary containing countably many constants, has been introduced which lacks the two unwanted c.q. pathological features of ZF. Each axiom of $\mathfrak{T}$ is a typographically finite sentence, so contrary to what is the case with infinitary logics, each axiom can be written down explicitly. However, not just that: $\mathfrak{T}$ is finitely axiomatized, so contrary to what is the case with ZF, the entire theory $\mathfrak{T}$ can be written down explicitly on a piece of paper. In addition, it has been shown that $\mathfrak{T}$, contrary to ZF, does not have a countable model—if it has a model at all, that is. This failure of the downward Löwenheim–Skolem theorem for $\mathfrak{T}$ is due to the non-classical nature of $\mathfrak{T}$.

Furthermore, three reasons can be given as to why $\mathfrak{T}$ might be potentially applicable as a foundational theory for mathematics. First of all, it has been proven that the axioms of ZF, translated in the language $L_{\mathfrak{T}}$ of $\mathfrak{T}$, can be derived from $\mathfrak{T}$. While we acknowledge that this result does not automatically imply that all theorems about sets derived within the framework of ZF are necessarily also true in the framework of $\mathfrak{T}$ because in the latter framework sets exist whose elements are not sets, it nevertheless shows that the tools available in the framework ZF for constructing sets are also available in the framework of $\mathfrak{T}$. Secondly, it has been proved that the axioms of a category hold for the universe of discourse that is associated to $\mathfrak{T}$, which is a category of sets and functions: this universe might then serve as the ontological basis for the various (large) categories studied in category theory. Thirdly, $\mathfrak{T}$ is easy to use in everyday mathematical practice because for any set X we can construct a function f_X by giving a defining function prescription $f_X : X \twoheadrightarrow Y$, $f_X : \alpha \overset{\text{def}}{\longmapsto} \iota\beta\Phi(\alpha, \beta)$ where Φ is some functional relation: $\mathfrak{T}$ then guarantees that F_X exists, as well as its graph, its image set, and the inverse image sets for every element of its codomain—ergo, giving a defining function prescription is a tool for constructing sets.

That being said, there are also arguments why $\mathfrak{T}$ cannot be generally accepted as a new foundational theory for mathematics *right now* by a collective act of instant rationality. The strongest of these may be that the methamathematics have not been studied: contrary to the purely aesthetic arguments against $\mathfrak{T}$, negative results in that direction may yield a decisive argument to reject $\mathfrak{T}$ as not suitable as a foundational theory for mathematics. Therefore, this topic should be given highest priority in further research; the prospect is that it should become clear within a few years whether or not the various soundness and completeness properties apply.

The bottom line is that the present results are rather avant-garde and that further research is necessary to establish whether the non-classical theory $\mathfrak{T}$ introduced in this paper constitutes an advancement in the foundations of mathematics. The proven fact that $\mathfrak{T}$ lacks the pathological features of ZF may provide a reason for such further research, but it is emphasized that it may turn out to be a dead end. That is to say: the present marriage of set theory and category theory—as we called it in the introduction—may look promising from a certain perspective, but it still may end in divorce.



4.5 Objections and replies

The material of this chapter has been published in the journal *Axioms*, which is indexed by Clarivate in the Scientific Citation Index Expanded; see (Cabbolet, 2021a). That demonstrates is that there is nothing wrong with the material—at least not at first sight. Before publication in *Axioms*, the same paper has been rejected by several journals in mathematics c.q. mathematical logic. Below an overview of the arguments for rejection is given. It may very well be that the theory $\mathfrak{T}$ presented in this chapter has unintended consequences on account of which it has to be rejected, but if that's the case then it is not because of the arguments discussed below.

Objection 4.5.1. "*According to your definition [4.2.1], your language has just three constants (which you specify are to be interpreted as the empty set, the first infinite ordinal, and the inactive function). Yet ... you frequently say the language has just countably many constants, which indeed is true if it has just three, but why say countably many if you mean three?*"—anonymous referee of one of the top journals in logic, providing an argument for his recommendation to reject the submitted paper. ■

Reply 4.5.2. First of all, note that the objection concerns a single word in a paper of 20+ pages—an objection that leaves the research question and the entire structure presented in the paper untouched. Secondly, note that the number of constants in the language is changed by Def. 4.2.14, which extends the formal language: this has been overlooked by the referee.

This objection lacks substance to such a degree that the term 'pseudoskepticism' applies. For comparison, imagine that an editor of Palgrave Macmillan would have commented as follows to the now historical manuscript that Keynes submitted in 1936:

> *Dear Dr. Keynes, we have read your 'General Theory of Employment, Interest and Money'. However, on p. 5 you write that "the wage of an employed person is equal to the value which would be lost if employment were to be reduced by one unit". Obviously, it should be "... the value* <u>*that*</u> *would be lost ... ". We therefore think that your general theory is not worthy of further consideration: we see no reason to publish your book.*

Just imagine it. ■

Objection 4.5.3. "*This paper cannot be published in ... any mathematical logic journal as it is highly philosophical in nature, with little-to-no mathematical content. It is the description of a system that—if consistent—overcomes some issues that the author thinks are a problem with ZFC.*

The author provides some meta-arguments about there being something wrong with ZF (this discussion belongs into a philosophy journal, but even then, it would need to be part of a proper engagement with the existing literature about why axiom systems are accepted or not). He then introduces an unwieldy system T with lots of technicalities that may overcome the aforementioned problems (no consistency proof of T is however given). In order to be publishable, the author needs to show the relative consistency of T relative to some natural assumption (e.g., large cardinals) and convince the reader that the system has some mathematical properties that are lacking in ZFC."—first objection of the referee of a journal in mathematical logic, rejecting my submitted paper (Cabbolet, 2018b) ■

Reply 4.5.4. First of all, note that the referee rejects the paper not only for "his" journal, but also for all other mathematical logic journals.

Secondly, he provides some meta-arguments about the paper being unpublishable: this is a personal opinion piece at best. He then introduces an unconvincing criterion for publishability: meeting this criterion requires so much additional technicalities that it is a research project on its own. There is no point in demanding that a new theory can only be published if one proves that it is correct in every thinkable aspect. For comparison, consider the case that a referee of *Comptes Rendus de l'Académie des Sciences* would have commented as follows to Pierre and Marie Curie's groundbreaking paper on the discovery of Polonium (1898):

> "*Dear Mr. and Mrs. Curie,*
> *This paper cannot be published in Comptes Rendus or any other physics journal. In the paper you claim to have isolated a new substance, but in your concluding paragraph you mention that M. Demarçay could not distinguish the spectral lines of the substance from those ascribable to impurities. So, you have no proof whatsoever for the discovery of a new substance, which you based on Demarçay's findings might want to rename "Pollutionium".*"

Just think about it. ■

Objection 4.5.5. "*The use of 'non-standard' constructs is a real cause for concern, as history has shown time and again that either these are trivial or fundamentally flawed (uncountable sums and the type of all types come to mind).*"—second objection of the same referee of a journal in mathematical logic, rejecting my submitted paper (Cabbolet, 2018b) ■

Reply 4.5.6. His argument why "the use of 'non-standard' constructs is a real reason for concern" is a real reason for concern. He says essentially that this paper should be rejected because other papers were wrong. To see that this argument is inadmissible in a scientific discourse, consider the case that Max Planck, in 1905 editor of *Ann. Phys.*, would have replied as follows to Einstein:

> "*Dear Dr. Einstein,*
> *we are not going to publish your theory of relativity because other papers about fundamental physics were wrong too.*"

Just think about it. ■

Objection 4.5.7. "*The paper is also not well-written, with poor English in places.*"—third objection of the same referee of a journal in mathematical logic, rejecting my submitted paper (Cabbolet, 2018b) ■

Reply 4.5.8. The referee report was also not free of mistakes in English. All in all, this referee report is yet another example of the abuse of peer review to express one's dislike of a submitted paper. But I can tell you where this is coming from: we can infer from Obj. 4.5.3 that the referee's dislike of the submitted paper is most probably a dislike of the idea that ZF has issues—as stated in Sect. 4.4, the present theory may "evoke feelings of dislike among mathematical monists who hold the position that set theory, in particular ZF or ZFC, has to be the foundation for mathematics".

This response is in line with the response-in-an-outburst model on p. li, and has most probably been written by the managing editor of the journal, who happens to teach axiomatic set theory to his students, on the same day that he read the manuscript for the first time. This is speculation, but it is supported by the observation that the status of the paper, which is visible online in the editorial manager of the journal, went in one day from "Submitted" to "Pending Decision" without ever having had the status "Under Review". ■

Objection 4.5.9. "*Thank you for allowing us to consider your manuscript for publication in [our journal]. Unfortunately, we will not be able to publish it because it is outside of the scope of [our journal]. Thank you for considering [our journal] for the publication of your paper.*"—managing editor of the top journal in mathematical logic, rejecting my submitted paper (Cabbolet, 2018b) ■

Reply 4.5.10. The journal is by no means obliged to publish my submission. But in this case the reason given for rejection is interesting, namely that in it is outside the scope of the journal. The homepage of the journal states that it "provides an important forum for the communication of original contributions in all areas of mathematical logic and its applications." So by claiming that the submitted paper lies outside the scope of the journal, it is claimed that the submitted paper has nothing to do with mathematical logic, which is preposterous. For comparison, just changing names, consider that a referee of *Phys. Rev.* would have responded as follows to the famous paper by Einstein, Podolsky, and Rosen (1935):

> *Dear Dr. Einstein, Dr. Podolsky, Dr. Rosen,*
> *Thank you for allowing us to consider your manuscript for publication in Physical Review. Unfortunately, we will not be able to publish it because it is outside of the scope of Physical Review. Thank you for considering Physical Review for the publication of your paper.*

Just think about it. ■

Objection 4.5.11. "*The submission is not a good enough match with the intended scope and methodology of the journal. The paper should rather be sent to a journal that specializes in logic; when accepted there, a second paper that reconstructs, discusses, and assesses the formal and philosophical implications of the system contained in the present submission could constitute a submission that will fit [our journals'] agenda.*"—editor of a philosophy journal that also accepts papers on the foundations of mathematics, rejecting my submitted paper (Cabbolet, 2018b) ■

Reply 4.5.12. The journal is by no means obliged to publish my submission. What is interesting here is that the above objection by a philosophy journal goes squarely against Obj. 4.5.3, in which the referee claimed that the paper belongs in a philosophy journal. ■

Objection 4.5.13. "*This paper begins by noting two features of ZF that may be considered undesirable: it cannot be finitely axiomatized, and it has a countable model. The goal of the paper is to provide a new theory $\mathfrak{T}$ that implies ZF and avoids these two features, and in addition may serve as an ontological basis for category theory. This seems like an interesting project. However, the paper suffers from a pervasive lack of clarity, and I largely failed to understand it. Therefore I have to recommend rejection, I'm afraid.*"—editor of a journal in mathematical logic, rejecting my submitted paper (Cabbolet, 2018b) ■

Reply 4.5.14. The objection here is thus that the material in this chapter is unfathomable. It is, admittedly, a hard read, but others understood it. So, it seems to be a matter of being willing to make the effort. ■

Chapter 5

Axiomatic introduction of the EPT

> "*Cabbolet's theory had a high score on the Baez crackpot index.*"—Reinier Post, coworker of Eindhoven University of Technology, contributing to the online encyclopedia Wikipedia (2008)

5.1 On the meaning of 'theory'

In everyday language, the term 'theory' can be used casually to mean simply an idea, a speculation, or a hunch. We can have a theory about what that drug dealer must have seen when he swallowed all that LSD to avoid arrest, we can have a theory about the child of a werewolf and a vampire, we can have a theory about why Brat and Angelina divorced, and so on. The use of the term 'theory' in science, however, is distinct from everyday use in that it is **never** used to mean a hunch, a guess, or idle speculation. But that doesn't mean that there is consensus in science about what the term 'theory' actually means—in fact, there is a plethora of views on what 'theory' means. Of historical importance are the *syntactic view*, the core of which has been formulated by Carnap (1923), and the *semantic view*, originally proposed by Suppes (1960).

Naively put, the syntactic view—also called the *received view* by Putnam (1962)—is that a theory is a collection of axioms expressed in a formal system, together with an empirical interpretation of the terms. An example is Newtonian mechanics: this can be called a 'theory' from the syntactic viewpoint. The most obvious argument against the corresponding monistic position that the term 'theory' should *only* be used in this sense is that then squarely against existing scientific practice, several widely accepted bodies of knowledge cannot be called a 'theory', cf. (Halvorson, 2016). Examples are Darwin's theory of evolution and QED. Darwin's theory is expressed in natural language and not in a formal system, and QED is not a collection of axioms since no axiomatization of QED has been developed: therefore, neither can be called a 'theory' from the syntactic viewpoint. These two examples alone suffice to reject this monistic position. In addition to this, several other arguments have been put forward; see e.g. (Craver, 2002) for an overview. But we may still use this view as a *possible meaning* of 'theory'. A nuance that we must then take into account—a nuance that is not obvious from the above naive description—is that the syntactic view is not intended to imply that the language-of-formulation is an essential characteristic of a theory (Halvorson, 2016). If that would be the case, then different axiomatizations would correspond to different theories. Consider, for example, Maxwell's equations: these may be expressed

(i) using vector fields to represent the electromagnetic field;

(ii) using potentials to represent the electromagnetic field;

(iii) using multivector fields to represent the electromagnetic field.

This list is not complete, but the point is that these three descriptions of the electromagnetic field would refer to three different theories if the formal expression of a theory would be an essential characteristic. That would be plain wrong: these different formulations express the same physics, and among physicists these are rightfully viewed as different formulations of one and the same theory of the electromagnetic field. To make a distinction between *theories* and *theory formulations* the notion of 'equivalent formulations' has been introduced; see e.g. (Barrett and Halvorson, 2015) for a discussion. So, from the syntactic viewpoint a theory may have several equivalent formulations.

The semantic view, which emerged from criticism of the syntactic view, is, naively put, that a theory is a collection of models. It is true that several versions of the semantic view have been developed that are more elaborate than this naive formulation, e.g. by Suppes (1967) and by Van Fraassen (1980), but these all "share a core commitment to viewing theories as an abstract specifications of a class of models" (Craver, 2002). An example is the simple pendulum: this can be called a 'theory' from the semantic viewpoint since it consists of an idealized model of a pendulum for every real value of the length ℓ of the rod and for every real value of the initial angle θ_0. But like the monistic position corresponding to the syntactic view, the monistic position corresponding to the semantic view has drawn severe criticism as well. An example is this one by Halvorson (2012):

> "*... the semantic view gives an incorrect account of the identity of theories. Its failure here is complete: it identifies theories that are distinct, and it distinguishes theories that are identical (or at least equivalent by the strictest of standards).*"

For a fairly recent encyclopedic overview of the criticisms published in the literature, see e.g. (Frigg, 2014). Another criticism on this view that I add here from the perspective of theory and model development is this: it may be true that a theory specifies a collection of models, but what the semantic view fails to take into account is that this collection of models is unknown at the moment a theory is formulated—usually, the development of even one model of a theory is an enterprise in itself. For example, it is certainly true that GR corresponds to a collection of models, but to date—more than a century after the publication of GR—no model of GR with two or more interacting massive bodies has ever been developed. There is no general solution of any of the n-body problems in GR; in particular, there is no model of GR that describes our solar system. The few models available concern either systems with one massive body (such as a black hole) in an otherwise empty spacetime, or concern systems that in one way or another are restricted (such as systems with a test particle, which is assumed to leave the gravitational field undisturbed). That is to say: GR has already been formulated (as a set of mathematically expressed equations with a physical interpretation), but the collection of models it specifies has not (yet) been developed. So let us not kid ourselves by saying that the one is identical or equivalent to the other. A similar argument can be made with QM: there are no models (solutions of the Schroedinger equation) that describe atoms with more than one electron.

The prolonged debate of the syntactic view versus the semantic view has led to highly differentiated analyses of the circumstances under which the use of the term 'theory' is justified. However, the state of affairs at the beginning of this decade was that the philosophical problem of what a theory is had not yet been solved (Muller, 2011). Shortly after Muller published his conclusion, Halvorson reported that "some philosophers have suggested that we should stop trying to answer the question what a theory is" (2016). Fact of the matter is that this debate has far from settled up until now, and here we take that fact to mean that the outcome of the debate is that it has turned out to be impossible to give an all-encompassing *positive* definition of the term 'theory' based on either the syntactic or the semantic view such that everything that is widely agreed on to be a 'theory' fits that definition. That, however, does not necessarily mean that the discussion on 'theory' has ended in a deadlock: below a pluralist view on theories is put forward that incorporates both the syntactic and the semantic view. This view is not positively defined, but that doesn't mean that it's useless—it may even be the only view that is generally defendable.

The pluralistic view

First of all we note that in scientific practice the word 'theory' is used as a predicate: the question is not what a theory 'is', but rather when the predicate 'theory' applies to the output of a research c.q. research program. That said, the **pluralist view** on 'theory' is the following:

(i) 'theory' is a predicate that applies to *explanantia* (i.e. bodies of statements that can be used to explain phenomena);

(ii) the predicate 'theory' is a primitive notion that defies a precise definition in terms of other well-defined notions in philosophy of science;

(iii) there is no uniform set of criteria, such that the predicate 'theory' applies to the output of a research program in science if and only if these criteria are satisfied;

(iv) there can be no gratuitous use of the predicate 'theory': in each instance, a (scientific) justification has to be given for its application.

From this pluralist viewpoint the scope of the meaning of 'theory' can then be gauged by the collection of research outputs to which it applies.

This view incorporates the syntactic view in the sense that if we adopt this pluralist view, then we agree with proponents of the syntactic view that a set of formalized statements with an empirical interpretation can be called a 'theory'; however, we do not agree with the corresponding monistic view that the predicate 'theory' *only* applies to a set of formalized statements with an empirical interpretation. Likewise, this view incorporates the semantic view in the sense that if we adopt this pluralist view, then we agree with proponents of the semantic view that a collection of models can be called a 'theory'; however, we do not agree with the corresponding monistic view that *only* a collection of models can be called a 'theory'.

Furthermore, the pluralist view is not merely the dualist view that the predicate 'theory' applies when it applies from either the syntactic or the semantic viewpoint. To see that, let's look at 'string theory' in physics:

(i) there is no such thing as string theory from the syntactic viewpoint, because up till now no mathematically expressed description of a unified field based on the notion of a string has been axiomatically introduced—of course, a not-yet-formulated collection of axioms that exists only *hypothetically* cannot be called a theory;

(ii) there is no such thing as string theory from the semantic viewpoint either, because no collection of models has so far been specified.

That said, let us investigate the aforementioned dualistic view using Kant's categorical imperative. So, let's consider that everyone should adopt the dualistic view that the term 'theory' can only be used in accordance with the syntactic or the semantic view. A consequence is then all physicists would have to stop talking about "string theory". Obviously, this goes squarely against everyday scientific practice. Ergo, this dualist view is untenable, and so are the two monistic views. From the pluralistic viewpoint, however, there is no objection against the application of the predicate 'theory' to the combined output of the research program on string theory: even though the physics are speculative, the rigourous application of mathematics is enough of a justification. So, in this case the predicate 'theory' applies to a (dynamic) body of statements that is so far not axiomatized and that so far doesn't specify a model. Contrary to the syntactic view and the semantic view, the pluralistic view on 'theory' is thus consistent with existing scientific practice when it comes to string theory.

Last but not least, adopting this pluralist view does not imply that one suddenly has to consider any statement to be a 'theory'. Consider, for example, the statement 'the child of a werewolf and a vampire can only be killed by a silver bullet and a stake through the heart'. This statement is not a theory from the pluralist viewpoint, because there is no scientific justification for calling this a theory. This admittedly trivial example shows that it is not the case that all of a sudden everything becomes a 'theory' when one adopts the pluralist view.

Summarizing, we adopt a pluralist view on 'theory'. On the one hand, this means that we take the view that the predicate 'theory' applies under those circumstances under which it applies from the syntactic or the semantic viewpoint. On the other hand, however, this means that we take the view that there are not only circumstances under which the predicate 'theory' does apply in spite of the fact that it doesn't apply from the syntactic or the semantic viewpoint, but also circumstances under which the predicate 'theory' doesn't apply at all—there is no 'anything goes' from the pluralistic viewpoint.

Professionals working in the sciences, however, will say that this pluralist view is not an acceptable view on what 'theory' means. In the sciences, namely, the word 'theory' is used as an abbreviation for 'scientific theory', which means a body of statements that (i) has been repeatedly tested in accordance with the scientific method and (ii) has been accepted as valid. But no matter how common this practice is in the sciences, here we take the position that this use of the word 'theory' ignores developments in philosophy of science that have established that the scientific landscape is one of *Lakatosian research programs* rather than one of *theories*. That is to say, here we take the position that there is no such thing as a 'scientific theory': there are only scientific research programs. A theory—be it a set of axiomatized statements, be it a collection of models—can of course be tested according to the scientific method. But a result of such testing, however, is something that is *external* to the theory. For example, the finding by Eddington et al. that light is deflected by the sun is not a part of GR, although it is predicted by GR. The predicate 'scientific' therefore does not apply to a theory, but to an extension thereof that includes these test results: the Lakatosian notion of a research program is such an extension.

The EPT as an abstract physical theory

To give a justification for the use of the word 'theory' in the name 'Elementary Process Theory', the crux is that the EPT is an *abstract physical theory.* That is, the EPT consists of

(i) the **language** $\mathcal{L}(EPT)$ of the EPT, which is the language $\mathcal{L}(\mathfrak{T})$ of the theory $\mathfrak{T}$ of Ch. 4 extended with

- a nonempty set U_{EPT}, whose elements are **individual constants**;
- a nonempty set R_{EPT}, whose elements are the **unary relation** R_1, the **binary relation** R_2, and the **ternary relation** R_3;

(ii) a collection of **formal axioms** of the EPT:

- for every concrete constant $c \in U_{EPT}$, a constructive axiom;
- for every abstract constant $\Phi \in U_{EPT}$, an axiom

$$\exists\alpha(\alpha = \Phi) \tag{5.1}$$

- for every n-ary relation $\rho \in R_{EPT}$, an axiom

$$\exists\alpha(\alpha = \rho \wedge \rho \subset (U_{EPT})^n) \tag{5.2}$$

(iii) a collection of well-formed formulas in $\mathcal{L}(EPT)$, to be called the **process-physical axioms** of the EPT;

(iv) a collection of statements in ordinary language, called the **interpretation rules** of the EPT, which give a physical meaning to the individual constants and relations of the EPT.

Furthermore, let Σ_{EPT} be the total collection of formal and process-physical axioms of the EPT; a **theorem of** the EPT is then any formula Ψ that can be inferred from Σ_{EPT} within the framework of $\mathfrak{T}$ as in

$$\Sigma_{EPT} \vdash_{\mathfrak{T}} \Psi \tag{5.3}$$

To introduce the EPT, it thus suffices to introduce the individual constants of the EPT, the process-physical axioms of the EPT, and the interpretation rules by which theorems of the formal axiomatic system can be translated into statements about physical reality.

That said, the EPT can thus be called a 'theory' from the syntactic viewpoint. And the EPT is then a *physical* theory, because its process-physical axioms have a meaning as testable physical principles—these are not metaphysical principles or anything like that. It is then important to understand that, as Halvorson also noted (2016), the process-physical axioms would have no physical meaning whatsoever without interpretation rules. Therefore, as already mentioned on page 123 in Sect. 3.3, in the framework of the EPT we have to distinguish between the *material object*, i.e. the (postulated) thing in the physical universe that is referred to, and the *formal object*, i.e. the thing in the mathematical universe that refers to the material object. Moreover, the EPT is an *abstract* physical theory because the formal objects that refer to ultimate constituents of the physical world are *abstract constants*. Now the ontological status of abstract constants can probably be debated forever, but here the following position is taken: an individual constants of the language is abstract *if and only if* nothing but the existence of a thing in the mathematical universe identical to that constant is assumed. So, a formal axiom (5.1) for an individual constant φ of the EPT guarantees that there is an object in the mathematical universe whose name is φ, but without any further information on which object that precisely is. The important point here is that we do not have assumed *new objects* in the mathematical universe.

Altogether, the EPT has a higher degree of abstractness than the cornerstones of modern physics, QM and GR. While in the frameworks of QM and GR (states of) material objects are *quantitatively represented* by mathematically concrete formal objects, in the framework of the EPT mathematically abstract formal objects thus *designate* material objects *without* quantitatively representing their state, that is, *without* containing information of (expectation values of) quantitative properties of the material objects—this allows to express generalized process-physical principles without reference to a coordinate system of an observer. A consequence of this higher degree of abstractness is that the truth or falsehood of the successful predictions of modern interaction theories in the framework of the EPT cannot be shown by means of a so-called *direct proof*. However, part IV of this monograph will set forth a formal method to (dis-)prove that the fundamental interactions—as we know them from the successful predictions of modern theories—can take place in the processes described by the EPT.

5.2 Language and interpretation rules

Definition 5.2.1. *The* ***concrete constants*** *of the language for the EPT are the following:*

(i) the finite abelian group $(Z_N, +)$ *under addition modulo* N*; for the set* Z_N *we have*

$$\forall \alpha(\alpha \in Z_N \Leftrightarrow \alpha = 0 \vee \alpha = 1 \vee \alpha = 2 \vee \ldots \vee \alpha = N - 1) \tag{5.4}$$

so that $(N-1)+1=0$*;*

(ii) for every $x \in Z_N$*, an initial segment* $I_{z(x)}$ *of the positive integers for which*

$$\forall \alpha(\alpha \in I_{z(x)} \Leftrightarrow \alpha = 1 \vee \alpha = 2 \vee \ldots \vee \alpha = z(x)) \tag{5.5}$$

For $(Z_N, +)$ *the axioms of an abelian group hold; an explicit formulation is omitted.* ■

Remark 5.2.2. In Def. 5.2.1 it has to be taken that the number N in clause (iii) and the numbers $z(x)$ in clause (iv) are generic constants: each of these numbers does have an exact value, but this value is unknown at the moment and will have to be determined c.q. estimated experimentally. The exact values are irrelevant for the description of a single elementary process: these numbers only play a role in the description of the universe as a whole (vide infra). ■

Definition 5.2.3. *A* 2×1 *matrix* $\begin{bmatrix} \alpha \\ \beta \end{bmatrix}$ *is identified with the graph of a function on the set* $\{\langle 1,1\rangle, \langle 2,1\rangle\}$ *given by*

$$f_{\{\langle 1,1\langle,\langle 2,1\rangle\}} : \begin{cases} \langle 1,1\rangle \mapsto \alpha \\ \langle 2,1\rangle \mapsto \beta \end{cases} \tag{5.6}$$

The above 2×1 *matrix is thus a pair set for which*

$$\forall \gamma(\gamma \in \begin{bmatrix} \alpha \\ \beta \end{bmatrix} \Leftrightarrow \gamma = \langle\langle 1,1\rangle, \alpha\rangle \vee \gamma = \langle\langle 2,1\rangle, \beta\rangle) \tag{5.7}$$

See also Eq. (3.20). ■

Agreement 5.2.4. To increase readability of this treatise, in the remainder of this text set-builder notation will be used where appropriate to denote sets. E.g. we may write $\{0, 1, 2, \ldots, N-1\}$ for Z_N, and $\{1, \ldots, z(x)\}$ for $I_{z(x)}$. ■

Definition 5.2.5. *The* ***abstract constants*** *of the language for the EPT are the following:*

(i) a finite number Ω of sets $\mathfrak{m}_1, \mathfrak{m}_2, \ldots, \mathfrak{m}_\Omega$;

(ii) the elements of the free semigroup G^+ on the set G under addition, with G being the finite set made up of the constant $\begin{bmatrix} 0 \\ 0 \end{bmatrix}$ and, for every $n \in Z_N$ and for every $k \in I_{z(x)}$, the following constants:

- *one 2×1 matrix* $\begin{bmatrix} {}^{EP}\varphi_k^n \\ {}^{EP}\overline{\varphi}_k^n \end{bmatrix}$;
- *one 2×1 matrix* $\begin{bmatrix} {}^{NW}\varphi_k^n \\ {}^{NW}\overline{\varphi}_k^n \end{bmatrix}$;
- *one 2×1 matrix* $\begin{bmatrix} {}^{NP}\varphi_k^{n+1} \\ {}^{NP}\overline{\varphi}_k^{n+1} \end{bmatrix}$;
- *one 2×1 matrix* $\begin{bmatrix} {}^{LW}\varphi_k^{n+1} \\ {}^{LW}\overline{\varphi}_k^{n+1} \end{bmatrix}$;
- *one 2×1 matrix* $\begin{bmatrix} {}^{S}\varphi_k^{n+1} \\ {}^{S}\overline{\varphi}_k^{n+1} \end{bmatrix}$;
- *$p(n, k)$ 2×1 matrices* $\begin{bmatrix} {}^{EP}\mu_{\mathfrak{m}_i}^n \\ {}^{EP}\overline{\mu}_{\mathfrak{m}_i}^n \end{bmatrix}$ *and* $\begin{bmatrix} \psi_{\mathfrak{m}_i}^n \\ \overline{\psi}_{\mathfrak{m}_i}^n \end{bmatrix}$;
- *$q(n, k)$ 2×1 matrices* $\begin{bmatrix} {}^{NP}\mu_{\mathfrak{m}_j}^{n+1} \\ {}^{NP}\overline{\mu}_{\mathfrak{m}_j}^{n+1} \end{bmatrix}$;

(iii) for every $n \in Z_N$ and $k \in I_{z(n)}$, a set Θ_k^{n+1} for which ${}^{NP}\varphi_k^{n+1} \in \Theta_k^{n+1}$;

(iv) for every Θ_k^{n+1}, an ur-function $f_{(\Theta_k^{n+1})^+} : \Theta_k^{n+1} \mapsto {}^{NP}\varphi_k^{n+1}$.

■

Agreement 5.2.6. In the remainder of this text, the symbols $\text{M}_1, \text{M}_2, \ldots$ (small capital letters 'm' with an integer-valued numerical subscript) are used **exclusively** for variables that range over the sets $\mathfrak{m}_1, \mathfrak{m}_2, \ldots, \mathfrak{m}_\Omega$ introduced in clause (i) of Def. 5.2.5. ■

Definition 5.2.7. *The* ***relations*** *of the language for the EPT are the following:*

(i) the unary relation $R_1 \subset G^+$*;*

(ii) the binary relation $R_2 \subset (G^+)^2$*;*

(iii) the ternary relation $R_3 \subset (G^+)^3$*.*

For all three relations a formal axiom (5.2) *holds.* ■

Notation 5.2.8. The following special notations will be used for atomic expressions in which the relations R_1, R_2, and R_3 occur:

$$\mathbb{E}\begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix} \Leftrightarrow \begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix} \in R_1 \tag{5.8}$$

$$\begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} \beta \\ \overline{\beta} \end{bmatrix} \Leftrightarrow \langle \begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix}, \begin{bmatrix} \beta \\ \overline{\beta} \end{bmatrix} \rangle \in R_2 \tag{5.9}$$

$$\begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix} : \begin{bmatrix} \beta \\ \overline{\beta} \end{bmatrix} \begin{matrix} \dashrightarrow \\ \dashleftarrow \end{matrix} \begin{bmatrix} \gamma \\ \overline{\gamma} \end{bmatrix} \Leftrightarrow \langle \begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix}, \begin{bmatrix} \beta \\ \overline{\beta} \end{bmatrix}, \begin{bmatrix} \gamma \\ \overline{\gamma} \end{bmatrix} \rangle \in R_3 \tag{5.10}$$

Here $\begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix}, \begin{bmatrix} \beta \\ \overline{\beta} \end{bmatrix}, \begin{bmatrix} \gamma \\ \overline{\gamma} \end{bmatrix} \in G^+$. ■

As said, the formulas that can be deduced within the axiomatic system containing the EPT are in themselves just mathematical expressions with no physical meaning. Thus, to convert the theorems of the system into statements about the physical universe a set of *interpretation rules*—also called: *correspondence rules*—is required. The interpretation rules that concern the individual constants of the language for the EPT are introduced below. Additional interpretation rules that concern the axioms of the EPT are given in Sect. 5.3.

Interpretation Rule 5.2.9. *A number* $n \in Z_N$ *is to be interpreted as an integer-valued degree of evolution.* ■

Interpretation Rule 5.2.10. *The largest element* $z(n)$ *of every initial segment* $I_{z(n)}$ *is to be interpreted as the number of elementary processes from the* n^{th} *to the* $(n+1)^{\text{th}}$ *degree of evolution. The numbers* $k \in I_{z(n)}$ *are thus counting numbers for the elementary processes from the* n^{th} *to the* $(n+1)^{\text{th}}$ *degree of evolution.* ■

The labeling of elementary processes with initial and final degrees of evolution $n, n+1 \in Z_N$ and with a counting number $k \in I_{z(n)}$ is based on the labeling of extended particlelike phase quanta, since each of these marks the beginning of an elementary process. To get a grasp of the idea, it may be helpful look at an oversimplification of the sea of extended particlelike phase quanta as a bounded, graded lattice $(L, \leq)$ with rank function $\rho : L \to \mathbb{N}$. The elements of L are the extended particlelike phase quanta, which we designate with symbols ${}^{EP}\varphi_k^n$: there is one such symbol for each $n \in Z_N$ and for each $k \in I_{z(n)}$. For $n = 0$ and $n = N-1$, let $z(n) = 1$; at each of these degrees of evolution, there is thus only one extended particlelike phase quantum—to wit: ${}^{EP}\varphi_1^0$ and ${}^{EP}\varphi_1^{N-1}$, respectively. For the intermediate degrees of evolution $0 \neq n \neq N-1$, let $z(n) = \omega$ be fixed; at such an intermediate degree of evolution n, there are thus ω extended particlelike phase quanta ${}^{EP}\varphi_1^n, \ldots, {}^{EP}\varphi_\omega^n$. The rank of an extended particlelike phase quantum ${}^{EP}\varphi_k^n$ is the degree of evolution assigned to it: $\rho({}^{EP}\varphi_k^n) = n$. The lowest ranked and the highest ranked extended particlelike phase quanta, ${}^{EP}\varphi_1^0$ and ${}^{EP}\varphi_1^{N-1}$, are respectively the bottom and the top of the lattice:

$$ {}^{EP}\varphi_1^0 \leq {}^{EP}\varphi_k^n \leq {}^{EP}\varphi_1^{N-1} \tag{5.11}$$

Furthermore, in this sea of extended particlelike phase quanta, there are ω maximal chains from top to bottom with length $N-1$; the j^{th} maximal chain $C_j \subset L$ is the set

$$C_j = \{{}^{EP}\varphi_1^0,\ {}^{EP}\varphi_j^1,\ {}^{EP}\varphi_j^2, \ldots,\ {}^{EP}\varphi_j^{N-2},\ {}^{EP}\varphi_1^{N-1}\} \tag{5.12}$$

In general, for ${}^{EP}\varphi_j^n \neq {}^{EP}\varphi_1^0$ and ${}^{EP}\varphi_k^p \neq {}^{EP}\varphi_1^{N-1}$ we have

$$ {}^{EP}\varphi_j^n \leq {}^{EP}\varphi_k^p \Leftrightarrow \rho({}^{EP}\varphi_j^n) \leq \rho({}^{EP}\varphi_k^p) \wedge j = k \tag{5.13}$$

Furthermore, a pair set $\{\varphi, \varphi'\} \subset L$ with $\varphi \leq \varphi'$ is a **minimal chain** if and only if $\rho(\varphi') = \rho(\varphi) + 1$. If $\{\varphi, \varphi'\}$, with $\varphi \leq \varphi'$, is a minimal chain, then φ' is a *successor* of φ. Except for the top of the lattice, every element in this sea of extended particlelike phase quanta marks the beginning of an elementary process; the k^{th} elementary process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution corresponds with the collection of all minimal chains in which ${}^{EP}\varphi_k^n$ is the smallest element. See Fig. 5.1 for a Hasse diagram.

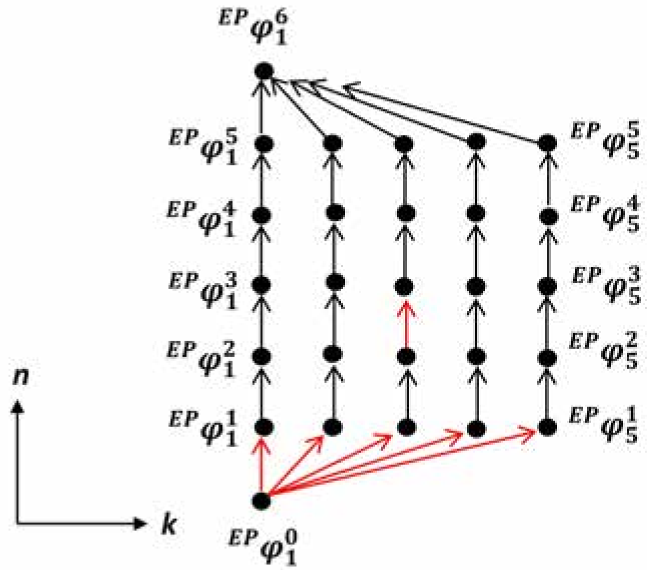


Figure 5.1: Hasse diagram of the graded, bounded lattice with $N = 6$ and $\omega = 5$, so $Z_N = \{0, 1, \ldots, 6\}$ and $I_{z(n)} = \{1, \ldots, 5\}$ for $n \in Z_N \backslash \{0, 6\}$. The dots represent the sea of extended particlelike phase quanta, which are labeled with a degree of evolution $n \in Z_N$ and with a counting number $k \in I_{z(n)}$: the degree of evolution increases in the upwards direction and the counting numbers increases in the horizontal direction to the right as indicated. The names of the elements of the two maximal chains C_1 and C_5, with $C_1 = \{^{EP}\varphi_1^0,\ ^{EP}\varphi_1^1,\ ^{EP}\varphi_1^2, \ldots,\ ^{EP}\varphi_1^5,\ ^{EP}\varphi_1^6\}$ and $C_5 = \{^{EP}\varphi_1^0,\ ^{EP}\varphi_5^1,\ ^{EP}\varphi_5^2, \ldots,\ ^{EP}\varphi_5^5,\ ^{EP}\varphi_1^6\}$, are explicitly shown. The arrows between the dots are the minimal chains, collections of which correspond to elementary processes. So, the first (and only) process from the zeroth to the first degree of evolution corresponds to the collection of minimal chains represented by the red arrows at the bottom of the figure; the third process from the second to the third degree of evolution corresponds to the singleton of the minimal chain represented by the red arrow in the middle of the figure. Recall that extended particlelike phase quanta can be viewed as massive systems in a particle state; so, all in all, what happens in this toy universe is that the massive system at the beginning of the universe splits up during the Big Bang (i.e., the first process from the zeroth to the first degree of evolution) in five new massive systems, which then evolve separately in time until they fuse again into one final massive system during the Big Crunch. The EPT then describes what happens in the elementary processes: these are in essence all the same.

Interpretation Rule 5.2.11. *A* 2×1 *matrix* $\begin{bmatrix} {}^{EP}\varphi_k^n \\ {}^{EP}\overline{\varphi}_k^n \end{bmatrix}$ *is to be interpreted as the component of the universe, consisting of the extended particlelike phase quantum at the* n^{th} *degree of evolution in the* k^{th} *process from the* n^{th} *to the* $(n+1)^{\text{th}}$ *degree of evolution in the world, and the conjugated extended particlelike phase quantum in the antiworld.* ■

Interpretation Rule 5.2.12. *A* 2×1 *matrix* $\begin{bmatrix} {}^{NW}\varphi_k^n \\ {}^{NW}\overline{\varphi}_k^n \end{bmatrix}$ *is to be interpreted as the component of the universe, consisting of the nonlocal wavelike phase quantum created at the* n^{th} *degree of evolution in the* k^{th} *process from the* n^{th} *to the* $(n+1)^{\text{th}}$ *degree of evolution in the world, and the conjugated nonlocal wavelike phase quantum in the antiworld.* ■

Interpretation Rule 5.2.13. *A* 2×1 *matrix* $\begin{bmatrix} {}^{NP}\varphi_k^{n+1} \\ {}^{NP}\overline{\varphi}_k^{n+1} \end{bmatrix}$ *is to be interpreted as the component of the universe, consisting of the nonextended particlelike phase quantum at the* $(n+1)^{\text{th}}$ *degree of evolution in the* k^{th} *process from the* n^{th} *to the* $(n+1)^{\text{th}}$ *degree of evolution in the world, and the conjugated nonextended particlelike phase quantum in the antiworld.* ■

Interpretation Rule 5.2.14. *A* 2×1 *matrix* $\begin{bmatrix} {}^{LW}\varphi_k^{n+1} \\ {}^{LW}\overline{\varphi}_k^{n+1} \end{bmatrix}$ *is to be interpreted as the component of the universe, consisting of the local wavelike phase quantum created at the* $(n+1)^{\text{th}}$ *degree of evolution in the* k^{th} *process from the* n^{th} *to the* $(n+1)^{\text{th}}$ *degree of evolution in the world, and the conjugated local wavelike phase quantum in the antiworld.* ■

Interpretation Rule 5.2.15. *A* 2×1 *matrix* $\begin{bmatrix} {}^{S}\varphi_k^{n+1} \\ {}^{S}\overline{\varphi}_k^{n+1} \end{bmatrix}$ *is to be interpreted as the component of the universe, consisting of the spatial phase quantum created at the* $(n+1)^{\text{th}}$ *degree of evolution in the* k^{th} *process from the* n^{th} *to the* $(n+1)^{\text{th}}$ *degree of evolution in the world, and the conjugated spatial phase quantum in the antiworld.* ■

Interpretation Rule 5.2.16. *The* Ω *sets* $\mathfrak{m}_1, \mathfrak{m}_2, \ldots, \mathfrak{m}_\Omega$ *are to be interpreted as monads, with* $\mathfrak{m}_j$ *designating the* j^{th} *monad; each such set thus designates an immaterial bundle of invariant properties.* ■

In Part IV, the j^{th} monad $\mathfrak{m}_j$ will be minimally modeled as a three-tuple $\langle j, s(j), c_n(j)\rangle$ where $s(j)$ is a *rest mass spectrum* and $c_n(j)$ a *characteristic number of normality*—cf. Sect. 3.2.

Interpretation Rule 5.2.17. *A* 2×1 *matrix* $\begin{bmatrix} \psi^n_{\mathfrak{m}_i} \\ \overline{\psi}^n_{\overline{\mathfrak{m}}_i} \end{bmatrix}$ *is to be interpreted as a component of the universe, consisting of the monadic occurrent carrying the* i^{th} *monad from the* n^{th} *to the* $(n+1)^{\text{th}}$ *degree of evolution in the world, and the conjugated monadic occurrent in the antiworld carrying the conjugated set of properties.* ■

Interpretation Rule 5.2.18. *A* 2×1 *matrix* $\begin{bmatrix} {}^{EP}\mu^n_{\mathfrak{m}_i} \\ {}^{EP}\overline{\mu}^n_{\overline{\mathfrak{m}}_i} \end{bmatrix}$ *is to be interpreted as a component of the universe, consisting of the extended particlelike matter quantum carrying the* i^{th} *monad at the* n^{th} *degree of evolution in the world, and the conjugated extended particlelike matter quantum carrying the conjugated monad in the antiworld.* ■

Interpretation Rule 5.2.19. *A* 2×1 *matrix* $\begin{bmatrix} {}^{NP}\mu^{n+1}_{\mathfrak{m}_j} \\ {}^{NP}\overline{\mu}^{n+1}_{\overline{\mathfrak{m}}_j} \end{bmatrix}$ *is to be interpreted as a component of the universe, consisting of the nonextended particlelike matter quantum carrying the* j^{th} *monad at the* $(n+1)^{\text{th}}$ *degree of evolution in the world, and the conjugated nonextended particlelike matter quantum carrying the conjugated monad in the antiworld.* ■

Interpretation Rule 5.2.20. *A set* Θ^{n+1}_k *is to be interpreted as the set of parallel possible nonextended particlelike phase quanta at the* $(n+1)^{\text{th}}$ *degree of evolution in the* k^{th} *individual process from the* n^{th} *to the* $(n+1)^{\text{th}}$ *degree of evolution.* ■

The idea is that an extended particlelike matter quantum ${}^{EP}\mu^n_{\mathfrak{m}_i}$ is a *spatial part* of an extended particlelike phase quantum ${}^{EP}\varphi^n_k$, but a *temporal part* of the monadic occurrent $\psi^n_{\mathfrak{m}_i}$ that carries the i^{th} monad from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution in the world—in fact, it is the *initial* temporal part of the monadic occurrent.

A nonextended particlelike matter quantum ${}^{NP}\mu^{n+1}_{\mathfrak{m}_j}$, on the other hand, can be viewed as a point-like object that *becomes* the monadic occurrent carrying the j^{th} monad from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution in the world. But for the material object ${}^{NP}\mu^{n+1}_{\mathfrak{m}_j}$ to exist *in act*, a necessary condition is its prior existence *in potential*—in concreto this means that for a massive system made up of one electron to occur in a particle state at a spatiotemporal position (t, X), a requirement is thus that it beforehand must be *possible* to occur in a particle state at that spatiotemporal position (t, X). The set Θ_k^{n+1} of parallel possible nonextended particlelike phase quanta is thus a set of things that exist only in potential: only one element of this set comes to existence in act. And that implies that at the fundamental level a choice is made in every elementary process, namely the choice that determines *which* of the elements of Θ_k^{n+1}—which exist in potential—comes to existence in act. The ur-function $f_{(\Theta_k^{n+1})^+}$ of Def. 5.2.5 reflects this choice. At the level of abstractness of the EPT, we describe *that* a choice is made in every elementary process; in a concrete model of the EPT, we can describe *which* choice is made by the fundamental interactions—given the initial state of a process by which a massive system made up of one electron interacts with its environment, a model of the gravitational and electromagnetic aspects of the interaction will predict where the electron will be after one process of interaction has taken place.

Interpretation Rule 5.2.21. *An* $\in$*-relation* $\mathbb{E}\begin{bmatrix}\alpha\\\overline{\alpha}\end{bmatrix}$ *is to be interpreted as: the component* $\begin{bmatrix}\alpha\\\overline{\alpha}\end{bmatrix}$ *exists—exists* ***in act****, that is.* ■

Interpretation Rule 5.2.22. *An* $\in$*-relation* $\begin{bmatrix}\alpha\\\overline{\alpha}\end{bmatrix}\begin{matrix}\rightarrow\\\leftarrow\end{matrix}\begin{bmatrix}\beta\\\overline{\beta}\end{bmatrix}$ *is to be interpreted as: the component* $\begin{bmatrix}\alpha\\\overline{\alpha}\end{bmatrix}$ *is in equilibrium with the component* $\begin{bmatrix}\beta\\\overline{\beta}\end{bmatrix}$*. That is, in the world spontaneously a discrete transition takes place by which the occurrent* α *transforms into the occurrent* β*, while in the antiworld a discrete transition takes place in opposite direction.* ■

Interpretation Rule 5.2.23. *An* $\in$*-relation* $\begin{bmatrix}\alpha\\\overline{\alpha}\end{bmatrix}:\begin{bmatrix}\beta\\\overline{\beta}\end{bmatrix}\begin{matrix}\dashrightarrow\\\dashleftarrow\end{matrix}\begin{bmatrix}\gamma\\\overline{\gamma}\end{bmatrix}$ *is to be interpreted as: the component* $\begin{bmatrix}\alpha\\\overline{\alpha}\end{bmatrix}$ *mediates an equilibrium between the components* $\begin{bmatrix}\beta\\\overline{\beta}\end{bmatrix}$ *and* $\begin{bmatrix}\gamma\\\overline{\gamma}\end{bmatrix}$*, which is to say that in the world the occurrent* α *effects that the occurrent* β *is succeeded by the occurrent* γ*, while in the antiworld the occurrent* $\overline{\alpha}$ *effects that the occurrent* $\overline{\gamma}$ *is succeeded by the occurrent* $\overline{\beta}$*. The dashed arrows indicate that the successions are not* ***direct*** *transformations.* ■

5.3 Axioms

The EPT has seven axioms; these are supplemented with a number of analytic postulates—the non-formal axioms of the axiomatic system containing the EPT are thus the axioms of the EPT plus these analytic postulates. It has to be taken that the axioms are synthetic propositions, while the analytic postulates merely explicate a meaning that is included in the axioms. For most axioms and postulates, the physical meaning is straightforward from the definition of the language and the interpretation rules in the previous section: this physical meaning will not be written out explicitly in this section. Furthermore, for components $\begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix}, \begin{bmatrix} \beta \\ \overline{\beta} \end{bmatrix} \in G^+$ we have

$$\begin{bmatrix} \alpha + \beta \\ \overline{\alpha} + \overline{\beta} \end{bmatrix} \equiv \begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix} + \begin{bmatrix} \beta \\ \overline{\beta} \end{bmatrix} \tag{5.14}$$

Sums of components, like in Eq. (5.14), will be called *superpositions*. The constant $\begin{bmatrix} 0 \\ 0 \end{bmatrix} \in G^+$, to be interpreted as *physical emptyness*, is the additive identity: algebraically, the binary structure $(G^+, +)$ is thus a commutative monoid.

Remark 5.3.1. To increase readability of this treatise, below the axioms and analytic postulates will be presented in the form of *open formulas*. So, we consider the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution for an arbitrary $n \in Z_N$ and an arbitrary $k \in I_{z(n)}$. ∎

Axiom 5.3.2 (Generalized Existential Axiom)**.**

$$\mathbb{E} \begin{bmatrix} {}^{EP}\varphi_k^n \\ {}^{EP}\overline{\varphi}_k^n \end{bmatrix} \tag{5.15}$$

∎

Remark 5.3.3. Ax. 5.3.2 is **not** an axiom of the EPT in the previously published versions of the EPT. When I formulated the EPT for publication in *Annalen der Physik* and my dissertation, I was of the opinion that ∈-relation (5.15) was an obvious presupposition, for how can one talk about countable processes in a system when it isn't assumed beforehand that the components of the system with which the processes begin exist and are countable? But a post-publication discussion with an analytic philosopher made me realize that I was mistaken to relegate $\in$-relation (5.15) to the realm of presuppositions-not-worth-mentioning: $\in$-relation (5.15) is a proposition about the existence of things in the outside world that is assumed to be true, and as such it is an axiom of the EPT. ■

Analytic Postulate 5.3.4 (Generalized Exclusion Principle)**.**

$$\neg\mathbb{E}\begin{bmatrix} \alpha+\alpha \\ \overline{\alpha}+\overline{\alpha} \end{bmatrix} \qquad \text{for any } \begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix} \in G^+$$

■

Corollary 5.3.5.

$$\neg\mathbb{E}\begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

■

The proof is left as an exercise. The constant $\begin{bmatrix} 0 \\ 0 \end{bmatrix}$ does, thus, not designate a component of the universe to which the existence predicate applies.

Corollary 5.3.6.

$$\mathbb{E}\begin{bmatrix} {}^{EP}\varphi_k^n \\ {}^{EP}\overline{\varphi}_k^n \end{bmatrix} \Rightarrow \begin{bmatrix} {}^{EP}\varphi_k^n \\ {}^{EP}\overline{\varphi}_k^n \end{bmatrix} \neq \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

■

Proof: this follows straight from Ax. 5.3.2 and Cor. 5.3.5. ■

Analytic Postulate 5.3.7.

$$\mathbb{E}\begin{bmatrix} \varphi_1 \\ \overline{\varphi}_1 \end{bmatrix} \wedge \ldots \wedge \mathbb{E}\begin{bmatrix} \varphi_1 \\ \overline{\varphi}_1 \end{bmatrix} \Rightarrow \mathbb{E}\begin{bmatrix} \varphi_1+\ldots+\varphi_n \\ \overline{\varphi}_1+\ldots+\overline{\varphi}_n \end{bmatrix}$$

for any n different generators $\begin{bmatrix} \varphi_j \\ \overline{\varphi}_j \end{bmatrix} \in G$ designating phase quanta. ■

Analytic Postulate 5.3.8.

$$\exists \mathrm{M}_1 \cdots \exists \mathrm{M}_p \begin{bmatrix} {}^{EP}\varphi_k^n \\ {}^{EP}\overline{\varphi}_k^n \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_{\mathrm{M}_1}^n+\ldots+{}^{EP}\mu_{\mathrm{M}_p}^n \\ {}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_1}^n+\ldots+{}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_p}^n \end{bmatrix} \qquad \text{for some } p \in \omega.$$

■

Every extended particlelike phase quantum in our world is thus, for some integer p, a superposition of p extended particlelike matter quanta, and each of these matter quanta is thus the carrier of a monad—recall that the monad itself is a set of invariant properties.

Remark 5.3.9. The value of p in analytic postulate 5.3.8 depends on the value of n and k: $p = p(n, k)$. But that means that the length of the formula also depends on the value of p. So, it can be viewed as a scheme of formulas of different length. It is left as an exercise to capture this scheme in a single closed formula. ■

Axiom 5.3.10 (Generalized Principle of Nonlocal Equilibrium)**.**

$$\begin{bmatrix} {}^{EP}\varphi_k^n \\ {}^{EP}\overline{\varphi}_k^n \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NW}\varphi_k^n \\ {}^{NW}\overline{\varphi}_k^n \end{bmatrix}$$

■

In accordance with Interpretation Rule 5.2.22, Ax. 5.3.10 means that in the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution, an equilibrium occurs between the components $\begin{bmatrix} {}^{EP}\varphi_k^n \\ {}^{EP}\overline{\varphi}_k^n \end{bmatrix}$ and $\begin{bmatrix} {}^{NW}\varphi_k^n \\ {}^{NW}\overline{\varphi}_k^n \end{bmatrix}$. That is, spontaneously a discrete transition ${}^{EP}\varphi_k^n \rightarrow {}^{NW}\varphi_k^n$ takes place in the world, and this is accompanied by a discrete transition ${}^{NW}\overline{\varphi}_k^n \rightarrow {}^{EP}\overline{\varphi}_k^n$ in the anti-world. In the world, the genuinely new occurrent ${}^{NW}\varphi_k^n$ is then created. It has to be taken that every instance of the principle 5.3.10 corresponds with an event causation in the world: the discrete transition ${}^{EP}\varphi_k^n \rightarrow {}^{NW}\varphi_k^n$ (an event) *causes* ${}^{NW}\varphi_k^n$ to come into existence.

Axiom 5.3.11 (Generalized Principle of Particle/Wave Duality)**.**

$$\exists \mathrm{M}_1 \cdots \exists \mathrm{M}_p \begin{bmatrix} {}^{EP}\varphi_k^n + {}^{NW}\varphi_k^n \\ {}^{EP}\overline{\varphi}_k^n + {}^{NW}\overline{\varphi}_k^n \end{bmatrix} = \begin{bmatrix} \psi_{\mathrm{M}_1}^n + \ldots + \psi_{\mathrm{M}_p}^n \\ \overline{\psi}_{\overline{\mathrm{M}}_1}^n + \ldots + \overline{\psi}_{\overline{\mathrm{M}}_p}^n \end{bmatrix} \qquad \text{for some } p \in \omega$$

■

N.B. What has been said in Rem. 5.3.9 also goes here.

Let $p = 1$; reading Ax. 5.3.11 from right to left then yields that the monadic occurrent $\psi_{\mathrm{M}_1}^n$, which carries the monad M_1 from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution, is a superposition of the extended particlelike phase quantum ${}^{EP}\varphi_k^n$ and the nonlocal wavelike phase quantum ${}^{NW}\overline{\varphi}_k^n$ for some $k \in I_{z(n)}$. As we will see, this translates into the idea that a massive system made up of one electron alternates between a particle state and a wave state.

Axiom 5.3.12 (Generalized Principle of Nonlocal Mediation).

$$\begin{bmatrix} {}^{NW}\varphi_k^n \\ {}^{NW}\overline{\varphi}_k^n \end{bmatrix} : \begin{bmatrix} {}^{EP}\varphi_k^n \\ {}^{EP}\overline{\varphi}_k^n \end{bmatrix} \begin{matrix} \dashrightarrow \\ \dashleftarrow \end{matrix} \begin{bmatrix} {}^{NP}\varphi_k^{n+1} \\ {}^{NP}\overline{\varphi}_k^{n+1} \end{bmatrix}$$

■

In accordance with Interpretation Rule 5.2.23, Ax. 5.3.12 means that in the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution, the component $\begin{bmatrix} {}^{NW}\varphi_k^n \\ {}^{NW}\overline{\varphi}_k^n \end{bmatrix}$ mediates an equilibrium between the components $\begin{bmatrix} {}^{EP}\varphi_k^n \\ {}^{EP}\overline{\varphi}_k^n \end{bmatrix}$ and $\begin{bmatrix} {}^{NP}\varphi_k^{n+1} \\ {}^{NP}\overline{\varphi}_k^{n+1} \end{bmatrix}$. That is, in the world the phase quantum ${}^{NW}\varphi_k^n$ effects that ${}^{EP}\varphi_k^n$ is succeeded by ${}^{NP}\varphi_k^{n+1}$, while in the antiworld the phase quantum ${}^{NW}\bar{\varphi}_k^n$ effects that ${}^{NP}\overline{\varphi}_k^{n+1}$ is succeeded by ${}^{EP}\overline{\varphi}_k^n$. It has to be taken that the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^n$ *collapses* into the nonextended particlelike phase quantum ${}^{NP}\varphi_k^{n+1}$.

Axiom 5.3.13 (Generalized Principle of Choice).

$$\begin{bmatrix} {}^{NP}\varphi_k^{n+1} \\ {}^{NP}\overline{\varphi}_k^{n+1} \end{bmatrix} = \begin{bmatrix} f_C(\Theta_k^{n+1}) \\ {}^{NP}\overline{\varphi}_k^{n+1} \end{bmatrix}$$

where $f_C(\Theta_k^{n+1}) = \imath\beta(f_{(\Theta_k^{n+1})^+} : \Theta_k^{n+1} \mapsto \beta)$. ■

By a nonlocal mediation, in the world the genuinely new occurrent ${}^{NP}\varphi_k^{n+1}$ is created. The function of the phase quantum ${}^{NW}\varphi_k^n$ is thus that it causes the succession of the phase quantum ${}^{EP}\varphi_k^n$ by the phase quantum ${}^{NP}\varphi_k^{n+1}$: every instance is thus an *agent causation*. This cannot be reduced to an event causation, because a choice is involved: the nonextended particlelike phase quantum ${}^{NP}\varphi_k^{n+1}$ is *chosen* from the set Θ_k^{n+1} by the nonlocal wavelike phase quantum ${}^{NW}\varphi_k^n$—which is an agent, not an event—by its act of collapsing. This is expressed by the following lemma:

Lemma 5.3.14 (Choice Lemma of the EPT).

$$\begin{bmatrix} {}^{NW}\varphi_k^n \\ {}^{NW}\overline{\varphi}_k^n \end{bmatrix} : \begin{bmatrix} {}^{EP}\varphi_k^n \\ {}^{EP}\overline{\varphi}_k^n \end{bmatrix} \begin{matrix} \dashrightarrow \\ \dashleftarrow \end{matrix} \begin{bmatrix} f_C(\Theta_k^{n+1}) \\ {}^{NP}\overline{\varphi}_k^{n+1} \end{bmatrix}$$

■

Furthermore, the collapse of the nonlocal wavelike phase quantum takes place in the physical world: this is not to be confused with the collapse of the wave function in QM, which takes place in a mathematical space. For example, if we perform a position measurement with outcome x on a quantum system with wave function $|\psi\rangle$, then the wave function $|\ \psi\rangle$ collapses (i.e., discretely transforms) to an eigenstate $|x\rangle$ of position. But this transition $|\psi\rangle \to |x\rangle$ does not correspond to a transition in the physical world whereby a wavelike continuant transforms into a particlelike continuant.

Analytic Postulate 5.3.15.

$$\exists \mathrm{M}_{p+1} \cdots \exists \mathrm{M}_{p+q} \begin{bmatrix} {}^{NP}\varphi_k^{n+1} \\ {}^{NP}\overline{\varphi}_k^{n+1} \end{bmatrix} = \begin{bmatrix} {}^{NP}\mu_{\mathrm{M}_{p+1}}^{n+1} + \ldots + {}^{NP}\mu_{\mathrm{M}_{p+q}}^{n+1} \\ {}^{NP}\overline{\mu}_{\overline{\mathrm{M}}_{p+1}}^{n+1} + \ldots + {}^{NP}\overline{\mu}_{\overline{\mathrm{M}}_{p+q}}^{n+1} \end{bmatrix}$$

for some $q \in \omega$ ■

N.B. Again, what has been said in Rem. 5.3.9 also goes here.

So, the newly created nonextended particlelike phase quantum ${}^{NP}\varphi_k^{n+1}$ consists of q nonextended particlelike matter quanta ${}^{NP}\mu_{\mathrm{M}_{p+1}}^{n+1}, \ldots, {}^{NP}\mu_{\mathrm{M}_{p+q}}^{n+1}$: in a nonlocal mediation a component $\begin{bmatrix} {}^{NW}\varphi_k^{n} \\ {}^{NW}\overline{\varphi}_k^{n} \end{bmatrix}$ thus mediates an equilibrium between a component $\begin{bmatrix} {}^{EP}\varphi_k^{n} \\ {}^{EP}\overline{\varphi}_k^{n} \end{bmatrix}$, constituted of p subcomponents $\begin{bmatrix} {}^{EP}\mu_{\mathrm{M}_i}^{n} \\ {}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_i}^{n} \end{bmatrix}$ and a component $\begin{bmatrix} {}^{NP}\varphi_k^{n+1} \\ {}^{NP}\overline{\varphi}_k^{n+1} \end{bmatrix}$, constituted of q subcomponents $\begin{bmatrix} {}^{NP}\mu_{\mathrm{M}_j}^{n+1} \\ {}^{NP}\overline{\mu}_{\overline{\mathrm{M}}_j}^{n+1} \end{bmatrix}$. The numbers p and q need not be identical: if $p \neq q$, then a nuclear reaction takes place in the world. The opposite is not necessarily true, but if a nuclear reaction takes place then

$$\{\mathrm{M}_1, \ldots, \mathrm{M}_p\} \cap \{\mathrm{M}_{p+1}, \ldots, \mathrm{M}_{p+q}\} = \emptyset \tag{5.16}$$

On the other hand, if no nuclear reaction takes place, then $p = q$ and

$$\{\mathrm{M}_1, \ldots, \mathrm{M}_p\} = \{\mathrm{M}_{p+1}, \ldots, \mathrm{M}_{p+q}\} \tag{5.17}$$

(Recall that $\mathrm{M}_1, \ldots, \mathrm{M}_p, \mathrm{M}_{p+1}, \ldots, \mathrm{M}_{p+q}$ are variables whose values range over the Ω constants $\mathfrak{m}_1, \ldots, \mathfrak{m}_\Omega$ which are to be interpreted as monads. The above two Eqs. are thus valid for the values of the variables for which the axioms and analytic postulates of the EPT are true.)

Axiom 5.3.16 (Generalized Principle of Local Equilibrium).

$$\exists \mathrm{M}_{p+1} \cdots \exists \mathrm{M}_{p+q} \begin{bmatrix} {}^{NP}\varphi_k^{n+1} \\ {}^{NP}\overline{\varphi}_k^{n+1} \end{bmatrix} \begin{matrix} \to \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{LW}\varphi_k^{n+1} + {}^{EP}\mu_{\mathrm{M}_{p+1}}^{n+1} + \ldots + {}^{EP}\mu_{\mathrm{M}_{p+q}}^{n+1} \\ {}^{LW}\overline{\varphi}_k^{n+1} + {}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_{p+1}}^{x+1} + \ldots + {}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_{p+q}}^{x+1} \end{bmatrix}$$

for some $q \in \omega$—cf. Rem. 5.3.9 ■

In accordance with Interpretation Rule 5.2.22, Ax. 5.3.16 means that in the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution, the components $\begin{bmatrix} {}^{NP}\varphi_k^{n+1} \\ {}^{NP}\overline{\varphi}_k^{n+1} \end{bmatrix}$ and $\begin{bmatrix} {}^{LW}\varphi_k^{n+1} + {}^{EP}\mu_{\mathrm{M}_{p+1}}^{n+1} + \ldots + {}^{EP}\mu_{\mathrm{M}_{p+q}}^{n+1} \\ {}^{LW}\overline{\varphi}_k^{n+1} + {}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_{p+1}}^{x+1} + \ldots + {}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_{p+q}}^{x+1} \end{bmatrix}$ are in equilibrium. It has to be taken that upon coming into existence in the world, the nonextended particlelike phase quantum ${}^{NP}\varphi_k^{n+1}$ emits the local wavelike phase quantum ${}^{LW}\varphi_k^{n+1}$ and transforms into the component ${}^{EP}\mu_{\mathrm{M}_{p+1}}^{n+1} + \ldots + {}^{EP}\mu_{\mathrm{M}_{p+q}}^{n+1}$: this can be viewed as a single discrete transition ${}^{NP}\varphi_k^{n+1} \to {}^{LW}\varphi_k^{n+1} + {}^{EP}\mu_{\mathrm{M}_{p+1}}^{n+1} + \ldots + {}^{EP}\mu_{\mathrm{M}_{p+q}}^{n+1}$. In the antiworld, the discrete transition ${}^{LW}\overline{\varphi}_k^{n+1} + {}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_{p+1}}^{x+1} + \ldots + {}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_{p+q}}^{x+1} \to {}^{NP}\overline{\varphi}_k^{n+1}$ in opposite direction takes place.

In case $\begin{bmatrix} {}^{EP}\mu_{\mathrm{M}_{p+1}}^{x+1} + \ldots + {}^{EP}\mu_{\mathrm{M}_{p+q}}^{n+1} \\ {}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_{p+1}}^{x+1} + \ldots + {}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_{p+q}}^{x+1} \end{bmatrix} \neq \begin{bmatrix} 0 \\ 0 \end{bmatrix}$, the genuinely new occurrent ${}^{EP}\mu_{\mathrm{M}_{p+1}}^{x+1} + \ldots + {}^{EP}\mu_{\mathrm{M}_{p+q}}^{n+1}$ is created in the world. And in case $\begin{bmatrix} {}^{LW}\varphi_k^{n+1} \\ {}^{LW}\overline{\varphi}_k^{n+1} \end{bmatrix} \neq \begin{bmatrix} 0 \\ 0 \end{bmatrix}$, in a local mediation the genuinely new occurrent ${}^{LW}\phi_k^{x+1}$ is created in the world. In both cases the principle 5.3.16 thus corresponds with an *event causation* in the world, in which the discrete transition ${}^{NP}\varphi_k^{n+1} \to {}^{LW}\varphi_k^{n+1} + {}^{EP}\mu_{\mathrm{M}_{p+1}}^{n+1} + \ldots + {}^{EP}\mu_{\mathrm{M}_{p+q}}^{n+1}$ (an event) causes the existence of ${}^{LW}\phi_k^{x+1}$ c.q. ${}^{EP}\mu_{\mathrm{M}_{p+1}}^{x+1} + \ldots + {}^{EP}\mu_{\mathrm{M}_{p+q}}^{n+1}$.

Analytic Postulate 5.3.17. Let $\begin{bmatrix} {}^{EP}\mu_{\mathrm{M}_j}^{n+1} \\ {}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_j}^{x+1} \end{bmatrix} \neq \begin{bmatrix} 0 \\ 0 \end{bmatrix}$ for a given monad $\mathrm{M}_j \in \{\mathrm{M}_{p+1}, \ldots, \mathrm{M}_{p+q}\}$; then

$$\exists l \in I_{z(n+1)} \exists \mathrm{M}_{p+q+1} \cdots \exists \mathrm{M}_{p+q+r} \begin{bmatrix} {}^{EP}\mu_{\mathrm{M}_j}^{n+1} \\ {}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_j}^{x+1} \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_{\mathrm{M}_{p+q+1}}^{n+1} \\ {}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_{p+q+1}}^{x+1} \end{bmatrix} \wedge$$

$$\begin{bmatrix} {}^{EP}\varphi_l^{n+1} \\ {}^{EP}\overline{\varphi}_l^{n+1} \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu_{\mathrm{M}_{p+q+1}}^{n+1} + \ldots + {}^{EP}\mu_{\mathrm{M}_{p+q+r}}^{n+1} \\ {}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_{p+q+1}}^{x+1} + \ldots + {}^{EP}\overline{\mu}_{\overline{\mathrm{M}}_{p+q+r}}^{x+1} \end{bmatrix}$$

And again, what has been said in Rem. 5.3.9 also goes here. ■

So, this analytic postulate means that if the monad M_j is carried at the $(n+1)^{\text{th}}$ degree of evolution in the world by an extended particlelike matter quantum ${}^{EP}\mu^{n+1}_{\mathrm{M}_j}$, then this nonextended particlelike matter quantum is *always* a part of an extended particlelike phase quantum. That is, for some $l \in I_{z(n+1)}$, the matter quantum ${}^{EP}\mu^{n+1}_{\mathrm{M}_j}$ is always one of the matter quanta in a superposition ${}^{EP}\mu^{n+1}_{\mathrm{M}_{p+q+1}} + \ldots + {}^{EP}\mu^{n+1}_{\mathrm{M}_{p+q+r}}$ that forms the extended particlelike phase quantum ${}^{EP}\varphi^{n+1}_l$ at the $(n+1)^{\text{th}}$ degree of evolution in the l^{th} process from the $(n+1)^{\text{th}}$ to the $(n+2)^{\text{th}}$ degree of evolution.

Axiom 5.3.18 (Generalized Principle of Formation of Space)**.**

$$\mathbb{E}\begin{bmatrix} {}^{S}\varphi^{n+1}_k \\ {}^{S}\overline{\varphi}^{n+1}_k \end{bmatrix} \Rightarrow \mathbb{E}\begin{bmatrix} {}^{LW}\varphi^{n+1}_k \\ {}^{LW}\overline{\varphi}^{n+1}_k \end{bmatrix}$$

■

Ax. 5.3.18 means that the existence of $\begin{bmatrix} {}^{S}\varphi^{n+1}_k \\ {}^{S}\overline{\varphi}^{n+1}_k \end{bmatrix}$ *requires* the existence of $\begin{bmatrix} {}^{LW}\varphi^{n+1}_k \\ {}^{LW}\overline{\varphi}^{n+1}_k \end{bmatrix}$. The idea is that a genuinely new occurrent ${}^{S}\varphi^{n+1}_k$ is formed continuously—not at once—from the phase quantum ${}^{LW}\phi^{n+1}_k$. But the existence of the latter is not sufficient: there are local wavelike phase quanta that do not form spatial phase quanta.

Remark 5.3.19. In general, the inference rules

$$\mathbb{E}\begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix}, \begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} \beta \\ \overline{\beta} \end{bmatrix} \vdash \mathbb{E}\begin{bmatrix} \beta \\ \overline{\beta} \end{bmatrix} \tag{5.18}$$

$$\mathbb{E}\begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix}, \mathbb{E}\begin{bmatrix} \beta \\ \overline{\beta} \end{bmatrix}, \begin{bmatrix} \beta \\ \overline{\beta} \end{bmatrix} : \begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix} \begin{matrix} \dashrightarrow \\ \dashleftarrow \end{matrix} \begin{bmatrix} \gamma \\ \overline{\gamma} \end{bmatrix} \vdash \mathbb{E}\begin{bmatrix} \gamma \\ \overline{\gamma} \end{bmatrix} \tag{5.19}$$

are valid. On account of these inference rules, existential predictions can be derived from the EPT. ■

This concludes the axiomatic introduction of the EPT. The four generalized process-physical principles 5.3.10, 5.3.12, 5.3.16, and 5.3.18 are causal laws: all other causal laws are hereby rejected as invalid at the supersmall scale. The generalized existential axiom 5.3.2, the generalized principle of choice 5.3.13, and the generalized principle of duality 5.3.11 are not causal laws, but are still synthetic propositions.

5.4 Discussion

Particle/wave duality

Theorem 5.4.1 (Individually existing dual parts).
Let the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution be a process in which only one monad M_1 is carried from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution; then

$$\mathbb{E}\begin{bmatrix} \psi^n_{\mathrm{M}_1} \\ \overline{\psi}^n_{\overline{\mathrm{M}}_1} \end{bmatrix} \Rightarrow \mathbb{E}\begin{bmatrix} {}^{EP}\mu^n_{\mathrm{M}_1} \\ {}^{EP}\overline{\mu}^n_{\overline{\mathrm{M}}_1} \end{bmatrix} \wedge \mathbb{E}\begin{bmatrix} {}^{NW}\varphi^n_k \\ {}^{NW}\overline{\varphi}^n_k \end{bmatrix}$$

■

Proof: The proof is omitted. ■

The condition assumed in Th. 5.4.1, that only one monad is carried in the mentioned process, means that it is assumed that the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution is such that the generalized principle of particle/wave duality, Ax. 5.3.11, holds with $p = 1$ for this process. Now recall from Sect. 3.2 that under this condition, a state of a temporal part of a monadic occurrent can be viewed as a state of a massive system made up of one indivisible component—this can be an electron, a positron, or, if we want to treat (anti)protons and (anti)neutrons as indivisible, a free nucleon. Th. 5.4.1 thus translates to the view that a massive system made up of one indivisible component will occur both in a particle state and in a wave state in each elementary process of its temporal evolution. Ergo, in the framework of the EPT an electron has countably many times a definite position in absence of observation.

Th. 5.4.1 can be generalized to elementary processes in which a number p of monads $\mathrm{M}_1, \ldots, \mathrm{M}_p$ are carried from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution. To put things in perspective this is a good time to reflect back on the principle of gravity of p. 92: in Ch. 3 we have argued that repulsive gravity is possible in a universe where massive systems go through cycles of ground state, transition state, and excited state. The EPT thus provides the precise mechanism, and the above theorem guarantees that both the ground state and the transition state exist.

Proposition 5.4.2 (Incompatibility of the EPT and orthodox QM).
Let the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution be a process in which only one monad M_1 *is carried from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution; then the implication*

$$\mathbb{E}\begin{bmatrix} \psi^n_{\mathrm{M}_1} \\ \overline{\psi}^n_{\overline{\mathrm{M}}_1} \end{bmatrix} \Rightarrow \neg\mathbb{E}\begin{bmatrix} {}^{EP}\mu^n_{\mathrm{M}_1} \\ {}^{EP}\overline{\mu}^n_{\overline{\mathrm{M}}_1} \end{bmatrix} \tag{5.20}$$

is false. ■

Proof: Implication (5.20) is a contraposition of Th. 5.4.1. ■

In the framework of orthodox QM (OQM), a quantum system can behave like a particle or like a wave depending on which properties we measure, but it is not the case that this dual nature derives from individually existing parts of the quantum system: the quantum system is *indivisible.* Now recall from Sect. 1.1 that such an indivisible quantum system does not have a definite position in absence of observation due to the Berkeleyan idealism regarding properties. This is an essential feature of OQM, which can be expressed in the framework of the EPT by implication (5.20). Suppose, namely, that we consider a monadic occurrent *in absence of observation*: if its temporal parts could be viewed as a 'quantum system' as in OQM, then

(i) the monadic occurrent would not have a definite position at any point in its time span;

(ii) the monadic occurrent would not have a temporal part that can be identified with an extended particlelike matter quantum, because the latter does have a definite position in violation of (i) above.

That yields the implication (5.20). But this implication is *false* in the framework of the EPT.

That means that the EPT is fundamentally incompatible with orthodox QM. The root cause of this incompatibility lies at the conceptual level: in the framework of the EPT a monadic occurrent has both particlelike and wavelike temporal parts, whereas in the framework of orthodox QM a quantum system going through time does not spontaneously become a purely particlelike continuant in absence of observation.

Proposition 5.4.3 (Incompatibility of the EPT and classical mechanics).
Let the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution be a process in which only one monad M_1 *is carried from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution; then the implication*

$$\mathbb{E}\left[\begin{array}{c}\psi^n_{\mathrm{M}_1}\\ \overline{\psi}^n_{\overline{\mathrm{M}}_1}\end{array}\right] \Rightarrow \neg\mathbb{E}\left[\begin{array}{c}{}^{NW}\varphi^n_k\\ {}^{NW}\overline{\varphi}^n_k\end{array}\right] \tag{5.21}$$

is false. ■

Proof: Implication (5.21) is a contraposition of Th. 5.4.1. ■

In classical mechanics (including GR), the view is incorporated that a particle is and remains a particle at every point of its worldline: at no point in time does the particle spontaneously transform into a wave. This is an essential feature of classical mechanics, which can be expressed in the framework of the EPT by implication (5.21). Suppose, namely, that we consider a monadic occurrent: if its temporal parts could be viewed as a massive system made up of a "classical" particle, then

(i) the monadic occurrent would be localized at a definite position at every point in its time span;

(ii) the monadic occurrent would not have temporal parts that can be identified with the temporal parts of an nonlocal wavelike phase quantum, because the latter are not localized at a definite position in violation of (i) above.

That yields the implication (5.21). But this implication is *false* in the framework of the EPT.

That means that the EPT is fundamentally incompatible with classical mechanics, and thus also with GR. The root cause of this incompatibility lies again at the conceptual level: in the framework of the EPT a monadic occurrent has both particlelike and wavelike temporal parts, whereas in the framework of classical mechanics a massive system made up of a single particle that goes through time does not spontaneously become a wavelike continuant. The EPT should thus not be mistaken for an attempt to unify GR and QM. Instead, the EPT is a proposal for a *unifying scheme*: this will be precisely defined in part IV.

Established laws in the framework of the EPT

Proposition 5.4.4 (General Principle of Relativity)**.**
The EPT satisfies the general principle of relativity in the sense that the generalized principles of the EPT are the same for all observers. ■

Proof: The following four statements hold:

(i) a degree of evolution is the same for all observers;

(ii) the kind of a phase quantum is the same for all observers;

(iii) the generalized principles, laid down in the EPT, do not depend on the numbering of the individual processes;

(iv) the generalized principles, laid down in the EPT, do not depend on the numbering of the matter quanta.

From this it follows that the generalized principles of the EPT are the same for all observers, and the EPT hence satisfies the general principle of relativity. ■

N.B. This general principle of relativity is not formulated exactly, that is, word for word, the same as the general principle of relativity formulated by Einstein:

> "*the laws of physics must be of such a nature that they apply to systems of reference in any kind of motion*"—Einstein (1916).

But because of the similarity in intended meaning, the same name is given to the present principle.

Proposition 5.4.5 (Compatibility with Special Relativity)**.**
The EPT agrees with SR. ■

Proof: In Part IV a model of the EPT is fully specified, in which both the EPT and SR are valid. ■

Proposition 5.4.6 (Law of conservation of energy)**.**
In the elementary processes described by the EPT, energy is conserved. ■

Proof: Let M be the monoid introduced in Def. 5.2.5, and let π be a function on M such that we have

$$\pi : \begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix} \mapsto \alpha \tag{5.22}$$

for any $\begin{bmatrix} \alpha \\ \overline{\alpha} \end{bmatrix} \in G^+$—ergo, π is a projection that maps an element of M to the entry in its upper row. Let $\mathcal{O}$ be an arbitrary observer, and let $E_{\mathcal{O}}(.)$ be a real-valued function on the image set $\pi[M]$ such that $E_{\mathcal{O}}(\alpha)$ can be interpreted as the energy of the constituent of the outside world designated by α in the reference frame of $\mathcal{O}$. We then have the following for any $n \in Z_N$ and for any $k \in I_{z(n)}$:

(i) The extended particlelike phase quantum made up of p extended particlelike matter quanta, with which the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution begins, has positive energy:

$$E_{\mathcal{O}}({}^{EP}\varphi_k^n) = E_{\mathcal{O}}({}^{EP}\mu^n_{\mathrm{M}_1} + \ldots + {}^{EP}\mu^n_{\mathrm{M}_p}) > 0 \tag{5.23}$$

(ii) Upon the transition $E_{\mathcal{O}}({}^{EP}\varphi_k^n) \to E_{\mathcal{O}}({}^{NW}\varphi_k^n)$, the nonlocal wavelike phase quantum has at least as much energy as the extended particlelike phase quantum from which it has arisen:

$$E_{\mathcal{O}}({}^{NW}\varphi_k^n) \geq E_{\mathcal{O}}({}^{EP}\varphi_k^n) \tag{5.24}$$

In case $E_{\mathcal{O}}({}^{NW}\varphi_k^n) > E_{\mathcal{O}}({}^{EP}\varphi_k^n)$ it has to be taken that the excess energy is absorbed from the surroundings when the discrete transition $E_{\mathcal{O}}({}^{EP}\varphi_k^n) \to E_{\mathcal{O}}({}^{NW}\varphi_k^n)$ took place.

(iii) Energy is conserved at the collapse of the nonlocal wavelike phase quantum into a nonextended particlelike phase quantum:

$$E_{\mathcal{O}}({}^{NP}\varphi_k^{n+1}) = E_{\mathcal{O}}({}^{NW}\varphi_k^n) \tag{5.25}$$

(iv) Energy is conserved at the decay of the nonextended particle phase quantum into a local wavelike phase quantum and a superposition of

q extended particlelike matter quanta:

$$E_{\mathcal{O}}({}^{NP}\varphi_k^{n+1}) = E_{\mathcal{O}}({}^{LW}\varphi_k^{n+1}) + E_{\mathcal{O}}({}^{EP}\mu_{\mathrm{M}_{p+1}}^{n+1} + \ldots + {}^{EP}\mu_{\mathrm{M}_{p+q}}^{n+1}) \quad (5.26)$$

(v) The superposition of q extended particlelike matter quanta, with which the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution ends, has positive or zero energy:

$$E_{\mathcal{O}}({}^{EP}\mu_{\mathrm{M}_1}^{n+1} + \ldots + {}^{EP}\mu_{\mathrm{M}_q}^{n+1}) \geq 0 \quad (5.27)$$

In case the energy is zero, it has to be taken that an annihilation reaction has taken place: all initial energy is then emitted in the form of a local wavelike phase quantum (which may consist of two photons).

N.B. Strictly speaking, these laws of conservation of energy are not a part of the EPT, nor can they be derived from the EPT—note that the function $E(.)_{\mathcal{O}}$ is not a part of the language. So, the above laws of conservation of energy have to be seen as *additional analytic postulates.* Furthermore, while the above expressions hold for any observer $\mathcal{O}$, for two *different* observers $\mathcal{O}$ and $\mathcal{O}'$ we do not necessarily have $E_{\mathcal{O}}(\alpha) = E_{\mathcal{O}'}(\alpha)$ for a material object designated by α! ■

In an elementary process, energy is thus only once absorbed and only once emitted: the EPT therefore corresponds to the idea that there is only one cosmic interaction, of which gravitation and electromagnetism are but aspects. In the framework of the EPT there is thus no such thing as an electromagnetic interaction or a gravitational interaction: there are only electromagnetic and gravitational aspects of a single cosmic interaction. The EPT is thus not a theory of this cosmic interaction, but rather a theory of the elementary processes by which this cosmic interaction has to take place in order for repulsive gravity to exist. The degree of abstractness adds a feature of generality to the EPT: the process-physical principles of the EPT apply to the components involved regardless of their position, mass, momentum, etc. In addition, even though the formalism of the EPT may look cumbersome, at this degree of abstractness the process-physical principles of the EPT are of great simplicity: the workings of the universe would thus be a lot simpler if gravitation would not be attraction only.

Analytic-philosophical aspects

By viewing the EPT as an abstract physical theory—as has been done in Sect. 5.1—a number of philosophical views are taken implicitly. This section makes those views explicit and compares them to the philosophical literature: as such, this section falls under analytic philosophy.

For starters, viewing the EPT as an abstract physical theory means that the EPT is viewed as a theory that lays bare the true nature of the physical universe in a number of abstract first principles. If we look at the method of development, then what we have is that the EPT has been developed by Hegelian dialectics—see Sect. 3.4. That means that implicitly the view is taken that this method can lead to knowledge of the outside world: this entails acceptance of Hegel's view, that the truth can be attained by a finite number dialectic cycles. A nuance here is that the starting point is a clear and distinct idea: the view here is thus that the development of *that idea* by means of Hegelian dialectics can lead to knowledge of the outside world. Additional philosophical views that have been developed from the confrontation with Kant's work, in particular the view on how a clear and distinct idea can *at all* be a source of knowledge of the outside world, are treated separately in Part IV.

Furthermore, by viewing the EPT as an abstract physical theory implicitly the view is taken (i) that there actually is a physical universe, independent of whether or not anyone may be perceiving it in one way or another, and (ii) that the true nature of this universe can be laid down in abstract first principles. This is a view that is close to what Sachs called 'abstract realism' (1988). Furthermore, since the EPT has been developed from a clear and distinct idea about the fundamental workings of a universe *with repulsive gravity*, a first experimental test of the EPT is measuring the interaction of massive antiparticles with the gravitational field of bodies of ordinary matter: if it would be established that gravity is attraction only, then the EPT has been developed from a falsehood and should be rejected.

In addition, by viewing the EPT as an abstract physical theory implicitly the view is taken the EPT is *experimentally testable*. That immediately raises the question *how* the EPT is testable. What we have is that the general method for testing derives from the methodology of research programs described by Lakatos (1970):

(i) the EPT is the hard core of a research program;

(ii) a concrete mathematical model of the EPT has to be developed, which in Lakatos' terminology has the status of a collection of auxiliary hypotheses;

(iii) from that model predictions can be derived that are testable by means of an experiment.

This research program is treated in Part IV. Furthermore, due to the degree of abstractness of the EPT it is not possible to prove that the EPT "corresponds" to currently accepted theories by proving that the EPT reduces to contemporary theories upon applying some limitation procedure. So, this whole view that any 'new physics' has to satisfy the condition that it formally reduces to 'old physics' is rejected as a widely held misconception—the fact that this view is so widely held among theorists may even be the very reason that little to no advancement has been made in the foundations of physics since the 1920's. Of course it must be shown that the EPT agrees with knowledge that derives from the successful predictions of modern physics, but for that matter a weak correspondence principle is sufficient: this will be presented in detail in Part IV.

Next, it is a fact that five of the seven axioms of the EPT are (generalized) $\in$-relations. So viewing the EPT as a *fundamental* theory implicitly entails a departure from the view, widely held among physicists, that the fundamental laws of physics need to be expressed in the form of *equations*—in particular, it's a departure from the view that the most fundamental equation of physics has to define the Lagrangian of a unified field. Furthermore, fundamentality of the EPT entails the view that the generalized process-physical principles were already valid in the era in the history of the universe *before* there were interactions. Therefore, the EPT should in particular be applicable to describe the Planck era; see Part IV for speculation on the Planck era of the universe.

It is important to understand, however, that the views referred to in this section are general philosophical views that have been taken *implicitly* during the development of the EPT. It is, thus, **not** the case that the EPT has been developed (in the sense of 'deduced') from these views.

5.5 Objections and replies

Objection 5.5.1. "*The Editor has decided to reject your paper without inviting a resubmission.*"—Editorial Assistant of a top philosophy journal specializing in short papers, rejecting my submitted paper (Cabbolet, 2019a), which presents the pluralist view of theories of Sect. 5.1 ■

Reply 5.5.2. The objection here is that the pluralist view on theories is not worthy of further consideration—that's what a rejection means. Everyone is entitled to his own opinion, but that's what it is—a personal opinion. ■

Objection 5.5.3. "*I am sorry to report that [your paper] is not well suited for publication in [our journal]. The paper is much shorter than our typical research articles, and as a consequence, the analysis is less developed. In addition, the paper never discusses what is at stake in the debate under consideration. In these ways, the potential impact of the paper is undercut.*"—Editor-in-Chief of a tier-1 journal in philosophy of science, rejecting my submitted paper on the pluralist view of theories ■

Reply 5.5.4. This objection presents two arguments against the submitted paper: the shortness of the paper, and the lack of an explanation of what the debate on the meaning of 'theory' is about. First of all, note that the two arguments have nothing whatsoever to do with the new idea actually presented in the paper—to wit: the pluralist view on theories. That being said, the shortness of a paper is in itself not a valid argument. To see that, imagine that the editor of Nature would have replied the following to the ground-braking two-page paper (Watson and Crick, 1953):

> *Dear Dr. Watson, Dr. Crick,*
> *I am sorry to report you that your paper on the double helix structure of DNA is not well suited for publication in Nature. The paper is much shorter than our typical research articles, and as a consequence, the analysis is less developed.*

Just think about it. As to the analysis, in my opinion a paper introducing a new idea has to be distinguished from the papers that chew on the same old ideas over and over again. For a paper in the latter category a highly differentiated analysis is required to be able to contribute to the discourse. But for a paper in the first category it is, I believe, sufficient to address the things that first come to mind: for existing ideas those things have already been discussed, but not so for a new idea.

The second argument is a non-argument: the question "what is at stake in the debate on the meaning of 'theory'?" is a no-brainer—it goes without saying that what is at stake is a criterion by which a body of statements can be called a 'theory', which is generally seen as a positive value. When I submitted the paper, I believed that this was so obvious that I saw no need to mention it explicitly. But after Obj. 5.5.3, I added a sentence to that extent to the preprint that I uploaded to philpapers.org (2019a)—that one sentence is the only difference with the paper submitted to the journal meant above. ■

Objection 5.5.5. "*The author's way of arguing for pluralism seems to make every scientific statement a theoretical statement. If the qualifications are that the there's a scientific justification for application of the term 'theory', that 'theory' is primitive, and that there's no uniform set of criteria for application of 'theory,' then it seems that statements of data can be theory. ... The author's way out of that is to say not every statement is scientific. But then it's not clear why it isn't that every scientific statement is a theory.*"—anonymous referee of a philosophy journal, rejecting my submitted paper on the pluralist view of theories ■

Reply 5.5.6. The referee alleges that the pluralist view is the same as saying that every scientific statement is a theory. So, the referee alleges that the pluralist view is actually the monist view that there is a uniform set of criteria—in casu the single criterion that a statement has to be scientific—such that every body of statements that satisfies the criteria is a theory. But the pluralist view is precisely denying that such uniform set of criteria exists. This is a straw man argument—what the referee rejects is his own false metaphor.

Of course it goes without saying that the definition of the pluralist view is not meant to imply that statements of data can be called a 'theory'. But to the defense of the referee, that was not mentioned explicitly in the submitted paper: clause (i) on page 196—stating that the predicate 'theory' only applies to explanantia—was absent, so if one wants to split hairs one can indeed make that objection. The addition of clause (i) thus invalidates the objection that a series of statements of data can be called a 'theory'.

So, I resubmitted the paper with the extra clause added to the definition of the pluralist view, so that the objection no longer applied. However, the editor of the journal replied that "the Journal does not accept resubmissions of papers that have been previously rejected." ■

Having treated objections against the pluralist view on theories, I'll proceed with objections against the EPT. These are grouped as follows:

(i) objections against viewing the EPT as a theory;

(ii) objections against viewing the EPT as a scholarly work;

(iii) objections against viewing the EPT as physics;

(iv) objections against principles of the EPT.

I'll treat the objections per group.

Objections against viewing the EPT as a theory

Objection 5.5.7. "*That he 'has developed a theory' is simply nonsense*"—'t Hooft, commenting about my work in the widely-read popular science journal *Eos* (Botte, 2014) ■

Objection 5.5.8. "*It is downright pretentious to call this work a new physical theory when there is so little evidence that the theory can adequately describe known physical phenomena and can explain more than the established theories.*"—Kees van Hee, commenting on my work in an unpublished pamphlet that he had circulated behind closed doors (2008a) ■

Reply 5.5.9. The EPT is a *theory* from the perspective of the syntactic view on theories: that's an objective fact and it's true even if one doesn't like it—see Sect. 5.1. But I can tell you where these two objections are coming from. 't Hooft and Van Hee have never heard of the syntactical or the semantical views on theories: all they know is the usage of the word 'theory' in the sciences as an abbreviation of the term 'scientific theory', which refers to an explanans—a body of statements that can be used to explain phenomena—that *has already been* tested and widely accepted as valid. And they've seen that my work has neither been tested nor accepted and so they have concluded that it is not a theory *in the above sense.* That assessment is true, but the crux is that I have never claimed to have developed a theory *in that sense.* ■

Objection 5.5.10. "*I'm not a physicist, but also in the physics part I have found nothing of any value ... The way he develops a 'new theory' is clumsy, and insufficient, and wrong. I wonder whether the author is honest. I mean: we see that this is nonsense. But it seems to me that he is aware of that too.*"—Brouwer, commenting on my 2007 concept-dissertation (2008b) ■

Reply 5.5.11. First a remark: with "the way he develops a new theory" Brouwer means "the way he introduces a new theory". The objection here is thus that the EPT has not correctly been introduced as a theory. And not only that: the three sentences from "I wonder whether ..." to "... aware of that too" are nothing but a thinly veiled accusation of intentional deceit: what he insinuates is that I have submitted the concept-dissertation despite of the fact that I was aware that the EPT was not correctly introduced. That said, these are outright fabrications by Brouwer which have been passed off as "facts" about my work: as a theory the EPT has been correctly introduced. ■

Objection 5.5.12. "*The fact that a new theory is sought which may yield a world view that differs widely from the presently accepted one, does absolutely not mean that you therefore have to take every haphazard attempt at a theory into consideration.*"—Gerard 't Hooft, defending his hostile attitude towards my work in an untitled pamphlet (2008a). ■

Reply 5.5.13. For once I agree with 't Hooft. But the EPT ***is*** a theory, not a haphazard attempt at a theory. And never asked anyone to take every haphazard attempt at a theory into consideration. ■

Objection 5.5.14. "*Cabbolet's theory had a high score on the Baez crackpot index.*"—Reinier Post, coworker of Eindhoven University of Technology, contributing to the online encyclopedia Wikipedia (2008) ■

Reply 5.5.15. While we may think of Van Joolingen's comment on p. 141 as a very short opinion piece—we don't have to think highly of it—Obj. 5.5.14 is demonstrably a false statement of fact, which Post passed off as encyclopedic "knowledge" about my work on Wikipedia.

For those not familiar with it: the 'crackpot index' has been introduced by the physicist John Baez in a satirical piece, which can be found at his university homepage. These days there are many (probably thousands) pamphlets circulating on the internet, in which revolutionary physical claims are made by individuals without any background in science—e.g. with a high-school education only. The Baez crackpot index then provides a method to stigmatize these pamphlets (or the theories c.q. claims therein) with an integer-valued rating—its *score on the Baez crackpot index*. The point is that these pamphlets contain elementary mistakes, and Baez has identified the most common ones: making this mistake can be rated with 10 points, making that mistake can be rated with 20 points, etc. So, the more mistakes and the more serious the mistakes, the higher the score on the Baez crackpot index. So, saying that a theory has a high score on the Baez crackpot index is equivalent to saying that the theory contains many gross errors—it is needless to say that an accusation of gross incompetence at the address of the author of the theory is then implied. Fact of the matter is that my work has a score of -5 on the Baez crackpot index. ■

Objection 5.5.16. "*It was a little bit blunt but I still stand behind it.*"—Reinier Post, publicly maintaining objection 5.5.14 even after an independent committee had judged that it violated basic principles of good scientific practice (Konings, 2008c) ■

Reply 5.5.17. This is exemplary evidence supporting the proposition that the archetypical pseudoskeptic will stick to his allegations even when confronted with conclusive proof to the contrary—as in the Biblical proverbs, like a dog back to his own vomit, or like a washed sow back to the mud pool (2 Pet. 2:22). Other pseudoskeptics featured in this monograph will not behave differently: not a single one of them will ever admit any wrongdoing, or will ever retract anything. ■

Objection 5.5.18. "*substandard*"—Robbert Dijkgraaf, former PhD student of 't Hooft and then president of the Royal Dutch Academy of Sciences, commenting on the EPT in (Dzikanowice, 2012) ■

Reply 5.5.19. Dijkgraaf labels the EPT with the pejorative 'substandard' in a national newspaper in Belgium, but without specifying which aspects of the work are substandard and why they are substandard. This is pseudoskepticism: making negative claims about someone else's work without satisfying the burden of proof that these claims require. In fact, I have compiled seven tell-tale signs of pseudoskepticism in an essay (2018d): the use of pejoratives is one of them. ■

Objections against viewing the EPT as a scholarly work

Objection 5.5.20. "*Our moderators have decided that a new article that combines the already published articles would not be accepted in arXiv.*"—arXiv administrator, replying to my question whether or not they would allow a preprint that combines my three papers in *Annalen der Physik* (as this chapter does) on arXiv.org (2018) ■

Reply 5.5.21. I have to admit that the preprint repository arXiv.org as originally intended may be the best idea in the history of scientific publication. However, after an initial period during which everyone could upload preprints to arXiv.org, a moderation system has been installed: as a result, there are now anonymous 'moderators' who have the right to remove any submissions uploaded to the repository for reasons that they do not have to disclose. Now of course, arXiv.org is a private initiative and by no means are they obliged to publish any of the uploaded preprints, including mine. But nevertheless, the growth of the repository and the developments in its management have led to the present situation that on the one hand arXiv.org has become the single most important venue for disseminating research results, while on the other hand submissions to arXiv.org are screened by a *central censorship committee*. Now arXiv.org will deny that there is any censorship, but the moderators do form a committee that limits the ideas that people are allowed to express and that has the authority to prevent documents from being made available to the public because they include or support certain ideas: that satisfies the definition of 'censorship' in the Cambridge English dictionary. So in spite of all good intentions, the sad reality is that this screening not only weeds out nonsensical preprints uploaded by amateurs: also unconventional preprints uploaded by professionals are removed at the discretion of the central censorship committee. It is therefore my opinion that ever since the installation of the moderation system, arXiv.org has moved further and further away from the ideal picture of a forum for an open discussion of new ideas.

While there is not a shadow of doubt in my mind that my opponents will be delighted when they learn of arXiv.org's attitude as expressed by objection 5.5.20, a detection of repulsive gravity might lead a future community to agree with me that the present situation—i.e. the situation in which it is not only the case that one publication venue has become more influential than all others combined, but in which it is also the case that submissions to that most influential publication venue are screened by a central censorship committee—is so far away from the ideal picture that it can actually be called a dystopian situation. That is say: a detection of repulsive gravity might lead a future community to see the need for reforms in scientific publication. An idea for such reforms, to be implemented in Europe, is the following:

(i) every European research institute has its own repository for preprints;

(ii) every upload to the repository has standard metadata, for example: title, abstract, author(s), affiliation(s), date stamp, topic;

(iii) it is at the discretion of the research institutes themselves who is authorized to upload preprints on a given topic;

(iv) anyone who uploads a preprint has to check a box, thereby guaranteeing that the preprint does not amount to Type I Scientific Misconduct or Type II Scientific Misconduct as defined in (Cabbolet, 2014d);

(v) violations of the previous clause can be reported by anyone to the committee for scientific integrity of the authors' institute, and appeals to decisions by such committees should be filed to a European committee for scientific integrity where the appeal shall be treated by unrelated scientists from unrelated countries;

(vi) a central abstract service publishes the metadata of all new uploads on its website on a daily basis—the metadata can be ordered by topic;

(vii) the abstract service does not have the right to reject the metadata of any uploaded preprint for publication;

(viii) individuals who have subscribed to a mailing list for a given topic receive a file with the metadata of all preprints on that topic.

This way the good things of arXiv.org are kept—free and immediate dissemination of research results—but power is *decentralized*: there is no central censorship committee. However, there is no point in realizing this idea unless European institutes are *forced* to use the venue, e.g. by making it a *conditio sine qua non* for receiving government funding. ■

Objection 5.5.22. "*Papers that lie outside the mainstream of current research must justify their publication by including a clear and convincing discussion of the motivation for the new speculation, with reasons for introducing any new concepts. ... **If the new formulation results in contradictions with the accepted theory, then there must be ... an analysis showing that the new theory is consistent with all existing experiments**. Upon reading your manuscript, I conclude that your paper fails to satisfy all of these requirements.*" (emphasis added)—editor of a top physics journal, replying in 2009 to my question whether the paper introducing the EPT, later published in *Ann. Phys.* (after revise and resubmit), would be publishable in that journal ■

Reply 5.5.23. We can take this as an objection against the EPT plus the additional results presented in the preceding sections of this chapter: although the submitted paper—just like the paper submitted to *Anal. Phys.*—did not contain these additional results, this objection would apply even if it would have contained these additional results.

That said, for any paper introducing a new theory one may of course be dissatisfied by the proof provided in the paper that the new theory applies to existing real-world problems. But the point here is the preposterous demand that for a new theory to be publishable, the condition has to be satisfied that it must have been proven that the new theory is consistent with every experiment ever done. That is pseudoskepticism: there is not a single paper in the history of physics that satisfies this requirement. Consider Edward Witten's famous paper on M-theory (1995), which contradicts accepted theories regarding the dimensionality of spacetime, and imagine the editor of *Nucl Phys. B.* having replied to Witten:

> "*Dear Dr. Witten,*
> *we have received your paper on M-theory. However, upon reading we conclude that your paper fails to satisfy the requirement that there must be an analysis showing that M-theory is consistent with all existing experiments. Therefore, we reject your paper.*"

Just think about it. Concluding, this demand may be a criterion for *acceptability* of a new theory, but if we apply it as a criterion for *publishability* then Witten's paper would not have been published. ■

Objection 5.5.24. "*A PhD graduation on this theme at Tilburg University would in itself already be a caricature, and Tilburg University—just like the TU/e—would disqualify itself as a research institute on the basis of this dissertation .*"—Kees van Hee, commenting on my work in yet another unpublished pamphlet (2008a) ■

Objection 5.5.25. "*Cabbolet's PhD graduation? The TU/e and Tilburg University should be ashamed of themselves. ... Unbelievable! What a blooper.*"—Frank Witte, then lecturer at Utrecht University, commenting on my work under the pseudonym 'Darth Tutor' on the widely-read forum of the Dutch national newspaper *De Volkskrant* in 2008 ■

Reply 5.5.26. Make no mistake: these are two attempts at convincing an audience of the preconceived opinion that the EPT does not have to be viewed as a scholarly work, but rather as the work of a crackpot who doesn't know the first thing about mathematics, physics, the scientific method, etc. And as such, each of the above two objections is a case of pseudoskepticism. ■

Objection 5.5.27. "*Cabbolet also made an appeal to the 'lengthy study' that preceded the manuscript: a period of 10 years, whereas a PhD graduate usually gets four years for his PhD work.*"—Fred Lambert, adding encyclopedic "knowledge" about my reply to the criticisms of my work to Wikipedia (2008) ■

Reply 5.5.28. Make no mistake: with this statement Lambert wants to insinuate that I claimed that the EPT is true *because* I worked on it for a long time. If true, that would mean that the EPT is the work of a crackpot who doesn't know the first thing about the scientific method. But this is an outright fabrication by Lambert. I never made such a claim, but note that Lambert uses quotation marks to insinuate that I did.

The free online encyclopedia Wikipedia is a very interesting development, but on the downside it cannot be denied that it is currently abused as a forum for smearing anyone who in any way challenges the orthodoxy—it has become an instrument for the Mill's *tyranny of the prevailing opinion.* (It also has become a PR forum for American scientists.) ■

Objection 5.5.29. "*I think that this messing around with axioms is, viewed from the perspective of mathematical logic, barely at the level of a master's thesis*"—Nienhuys, commenting on the EPT (2015) ■

Reply 5.5.30. Just imagine *Philos. Trans. Royal Soc.* in the 1830's responding as follows to Hamilton's celebrated *General Method in Mechanics*:

> *Dear Dr. Hamilton,*
> *We have read your submission, but this messing around with differential and variational equations is, viewed from the perspective of mathematics, barely at the level of a master's thesis. Any master's student can easily prove that your function $\mathcal{H}$ is conserved if it is defined in terms of the Lagrangian $\mathcal{L}(q_i, \dot{q}_i)$ and the momenta $p_i = \frac{\partial \mathcal{L}}{\partial \dot{q}_i}$ as $\mathcal{H} = \sum_i p_i \dot{q}_i - \mathcal{L}$, and that your equations $\frac{\partial \mathcal{H}}{\partial p_i} = \dot{q}_i$ and $\frac{\partial \mathcal{H}}{\partial q_i} = -\dot{p}_i$ then follow from Lagrange's equations $\frac{d}{dt}\frac{\partial \mathcal{L}}{\partial \dot{q}_i} = \frac{\partial \mathcal{L}}{\partial q_i}$. We therefore see no reason to publish your paper.*

Just think about it. ■

Objection 5.5.31. "*His ideas are by themselves not despicable, but the physical development of these ideas is at the level of a sophomore in physics who philosophizes with his classmates about the foundations of physics.*"—Anonymous coworker of Utrecht University, commenting as 'Lezer69' about my then unpublished 2007 concept-dissertation (2008) ■

Reply 5.5.32. As to the sophomore level, an interesting fact is that the Higgs mechanics actually has been published independently by two Russian sophomores, Alexander Migdal and Alexander Polyakov (1967). So even without making stuff up, we can also say that the celebrated Higgs mechanics is at the level of sophomores philosophizing about the foundations of physics. But the question is then: is this belittling a scientific argument against the Higgs mechanism? Any physicist will agree with me that it isn't. The same goes for the above objections: the belittling statements are nothing but dishonest tricks to win the respective readerships over for the preconceived position that I'm a crackpot who doesn't know the first thing about physics—it is a tell-tale sign of pseudoskepticism. ■

Objection 5.5.33. "*The reasonings that Cabbolet uses, are indeed absurd and childish.*"—'t Hooft, commenting on my work in (Botte, 2014) ■

Reply 5.5.34. 't Hooft has passed off this judgment as a "fact" about my work in the widely-read popular science journal *Eos*—*as if* he had understood my work. Yet objection 5.5.55 below reveals the true level of understanding that 't Hooft had of my work—none whatsoever, that is. ■

Objection 5.5.35. "*It is remarkable that references to experimental knowledge mainly concern the experimental physics of the '20s and '30s of the previous century. Not even been an attempt has been made to show how the impressive amount of experimental results of the last fifty years can be explained by the EPT*".—Boudewijn Verhaar, eminent physicist, on the 2007 concept-dissertation (2008) ■

Reply 5.5.36. Apart from the fact that Verhaar has made no attempt to clearify *which* experimental results of the last fifty years precisely should be explained by the EPT, there are two things to say about this objection. First of all, like Objection 5.5.22 this is an objection by someone who has failed to understand what it means that the EPT has to be seen as the hard core of a potentially progressive research program. The aim of the PhD project was to identify principles underlying an assumed repulsive gravity: the aim was not to prove that these principles are consistent with all existing knowledge about the outside world. That's the aim of further research (see part IV).

Secondly, this objection is **false**. In the concept-dissertation I argued, namely, that the EPT provides a explanation for the so-called Horizon Problem in physical cosmology: according to Brawer (1996), "Misner's paper on the mixmaster universe in 1969 contains the earliest published statement of the horizon problem"—this refers to (Misner, 1969), to which was also referred in the 2007 concept-dissertation. So contrary to Verhaar's claim, the 2007 concept-dissertation did deal with a major real-world problem that arose in physics in the last fifty years. In a nutshell, this horizon problem is the following: taking into account the estimated age of the universe, then the currently most distant galaxies could never have originated from one point, even if they would have traveled close to the speed of light: during the Planck era, they must have been lightyears apart. The explanation that the EPT offers is that space expands enormously in the Planck era by cooling off: this leads to the fact that some of the $\omega(2)$ spatially separated ground states of massive systems at the second degree of evolution, designated by the constants ${}^{EP}\varphi^2_j$, can find themselves <u>outside</u> the particle horizon that we get if we think of the preceding massive system in its ground state ${}^{EP}\varphi^1_1$ as a continuant existing in an environment with the properties of the our present solar system. See Fig. 5.2 for an illustration. The expansion of space continues after the Planck era: it is not the case that the spatial phase quantum ${}^{S}\varphi_1^0$ ceases to exist. So in fact, the horizon problem *occurs naturally* in the universe of the EPT. Further research has to establish whether the spatial phase quantum is really exactly the same as the *inflaton field*, a scalar field originally introduced by Alan Guth (1981). Although both ideas are similar *at the metalevel*, it is **absolutely not** the case that Guth's idea of the inflationary universe provided the motivation for the addition of spatial phase quanta to the ontology of the EPT: that motivation was provided by my own clear and distinct idea about the fundamental workings of the universe and nothing else than that! ■

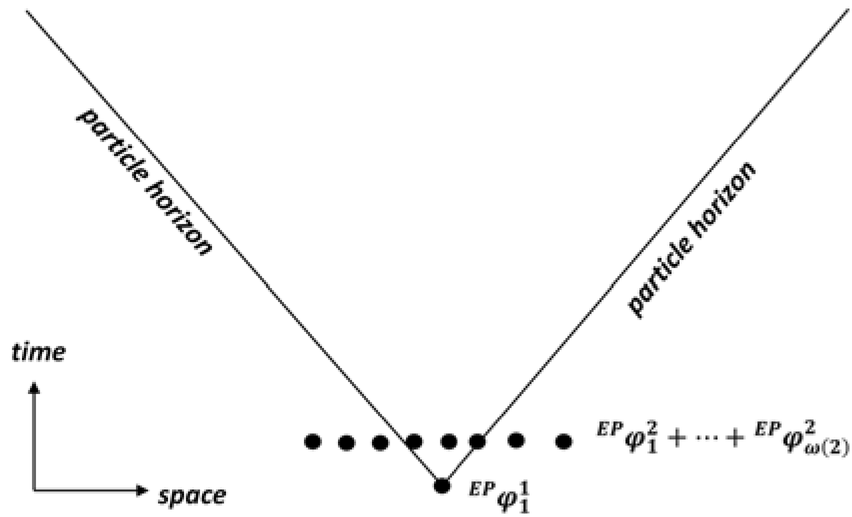


Figure 5.2: Illustration of the explanation of the horizon problem provided by the EPT. In a space vs. time diagram, the lowest black dot represents the position of the Planck-era system in its normal particle at the first degree of evolution, ${}^{EP}\varphi_1^1$, and the array of black dots represents the superposition ${}^{EP}\varphi_1^2 + \ldots + {}^{EP}\varphi_{\omega(2)}^2$ of ground states of massive systems at the second degree of evolution. The two V-shaped black lines represent the particle horizon that we get if we think of the object ${}^{EP}\varphi_1^1$ as existing in an environment with the properties of our present-day solar system. Some individuals in the superposition ${}^{EP}\varphi_1^2 + \ldots + {}^{EP}\varphi_{\omega(2)}^2$ then find themselves outside the particle horizon due to the expansion of the spatial phase quantum ${}^{S}\varphi_1^0$ that came into existence at the zeroth degree of evolution.

Objection 5.5.37. "*the position taken in a theoretical controversy ... does not exclude that the manuscript is nevertheless of insufficient scientific quality*"—the members of the Dutch National Committee for Scientific Integrity (LOWI), commenting about my 2007 concept-dissertation (Schuyt et al., 2009) ■

Reply 5.5.38. With that statement, the members of the LOWI—the highest organ for scientific integrity in the Netherlands—sided with my opponents in the controversy about my work. Now viewed in itself, this is a true, general statement. However, it does not apply to my case: the scientific quality of my work has, namely, never been assessed—my opponents have merely reacted emotionally to my hypothesis of repulsive gravity (to which "the position taken in a theoretical controversy" in the above quote refers). ■

Objection 5.5.39. "*His formulas are of the phony kind.*"—Brouwer, commenting on the EPT in his pamphlet about my 2007 concept-dissertation (2008b) ■

Reply 5.5.40. The mathematical expression of the EPT is correct, that is, these are all well-formed formulas in the language of mathematics.

This is an outright fabrication by Brouwer, which he passed off as a fact about my work without any proof whatsoever. As I see it, this is scientific misconduct. ■

Objection 5.5.41. "*The contents are severely limited: approximately 160 pages with lots of motivations and philosophizing and double spacing.*"—Kees Van Hee, commenting on my 2007 concept-dissertation (2008b) ■

Reply 5.5.42. Just imagine Max Planck, then editor of *Annalen der Physik*, replying to Einstein:

> "*Dear Dr. Einstein,*
> *I have received your paper on General Relativity, but unfortunately I have to reject it. The contents are, namely, severely limited: just 53 pages with lots of formulas and words in it.*"

Just think about it. This shows that Van Hee's objection is at the level of pseudoskepticism. ■

Objection 5.5.43. "*A manuscript can be of (grossly) insufficient scientific quality. If one has a lot of experience with such manuscripts one doesn't respond, unless one is formally asked to do so as an expert. In that case the substandardness must be substantiated with at least one decisive argument. That is what 't Hooft has done efficiently, but nevertheless with integrity.*"—philosopher evaluating 't Hooft's evaluation of my 2007 concept-dissertation on behalf of the LOWI, after I filed a complaint about misconduct by 't Hooft (2008) ■

Reply 5.5.44. In the 1970s we had this kids' joke about two loonies who wanted to see who could tell the biggest lie. The first loony said: "This morning I woke up, did 37 somersaults in a row and then flew around the church tower." The second loony then said: "That's true. I saw it."

Now fast forward to 2008. First 't Hooft claims that my work is "a disgrace" for the reasons mentioned in his 2008 pamphlet—see page xxxvi ff.—which are false statements of fact. Next, the philosopher—who had the proof that 't Hooft's statements were false right under his nose—claims that it is correct that my work is a disgrace because he has checked the arguments by 't Hooft. I assume the metaphor of the kids' joke is crystal clear. ■

Objection 5.5.45. "*I cannot tell whether the formalism makes any contact with physics: I find no hint of emergence of Newton's laws, or Schroedinger's equation, or the Einstein field equation. I see no reason to publish this paper. ... You might consider running this paper by [another referee], but ... I can't imagine your getting a positive response from ... any other competent physicist.*"—referee #1 of a journal in applied mathematics, commenting in 2006 about my submitted paper in which the EPT was still formalized as 'just' a first-order theory (cf. page xxxi) ■

Reply 5.5.46. This referee would have given precisely the same comment about the paper that was eventually published in *Ann. Phys.*, in which the EPT was formalized in mathematical language: given the degree of abstractness of the EPT, it remains namely the case that it cannot be shown by means of a so-called *direct proof* that Newton's law, or Schroedinger's equation, or the Einstein field equations emerge from the EPT. Therefore, a proof that the EPT agrees with established laws of physics in their respective area of application requires an entirely different *proof method*: to prove that the EPT agrees with an existing theory T, the method is that first a model of the EPT has to be developed and then it has to be shown that this model *reduces empirically* to T—in part IV it will be described precisely what that means. In the submitted manuscript this method was indicated, but the problem is that on the one hand it requires some competence in (mathematical) logic to understand the method, while on the other hand the average modern physicist lacks this required competence. So in a sense his last remark ("I can't imagine ...") is spot-on. ■

Objections against viewing the EPT as physics

Objection 5.5.47. "*On my look through the paper, there is no physics. ... His notation and formalism, while perhaps clear to him, is certainly not clear to me. What in the world does his equation [below Ax. 5.3.12] mean but a concatenation of symbols from some typeface. ... If a new approach to the foundational problem of physics has been presented, it has entirely passed me by.*"—referee #2 of a journal in applied mathematics, commenting in 2006 about my submitted paper in which the EPT was still formalized as 'just' a first-order theory (cf. page xxxi) ■

Reply 5.5.48. The rant of this referee is yet another example of the abuse of the peer-review report to express one's dislike of a submitted paper. For comparison, just imagine a referee of *J. Ecole Polytechn.* commenting in 1809 as follows to Poisson's paper introducing his celebrated brackets:

> *Dear Dr. Poisson,*
> *on my look through your paper, there is no physics. Your formalism, while perhaps clear to you, is certainly not clear to me. What in the world does your equation* $\dot{F} = \{F, H\}$ *mean but a concatenation of symbols of some typeface? I mean, you have an 'F' with a dot on top, and then the identity symbol followed by an 'F' and an 'H' between curly brackets. If a new approach to mechanics has been presented, it has entirely passed me by.*

Just think about it. ■

Objection 5.5.49. "*I have struggled my way through a part of Cabollet's [sic] paper. One thing is clear: this isn't physics.*"—Van Joolingen, commenting on my 2010 paper in *Annalen der Physik* (2011b) ■

Objection 5.5.50. "*Read [Van Joolingen's] article about Cabbolet. Agree regarding the physics*"—Christian Bokhove (2011), PhD graduate of Utrecht University, twittering his support for the hostile opinion piece (Van Joolingen, 2011c) ■

Objection 5.5.51. "*The dissertation of Marcoen Cabbolet is very bad as a physical dissertation. ... It should be judged as a philosophical dissertation. ... Marcoen will have to admit that his dissertation is no research in physics. It's a waste of so many years work, but to avoid a further loss of reputation that is the best he can do.*".—Anonymous coworker of Utrecht University, commenting as 'Lezer69' about my 2007 concept-dissertation on the widely-read forums nujij.nl and leugens.nl (2008) ■

Reply 5.5.52. The founders of the cornerstones of modern physics—Einstein, Bohr, Heisenberg and the like—were not only competent physicists: they were competent in philosophy as well. Thanks to their efforts, the two cornerstones of modern physics, QM and relativity, have been thoroughly grounded in philosophy. As a result, these theories can *now* be used without having to worry about basic philosophical questions: that work has already been done.[52] The EPT, on the other hand, is a fundamentally new theory, meaning that it cannot be formulated in terms of the ontological concepts and physical principles of any of the accepted theories. And therefore this thoroughly grounding in philosophy had to be done all over again during the development of the EPT. Consequently, my work contains both speculative philosophy and analytic philosophy. So, to the defense of my opponents it can be said that this thoroughly grounding in philosophy may give the impression that this is a philosophical work. But that is nothing but a superficial impression: the main result is a theory of physics. ■

Objection 5.5.53. "*As far as I am concerned this is gibberish.*"—Brouwer, commenting on the physical interpretation of the formalism of the EPT in his pamphlet about my 2007 concept-dissertation (2008b) ■

Reply 5.5.54. The terms and expressions of the formalism have been given a physical interpretation by means of these interpretation rules: that's the correct way to give the formalism a physical interpretation. The fact that the physical interpretation uses new, four-dimensionalistic terminology doesn't make it gibberish: that is a false statement of fact by Brouwer. ■

Objection 5.5.55. "*A ghost driver is someone who drives in the wrong direction against all other traffic. The impossible situations that he or she (usually he) ends up in, are steadfastly blamed on all other drivers. The ghost driver thinks that he is doing well and that all others are the cause of his problems. Most of the times he isn't even aware that he doesn't know the traffic rules, or even that there are traffic rules. That person is then thoroughly messed up.*

With similar behavior we are also often confronted in the natural sciences. Particularly the last hundred or two hundred years quite some 'traffic rules', or laws of physics, have been established, and these have become the standard arsenal of professional scientists. During those years these laws of physics have been studied and tested from all sides, so that we nowadays know precisely which truths can be considered absolute ... The subject of this paper is that there are individuals who don't care about any of this. They think that everything that we have come to known during hundreds of years has to be thoroughly revised and that they themselves have the panacea that can replace it all.

(...) ***Someone who does have all characteristic features of a ghost driver is one Marcoen Cabbolet. ... He used the physical ideas of Sannikov to develop his 'Elementary Process Theory', an idea that you can get to new, deeper insights in physics by means of linguistic, axiomatic logic. Not a single physicist could be found who seriously wanted to talk with Cabbolet about his ideas, and so it was clear that physics was in a deep crisis, waiting for a paradigm shift.***" (emphasis added)—'t Hooft, writing about me and my work (2015b) ■

Reply 5.5.56. 't Hooft later admitted that he wrote his paper on ghost drivers in science in an angry response to my letter to him in which I called him a charlatan: that letter of mine was a (delayed) response to the verdict by the LOWI that scientific integrity was not violated when Brouwer called me a 'charlatan' (see page xix). 't Hooft's paper, with its duplicate publication in both *DUB* and *Skepter*, is riddled with false statements of fact about me and my work: since these do not follow from the real facts, these are made up by 't Hooft. But I can tell you where that comes from: it's because right from the start he has been manipulated by Kees van Hee to think of me as a crackpot who doesn't know the first thing about mathematics and physics—at the time Van Hee made the first contact with ‘t Hooft and wanted him to disapprove my 2007 concept-dissertation; see the section ‘Events leading to the cancelation of my PhD graduation’ on page xxxii ff.

That said, by comparing me to a ghost driver ‘t Hooft is once more trying to depict me as an amateur who doesn't know the first thing about physics—even worse, as an amateur who doesn't even know that he doesn't know the first thing about physics. This is a false picture: I know very well what is known and what is not known in fundamental physics. For example, it is not known how massive antiparticles interact with the gravitational field of bodies of ordinary matter: ‘t Hooft may shout all that he wants, but it is simply not true that the contemporary theory of gravity (GR) has been tested in all aspects. Furthermore, I do not consider that everything we have come to known has to be thoroughly revised: contemporary theories will always remain valid as approximate laws in their established area of application. But to quote Feynman:

> "*Finally, and most interesting,* ***philosophically we are completely wrong*** *with the approximate law. Our entire picture of the world has to be altered even though [one aspect] changes only by a little bit. This is a very peculiar thing about the philosophy, or the ideas, behind the laws. Even a very small effect sometimes requires profound changes in our ideas.*"—Feynman (2011)

That is to say: if antiparticles indeed have negative gravitational mass, then the universe at supersmall scale looks nothing like the world view of modern physics.

Proceeding, the one but last statement by ‘t Hooft ("He used ... logic") is a false statement of fact: it is neither the case that I based the EPT on ideas of Sannikov, nor is it the case that the EPT embodies the idea that you can get to new, deeper insights in physics by means of linguistic, axiomatic logic. I can tell how this has come about: these are figments of ‘t Hooft's imagination that have popped up upon a very superficial reading of my work in accordance with the response-in-an-outburst model on page li. So to make this clear: this objection 5.5.55 by ‘t Hooft reveals that even after seven years he still has not understood my work, not even in broad lines.

‘t Hooft and I met in 2016 at a conference in Varna (BG), see the picture below. We came somewhat closer together, agreeing that we are both in it for truth-finding. The personal conflict, however, has not been resolved: as far as I am concerned, fact of the matter remains that ‘t Hooft has made countless false statements of fact about me and my work both in public and behind closed doors. As long as these are not retracted—and they never will be—I don’t see eye to eye with him. The same goes for other opponents of mine who have made false statements of fact about me or my work: I will *never* concede that the right to freedom of opinion includes a right to make false statements of fact. ■

Figure 5.3: ‘t Hooft (left) and I at the Fourth International Conference on the Nature and Ontology of Spacetime, Varna, 2016. Picture by Ivan A. Karpenko.

Objection 5.5.57. "*[A]nother person who went off the rails whilst pursuing a PhD ... was Marcoen Cabbolet and his 'Elementary Process Theory' claiming that linguistic axiomatic logic is a gateway to new insights in physics. ... The quality of contemporary academic analytical philosophy is apparent from the fact that this rubbish got published.*"—Hab (2018) ■

Reply 5.5.58. Objection 5.5.55 was published in Dutch language. Make no mistake: here a Dutch individual writing under the name 'Harry Hab' has uncritically parroted the judgment by 't Hooft in English to disseminate it to a wider audience. This is indicative of the present professional atmosphere in theoretical physics. ■

Objection 5.5.59. "*Professor 't Hooft has had a superficial look at his dissertation and has of course been able to recognize that it contains physical falsehoods.*—Anonymous coworker of Utrecht University, commenting as 'Lezer69' about my then unpublished 2007 concept-dissertation on the widely-read forums nujij.nl and leugens.nl (2008) ■

Reply 5.5.60. I repeat: the level of understanding that 't Hooft had of my work may be obvious from objection 5.5.55. So, this objection stems from uncritically accepting 't Hooft's false statements of facts about my work. To comment: 't Hooft hasn't recognized any physical falsehoods, he has merely reacted emotionally to my hypothesis of repulsive gravity. ■

Objection 5.5.61. "*You can forget about creating new physics by merely talking in a different and extremely cumbersome way about infinite sets.*"—Nienhuys, commenting on my dissertation (2014) ■

Reply 5.5.62. This objection, which is close to Obj. 5.5.55, has already been treated on page xliv ff.: it's a false statement of fact that I have created new physics by talking about infinite sets, that is, by first developing new mathematical logic and then giving it a physical interpretation. ■

Objection 5.5.63. "*[Cabbolet's] theory can,* ***in his own words****, replace quantum mechanics and general relativity ... [But] his theory is unacceptable because it starts with looking for an explanation for a hitherto unobserved phenomenon, and because a beginning of a correspondence principle is missing. A theory that cannot explain what we could already explain earlier cannot ever mean progress.*" (emphasis added)—Van Joolingen (2011c) ■

Reply 5.5.64. In his hostile opinion piece, Van Joolingen explained for a layman audience in the widely-read national newspaper *De Volkskrant* why Erik Verlinde and I, two individuals who had both come up with an unorthodox theory, received such different responses from the physics community: Verlinde received the prestigious Spinoza prize, whereas I received nothing but derision. In a nutshell, Van Joolingen argued that the reason for the different receptions of the works is that Verlinde's theory was built on an existing idea by 't Hooft and was shown to satisfy the principle of correspondence, whereas my theory was unacceptable for the reasons mentioned in Objection 5.5.63. This analysis by Van Joolingen is more or less correct: if we look beyond the lies and insults then the controversy on my work had scientific reasons, and two of the main reasons are

(i) that I, with my hypothesis that repulsive gravity exists, called into question the assumption that gravity is attraction only—an assumption considered untouchable by the overwhelming majority of theoretical physicists—without an objectively compelling reason to do so;

(ii) that I did not provide a proof that my theory corresponds to the established theories of modern physics by showing that the established theories emerge from my theory by applying some limit procedure.

I'm well aware of that. What's wrong with Van Joolingen's opinion piece, however, is that it conveys the misleading impression that I not only literally claimed that my theory, the EPT, can replace QM and GR—see the emphasized part in Objection 5.5.63—but that I also expected that my theory was going to be accepted instantly *even though* repulsive gravity hadn't been observed and correspondence to existing theories was not proven. The real situation is completely different: opponents of mine, who have claimed or insinuated that I expected instant acceptance of my theory, do not know me and have not understood the philosophy of science behind my work. First and foremost, I do not believe in this overly simplistic view that a scientific revolution occurs by a collective act of instant rationality, whereby a new theory instantly becomes widely accepted as a replacement for a theory that has become obsolete: Van Joolingen has wrongly projected that view onto me, as have others. I believe in the basic correctness of Lakatos' view that scientific revolutions occur by prolonged 'battles' of research programs, whereby degenerative research programs are eventually superseded by progressive research programs: my theory, the EPT, has to be seen as the hard core of a potentially progressive research program. And that has been explicitly mentioned in my publications, but of course it requires familiarity with Lakatos' methodology of research programs to understand what that means. Secondly, I consider it *obsolete* to think that a new theory of physics has to satisfy the correspondence principle as formulated under (ii) above. That is, I consider it not at all necessary that the EPT has to correspond to established theories by means of a *formal reduction*—as Rosaler (2015) called it. Instead, I consider it sufficient that the EPT satisfies a *weaker* correspondence principle—namely, that the EPT has a model that corresponds to established theories by means of what Rosaler called an *empirical reduction*, meaning that it reproduces only the empirically successful predictions of established theories. This has been (briefly) discussed in my 2010 paper in *Ann. Phys.* and in my dissertation, but Part IV of this monograph treats this subject in great detail. ■

Objection 5.5.65. "*Physics is a field of small steps. The idea of a scientist who on his own in a study room 'solves' the problem of the universe is not right ... Cabollet* [sic] *draws suspicion by claiming to have constructed the final theory at one blow. With a story that he and a colleague worked out some formulas on the steamed windows of a tram he tries to mystify its historical development.*"—Van Joolingen (2011c) ■

Reply 5.5.66. Here Van Joolingen is fabricating "facts". In the first place, it's a fabrication that I claimed to have constructed the final theory at one blow: I have never made any claim to that extent. But a simple explanation for how that thought has popped up in Van Joolingen's mind is that he is not familiar with Lakatos' methodology of research programs, and therefore jumped to the conclusion that I must have been thinking that my theory is the final answer to all problems in physics. This is just plain wrong.

In the second place, it's also a fabrication that I have tried to mystify the historical development of the EPT with a story about events in a tram. In the **informal (!!!)** 'Acknowledgements' section of my dissertation I wrote an anecdote about a discussion I had in a tram with Sannikov—the first supervisor of my PhD project, who died before my PhD defense, cf. page xxxi ff.—to commemorate what kind of a person Sannikov was. This has nothing to do with mystifying the historical development of the theory.

Like many other objections, this one also illustrates the enormous ease with which false statements of fact about me and my work have been passed off in national newspapers *as if* these were the sound conclusions of a serious investigation into the quality of my work. And make no mistake: they all get away with it scotfree. ■

Objection 5.5.67. "*I found my way to Cabbolet's story because I will soon get a PhD degree myself, and I wondered whether someone can 'fail' his PhD defense. But that didn't happen to this man: he didn't get that far. ... But it's an interesting case because this fantasist still got quite far. There have always been fantasists in science, but this one had even supporters. Perhaps the supervisor had an urge to score? Luckily it turns out that the 'system' has sufficient self-correcting capacity, although this was a close call. The layman in the meantime is stuck with doubts as to whether he is an unrecognised genius (but as a physicist I know better than that).*"—Reinier Bakels, commenting in 2008 on the news that my PhD graduation was cancelled. ■

Reply 5.5.68. Bakels thus argues that the EPT is not physics, because as a physicist he *knows* that my work is the work of a fantasist. Fact of the matter is that Bakels has a masters degree in engineering physics, and had never read or even seen my work at the time of writing. ■

Objections against principles of the EPT

Objection 5.5.69. "*Where possible, I've tried to follow his reasonings and check the calculations. But often it concerns just isolated statements, not mathematical proofs that you can get into.*"—'t Hooft, commenting on my work in the popular-science journal *Natuurwetenschap & Techniek* (2008b) ■

Reply 5.5.70. Here the objection by 't Hooft is thus that the principles of the EPT are just a bunch of isolated statements and *therefore* the EPT should be rejected as the work of someone who doesn't know the first thing about physics. The real situation, however, is the exact opposite: the EPT has been correctly introduced and this is a typical objection by someone who is not familiar with axiomatic systems. If you want to introduce a physical theory as an axiomatic system within an existing framework of (mathematical) logic, then it suffices to define the terms of the language, the non-logical axioms of the system, and the interpretation rules for the terms and predicates, cf. page 199. The axiomatic system is then completely determined, and everyone with a background in logic knows that. However, for someone who has no background in logic, such as 't Hooft, such an introduction of an axiomatic system indeed comes across as a bunch of isolated statements. But it is precisely those "isolated statements" that determine the axiomatic system—the logical framework contains a so-called predicate calculus that allows the deduction of theorems. ■

Objection 5.5.71. "*Now one can always try to understand what he tries to express with his formalism. It seems that he starts with our universe U, and then makes up an anti-universe U-bar, in which all particles are conjugated and time goes in the other direction, so that the ordered pair (U, U-bar) does not contain more information than U alone because U-bar is nothing but some sort of mirror image.*"—Brouwer (2008b) ■

Reply 5.5.72. This objection is an attempt by Brouwer to ridicule the idea that the universe consists of a world and an antiworld: the idea is bad *because* the antiworld is nothing but some sort of mirror image of the world. This ridicule, however, applies word for word also to Feynman's theory of a positron (1949). Just imagine that a reviewer of *Phys. Rev.* would have commented as follows on Feynman's submission:

> *Dear Dr. Feynman,*
> *We have attempted to understand what you tried to express with your formalism. It seems to us that you start with an electron in our world, and then make up that a positron is an electron traveling backwards in time, so that the ordered pair (electron, positron) does not contain more information than the electron alone because the positron is nothing but some sort of mirror image. This is ridiculous and we are not going to publish it.*

Just think about it—this is pseudoskepticism. ■

Objection 5.5.73. "*These assumptions about the elementary processes, by which these so-called phase quanta transform into each other, seem to be made up out of thin air. Any and all motivation is lacking.*"—Jos Uffink, then at Utrecht University, commenting on my work (2008) ■

Reply 5.5.74. The axioms of the EPT have, ultimately, been developed from a clear and distinct idea. The principle of gravitation is put into words on p. 92: the idea that a massive system goes through cycles of ground state, transition state, and excited state, requires a number of assumptions that state transitions take place by which the life of the system in one state is succeeded by the life of the system in another state—that is the motivation for the axioms of the EPT about state transitions between phase quanta. On this is elaborated in Ch. 3. ■

Objection 5.5.75. "*An important concept is an elementary process, but a definition is nowhere to be found. During the conversation [between Van Hee and me, MC] it emerged that these are nothing but transition systems with the extra that there is a dual process connected to it. ... Marcoen knows nothing about transition systems and according to me he hasn't contributed anything to this field.*"—Van Hee on my 2007 concept-dissertation (2008b) ■

Reply 5.5.76. Van Hee hadn't even understood that I had given the Elementary Process Theory precisely that name because it is a theory of elementary processes: an elementary process is what is described by the theory. That said, this objection by Van Hee is nothing but an attempt to belittle the EPT by saying that it is not something new, but rather just a transition system—something that he and his colleagues at the TU/e work(ed) with on a daily basis. However, it's a false statement of fact that the processes that take place in the physical world as described by the EPT—so, we ignore the dual process in the antiworld—can be described with transition systems. The latter is concept from theoretical computer science: a transition system is just a pair $(S, \to)$ where S is a set of states and $\to$ a subset of $S \times S$ whose elements are interpreted as state transitions. A *labeled* transition system is an extension hereof with a set of labels Λ: an element (s_1, λ, s_2) of $\to \subset S \times \Lambda \times S$ is then a labeled state transition denoted as $s_1 \xrightarrow{\lambda} s_2$. The (labeled) transition systems can be used to describe discrete systems. But the generalized principle of formation of space, Ax. (5.3.18), is not a discrete transition. And the generalized existential axiom and the generalized principle of choice, Axs. (5.3.2) and (5.3.13), are not even state transitions. It is also doubtful that the nuances involving monads can be expressed with (labeled) transition systems.[53] ■

Objection 5.5.77. "*His theory does not lead to equations. Cabbolet cannot even explain that particles move linearly on a straight line when there is no net force on it.*"—Nienhuys (2015) ■

Reply 5.5.78. Strictly speaking, the first statement is false: the EPT contains a generalized equation, Ax. (5.3.13), so every instantiation thereof is an equation. But it is true that the other axioms of the EPT are generalized $\in$-relations and a generalized implication. That, however, cannot possibly be objectionable: given that the language of mathematics allows $\in$-relations as atomic formulas and implications as (composite) formulas, it is not the case that a theory *has to* be made up of equations, or *has to* lead to equations. Coincidentally, that same first statement can then also be used as an objection to transition systems: the state transitions are, namely, also $\in$-relations. Yet I don't see Nienhuys publicly denouncing the theory of his colleagues at the TU/e because it doesn't lead to equations.

So, to the defense of Nienhuys is must be taken that his first statement wasn't intended to be taken literally. If you think about it, then he must have meant 'equations of motion' where he wrote 'equations': then the above objection makes more sense. It is, namely, true that

(i) no equation of motion can be deduced from the EPT;

(ii) the EPT doesn't predict that particles move linearly on a straight line when there is no net force on it.

Viewed that way, the objection is thus that because the principles of the EPT do not satisfy (i) and (ii) above, the EPT has to be firmly rejected. But even though objection 5.5.77 makes more sense when read that way, it still demonstrates a lack of understanding. The EPT is a process theory: it is **not** a theory of interactions or a theory of mechanics. If we consider motion of a particle (such as an electron), then the EPT is an abstract theory of the process by which that motion takes place *regardless of the spatiotemporal aspects of that motion.* A *model of the EPT*, on the other hand, must give rise to equations of motion and must be able to explain that a particle moves on a straight line when no forces are acting on it. The models of the EPT presented in Ch. 6, 9, and 10 do precisely that. ■

Objection 5.5.79. "*Nearly everything can be axiomatized, and an axiomatization in itself is therefore not an extra merit of a physical theory.*"—Jos Uffink, then at Utrecht University, commenting on my work (2008) ■

Reply 5.5.80. What Uffink tries to say here is that the sheer fact that the principles of the EPT are the non-logical axioms of an axiomatic system, doesn't make them more true physically. With that, I agree. But fact of the matter is that I never claimed that the EPT is true *because* it is axiomatized.

That said, Hilbert's sixth problem is "how can physics be axiomatized?", see (Hilbert, 1902). An axiomatization is thus a standard of quality for a foundational physical theory: this standard pertains to the mathematical rigor of the theory, not its physical truthfulness. And the EPT has thus been rigorously formalized and axiomatized, so as to provide—at least in potential—a foundational theory for physics that satisfies the criteria of rigor of a solution to Hilbert's sixth problem.

This standard of quality is, however, **not satisfied** by the Standard Model: the latter has thus far not been axiomatized and the research program aimed at an axiomatization of the Standard Model has, to the best of my knowledge, been terminated. So if an axiomatization is no big deal and if an axiomatization is no extra merit, as Uffink alleges, then one cannot help but wonder: why is it then that tons of taxpayer's money have been poured into an axiomatization of the Standard Model, and why did that fail? If you think about it, then it is obvious that the above objection by Uffink is nothing but an attempt to belittle the present achievement—the axiomatization of the EPT, that is. ■

Objection 5.5.81. "*The author claims that EPS* [sic] *is an alternative to quantum mechanics ... As we know quantum mechanics works very well and there is no reason to modify it.*"—referee of a physics journal, commenting in 2009 on the same paper that, after a minor revision, was later published in *Ann. Phys.* ■

Objection 5.5.82. "*Historical developments in physics have led to the Standard Model, which has been experimentally established as accurate. If one or another change in the logic leads to conclusions [about fundamental laws of physics] that differ from the ones that are already established since decades, then this change is wrong.*"—'t Hooft, denouncing the EPT during a private meeting at Utrecht University in 2008 ■

Objection 5.5.83. "*I agree with 't Hooft.*"—Dennis Dieks, stating his support for Objection 5.5.82 by 't Hooft at the same private meeting. ■

Reply 5.5.84. Here we have three members of "the establishment" *de facto* rejecting the principles of the EPT as erroneous **because** these deviate from quantum physics. That said, according to Roy Wallis, characteristic signs of a sect are that they lay a claim to possess unique and privileged access to the truth, and that their committed adherents typically regard all those outside the confines of the collectivity as 'in error'. The physics community is of course not a sect, but it is my sincere opinion that the attitude reflected by the above three objections—and that ***is*** the prevailing attitude in the physics community—demonstrates that it starts to show the signs of a sect, due to the developments described on page lii ff. And I'm not the only one: before the controversy on my work erupted I was contacted by phone by a Dutch mathematician, who had learned that I tried to obtain a PhD in the Netherlands after Sannikov had gotten ill; he warned me that

> *"theoretical physics in the Netherlands is a closed clique that doesn't allow any interference from the outside."*

The truth of that statement has been proven by the controversy about my work that soon thereafter followed. Unfortunately, it is also true for the international physics community—although there are individual exceptions. ∎

Objection 5.5.85. "*For me, the fact that the theory* [i.e., the EPT] *dissents from research programs in quantum field theory, string theory or GR is not the decisive argument for the rejection of the PhD thesis. However, the theory is written in a formalism that is highly unusual, and that is the invention of the author.*"—Jos Uffink (Utrecht University), expressing his support for the decision to cancel my PhD graduation (2008) ∎

Reply 5.5.86. Uffink is thus of the opinion that the principles of the EPT are unacceptable *because* they are written in a highly unusual formalism that is invented by the author. Now just imagine that the Royal Society would have replied as follows to Newton's manuscript *Philosophiæ Naturalis Principia Mathematica*:

> *Dear Dr. Newton,*
> *we have had a look at your mathematical principles of natural philosophy. The fact that your theory dissents from Descartes' work and introduces forces that can act on a distance without*

a medium is not the decisive argument for the rejection of your work. However, the theory is written in a formalism that is highly unusual, and that is the invention of the author.

Just imagine it. This proves that Uffink's objection is at the level of pseudoskepticism. ■

Objection 5.5.87. "*His Elementary Process Theory is a theory that very broadly describes a physical reality in which a whole lot is possible, so also antimatter particles that move upwards. That doesn't mean that this then happens in reality too.* ***Mathematically it is formulated way too broadly to do physics.*** *Any theoretical physicist could have recognized this and could have told him that.*" (emphasis added)—Anonymous coworker of Utrecht University, commenting as 'Lezer69' about my then unpublished 2007 concept-dissertation on the widely-read forums nujij.nl and leugens.nl (2008) ■

Reply 5.5.88. The above statement in bold is the objection here against the EPT. This objection, however, does not demonstrate much understanding of *how to do physics* in the framework of the EPT. As is demonstrated in Part III and Part IV of this monograph, the EPT is not formulated too broadly to do physics: this objection is a false statement of fact. But I can tell you where this is coming from. The objector knows how to do physics in the frameworks of GR and the Standard Model—he probably is an excellent expert in it—and he has observed that he cannot do physics in precisely the same way in the framework of the EPT: given that the current parts III and IV were absent in the 2007 concept-dissertation, he has concluded from there that the EPT is formulated too broadly to do physics. But his conclusion is **false**. ■

Part III

Applications of the EPT

Chapter 6

Non-relativistic physics

> "*This is a paper to which Pauli's words 'it isn't even wrong' would seem to apply. It takes the point of view that since current theories have not been tested in all conceivable physical situations, they are obviously wrong, and must be replaced by the author's favourite theory.*"—referee of a respected journal in applied mathematics, rejecting in 2006 my submission in which the EPT was still formalized as 'just' a first-order theory (as meant on p. xxxi), but in which the point of view as claimed by the referee was **not** taken.

This chapter first develops the notion of a monadic system in the framework of the EPT, which corresponds to the intuitive idea of a one-component system (Sect. 6.1). The sections thereafter (Sects. 6.2-6.3) express views on elementary (anti)particles and fundamental interactions by developing *mathematical models* of a non-relativistic monadic system and the process by which it interacts with its environment. The term 'mathematical model', however, has a meaning in physics that differs from its meaning in mathematical logic. In this chapter we will practice mathematical modeling as in physics, meaning that we will develop mathematical models in the sense of descriptions of a physical system that use mathematical concepts and language. In Part IV we will practice mathematical modeling as in mathematical logic, meaning that we will specify set-theoretic and categorical models of the EPT—it will be rigorously defined what that means.

6.1 Monadic systems

We are interested in a notion of a one-component system in the framework of the EPT that resonates with intuitive ideas about physical systems. For that matter we have to make a translation from a world view in terms of phase quanta (occurrents) to a world view in terms of systems (continuants). Moreover, a distinction has to be made between the *system* and its *environment*. We are going to do make that distinction by positively identifying the system: all other things that coexist then form its environment. First we need a classification of elementary processes:

Definition 6.1.1 (Simple, simplest, and complex processes).
*The k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution is **simple*** if and only if *the p extended particlelike matter quanta that make up the extended particlelike phase quantum at the n^{th} degree of evolution in this process carry the same monads as the q nonextended particlelike matter quanta that make up the nonextended particlelike phase quantum at the $(n+1)^{\text{th}}$ degree of evolution in this process, that is,* if and only if *we have*

$$\begin{bmatrix} {}^{EP}\varphi_k^n \\ {}^{EP}\overline{\varphi}_k^n \end{bmatrix} = \begin{bmatrix} {}^{EP}\mu^n_{\mathrm{M}_1} + \ldots + {}^{EP}\mu^n_{\mathrm{M}_p} \\ {}^{EP}\overline{\mu}^n_{\overline{\mathrm{M}}_1} + \ldots + {}^{EP}\overline{\mu}^n_{\overline{\mathrm{M}}_p} \end{bmatrix} \tag{6.1}$$

$$\begin{bmatrix} {}^{NP}\varphi_k^{n+1} \\ {}^{NP}\overline{\varphi}_k^{n+1} \end{bmatrix} = \begin{bmatrix} {}^{NP}\mu^{n+1}_{\mathrm{M}_{p+1}} + \ldots + {}^{NP}\mu^{n+1}_{\mathrm{M}_{p+q}} \\ {}^{NP}\overline{\mu}^{n+1}_{\overline{\mathrm{M}}_{p+1}} + \ldots + {}^{NP}\overline{\mu}^{n+1}_{\overline{\mathrm{M}}_{p+q}} \end{bmatrix} \tag{6.2}$$

$$\{\mathrm{M}_1, \ldots, \mathrm{M}_p\} = \{\mathrm{M}_{p+1}, \ldots, \mathrm{M}_{p+q}\} \tag{6.3}$$

*So, it is then the case that $p = q$. A **simplest** process is a simple process for which $p = q = 1$, so that $\{\mathrm{M}_1\} = \{\mathrm{M}_{p+1}\}$. The k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution is **complex*** if and only if *we have*

$$\{\mathrm{M}_1, \ldots, \mathrm{M}_p\} \cap \{\mathrm{M}_{p+1}, \ldots, \mathrm{M}_{p+q}\} = \emptyset \tag{6.4}$$

in addition to Eqs. (6.1) *and* (6.2)*. (N.B. the M_j's are variables.)* ■

With these definitions in place, let us have a look at the things that exist and the things that happen *in the world*—we ignore the things that happen and the things that exist *in the antiworld*—if the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution is a simplest process. For that matter we will apply the existence predicate $\mathbb{E}$ to an occurrent in the world φ, if it applies to the corresponding component $\begin{bmatrix} \varphi \\ \overline{\varphi} \end{bmatrix}$ of the universe of the EPT. In other words, the existence predicate $\mathbb{E}$, which has been defined as a unary relation on the set of components of the universe consisting of an occurrent in the world and a conjugated occurrent in the antiworld (see Notation 5.2.8), can henceforth also be applied to occurrents in the world alone by applying the following formal rule:

$$\mathbb{E} \begin{bmatrix} \varphi \\ \overline{\varphi} \end{bmatrix} \Rightarrow \mathbb{E}\varphi \tag{6.5}$$

That being said, the following formulas, whose physical meaning can be derived from the interpretation rules given in Ch. 5, then describe the things that exist and happen in the world in a simplest process:

$$\mathbb{E}\ {}^{EP}\varphi_k^n \wedge {}^{EP}\varphi_k^n = {}^{EP}\mu_{\mathrm{M}_1}^n \tag{6.6}$$

$${}^{EP}\mu_{\mathrm{M}_1}^n \to {}^{NW}\varphi_k^n \tag{6.7}$$

$${}^{EP}\mu_{\mathrm{M}_1}^n + {}^{NW}\varphi_k^n = \psi_{\mathrm{M}_1}^n \tag{6.8}$$

$${}^{NW}\varphi_k^n : {}^{EP}\varphi_k^n \dashrightarrow {}^{NP}\varphi_k^{n+1} \tag{6.9}$$

$${}^{NP}\varphi_k^{n+1} = {}^{NP}\mu_{\mathrm{M}_1}^{n+1} \tag{6.10}$$

$${}^{NP}\varphi_k^{n+1} = f_{(\Theta_k^{n+1})^+}(\Theta_k^{n+1}) \tag{6.11}$$

$${}^{NP}\varphi_k^{n+1} \to {}^{LW}\varphi_k^{n+1} + {}^{EP}\mu_{\mathrm{M}_1}^{n+1} \tag{6.12}$$

$$\mathbb{E}\ {}^{LW}\varphi_k^{n+1} \Leftarrow \mathbb{E}\ {}^{S}\varphi_k^{n+1} \tag{6.13}$$

In words, the existence of the k^{th} extended particlelike phase quantum at the n^{th} degree of evolution marks the beginning of the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution; since this is a simplest process, the said phase quantum consists of only one matter quantum: the extended particlelike matter quantum that carries the set of properties M_1—this is the monad M_1—at the n^{th} degree of evolution, cf. Eq. (6.6). By a discrete transition, this extended particlelike matter quantum ceases to exist and a nonlocal wavelike matter quantum is created at the n^{th} degree of evolution in this process, cf. Eq. (6.7). Note however, that *even after* this discrete transition has taken place the existence predicate $\mathbb{E}$ still applies to the phase quantum ${}^{EP}\varphi_k^n$: the existence predicate is *atemporal*! Proceeding, the extended particlelike matter quantum and the nonlocal wavelike phase quantum together form the monadic occurrent that carries the monad M_1 from the n^{th} to the $(n+1)^{\mathrm{th}}$ degree of evolution, cf. Eq. (6.8). At the end of its time span, the nonlocal wavelike phase quantum collapses, thereby effecting that the initial extended particlelike matter quantum, which carries the monad M_1 at the n^{th} degree of evolution, is succeeded by the nonextended particlelike matter quantum that carries the same monad M_1 at the $(n+1)^{\mathrm{th}}$ degree of evolution, cf. Eq. (6.9). This nonextended particlelike matter quantum forms the nonextended particlelike phase quantum created at the $(n+1)^{\mathrm{th}}$ degree of evolution in this process, cf. Eq. (6.10); the latter is then *chosen* from a set of parallel possible phase quanta, cf. Eq. (6.11). If we assume that all matter is *inanimate*—the next chapter will show that this assumption is not trivial—then this choice is completely determined by the gravitational and electromagnetic interaction. Next, by a discrete transition the nonextended particlelike matter quantum transforms into a (possibly zero) local wavelike phase quantum and the extended particlelike matter quantum that carries the monad M_1 at the $(n+1)^{\mathrm{th}}$ degree of evolution is formed, cf. Eq. (6.12). The emitted local wavelike phase quantum is then a necessary cause for the (gradual) formation of a spatial phase quantum, cf. Eq. (6.13).

This elementary process is then succeeded by another one. Let us, for the sake of simplicity, assign the same counting number k to this next process; if it again is a simplest process, then we have

$$ {}^{EP}\mu_{\mathrm{M}_1}^{n+1} = {}^{EP}\varphi_k^{n+1} \wedge \mathbb{E}\ {}^{EP}\varphi_k^{n+1} \tag{6.14} $$

So, *if* the next process is a simplest process, *then* the extended particlelike matter quantum that carries the set of properties $\mathfrak{m}_1$ at the $(n+1)^{\mathrm{th}}$ degree of evolution forms the extended particlelike phase quantum that marks the beginning of the k^{th} process from the $(n+1)^{\mathrm{th}}$ to the $(n+2)^{\mathrm{th}}$ degree of evolution. The converse is not true: if we have Eq. (6.14), then the k^{th} process from the $(n+1)^{\mathrm{th}}$ to the $(n+2)^{\mathrm{th}}$ degree of evolution is not necessarily a simplest process—for that matter, all conditions of Def. 6.1.1 have to be satisfied.

Let the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution be a simplest process. We are then interested in the occurrent $\psi^n_{\text{M}_1} + {}^{NP}\mu^{n+1}_{\text{M}_1}$, which can be viewed as the monadic occurrent that carries the monad M_1 from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution *followed by* the nonextended particlelike matter quantum that carries the same monad M_1 at the $(n+1)^{\text{th}}$ degree of evolution; for this occurrent, we have

$$\psi^n_{\text{M}_1} + {}^{NP}\mu^{n+1}_{\text{M}_1} = {}^{EP}\varphi^n_k + {}^{NW}\varphi^n_k + {}^{NW}\varphi^{n+1}_k \tag{6.15}$$

Now let all observers be *inertial observers*, and let's assume that all reference frames of our observers are *Galilean reference frames*, which are defined using the definition of Euclidean space.

Definition 6.1.2 (Euclidean space, coordinate system)**.**
3D Euclidean space *is an affine space, whose elements will be called points, and whose associated vector space is a 3D Euclidean vector space with inner product. An orthonormal set of basis vectors* $\{\vec{e}_1, \vec{e}_2, \vec{e}_3\}$ *can be constructed by choosing a point* O *of the affine space as the origin and by choosing three points* E_1*,* E_2*, and* E_3*, such that the directed line segments* $\overrightarrow{OE}_1$*,* $\overrightarrow{OE}_2$*, and* $\overrightarrow{OE}_3$ *are mutual perpendicular and have unit length: the directed line segment* $\overrightarrow{OE}_j$ *is then the basis vector* $\vec{e}_j$ *and we have*

$$\vec{e}_i \cdot \vec{e}_j = \delta_{ij} \tag{6.16}$$

where δ_{ij} *is the Kronecker delta. Any point* $\mathcal{X}$ *in the affine space can then be viewed as the end point of a directed line segment* $\overrightarrow{O\mathcal{X}}$ *for which*

$$\overrightarrow{O\mathcal{X}} = x^1 \cdot \overrightarrow{OE}_1 + x^2 \cdot \overrightarrow{OE}_2 + x^3 \cdot \overrightarrow{OE}_3 = x^1 \cdot \vec{e}_1 + x^2 \cdot \vec{e}_2 + x^3 \cdot \vec{e}_3 \tag{6.17}$$

That way, there is a bijection between the points in 3D Euclidean space and the coordinate tuples in $\mathbb{R}^3$*. A* ***cartesian coordinate system*** *for 3D Euclidean space, i.e. a set of coordinate tuples that uniquely determine a point in 3D Euclidean space, can thus be constructed by choosing an origin and constructing an orthonormal set of basis vectors: a coordinate tuple* $X = (x^1, x^2, x^3) \in \mathbb{R}^3$ *then describes a point* $\mathcal{X}$ *in 3D Euclidean space.* ■

Agreement 6.1.3. We will use S.I. units of length, time, and mass. Units will be displayed between square brackets, e.g. as $[kg]$. ■

Definition 6.1.4. *A* ***Galilean reference frame*** *(GRF) of an (inertial) observer $\mathcal{O}$ is a cartesian coordinate system for 3D Euclidean space co-moving with $\mathcal{O}$, plus a (separate) time scale in S.I. units. The coordinates in space and time in the GRFs of any two observers $\mathcal{O}$ and $\mathcal{O}'$ are related by a Galilean transformation.* ■

Agreement 6.1.5. In the remainder of this section and the next, we will describe a point $\mathcal{X}$ in 3D Euclidean space by its coordinate tuple X in the GRF of an observer $\mathcal{O}$. That is, we say that an elementary particle has a position $X = (x^1, x^2, x^3)$ in the GRF of an observer $\mathcal{O}$. The purist, for whom a point in 3D Euclidean space and a coordinate tuple in $\mathbb{R}^3$ are conceptually different things, has to take this to mean that the elementary particle has a position in 3D Euclidean space whose corresponding coordinate tuple in the GRF of $\mathcal{O}$ is $X = (x^1, x^2, x^3)$. Likewise, we will describe the momentum of an elementary particle, to be denoted by a symbol $\vec{p}$, by a three-tuple (p^1, p^2, p^3) in the GRF of an observer $\mathcal{O}$. The p^j's are then the components of the momentum in x^1-, x^2-, and x^3-direction. ■

In the GRF of an observer $\mathcal{O}$, the extended particlelike matter quantum ${}^{EP}\mu^n_{\mathrm{M}_1}$ is then centered at a spatial position X_n at a point in time t_n, while the nonextended particlelike matter quantum ${}^{NP}\mu^{n+1}_{\mathrm{M}_1}$ is located at a spatial position X_{n+1} at a point in time t_{n+1}. So, the occurrent $\psi^n_{\mathrm{M}_1} + {}^{NP}\mu^{n+1}_{\mathrm{M}_1}$ has a time span $[t_n, t_{n+1}]$ in the GRF of $\mathcal{O}$.

We now assume **non-relativistic conditions**, so that in the GRFs of any two observers $\mathcal{O}$ and $\mathcal{O}'$, who use the same units of length and time,

(i) the duration δt_n of the time span $[t_n, t_{n+1}]$ in the GRF of $\mathcal{O}$ is the same as the duration $\delta t'_n$ of the corresponding time span $[t'_n, t'_{n+1}]$ in the GRF of $\mathcal{O}'$;

(ii) the distance $d(X_{n+1}, X_n)$ between the spatial positions X_n and X_{n+1} in the GRF of $\mathcal{O}$ is the same as the distance $d(X'_{n+1}, X'_n)$ between the corresponding positions X'_n and X'_{n+1} in the GRF of $\mathcal{O}'$;

(iii) the number $d(X_{n+1}, X_n)/\delta t_n$ is negligible compared to light speed.

For the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution, we can identify the duration of the process with the duration of the time span of the occurrent ${}^{EP}\varphi^n_k + {}^{NW}\varphi^n_k + {}^{NP}\varphi^{n+1}_k$. If this is a simplest process as described by Eqs. (6.6)-(6.13), then its duration is thus the duration of the time span of the occurrent $\psi^n_{\mathrm{M}_1} + {}^{NP}\mu^{n+1}_{\mathrm{M}_1}$, cf. Eq. (6.15).

Postulate 6.1.6 (Duration of an elementary process)**.**
Under non-relativistic conditions, all elementary process have the same duration of a Planck time in the GRF of any observer $\mathcal{O}$. ■

We are now ready for a definition of monadic systems:

Definition 6.1.7 (Monadic systems)**.**
Let the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution be a simplest process with the duration of a Planck time, and let the occurrent ${}^{EP}\varphi^n_k + {}^{NW}\varphi^n_k + {}^{NP}\varphi^{n+1}_k$ have a non-degenerate time span $[t_n, t_{n+1}]$ in the GRF of an observer $\mathcal{O}$, with

$$ {}^{EP}\varphi^n_k + {}^{NW}\varphi^n_k + {}^{NP}\varphi^{n+1}_k = \psi^n_{\mathrm{M}_1} + {}^{NP}\mu^{n+1}_{\mathrm{M}_1} \tag{6.18} $$

*Then the states of the temporal parts of the occurrent $\psi^n_{\mathrm{M}_1} + {}^{NP}\mu^{n+1}_{\mathrm{M}_1}$ in the GRF of $\mathcal{O}$ can be viewed as states of one and the same **monadic system:***

*(i) at $t = t_n$, the temporal part of the occurrent $\psi^n_{\mathrm{M}_1} + {}^{NP}\mu^{n+1}_{\mathrm{M}_1}$ is the extended particlelike matter quantum ${}^{EP}\mu^n_{\mathrm{M}_1}$ with degenerate time span $\{t_n\}$, whose state in the GRF of $\mathcal{O}$ can be viewed as the **ground state** of the monadic system;*

*(ii) at $t \in (t_n, t_{n+1})$, the temporal part of the occurrent $\psi^n_{\mathrm{M}_1} + {}^{NP}\mu^{n+1}_{\mathrm{M}_1}$ is a temporal part of the nonlocal wavelike phase quantum ${}^{NW}\varphi^n_k$ with time span (t_n, t_{n+1}), whose state in the GRF of $\mathcal{O}$ can be viewed as a **transition state** of the monadic system;*

*(iii) at $t = t_{n+1}$, the temporal part of the occurrent $\psi^n_{\mathrm{M}_1} + {}^{NP}\mu^{n+1}_{\mathrm{M}_1}$ is the nonextended particlelike matter quantum ${}^{NP}\mu^{n+1}_{\mathrm{M}_1}$ with degenerate time span $\{t_{n+1}\}$, whose state in the GRF of $\mathcal{O}$ can be viewed as the **excited state** of the monadic system.*

*More generally, if the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution is any process, then the states of the temporal parts of the occurrent ${}^{NP}\varphi^n_k + {}^{EP}\varphi^n_k + {}^{NW}\varphi^n_k$ can be viewed as excited states, ground states, and transition states of one and the same **supersmall massive system**. A monadic system is a special case of a supersmall massive system.* ■

Let us briefly reflect on this definition. First of all, there is no experimental justification for identifying the duration of an elementary process with a Planck time: this has to be taken as a fundamental postulate of (non-relativistic) Planck-scale physics in the framework of the EPT, which is based on nothing but the idea that "the Planck length and Planck time are conceptually linked at a fundamental physical level".[54]

Secondly, the distinction between a monadic system and its environment is merely *conceptual*. Recall from Ch. 3 that spatial phase quanta and nonlocal wavelike phase quanta form a (four-dimensional) homogenous phase; since (temporal parts of) spatial phase quanta are a part of the environment of a monadic system, that means that a monadic system is not *physically* separated from its environment when it is in a transition state. Quite the opposite: when a monadic system is in a transition state, it is *one with its environment* from a physical perspective.

Thirdly, if we have a sequence of p consecutive simplest processes, so that the set of properties M_1 is carried from the n^{th} to the $(n+p)^{\text{th}}$ degree of evolution, then the states of the temporal parts of the p occurrents $\psi^n_{\text{M}_1} + {}^{NP}\mu^{n+1}_{\text{M}_1}, \ldots, \psi^{n+p-1}_{\text{M}_1} + {}^{NP}\mu^{n+p}_{\text{M}_1}$ are all states of one and the same monadic system. At all the discrete times $t_j \in \{t_n, t_{n+1}, \ldots, t_{n+p}\}$ it thus happens that the monadic system transforms from an excited state at the spatial position X_j to a ground state centered at that same spatial position X_j, with which the next process of its temporal evolution begins. So, in every elementary process of its temporal evolution a monadic system 'leaps' in a transition state from one ground state to the next, thereby exhibiting stepwise motion as in the j^{th} of p consecutive processes a spatial displacement δX_j is accomplished in a Planck time.

The principle of choice of the EPT, which states that the nonextended particlelike phase quantum created in an elementary process is chosen from a set of parallel possible phase quanta as in Eq. (6.11), thus translates to the idea that (in inanimate matter) the 'leap' of a monadic system in an elementary process of its temporal evolution is completely determined by gravitation and electromagnetism. In particular, if gravitation and electromagnetism are negligible, then these 'leaps' are constant in a sequence of such processes: that is Newton's first law. The next two sections model non-relativistic elementary particles and their (semi-classical) interactions.

6.2 Elementary particles as monadic systems

Let us begin with this question: what is an electron? The existence of the building blocks of the outside world that we refer to as 'electrons' has been established beyond reasonable doubt by experiments: we can therefore say that we know that electrons exist. Likewise, it has become known what the main properties of an electron are: among other things, an electron 'has' an inertial rest mass of $9.1 \cdot 10^{-31}$ $[kg]$, an electric charge of $-1.6 \cdot 10^{-19}$ $[C]$, spin $\frac{1}{2}$, and it is stable. Nevertheless, the current state of affairs is that we still do not know *what* an electron actually is.

To model an electron in the framework of the EPT, the idea is to model a monadic system that can be viewed as a physical system made up of a single electron. Thus speaking,

(i) a system made up of a single electron is a monadic system that evolves in time by a sequence of elementary processes described by the EPT;

(ii) in each of these elementary processes a monad $\mathfrak{m}_1$ is carried from an initial degree of evolution to the next;

(iii) the monad $\mathfrak{m}_1$ is an *electronic monad*, meaning that it contains the rest mass spectrum s_e of an electron, as well as the characteristic number of normality $c_{\mathrm{n}}(e^-)$ of an electron (see Table 3.1):

$$\mathfrak{m}_1 \supset \{s_e, c_{\mathrm{n}}(e^-)\} = \{s_e, +1\} \tag{6.19}$$

(iv) an occurrent $\psi^n_{\mathfrak{m}_1} + {}^{NP}\mu^{n+1}_{\mathfrak{m}_1}$ is then a "Planck segment" of the life of an electron.

The idea is thus that the known properties of an electron then derive from the invariant properties of the monad $\mathfrak{m}_1$. However, since our aim here is to reproduce the results of non-relativistic classical mechanics, the property 'spin' is ignored in this chapter.

So, suppose the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution is a simplest process in which the electronic monad $\mathfrak{m}_1$ is carried from the initial degree of evolution n to the next: this is, thus, an elementary process by which a one-electron system evolves in time. Let the Planck segment of the life of 'our' electron in this process of its temporal evolution—i.e., the occurrent $\psi^n_{\mathfrak{m}_1} + {}^{NP}\mu^{n+1}_{\mathfrak{m}_1}$—have a time span $[t_n, t_{n+1}]$ in the GRF of an observer $\mathcal{O}$. Let t_P denote the Planck time, so that

$$t_{n+1} - t_n = t_\mathrm{P}\ [s] \tag{6.20}$$

In addition, we assume that at every time $t \in [t_n, t_{n+1}]$, the monadic system finds itself in a Euclidean space $(\mathbb{R}^3, d)$—with $d(\ ,\ )$ the Euclidean distance function—so that its state in the GRF of our observer $\mathcal{O}$ can be modeled by a function on $\mathbb{R}^3$ along the lines of Eq. (3.3).

Eqs. (6.6)-(6.13) describe this process in the formalism of the EPT, provided we substitute the constant $\mathfrak{m}_1$ for the variable M_1. We are now going to interpret these expressions physically in the language of systems theory along the lines of Def. 6.1.7, and we are going to model the states of the system in the GRF of our observer $\mathcal{O}$ along the lines set forth in Sect. 3.2. Thus speaking, this process begins at the point in time $t = t_n$ with the one-electron system being in a ground state centered at a position $X_n \in \mathbb{R}^3$. A **naive model** of this ground state is then a function f_{t_n} on $\mathbb{R}^3$ representing a uniform distribution of the electron's *gravitational rest mass* $m_g(t_n)$ over the closed ball $\overline{B}_{r_n}(X_n)$ with r_n being the mass radius of the electron in this process:

$$f_{t_n} : (x, y, z) \mapsto c_\mathrm{n}(e^-) \cdot \rho \cdot \chi_{\overline{B}_{r_n}(X_n)}(x, y, z) \tag{6.21}$$

$$\int\int\int_{\mathbb{R}^3} f_{t_n}(x, y, z)dxdydz = m_g(t_n) \tag{6.22}$$

Here $c_\mathrm{n}(e^-) \in \mathfrak{m}_1$ is the *characteristic number of normality*, which has the value $+1$ for an electron, $\chi_{\overline{B}_{r_n}(X_n)} : \mathbb{R}^3 \to \{0, 1\}$ is the characteristic function of the closed ball $\overline{B}_{r_n}(X_n)$, the real number ρ represents the universal mass density of ground states, and the gravitational rest mass $m_g(t_n)$ derives from $c_\mathrm{n}(e^-)$ and the *electronic rest mass spectrum* $s_e \in \mathfrak{m}_1$:

$$m_g(t_n) = c_\mathrm{n}(e^-) \cdot s_e(n) = 1 \cdot m^n_0 = m^n_0\ [kg] \tag{6.23}$$

Here m^n_0 is thus the inertial rest mass of our electron at the degree of evolution n as *predetermined* by the rest mass spectrum s_e. We will consider s_e to be a constant function; the electric charge $Q_e = -1.6 \cdot 10^{-19}\ [C]$ of the electron is then a (constant) primary property $Q_e \in \mathfrak{m}_1$.

Remark 6.2.1. Alternatively, we can treat electric charge as a secondary property that encodes a gradual change of gravitational rest mass, cf. pp. 117-118. In that case, the rest mass spectrum is not constant; the time-independent 'emergent charge' $q_e = -1$ is then given by

$$m_g(t_{n+1}) = m_g(t_n) - q_e \cdot \delta m \ [kg] \tag{6.24}$$

where δm is a supersmall unit of mass. We then relate this emergent charge q_e to the known electric charge Q_e of the electron by a constant $k > 0$:

$$Q_e = k \cdot q_e = -1.6 \cdot 10^{-19} \ [C] \tag{6.25}$$

■

Next, by the discrete transition of Eq. (6.7) our one-electron system transforms from its ground state into a transition state. This transition state has a lifetime of one Planck time: this is the duration t_{P} of the time span (t_n, t_{n+1}) of the occurrent ${}^{NW}\varphi_k^n$—recall from Def. 6.1.7 that the state of a temporal part of the occurrent ${}^{NW}\varphi_k^n$ in the GRF of an observer $\mathcal{O}$ can be viewed as a transition state of the monadic system. At every point in time $t \in (t_n, t_{n+1})$ the one-electron system then has a (time-independent) velocity $\vec{v}_n \in \mathbb{R}^3$: despite the level of abstractness of the description of the process in the language of the EPT, the occurrent in the outside world to which the designator ${}^{EP}\mu^n_{\mathfrak{m}_1}$ refers *does have* a definite position $X_n \in \mathbb{R}^3$, and the occurrent in the outside world to which the designator ${}^{NW}\varphi_k^n$ refers *does have* a constant velocity $\vec{v}_n \in \mathbb{R}^3$ associated to it. Let ℓ_{P} denote the Planck length; a **naive model** of the transition state of our one-electron system at a point in time $t \in (t_n, t_{n+1})$ is then a function f_t on $\mathbb{R}^3$ given by

$$f_t : (x, y, z) \mapsto m_g(t) \cdot \ell_{\mathrm{P}}^3 \cdot \sqrt{\pi^{-3}} e^{-r(t)^2/\ell_{\mathrm{P}}^2} \tag{6.26}$$

$$r(t) = d(X, X_t) \tag{6.27}$$

$$X_t = X_n + (t - t_n) \cdot \vec{v}_n \tag{6.28}$$

Here $m_g(t) \geq m_g(t_n)$: the idea is that the one-electron system absorbs energy from its environment when it is in a transition state, so that its gravitational mass $m_g(t)$ may exceed its gravitational rest mass $m_g(t_n)$—see Sect. 6.3 for a quantitative treatment. The gravitational mass $m_g(t)$

is thus distributed normally over the spatial extension of the transition state, and the associated constant velocity $\vec{p}_n$ is encoded in a change in that distribution over time. More precisely, for any $t \in (t_n, t_{n+1})$, the transition state of the one-electron system changes in an infinitesimal time span $[t, t+dt] \subset (t_n, t_{n+1})$ from f_t to f_{t+dt} by which the top of the bell curve thus moves from X_t to X_{t+dt}. The monadic system being non-relativistic then means that $d(X_t, X_{t+dt})/dt \ll c$ (with 'c' denoting light speed).

Proceeding, by the collapse of the transition state at $t = t_{n+1} = t_n + t_\mathrm{P}$ the one-electron system transforms from a transition state into an excited state; the segment of the life of the electron with time span (t_n, t_{n+1})—this is the occurrent ${}^{NW}\varphi_k^n$—thus effects that the preceding ground state of the system, designated by ${}^{EP}\varphi_k^n$, is succeeded by an excited state of the system, designated by ${}^{NP}\mu_{\mathfrak{m}_1}^{n+1}$, cf. Eq. (6.9). Again, despite the level of abstractness of the description of the process in the language of the EPT, the occurrent to which the designator ${}^{NP}\mu_{\mathfrak{m}_1}^{n+1}$ refers *does have* a definite spatial position $X_{n+1} \in \mathbb{R}^3$. This position X_{n+1} can be calculated from the position $X_n \in \mathbb{R}^3$ of the initial ground state of the one-electron system and the constant velocity $\vec{v}_n$ associated to the transition state:

$$X_{n+1} = X_n + t_\mathrm{P} \cdot \vec{v}_n = \lim_{t \to t_{n+1}} X_t \tag{6.29}$$

At $t = t_{n+1}$, the excited state of the monadic system is thus located at the position X_t where the top of the bell curve of Eq. (6.26) would have been at that time $t = t_{n+1}$. A **naive model** of the excited state of the system is the (hyperreal) delta function $f^*_{t_{n+1}}$ on $\mathbb{R}^3$, which for $X = (x, y, z)$ is given by

$$f^*_{t_{n+1}} : (x, y, z) \mapsto m_g^*(t_{n+1}) \cdot \delta^3(X - X_{n+1}) \tag{6.30}$$

$$m_g^*(t_{n+1}) = \lim_{t \to t_{n+1}} m_g(t) \tag{6.31}$$

Here $\delta^3(X - X_{n+1})$ is a Dirac delta function on $\mathbb{R}^3$, so that

$$X \neq X_{n+1} \Rightarrow f^*_{t_{n+1}}(x, y, z) = 0 \tag{6.32}$$

$$\int\int\int_{\mathbb{R}^3} f^*_{t_{n+1}}(x, y, z)dxdydz = m_g^*(t_{n+1}) \tag{6.33}$$

Ch. 9 introduces Dirac delta functions on $\mathbb{R}^n$ as hyperreal functions.

By the discrete transition of Eq. (6.12), the excited state of the one-electron system decays into radiation—a temporal part of the occurrent ${}^{LW}\varphi_k^{n+1}$ can be viewed as radiation, which is a continuant—and the next ground state of the one-electron system. Starting with the latter, this newly created normal article state can, as before, be represented by a function $f_{t_{n+1}} : \mathbb{R}^3 \to \mathbb{R}$ given by

$$f_{t_{n+1}} : (x, y, z) \mapsto c_{\mathrm{n}}(e^-) \cdot \rho \cdot \chi_{\overline{B}_{r_{n+1}}(X_{n+1})}(x, y, z) \tag{6.34}$$

$$\int\int\int_{\mathbb{R}^3} f_{t_n}(x, y, z) dx dy dz = m_g(t_{n+1}) \tag{6.35}$$

where $\chi_{\overline{B}_{r_{n+1}}(X_{n+1})} : \mathbb{R}^3 \to \{0, 1\}$ is the characteristic function of the closed ball $\overline{B}_{r_{n+1}}(X_{n+1})$ with center X_{n+1} and radius r_{n+1}, the new mass radius of the one-electron system. The ground state of the system, newly created at $t = t_{n+1}$, is thus centered at the position X_{n+1} of the preceding excited state of the system—note thus that at the one point in time $t = t_{n+1}$ two states exist: *first* an excited state and *thereupon* a ground state. The new gravitational rest mass $m_g(t_{n+1})$ derives as before from the characteristic number of normality c_{n} and the electronic rest mass spectrum s_e: analogous to Eq. (6.23) we have

$$m_g(t_{n+1}) = c_{\mathrm{n}}(e^-) \cdot s_e(n + 1)\ [kg] \tag{6.36}$$

The radiation, on the other hand, is a photon, which we may view as a 'momentum packet': the one-electron system receives an impulse by emitting a momentum packet—a massless point particle moving with light speed on a straight line.

Remark 6.2.2. When applying the alternative treatment of electric charge as a secondary property, the one-electron system also experiences a loss of gravitational rest mass at this event. The loss of gravitational rest mass is emitted in the form of a spherically symmetric local matter wave. In terms of occurrents we may then write

$${}^{LW}\varphi_k^{n+1} = \xi_k^{n+1} + \gamma_k^{n+1} \tag{6.37}$$

where the subatomic occurrent ξ_k^{n+1} is the life of the local matter wave, and the subatomic occurrent γ_k^{n+1} is life of the photon. ■

The radiation, however, is not a part of the system: we will therefore not model the local matter waves *hic et nunc*, nor the photons, nor their effect on the environment of a monadic system. The same goes for the formation of space, Eq. (6.13).

This concludes the description of an electron as a monadic system: its temporal evolution continues with the next process, which begins with the existence of the system in its ground state centered at X_{n+1}. In the next section, we will quantitatively describe the effect of the gravitational, electric, and magnetic fields in the environment of the monadic system on its subsequent states—assuming certain conditions, that is.

Having treated the electron, we can now turn to the positron. So, let the ℓ^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution be a simplest process in which the *positronic monad* $\mathfrak{m}_2$ is carried from the degree of evolution n to the degree of evolution $n+1$: this is, thus, an elementary process in the temporal evolution of a one-positron system. The monad $\mathfrak{m}_2$ being *positronic* means that it contains the rest mass spectrum s_e of an electron, as well as the characteristic number of normality $c_{\text{n}}(e^+)$ of a positron (see Table 3.1):

$$\mathfrak{m}_2 \supset \{s_e, c_{\text{n}}(e^+)\} = \{s_e, -1\} \tag{6.38}$$

This process is then described in the language of the EPT by the same Eqs. (6.6)-(6.13), provided the counting number k is substituted by ℓ and the variable M_1 by $\mathfrak{m}_2$. The occurrent $\psi^n_{\mathfrak{m}_2} + {}^{NP}\mu^{n+1}_{\mathfrak{m}_2}$ is a Planck segment of the life of a positron, and in the GRF of our observer $\mathcal{O}$ we have that

(i) the ground state of the monadic system is the ground state of the positron;

(ii) a transition state of the monadic system is a transition state of the positron;

(iii) the excited state of the monadic system is the excited state of the positron.

Note, however, that the occurrent $\psi^n_{\mathfrak{m}_1} + {}^{NP}\mu^{n+1}_{\mathfrak{m}_1}$ is a Planck segment of the life of an electron, an elementary particle of *ordinary matter*, whereas the occurrent $\psi^n_{\mathfrak{m}_2} + {}^{NP}\mu^{n+1}_{\mathfrak{m}_2}$ is the Planck segment of the life of the positron, an elementary particle of *antimatter*. The difference is that the occurrent $\psi^n_{\mathfrak{m}_1} + {}^{NP}\mu^{n+1}_{\mathfrak{m}_1}$ carries the electronic monad $\mathfrak{m}_1$ containing the characteristic number of normality +1, whereas the occurrent $\psi^n_{\mathfrak{m}_2} + {}^{NP}\mu^{n+1}_{\mathfrak{m}_2}$ carries the positronic monad $\mathfrak{m}_2$ containing the characteristic number of normality −1. We can then state the following general relation between the value of the characteristic number of normality c_{n} contained in a monad carried in a simplest process, and the nature of the monadic system that evolves in time by this process: for any degree of evolution n, for any simplest process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution, and for any monad M_1 carried in that process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution,

(i) if the occurrent $\psi^n_{\text{M}_1} + {}^{NP}\mu^{n+1}_{\text{M}_1}$ is a **normal occurrent**, that is, is endowed with the characteristic number of normality $c_{\text{n}} = +1$, then any of its temporal parts can be viewed as a monadic system made up of a single elementary particle of **ordinary matter**;

(ii) if the occurrent $\psi^n_{\text{M}_1} + {}^{NP}\mu^{n+1}_{\text{M}_1}$ is an **abnormal occurrent**, that is, is endowed with the characteristic number of normality $c_{\text{n}} = -1$, then any of its temporal parts can be viewed as a monadic system made up of a single elementary particle of **antimatter**.

Proceeding, let's assume that the occurrent $\psi^n_{\mathfrak{m}_2} + {}^{NP}\mu^{n+1}_{\mathfrak{m}_2}$ has the same time span $[t_n, t_{n+1}]$. At the point in time $t = t_n$ the gravitational rest mass $\overline{m}_g(t_n)$ of the positron is then the *opposite* of the inertial rest mass of the electron m^n_0; as required by our 'criterion of truth' of Ch. 1, Eq. (1.12),

$$\overline{m}_g(t_n) = c_{\text{n}}(e^+) \cdot s_e(n) = -1 \cdot s_e(n) = -m^n_0 < 0 \tag{6.39}$$

Remark 6.2.3. Should we treat electric charge as a secondary property, then the emergent charge $\overline{q}_e$ of the positron satisfies the same relation as the emergent charge q_e of the electron, cf. Eq. (6.24):

$$\overline{m}_g(t_{n+1}) = \overline{m}_g(t_n) - \overline{q}_e \cdot \delta m \; [kg] \tag{6.40}$$

We then obtain $\overline{q}_e = -q_e$; the electric charge of the positron $\overline{Q}_e$ is then opposite to that of the electron: $\overline{Q}_e = k \cdot \overline{q}_e = +1.6 \cdot 10^{-19}$ $[C]$. ■

This concludes the treatment of the positron; for the rest, its process of evolution is the same as that of the electron described in the foregoing.

Having treated electrons and positrons as monadic systems, let's proceed by treating the annihilation of an electron and a positron. For that matter, let an **annihilating system** be a special kind of supersmall non-monadic system that evolves in time by a complex process—for a definition thereof, see Def. 6.1.1—that can be called an annihilation process. So, let the k^{th} process from the x^{th} to the $(x+1)^{\text{th}}$ degree of evolution be process by which an electron and a positron annihilate. This annihilation process begins when the annihilating system exists in its ground state, designated by ${}^{EP}\varphi_k^x$. At this point the annihilating system is made up of two components: an electron in its ground state, designated by ${}^{EP}\mu_{\mathfrak{m}_1}^x$, and a positron in its ground state, designated by ${}^{EP}\mu_{\mathfrak{m}_2}^x$:

$$\mathbb{E}^{EP}\varphi_k^x \ \wedge \ {}^{EP}\varphi_k^x \ = \ {}^{EP}\mu_{\mathfrak{m}_1}^x + \ {}^{EP}\mu_{\mathfrak{m}_2}^x \tag{6.41}$$

The monads $\mathfrak{m}_1$ and $\mathfrak{m}_2$ in Eq. (6.41) are thus respectively the electronic monad $\mathfrak{m}_1$ and the positronic monad $\mathfrak{m}_2$ that we already encountered—let's just assume that the electron and the positron treated in the foregoing now annihilate in this process. The fact that the electron in its ground state and the positron in its ground state form an annihilating system in its ground state means that annihilation is inevitable: prior to this process we had thus *two* elementary processes, each of which began with a monadic system in its ground state.

Next, by the discrete transition ${}^{EP}\varphi_k^x \to \ {}^{NW}\varphi_k^x$ the annihilating system transforms from its ground state in a transition state. By the generalized principle of particle/wave duality, Ax. 5.3.11, we then have

$${}^{EP}\varphi_k^x + \ {}^{NW}\varphi_k^x = \psi_{\mathfrak{m}_1}^x + \psi_{\mathfrak{m}_2}^x \tag{6.42}$$

Ergo, the annihilating system in its transition state consists of the electron in its transition state plus the positron in its transition state. By the collapse of the (composite) transition state, the annihilating system transforms into its excited state: the occurrent ${}^{NW}\varphi_k^x$ thus effects that the ground state of the system is succeeded by an excited state. We have

$${}^{NW}\varphi_k^x : \ {}^{EP}\varphi_k^x \dashrightarrow \ {}^{NP}\varphi_k^{x+1} \tag{6.43}$$

However, in its excited state the supersmall system has only one component, which we denote by ${}^{NP}\mu_{\mathfrak{m}_3}^{x+1}$:

$$ {}^{NP}\varphi_k^{x+1} = {}^{NP}\mu_{\mathfrak{m}_3}^{x+1} \tag{6.44}$$

In the language of the interpretation rules of the EPT this is the nonextended particlelike matter quantum carrying the monad $\mathfrak{m}_3$ at the $(n+1)^{\text{th}}$ degree of evolution, cf. Interpretation Rule 5.2.19. In the language of systems theory, this matter quantum can be viewed as an annihilating system in its excited state. The occurrent ${}^{EP}\varphi_k^x + {}^{NW}\varphi_k^x + {}^{NP}\varphi_k^{n+1}$ with

$$ {}^{EP}\varphi_k^x + {}^{NW}\varphi_k^x + {}^{NP}\varphi_k^{x+1} = ({}^{EP}\mu_{\mathfrak{m}_1}^x + {}^{EP}\mu_{\mathfrak{m}_2}^x) + {}^{NW}\varphi_k^x + {}^{NP}\mu_{\mathfrak{m}_3}^{x+1} \tag{6.45}$$

is thus (the one Planck segment of) the life of an annihilating system.

The monad $\mathfrak{m}_3$ is an *annihilating monad*: its rest mass spectrum s_A is the zero function on Z_N and its characteristic number of normality $c_{\mathrm{n}}(A)$ is also zero; we thus have

$$ \mathfrak{m}_3 \supset \{s_A, c_{\mathrm{n}}(A)\} = \{s_A, 0\} \tag{6.46}$$

And *because* the rest mass spectrum s_A is the zero function, the next ground state of the annihilating system is zero and thus nonexistent:

$$ {}^{EP}\mu_{\mathfrak{m}_3}^{x+1} = 0 \tag{6.47}$$

We therefore get that the annihilating system in its excited state decays into two oppositely directed photons. Designating the lives of these photons by γ_1^{x+1} and γ_2^{x+1}, we thus have in terms of occurrents that

$$ {}^{NP}\mu_{\mathfrak{m}_3}^{x+1} \to \gamma_1^{x+1} + \gamma_2^{x+1} (+ {}^{EP}\mu_{\mathfrak{m}_3}^{x+1}) \tag{6.48}$$

The two occurrents γ_1^{x+1} and γ_2^{x+1} thus form the occurrent ${}^{LW}\varphi_k^{x+1}$ in the language of the EPT, as in ${}^{LW}\varphi_k^{x+1} = \gamma_1^{x+1} + \gamma_2^{x+1}$, cf. Ax. 5.3.16.

Summarizing, the process begins with the ground state of an annihilating system, initially made up of an electron-positron pair: annihilation is then inevitable. The annihilating system then spontaneously transforms into a transition state, which soon thereafter (i.e., a Planck time later) collapses into the excited state of the annihilating system: the latter then decays into two oppositely directed photons.

In cases where free (anti)nucleons—'free' in the sense of not being bound by the strong force—can be viewed as spinless and indivisible, which is for example when we are merely interested in long-distance interactions, these can be treated as monadic systems in the same way as has been done above for electrons and positrons. So, let the j^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution be a simplest process in which the monad M_1 is carried from the degree of evolution n to the degree of evolution $n+1$, and let this be an elementary process in the temporal evolution of a monadic system made up of one (anti)nucleon. The occurrent $\psi^n_{\text{M}_1} + {}^{NP}\mu^{n+1}_{\text{M}_1}$ is then a Planck segment of the life of an (anti)nucleon with time span $[t_n, t_{n+1}]$ in the GRF of our observer $\mathcal{O}$, and as before we have in this GRF that

(i) at $t = t_n$, the ground state of the monadic system is the ground state of the (anti)nucleon;

(ii) at $t \in (t_n, t_{n+1})$, the transition state of the monadic system is a transition state of the (anti)nucleon;

(iii) at $t = t_{n+1}$, the excited state of the monadic system is the excited state of the (anti)nucleon.

The value of the variable M_1 determines the nature of the component of the monadic system:

- if M_1 is a protonic monad, then the component is a proton;
- if M_1 is an antiprotonic monad, then the component is an antiproton;
- if M_1 is a neutronic monad, then the component is a neutron;
- if M_1 is an antineutronic monad, then the component is an antineutron.

The properties of these monads are given by Table 3.1. The process by which a nucleon-antinucleon pair annihilates can then be treated in the same way as the annihilation of an electron-positron pair.

Remark 6.2.4. Treating electric charge as a secondary property, a conjecture is that the rest mass spectra s_p and s_e of protons and electrons are related by $s_p(n) = s_e(N - n)$. The emergent charge q_p of the proton, and thus the electric charge Q_p, follows by applying Eq. (6.24). The positive electric charge $Q_p = -Q_e$ of the proton thus means that it slowly decays.■

Now that we have protons, electrons, and neutrons, we can treat the decay of a neutron into an electron, a proton and a neutrino as a complex process. So, let the i^{th} process from the x^{th} to the $(x+1)^{\text{th}}$ degree of evolution begin at $t = t_x$ in the GRF of an observer $\mathcal{O}$ when a supersmall system, initially made up of one neutron, exists in a ground state. Let $\mathfrak{m}_4$ be a neutronic monad; we then have

$$\begin{cases} \mathbb{E}^{EP}\varphi_i^x \\ {}^{EP}\varphi_i^x = {}^{EP}\mu_{\mathfrak{m}_4}^x \end{cases} \tag{6.49}$$

By the discrete transition ${}^{EP}\varphi_i^x \to {}^{NW}\varphi_i^x$, the supersmall system then spontaneously transforms from its ground state into a transition state; at any point in time $t \in (t_x, t_x + t_{\text{P}})$ the state of the system in the GRF of $\mathcal{O}$ is thus a transition state of a (decaying) neutron. A planck time later, at $t = t_{x+1} = t_x + t_{\text{P}}$, the transition state collapses and the supersmall system then exists in its excited state designated by ${}^{NP}\varphi_i^{x+1}$. By then, the supersmall system is made up of two components: an electron and a proton. So, let $\mathfrak{m}_5$ and $\mathfrak{m}_6$ respectively be an electronic monad and a protonic monad; we then have

$$\begin{cases} {}^{NW}\varphi_i^x : {}^{EP}\mu_{\mathfrak{m}_4}^x \dashrightarrow {}^{NP}\varphi_i^{x+1} \\ {}^{NP}\varphi_i^{x+1} = {}^{NP}\mu_{\mathfrak{m}_5}^{x+1} + {}^{NP}\mu_{\mathfrak{m}_6}^{x+1} \end{cases} \tag{6.50}$$

If we substitute the lower of the above equations in the upper one, we see that the occurrent ${}^{NW}\varphi_i^x$ effects that a neutron in its ground state is succeeded by an electron and a proton in excited states:

$${}^{NW}\varphi_i^x : {}^{EP}\mu_{\mathfrak{m}_4}^x \dashrightarrow {}^{NP}\mu_{\mathfrak{m}_5}^{x+1} + {}^{NP}\mu_{\mathfrak{m}_6}^{x+1} \tag{6.51}$$

The (composite) supersmall system in its excited state then emits a neutrino, and transforms into an electron in its normal particle ${}^{EP}\mu_{\mathfrak{m}_5}^{x+1}$ state plus a proton in its ground state designated by ${}^{EP}\mu_{\mathfrak{m}_6}^{x+1}$. The life of the neutrino is the local wavelike phase quantum designated by ${}^{LW}\varphi_1^{x+1}$, so in accordance with Ax. 5.3.16 we have

$${}^{NP}\varphi_i^{x+1} \to {}^{LW}\varphi_1^{x+1} + {}^{EP}\mu_{\mathfrak{m}_5}^{x+1} + {}^{EP}\mu_{\mathfrak{m}_6}^{x+1} \tag{6.52}$$

The idea is then that thereby the original supersmall system in its excited state splits into two new supersmall systems in their ground states. That is, by now the electron in its ground state forms a new monadic system in its ground state that further evolves in the, say, j^{th} process from the $(x+1)^{\text{th}}$ to the $(x+2)^{\text{th}}$ degree of evolution, while the proton in its ground state forms a new monadic system in its ground state that further evolves in the, say, $(j+1)^{\text{th}}$ process from the $(x+1)^{\text{th}}$ to the $(x+2)^{\text{th}}$ degree of evolution. So we have

$$\mathbb{E}^{EP}\mu^{x+1}_{\mathfrak{m}_5} \wedge {}^{EP}\mu^{x+1}_{\mathfrak{m}_5} = {}^{EP}\varphi^{x+1}_{j} \tag{6.53}$$
$$\mathbb{E}^{EP}\mu^{x+1}_{\mathfrak{m}_6} \wedge {}^{EP}\mu^{x+1}_{\mathfrak{m}_6} = {}^{EP}\varphi^{x+1}_{j+1} \tag{6.54}$$

So if we look at the occurrent ${}^{EP}\varphi^n_k + {}^{NW}\varphi^n_k + {}^{NP}\varphi^{n+1}_k$ with

$${}^{EP}\varphi^n_k + {}^{NW}\varphi^n_k + {}^{NP}\varphi^{n+1}_k = \psi^x_{\mathfrak{m}_4} + \left({}^{NP}\mu^{x+1}_{\mathfrak{m}_5} + {}^{NP}\mu^{x+1}_{\mathfrak{m}_6}\right) \tag{6.55}$$

and with time span $[t_x, t_{x+1}]$ in the GRF of $\mathcal{O}$, then we have that

(i) at $t = t_x$, the state of its temporal part in the GRF of $\mathcal{O}$ is a ground state of a neutron;

(ii) at any $t \in (t_x, t_{x+1})$, the state of its temporal part in the GRF of $\mathcal{O}$ is a transition state of that neutron;

(iii) at $t = t_{x+1}$, the state of its temporal part in the GRF of $\mathcal{O}$ consists of excited states of an electron and a proton;

This demonstrates that the EPT applies to a description of neutron decay; at this degree of abstractness, however, the process description yields no further insight into the precise conditions that trigger the decay.

Remark 6.2.5. One might object to the above treatment of neutron decay that according to the Standard Model, an *antineutrino* is emitted in neutron decay. Historically, Pauli was the first to postulate the existence of the neutrino (1930), while Fermi later postulated that a neutrino would be released in the decay of the neutron (1934). Later, however, this was changed into an antineutrino: the accepted view is now that an antineutrino is emitted in neutron decay. There is, however, not a shred of evidence that the emitted particle is an antineutrino and not a neutrino: this change has not been implemented on experimental grounds, but merely to save the law of conservation of lepton number from failure. ■

6.3 Semi-classical model of interaction processes

The previous section has treated elementary particles as monadic systems: by developing a mathematical model of the subsequent states of these monadic systems we have obtained a view on what elementary particles are in the framework of the EPT under non-relativistic conditions. This section treats the interaction between an elementary particle and its environment as a process by which a monadic system evolves in time: the idea is that every process in the temporal evolution of a monadic system is an interaction process. There are then two sides to every interaction process:

- the environment has an effect on the monadic system (i.e., the elementary particle);
- the monadic system has an effect on its environment.

We will only treat the effect of the environment on the monadic system, and this treatment is semi-classical. For that matter, we assume that the monadic system is non-relativistic, that it evolves in time by a simplest process described by Eqs. (6.6)-(6.13), and that the Planck segment of its life in this process—i.e., the occurrent $\psi^n_{\text{M}_1} + {}^{NP}\mu^{n+1}_{\text{M}_1}$—has a time span $[t_n, t_{n+1}]$ in the GRF of an observer $\mathcal{O}$. In addition, we assume that its environment can be modeled as follows in the GRF of $\mathcal{O}$:

(i) the environment is an open subset $U \subset \mathbb{R}^3$;

(ii) the gravitational potential Φ_G, the gravitational field $-\vec{\nabla}\Phi_G$, the electric potential Φ_E, the electric field $-\vec{\nabla}\Phi_E$, and the magnetic field $\vec{B}$ in the environment U can be modeled with classical mechanics.

The effect of the interaction on a monadic system is then an effect on its properties (position, velocity, mass, energy): this effect will be described quantitatively. Importantly, this effect is independent of any internal structure of a monadic system: it is not relevant whether e.g. the ground state of a monadic system is a ball, a cube, or just a point.

In this section we will thus assume that a state of a monadic system at a time t in its temporal evolution is fully specified by an array of properties. The values of the properties obtained from the semi-classical model of interaction processes can then be plugged into the models of the states of a monadic system of Sect. 6.2.

Gravitational interactions

A process of interaction will generally have gravitational and electromagnetic aspects, but if the gravitational aspect is *predominant* it can be called a process of gravitational interaction. So, let's focus first on an elementary process in the temporal evolution of a (monadic) system made up of one uncharged component, in which a gravitational interaction takes place between the system and its environment.

Let's begin with the invariant primary properties of the monadic system: its characteristic number of normality c_{n}, its rest mass spectrum s and its electric charge Q. We assume the following:

$$\begin{cases} c_{\mathrm{n}} \in \{-1, +1\} \\ \forall n : s(n) = m_0 \\ Q = 0 \end{cases} \tag{6.56}$$

Examples of such monadic systems are a one-neutron system ($c_{\mathrm{n}} = +1$) and a one-antineutron system ($c_{\mathrm{n}} = -1$).

So, let the k^{th} process from the n^{th} to the $(n+1)^{\mathrm{th}}$ degree of evolution begin at $t = t_n$ when the monadic system exists in a ground state. To this state, we associate

(i) a spatial position $X_n = (x_n^1, x_n^2, x_n^3)$, which we may view as the center of the closed ball in the model given by Eqs. (6.21) and (6.22);

(ii) a spatial momentum $\vec{p}_n = (p_n^1, p_n^2, p_n^3)$, which is inherited from the previous process by a law of conservation of momentum;

(iii) a total energy H_n, the system's Hamiltonian, which is the sum of rest energy, kinetic energy, and potential energy.

Thus speaking, for the system in its ground state at $t = t_n$, its inertial mass m_i, gravitational mass m_g, position X, momentum $\vec{p}$, and Hamiltonian H have the following values (c being the speed of light):

$$\begin{cases} m_i = m_0 \ [kg] \\ m_g = c_{\mathrm{n}} \cdot m_i \ [kg] \\ X = X_n \\ \vec{p} = \vec{p}_n \\ H = H_n = m_i c^2 + \vec{p}_n \cdot \vec{p}_n / 2m_i + m_g \cdot \Phi_G(X_n) \ [J] \end{cases} \tag{6.57}$$

In this ground state, the system "sees" the gradient of the potential field Φ_G: it is thereby determined what the gravitational impulse $\delta\vec{p}_n$ is, which the system will receive in this process. This gravitational impulse is the difference between the momenta of the current ground state and the next:

$$\delta\vec{p}_n = \vec{p}_{n+1} - \vec{p}_n \tag{6.58}$$

Its value is then modeled by

$$\delta\vec{p}_n = -m_g \cdot t_{\mathrm{P}} \cdot \vec{\nabla}\Phi_G \tag{6.59}$$

That is, we model the value of the impulse by a product of a duration and an average force, the duration being the duration t_{P} of the process—this is a Planck time—and the average force being the Newtonian gravitational force at $X = X_n$.

Now that we have established what the impulse is and what its value is, it remains to be established *how* the system receives the impulse. In a sentence, the idea is that the system, which will now go through a cycle of transition state, excited state, and next ground state, receives the impulse by

(i) absorbing the energy $\delta E_n = |\delta\vec{p}_n| \cdot c$ of a photon with spatial momentum $-\delta\vec{p}_n$ from its surroundings while being in a transition state;

(ii) emitting a photon with that momentum $-\delta\vec{p}_n$ when it falls back from the subsequent excited state to its next ground state.

Elaborating, at $t = t_n$ a state transition takes place by which the system transforms from a ground state to a transition state with lifetime t_P. To the transition state at a time $t \in (t_n, t_n + t_P)$, we associate

(i) an inertial mass $m_i(t) \geq m_0$;

(ii) a gravitational mass $m_g(t) = c_{\mathrm{n}} \cdot m_i(t)$;

(iii) a constant velocity $\vec{v}_n = \vec{p}_n/m_0$, inherited from the preceding ground state;

(iv) a Hamiltonian $H(t) = H_n + \delta E_n(t) = H_n + \frac{t-t_n}{t_P}\delta E_n$.

Modeling the Hamiltonian $H(t)$ of clause (iv) requires an additional postulate.

Postulate 6.3.1. *The energy $\delta E_n(t)$ that the system has absorbed from its surroundings in the time span (t_n, t) is stored as rest energy, kinetic energy and/or potential energy.* ■

We write $H(t)$ as a sum of rest energy, kinetic energy, and the potential energy at $X(t) = X_n + (t - t_n) \cdot \vec{v}_n$:

$$H(t) = m_i(t)c^2 + \frac{1}{2}m_i(t)\vec{v}_n \cdot \vec{v}_n + m_g(t) \cdot \Phi(X(t)) \tag{6.60}$$

Writing $\Phi(X(t)) = \Phi(X_n) + \delta\Phi(t)$, we can solve for $m_i(t)$:

$$\frac{m_i(t)}{m_0} = \frac{c^2 + \frac{1}{2}|\vec{v}_n|^2 + c_{\rm n} \cdot \Phi(X_n) + c(t - t_n)|\overrightarrow{\nabla}\Phi_G|}{c^2 + \frac{1}{2}|\vec{v}_n|^2 + c_{\rm n} \cdot \Phi(X_n) + c_{\rm n} \cdot \delta\Phi(t)} \tag{6.61}$$

We now limit the area of applicability of this semi-classical model to cases satisfying $m_i(t) \geq m_0$. This corresponds to applicability to weak gravitational fields only, where the Hamiltonian H_n satisfies $H_n > 0$.

At $t = t_{n+1} = t_n + t_P$, the next state transition takes place by which the system transforms from a transition state to an excited state. In this state at $t = t_{n+1}$, the system's inertial mass m_i, gravitational mass m_g, position X, momentum $\vec{p}$, and Hamiltonian H have the following values:

$$\begin{cases} m_i = m_i^* = \lim\limits_{t \to t_{n+1}} m_i(t) \ [kg] \\ m_g = m_g^* = c_{\rm n} \cdot m_i^* \ [kg] \\ X = X_{n+1} = X_n + t_P \cdot \vec{v}_n \\ \vec{p} = \vec{p}^{\,*}_{n+1} = m_i^* \cdot \vec{v}_n \\ H = H^*_{n+1} = \lim\limits_{t \to t_{n+1}} H(t) \ [J] \end{cases} \tag{6.62}$$

Still at $t = t_{n+1}$, the final event of the process takes place: the system emits a photon with energy δE_n and momentum $-\delta\vec{p}_n$, thereby transforming to the next ground state. To understand what happens at this event, it is important to understand that first the photon is emitted: what happens thereafter requires an additional postulate.

Postulate 6.3.2. *At $t = t_{n+1}$, upon emitting the photon with energy δE_n and spatial momentum $-\delta\vec{p}_n$ the remaining Hamiltonian of the system $H_{n+1} = H^*_{n+1} - \delta E_n$ is instantly divided between a new rest energy, a new kinetic energy, and a new potential energy.* ■

Thus speaking, in the new ground state at $t = t_{n+1}$, the system's inertial mass m_i, gravitational mass m_g, position X, momentum $\vec{p}$, and Hamiltonian H have the following values:

$$\begin{cases} m_i = m_0 \ [kg] \\ m_g = c_\text{n} \cdot m_i \ [kg] \\ X = X_{n+1} \\ \vec{p} = \vec{p}_{n+1} = \vec{p}_n + \delta\vec{p}_n = m_0 \cdot \vec{v}_{n+1} \\ H = H_{n+1} = m_i c^2 + |\vec{p}_{n+1}|^2/2m_0 + m_g \cdot \Phi_G(X_{n+1}) = H_n \ [J] \end{cases} \tag{6.63}$$

The monadic system in this new ground state then marks the beginning of a new elementary process in its temporal evolution.

Remark 6.3.3. We lead ourselves astray if we demand that a law of conservation of momentum has to hold in this semi-classical model at the final event. It is, namely, in general not true that the momentum of the excited state and the momentum of the emitted photon add up to the momentum of the new ground state, as in

$$\vec{p}^{\,*}_{n+1} - \delta\vec{p}_n \stackrel{?}{=} \vec{p}_{n+1} \tag{6.64}$$

This final event is better understood as an event that comes with an internal shift in energy $H^*_{n+1} \to H_{n+1} + \delta E_n$—that is, a shift

$$m_i^* \left[c^2 + \frac{1}{2}|\vec{v}_n|^2 + \Phi_G(X_{n+1}) \right] \to m_0 \left[c^2 + \frac{1}{2}|\vec{v}_{n+1}|^2 + \Phi_G(X_{n+1}) \right] + \delta E_n \tag{6.65}$$

whereby the energy δE_n is emitted as a photon and the energy H_{n+1} remains as the ground state. ■

Summarizing, for this generic process of gravitational interaction, the laws of conservation of energy and momentum are

$$H_n + \delta E_n = H^*_{n+1} \tag{6.66}$$

$$H^*_{n+1} - \delta E_n = H_{n+1} \tag{6.67}$$

$$\vec{p}_{n+1} = \vec{p}_n + \delta\vec{p}_n \tag{6.68}$$

Let's now illustrate this generic process with two concrete examples.

Example 6.3.4 (Neutron in the earth's gravitational field).
Let us consider a system made up of a single neutron that interacts with the gravitational field of the earth, initially moving away from the earth's surface; let us treat this as a monadic system using the semi-classical model of gravitational interaction processes set forth in this section. So, let us consider the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution as described by Eqs. (6.6)-(6.13) to be a single process in the evolution of this system, with the variable M_1 being a neutronic monad having the properties as in Table 3.1. So, the electric charge Q_n, inertial rest mass m_0, and characteristic number of normality c_{n} have the following values:

$$\begin{cases} Q_n = 0\ [C] \\ m_0 = 1.67493 \cdot 10^{-27}\ [kg] \\ c_{\text{n}} = +1 \end{cases} \tag{6.69}$$

Now let's model this process in the GRF of an observer $\mathcal{O}$, who is at rest at the earth's surface: let's take the following values for the mass of the earth M_E and the radius R_O of the earth at the origin O of the GRF of $\mathcal{O}$, located at the surface of the earth at the equator:

$$\begin{cases} M_E = 5.97237 \cdot 10^{24}\ [kg] \\ R_O = 6,378,137\ [m] \end{cases} \tag{6.70}$$

Let the positive x^3-axis of $\mathcal{O}$'s GRF coincide with increasing distance above the earth's surface, and let this process of gravitational interaction with duration $t_P = 5.391247 \cdot 10^{-44}\ [s]$ begin at the point in time $t = t_0 = 0$ on $\mathcal{O}$'s time scale with the neutron located *exactly* 100 $[m]$ above the earth's surface in a ground state with a momentum $100 \cdot m_0\ [kgm/s]$ directed away from the earth's surface. So, at $t = 0$ properties of the system and its environment have the following values (using $c = 299,792,458\ [m/s]$):

$$\begin{cases} X_0 = (0,0,100) \\ \Phi_G(X_0) = -G\frac{M_E}{R_O+100} = -6.24949 \cdot 10^7\ [J/kg] \\ \vec{p}_0 = (0,0,1.67493 \cdot 10^{-25}) \\ \vec{v}_0 = \vec{p}_0/m_0 = (0,0,100) \\ H_0 = m_0c^2 + \frac{1}{2}m_0|\vec{v}_0|^2 + m_g\Phi_G(X_0) = 1.505352 \cdot 10^{-10}\ [J] \end{cases} \tag{6.71}$$

At this very starting point of the process, it is already determined what the gravitational impulse $\delta\vec{p}_0$ will be that the system will receive in this process. For the value of the gravitational field at $X = X_0$ we have

$$-\overrightarrow{\nabla}\Phi_G(X_0) = (0, 0, -9.7983) \tag{6.72}$$

so the field is directed *towards* the earth's surface. Plugging the right values into Eq. (6.59) then gives the following value for the component δp_0^3 of the impulse $\delta\vec{p}_0 = (0, 0, \delta p_0^3)$:

$$\delta p_0^3 = c_{\mathrm{n}} m_0 t_P \frac{\partial \Phi_G}{\partial x^3}(X_0) = -8.847827 \cdot 10^{-70}\ [kgm/s] \tag{6.73}$$

Thus speaking, at $t = t_0 = 0$ the one-neutron system transforms by a state transition into a transition state with lifetime t_P, and during the time span $(0, t_P) = (0, 5.391247 \cdot 10^{-44})$ the system will absorb an energy δE_0 from its surroundings, which corresponds to the energy of a photon with momentum $-\delta\vec{p}_0$. With the value of the speed of light being , this gives

$$\delta E_0 = |\delta\vec{p}_0| \cdot c = 2.652312 \cdot 10^{-61}\ [J] \tag{6.74}$$

At $t = t_1 = t_0 + t_P = t_p$, the system transforms from a transition state to an excited state at a position $X_1 = X_0 + \delta X_0 = X_0 + t_P \cdot \vec{v}_0$ with Hamiltionian $H_1^* = m_i^* c^2 + \frac{1}{2} m_i^* |\vec{v}_n|^2 + m_i^* \Phi_G(X_{n+1}) = H_0 + \delta E_0$. Now the leading term in the Hamiltionian H_{n+1}^* is $m_i^* c^2$; writing $m_i^* = m_0 + \delta m_i$, we can easily approximate the increase in inertial mass δm_i:

$$\delta m_i \approx \delta E_0 / c^2 = 2.951098 \cdot 10^{-78}\ [kg] \tag{6.75}$$

This is thus the amount by which the inertial masses of the subsequent normal and excited states differ due to the absorption of energy.

At the final event of the process, at $t = t_1$, the system emits a photon with momentum $-\delta\vec{p}_0$ and transforms to the next ground state with momentum $\vec{p}_1 = \vec{p}_0 + \delta\vec{p}_0 = (0, 0, 1.67493 \cdot 10^{-25} - 8.847827 \cdot 10^{-70})$. So, it would take $1.89304 \cdot 10^{44}$ similar impulses for the neutron to loose its momentum: this takes 10.20585 $[s]$, which *exactly* matches the prediction by classical mechanics. The emitted photon is *gravitational Bremsstrahlung*: its wave length is $\lambda = 7.4889234 \cdot 10^{35}$ $[m]$ or, equivalently, a whopping $7.9159675 \cdot 10^{19}$ light years. Needless to say, this goes beyond detection. ■

Example 6.3.5. (Antineutron in the earth's gravitational field.)
Let us now see what happens if we replace the neutron with an antineutron, all other things equal as in Ex. 6.3.4. So first of all, the variable M_1 in Eqs. (6.6)-(6.13) is now an *antineutronic monad*, with the properties listed in Table 3.1. The electric charge $\overline{Q}_n$, inertial rest mass $\overline{m}_0$, and characteristic number of normality c_n of the system have the following values:

$$\begin{cases} \overline{Q}_n = 0 \ [C] \\ \overline{m}_0 = 1.67493 \cdot 10^{-27} \ [kg] \\ c_\text{n} = -1 \end{cases} \tag{6.76}$$

Importantly, its gravitational mass $\overline{m}_g$ is negative: $\overline{m}_g = c_\text{n} \cdot \overline{m}_0 < 0$. We assume that at $t = 0$, with the antineutron in a ground state, the initial properties X_0', $\Phi_G(X_0')$, $\vec{p}_0{}'$, and $\vec{v}_0{}'$ of the system and its environment have the same values as their unprimed counterparts in Ex. 6.3.4, given by Eq. (6.71). For the Hamiltonian $\overline{H}_0$, however, we have $\overline{H}_0 > H_0$ because the potential energy is *positive* for the antineutron—it is to be interpreted as the gain in kinetic energy when the antineutron accelerates away to infinity. However, $\overline{m}_0 c^2$ is the leading term in $\overline{H}_0$ so we don't see this difference back in the numerical value: $\overline{H}_0 \approx H_0 = 1.505352 \cdot 10^{-10}$ $[J]$.

Because $\overline{m}_g < 0$, the gravitational impulse $\delta\vec{p}_0{}'$ that the antineutron receives in this process is *the opposite* of that of the neutron: $\delta\vec{p}_0{}' = -\delta\vec{p}_0$. For the component $\delta p_0^{3\prime}$ of the impulse $\delta\vec{p}_0{}' = (0, 0, \delta p_0^{3\prime})$ we obtain

$$\delta p_0^{3\prime} = \overline{m}_g t_P \frac{\partial \Phi_G}{\partial x^3}(X_0') = +8.847827 \cdot 10^{-70} \ [kgm/s] \tag{6.77}$$

So, upon the transition to a transition state, the antineutron absorbs an energy $\delta\overline{E}_0 = |\delta\vec{p}_0{}'| \cdot c = 2.652312 \cdot 10^{-61}$ $[J]$ from its environment in the time span $(t_0, t_1) = (0, t_P)$.

At $t = t_1$ the antineutron gets in the excited state with the same inertial mass as the neutron of Ex. 6.3.4: $\overline{m}_i^* = m_i^* > m_0$. The Hamiltonian $\overline{H}_1^*$ then satisfies $\overline{H}_1^* = \overline{H}_0^* + \delta\overline{E}_0$.

Immediately after getting in the excited state, a photon with momentum $-\delta\vec{p}_0{}'$ is emitted—note that this photon moves towards earth—and the one-antineutron system ends up in the next ground state with momentum $\vec{p}_1{}' = \vec{p}_0{}' + \delta\vec{p}_0{}' = (0, 0, 1.67493 \cdot 10^{-25} + 8.847827 \cdot 10^{-70})$. So, the prediction is that the antineutron accelerates away from earth. ■

Interactions with gravitational and electromagnetic aspects

To move on to a model of interaction process with gravitational and electromagnetic aspects, we make the following assumptions for characteristic number of normality c_{n}, rest mass spectrum s, and electric charge Q:

$$\begin{cases} c_{\mathrm{n}} \in \{-1, +1\} \\ \forall n : s(n) = m_0 \ [kg] \\ Q = q \ [C] \end{cases} \tag{6.78}$$

Modelling a (non-relativistic) free (anti)particle as a monadic system is then a matter of choosing the right values for these three invariant properties.

For our model of the interaction processes, some changes have to be made to the model of the previous section. For starters, a term accounting for electric potential energy has to be added to the Hamiltionian H_n of the monadic system in its initial ground state at $t = t_n$, to the Hamiltonian $H(t)$ of the monadic system at a point in time $t \in (t_n, t_{n+1})$ when it is in a transition state, and the Hamiltonian H^*_{n+1} of the monadic system in its excited state at $t = t_{n+1}$:

$$H_n = m_i c^2 + \frac{1}{2} m_i |\vec{v}_n|^2 + c_{\mathrm{n}} m_i \Phi_G(X_n) + q\Phi_E(X_n) \ [J] \tag{6.79}$$

$$H(t) = m_i(t)c^2 + \frac{1}{2} m_i(t)\vec{v}_n \cdot \vec{v}_n + m_g(t) \cdot \Phi_G(X(t)) + q\Phi_E(X(t)) \ [J] \tag{6.80}$$

$$H^*_{n+1} = m^*_i c^2 + \frac{1}{2} m^*_i \vec{v}_n \cdot \vec{v}_n + m^*_g \cdot \Phi_G(X_{n+1}) + q\Phi_E(X_{n+1}) \ [J] \tag{6.81}$$

These replace the Hamiltonians H_n, $H(t)$, and H^*_{n+1} as given in the previous section.

Furthermore, the impulse $\delta\vec{p}_n$ that the system receives can still be written as a product of average force $\overrightarrow{F}_{av}$ and the Planck time t_P, but it now depends also on the electric and magnetic fields at $X = X_n$:

$$\delta\vec{p}_n = t_P \cdot \vec{F}_{av} \ [kgm/s] \tag{6.82}$$

$$\vec{F}_{av} = -c_{\mathrm{n}} m_i \overrightarrow{\nabla}\Phi_G(X_n) - q\overrightarrow{\nabla}\Phi_E(X_n) + q \cdot \vec{v}_n \times \vec{B}(X_n) \ [kgm/s^2] \tag{6.83}$$

Let’s call this the ‘gravitational-and-electromagnetic impulse’. It remains the case that the energy $\delta E_n = c|\delta\vec{p}_n|$ of a photon with momentum $-\delta\vec{p}_n$ is absorbed from the environment during the time span of the life of the monadic system in a transition state, and that a photon with momentum $-\delta\vec{p}_n$ is emitted by the monadic system at the final event.

Remark 6.3.6. Process-wise nothing has changed: a process in which an interaction takes place with gravitational and electromagnetic aspects is *the same* as a process in which an interaction takes place with only a gravitational aspect. That is, in this framework it is **absolutely not** the case that instead of a single process for one interaction with gravitational and electromagnetic aspects we have two separate processes taking place—one for a gravitational interaction and one for an electromagnetic interaction. The modern idea that interactions take place by exchanging mediating particles, on the other hand, inevitably leads to two separate elementary processes for electromagnetism and gravitation. ■

Example 6.3.7 (Electron in a uniform strong electric field)**.**
Let's consider a system made up of a single electron, and let's use the GRF of the observer $\mathcal{O}$ of Exs. 6.3.4 and 6.3.5 to model the main characteristics of a process of its temporal evolution as it moves through a stationary, uniform electric field. With the system in a ground state at $t = t_0 = 0$, the initial conditions are the following:

$$\begin{cases} m_0 = 9.109384 \cdot 10^{-31}\ [kg] \\ Q_e = -1.602177 \cdot 10^{-19}\ [C] \\ X_0 = (0,0,1) \\ \Phi_G(X_0) = -6.24959 \cdot 10^7\ [J/kg] \\ \Phi_E(X_0) = 25 \cdot 10^6\ [V] \\ -\overrightarrow{\nabla}\Phi_G(X_0) = (0,0,-9.7985) \\ -\overrightarrow{\nabla}\Phi_E(X_0) = (0, 25 \cdot 10^6, 0) \\ \vec{B}(X_0) = (0,0,0) \\ \vec{v}_0 = \vec{p}_0/m_0 = (0,100,0) \\ H_0 = m_0c^2 + m_g\Phi_G(X_0) + Q_e\Phi_E(X_0) = -3.923571 \cdot 10^{-12}\ [J] \end{cases} \tag{6.84}$$

Let $\vec{e}_2 = (0,1,0)$ and $\vec{e}_3 = (0,0,1)$ be the unit basis vectors in respectively x^2-direction and x^3-direction in the GRF of our observer $\mathcal{O}$; then the gravitational-and-electromagnetic impulse $\delta\vec{p}_0 = -t_P m_g \cdot \overrightarrow{\nabla}\Phi_G - t_P Q_e \cdot \overrightarrow{\nabla}\Phi_E$ that the system will receive due to the interaction with the gravitational and electric fields in its environment is determined at time $t = 0$ to be

$$\delta\vec{p}_0 = 2.159432 \cdot 10^{-55}\vec{e}_2 - 4.81214 \cdot 10^{-73}\vec{e}_3 \tag{6.85}$$

The energy of a photon with momentum $-\delta\vec{p}_0$, which has to be absorbed in the time span during which the system is in a transition state, is

$$\delta E_0 = |\delta\vec{p}_0| \cdot c = 6.473817 \cdot 10^{-47}\ [J] \tag{6.86}$$

At $t = t_1 = t_0 + t_P$, the one-electron system gets in an excited state at position $X = X_0 + t_P \cdot \vec{v}_0$ with Hamiltion $H_1^* = H_0 + \delta E_0$. The gain in electric potential energy is

$$Q_e(\Phi_E(X_1) - \Phi_E(X_0) = Q_e\frac{\partial\Phi_E}{\partial x^2}\delta x^2 = 2.159433 \cdot 10^{-55}\ [J] \tag{6.87}$$

This is much smaller than the amount of energy absorbed:

$$Q_e(\Phi_E(X_1) - \Phi_E(X_0) \ll \delta E_0 \tag{6.88}$$

So, the absorbed energy leads to an increased inertial rest mass m_i^* of the system in its excited state; neglecting the increase in electric potential energy, the increase is

$$\delta m_i = m_i^* - m_0 \approx \delta E_0/c^2 = 7.203093 \cdot 10^{-64}\ [kg] \tag{6.89}$$

At the final event, the system emits a photon with momentum $-\delta\vec{p}_0$; it thereby receives the gravitational-and-electromagnetic impulse and falls back to a new ground state with the following properties:

$$\begin{cases} m_i = m_0 = 9.109384 \cdot 10^{-31}\ [kg] \\ X = X_1 = (0, 5.391247 \cdot 10^{-42}, 1) \\ \vec{v} = \vec{v}_0 + \delta\vec{v}_0 = (0, 100 + 2.37056 \cdot 10^{-25}, -5.28262 \cdot 10^{-43}) \\ H_1 = H_0 + \delta mc^2 \approx -3.923571 \cdot 10^{-12}\ [J] \end{cases} \tag{6.90}$$

The existence of the system in its new ground state then marks the beginning of the next process. N.B. If electric charge is treated as a secondary property, then the excited state also emits a spherical wave, and the new rest mass m_0 is then slightly larger by δm, cf. Eq. (6.24). ■

Remark 6.3.8 (Choice in a process of interaction)**.**
Let the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution as described by Eqs. (6.6)-(6.13) be a simplest process in the temporal evolution of an elementary particle that interacts with the fields in its environment. The Generalized Principle of Choice (Ax. 5.3.13 on page 212) then states that in this process, the excited state of the elementary particle, i.e. the nonextended particlelike matter quantum ${}^{NP}\mu^{n+1}_{\mathrm{M}_1}$, is chosen from a set θ^{n+1}_k of possibilities: ${}^{NP}\mu^{n+1}_{\mathrm{M}_1} = f_C(\theta^{n+1}_k)$. This can be seen as follows. The process with duration t_P starts at time $t = t_n$ in the GRF of an observer $\mathcal{O}$ when the elementary particle exists in a ground state at the position $X = X_n$ with momentum $\vec{p}_n$. At this very moment, the not-yet-existing excited state ${}^{NP}\mu^{n+1}_{\mathrm{M}_1}$ can potentially still arise at a variety of spatial positions X_{n+1} at the time $t_{n+1} = t_n + t_P$: to each such potential position X_{n+1} corresponds a *parallel possible nonextended particlelike phase quantum*—these exist in potential, but not actual. By the process of interaction *only one of these* becomes actual (materializes): which one that is, is in this process thus determined by the set of properties M_1, the initial momentum $\vec{p}_n$ of the elementary particle in its ground state at $X = X_n$, the fields $-\vec{\nabla}\Phi_G$, $-\vec{\nabla}\Phi_E$, and $\vec{B}$ at $X = X_n$ at time $t = t_n$, and the gravitational-and-electromagnetic impulse given by Eqs. (6.82)-(6.83). So, we may write

$$ {}^{NP}\mu^{n+1}_{\mathrm{M}_1}(t_{n+1}, X_{n+1}) = f_C(\theta^{n+1}_k) \tag{6.91}$$

Of course, if the initial momentum would have been different from $\vec{p}_n$, then a different excited state would have materialized: we would then have a different choice function f'_C, and at $t = t_{n+1}$ the excited state of the elementary particle would then have arisen at a different position $X = X'_{n+1}$. In that case we would have had that

$$ {}^{NP}\mu^{n+1}_{\mathrm{M}_1}(t_{n+1}, X'_{n+1}) = f'_C(\theta^{n+1}_k) \neq {}^{NP}\mu^{n+1}_{\mathrm{M}_1}(t_{n+1}, X_{n+1}) \tag{6.92}$$

N.B. At the beginning of this section it has been explicitly assumed that the process takes place in *inanimate matter*. In *animate matter*, the nonlocal wavelike phase quantum ${}^{NW}\varphi^n_k$ can *by an intentional thought* collapse at a different position than the one determined by the initial conditions and the fundamental interactions—cf. Ch. 7. ■

Remark 6.3.9 (Correspondence).
A general conclusion is that this semi-classical model of the EPT corresponds with non-relativistic classical mechanics. In the framework of non-relativistic classical mechanics, the momentum $\vec{p}$ of a massive system changes continuously in time according to

$$\frac{d\vec{p}}{dt} = \overrightarrow{F}(t) \tag{6.93}$$

where $\overrightarrow{F}(t)$ is the net force on the system at the time t. In the framework of the semi-classical model, on the other hand, the momentum of a massive system changes by discrete impulses $\delta\vec{p}$ evenly separated by a Planck time t_P according to

$$\delta\vec{p}_j = t_P \cdot \overrightarrow{F}_j \tag{6.94}$$

where $\delta\vec{p}_j$ is the j^{th} impulse and $\overrightarrow{F}_j$ is the net force on the system at the start of the process in which the system receives that j^{th} impulse. The point is that this step size (in time) is so small, that if we consider a massive system with an initial momentum $\vec{p}_0$ at $t = t_0$ and we want to know its momentum $\vec{p}_N$ at a time $t = t_0 + N \cdot t_P$ with time difference $\Delta t = N \cdot t_P$ in the area of application of classical mechanics (e.g. $\Delta t > 1$ [μs], so $N > 10^{37}$), then for all practical purposes the semi-classical model will predict the same momentum $\vec{p}_1$ as non-relativistic classical mechanics:

$$\vec{p}_0 + \int_{t_0}^{t_N} \overrightarrow{F}(t)dt \approx \vec{p}_0 + \sum_{j=1}^{N} \delta\vec{p}_j = \vec{p}_0 + \sum_{j=1}^{N} t_P \cdot \overrightarrow{F}(t_{j-1}) \tag{6.95}$$

where $t_j = t_0 + j \cdot t_P$. On the left of the $\approx$-sign in Eq. (6.95) we have the value of $\vec{p}_N$ predicted by non-relativistic classical mechanics, on the right of the $\approx$-sign the value of $\vec{p}_N$ predicted by the semi-classical model. Mathematically, the value predicted by the semi-classical model is an approximation of the value predicted by classical mechanics, since the summation on the right hand side is a discrete approximation of the Riemann integral on the left hand side. Physically, however, it's the other way around: the Riemann integral is the approximation—in the framework of the EPT, the momentum of a massive system changes by discrete impulses. ■

6.4 QM in the framework of the EPT

Let us continue by quoting the late Michael Dummett on QM:

> "*Physicists know how to use quantum mechanics and, impressed by its success, think it is* ***true****; but their endless debates about the interpretation of quantum mechanics show that they do not know what it* ***means****.*" (emphasis original)—Dummet(1991)

These "endless debates" have by no means been settled in the meantime. The current situation is thus that distinct interpretations of QM coexist without there being an objective criterion to decide which is the best interpretation. An important distinction that we can make is between ψ-*ontic* and ψ-*epistemic* interpretations (Spekkens, 2007). A ψ-ontic interpretation entails the view that the wave function represents a state in reality. In particular the most widely held interpretation of QM, the 'orthodox' or 'Copenhagen' interpretation advocated by Bohr, entails the view that the wave function is a *complete* representation of a microsystem: the postulates of orthodox QM imply that, absent certain special preparations, a particle doesn't have a definite position in absence of measurement as shown in Sect. 1.1. A ψ-epistemic interpretation, on the other hand, entails the view that the wave function does <u>not</u> represent a state of a microsystem, but rather *what we know* of the microsystem. This distinction between ψ-ontic and ψ-epistemic interpretations is of course directly related to the question whether the universe is *fundamentally probabilistic* or *fundamentally deterministic*. In that context it is interesting to quote Feynman:

> "*Our most precise description of nature* ***must*** *be in terms of* ***probabilities****. There are some people who do not like this way of describing nature. They feel somehow that if they could only tell what is* ***really*** *going on with a particle, they could know its speed and position simultaneously. ... There are still one or two physicists who are working on the problem who have an intuitive conviction that it is possible somehow to describe the world in a different way and that all of this uncertainty about the way things are can be removed. No one has yet been successful.*" (emphasis original)—Feynman (2011)

Although originally published in 1963, this quote is still valid today. It is true that several authors have fairly recently speculated at the metalevel about a deterministic theory underlying QM, e.g. 't Hooft (2002) and Vervoort (2015; 2019), but so far no one has been successfully able to tell what really goes on with a particle at object level in such a way that the uncertainty about its properties is removed.

That being said, in the remainder of this section we will show that in the framework of the EPT our most precise knowledge of a supersmall system is *fundamentally probabilistic* even though the system itself is strictly deterministic: as such, the EPT gives rise to a foundational framework for physics in which on the one hand orthodox QM is not true, cf. Sect. 5.4, while on the other hand ψ-epistemic QM has a certain area of application in which it can be used for statistical predictions of the outcome of measurements on (a class of) supersmall systems. To show this, we consider the following experiment:

(i) the *initial condition* is that we have prepared a system made up of a single neutron that (in the GRF of the experimenter) at time $t = t_1$ is at rest at the spatial position $X = X_1$ in a force-free environment;

(ii) the *trial* is that the system evolves in time;

(iii) at the end of a time span $[t_1, t_\omega]$, with a duration not shorter than the shortest possible technologically measurable duration τ, that is, with a duration $t_\omega - t_1 \geq \tau$, we do a position measurement: the *outcome* of the experiment is the position of the neutron at the time $t = t_\omega$.

This experiment is then treated in the framework of the EPT by applying the semi-classical model of gravitational interaction processes of Sect. 6.3 to a force-free environment, i.e. an environment with the gravitational field $-\overrightarrow{\nabla}\Phi_G$, the electric field $-\overrightarrow{\nabla}\Phi_E$, and the magnetic field $\overrightarrow{B}$ satisfying

$$-\overrightarrow{\nabla}\Phi_G = -\overrightarrow{\nabla}\Phi_E = \overrightarrow{B} = 0 \tag{6.96}$$

So, the time span $[t_1, t_\omega]$ of the trial encompasses billions and billions of elementary processes with a duration t_P of a Planck time, cf. Post. 6.1.6, so that $t_\omega - t_1 = b \cdot t_P$ for some large integer $b \gg 1$. However, we assume that photons are present in the environment surrounding the experiment: therefore, a process of evolution may be a 'process I' or a 'process II' as defined below.

Definition 6.4.1. *The j^{th} process in the temporal evolution of the neutron is a* ***process I*** *if and only if it is a pure interaction process as described by the semi-classical model of gravitational interaction processes: the impulse given by Eqs.* (6.82)-(6.83) *that the neutron receives in the j^{th} process is then zero. So, for a process I we have $\delta\vec{p}_j = (0, 0, 0)$.* ■

Let's go through a process I. So, let the j^{th} process in the temporal evolution of the neutron be a process I, and let this be the 1^{st} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution for some $n \in Z_N$; the initial degree of evolution for the first process (right after preparation of the system at $t = t_1$) is then n_1, the initial degree of evolution of the last process before the measurement at $t = t_\omega$ is then n_b. At $t = t_j$ the neutron is then in a ground state; its inertial mass m_i, position X, momentum $\vec{p}$, and Hamiltonian H have the following values:

$$\begin{cases} m_i = m_0 = 1.67493 \cdot 10^{-27} \ [kg] \\ X = X_j \\ \vec{p} = \vec{p}_j = m_0 \cdot \vec{v}_j \\ H = H_j = m_i c^2 + \vec{p}_j \cdot \vec{p}_j / 2m_i \ [J] \end{cases} \tag{6.97}$$

Then the initial event takes place, by which the neutron transforms from its ground state into a transition state with lifetime t_P. Since the impulse to be received in this process I is zero, no energy is absorbed from the surroundings while the neutron is in a transition state. Consequently, at any time $t \in (t_j, t_j + t_P)$ the inertial mass $m_i(t)$ of the transition state, its associated velocity $\vec{v}(t)$, and its Hamiltonian $H(t)$ are given by

$$\begin{cases} m_i(t) = m_0 \\ \vec{v}(t) = \vec{v}_j \\ H(t) = H_j \end{cases} \tag{6.98}$$

At $t = t_{j+1} = t_j + \delta t$, a state transition takes place by which the neutron transforms into an excited state with the following properties:

$$\begin{cases} m_i = m_i^* = m_0 \\ X = X_{j+1} = X_j + \delta X_j = X_j + t_P \cdot \vec{v}_j \\ \vec{p} = \vec{p}^{\,*}_{j+1} = \vec{p}_j \\ H^*_{j+1} = H_j \end{cases} \tag{6.99}$$

This intermediate event is immediately followed by the final event: without emitting radiation, the neutron transforms from the excited state into the next ground state. Its properties are then the following:

$$\begin{cases} m_i = m_0 \\ X = X_{j+1} \\ \vec{p} = \vec{p}_{j+1} = \vec{p}_j \\ H = H_{j+1} = H_j \end{cases} \tag{6.100}$$

So, in this force-free environment a process I is a process in which the temporal evolution of the neutron amounts to inertial motion. See Fig. 6.1 for an illustration of a process I.

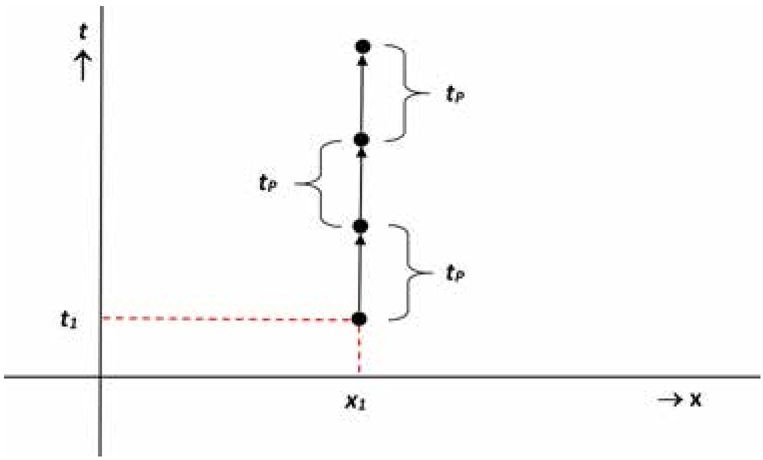


Figure 6.1: Illustration in a tx-diagram of the initial evolution of the system by three times a process I in a row; horizontally the x-axis, vertically the t-axis. In upwards direction, the four dots respectively represent the positions of the consecutive ground states of the neutron at $t = t_1$, at $t = t_2$, at $t = t_3$, and at $t = t_4$. The three upwards directed arrows represent the successive spatiotemporal displacements effected by the intermediate transition states. No spatial displacement of the neutron has occurred.

Now if the interaction with its environment would be all that mattered, then in this force-free environment the neutron would remain at rest at the initial position $X = X_1$ until the time of position measurement. However, since we have assumed that photons are present in the environment, we also consider the case that the system can collide with a photon. This is then a process II, to be distinguished from a process I.

Definition 6.4.2 (Photon capture).
The j^{th} process in the temporal evolution of the one-neutron system is a ***process II*** *if and only if the neutron captures an incident photon with momentum $\vec{p}_j^{\,\gamma}$ at the initial event and emits a photon with momentum $\vec{p}_{j+1}^{\,\gamma}$ at the final event, thereby receiving an impulse $\delta\vec{p}_j$.* ■

Let's go through such a process II. Both the initial state and the final state of the system are a superposition of two substates:

(i) at $t = t_j$, we have the neutron in a ground state at position $X = X_j$ with momentum $\vec{p} = \vec{p}_j$ and a photon with momentum $\vec{p}_j^{\,\gamma}$ incident on that particle state;

(ii) at $t = t_j + t_P$, we have the neutron in its next ground state at position $X = X_{j+1}$ with momentum $\vec{p} = \vec{p}_{j+1}$ and a photon with momentum $\vec{p}_{j+1}^{\,\gamma}$ emitted from the preceding excited state at that same position $X = X_{j+1}$;

Under non-relativistic conditions, the laws of conservation of energy and momentum for this process are respectively the following:

$$m_0c^2 + |\vec{p}_j|^2/2m_0 + |\vec{p}_j^{\,\gamma}| \cdot c = m_0c^2 + |\vec{p}_{j+1}|^2/2m_0 + |\vec{p}_{j+1}^{\,\gamma}| \cdot c \quad (6.101)$$

$$\vec{p}_j + \vec{p}_j^{\,\gamma} = \vec{p}_{j+1} + \vec{p}_{j+1}^{\,\gamma} \quad (6.102)$$

Let's solve this for $\vec{p}_j = \vec{0}$ by applying Compton's scattering theory (1923). First, we rewrite the law of conservation of momentum:

$$\delta\vec{p}_j = \vec{p}_j^{\,\gamma} - \vec{p}_{j+1}^{\,\gamma} \quad (6.103)$$

Now we take the inner product of each side of the equation with itself, and multiply both sides with c^2:

$$|\delta\vec{p}_j|^2c^2 = |\vec{p}_j^{\,\gamma}|^2c^2 + |\vec{p}_{j+1}^{\,\gamma}|^2c^2 - 2c^2|\vec{p}_j^{\,\gamma}||\vec{p}_{j+1}^{\,\gamma}|\cos\phi \quad (6.104)$$

Here $\phi \in [0, \pi]$ is the angle between the momenta of the captured photon and the emitted photon. To explain this angle, we can imagine the ground state as an extended object with a surface: if $-\vec{p}_j$ makes an angle $\alpha \in [0, \frac{\pi}{2}]$ with the surface normal $\vec{n}$, then $\phi = 2\alpha$.

Proceeding, since $\vec{p}_j = \vec{0}$ we have $\vec{p}_{j+1} = \delta\vec{p}_j$, which we may use in Eq. (6.101). In addition, since $|\vec{v}_{j+1}| \ll c$ under our non-relativistic conditions, we have $m_0c^2 \gg |\delta\vec{p}_j|^2/2m_0 = \frac{1}{2}m_0|\vec{v}_{j+1}|$. We can use this to our advantage. First we observe that

$$m_0c^2 + |\delta\vec{p}_j|^2/2m_0 = m_0c^2\left(1 + \frac{|\delta\vec{p}_j|^2}{2(m_0)^2c^2}\right) = m_0c^2\left(1 + \frac{|\delta\vec{p}_j|^2c^2}{2(m_0c^2)^2}\right) \tag{6.105}$$

Now using $m_0c^2 \gg |\delta\vec{p}_j|^2/2m_0$, we can write

$$m_0c^2\left(1 + \frac{|\delta\vec{p}_j|^2c^2}{2(m_0c^2)^2}\right) \approx m_0c^2\sqrt{1 + \frac{|\delta\vec{p}_j|^2c^2}{(m_0c^2)^2}} \tag{6.106}$$

Ergo,

$$m_0c^2 + |\delta\vec{p}_j|^2/2m_0 \approx \sqrt{(m_0c^2)^2 + |\delta\vec{p}_j|^2c^2} \tag{6.107}$$

We substitute this in Eq. (6.101), which after rearranging the terms and squaring both sides of the equation yields

$$|\delta\vec{p}_j|^2c^2 = \left(m_0c^2 + |\vec{p}_j^{\,\gamma}|\cdot c - |\vec{p}_{j+1}^{\,\gamma}|\cdot c\right)^2 - (m_0c^2)^2 \tag{6.108}$$

We now identify the right-hand sides of Eqs. (6.104) and (6.108); substituting E_j^{γ} and E_{j+1}^{γ} for $|\vec{p}_j^{\,\gamma}|\cdot c$ and $|\vec{p}_{j+1}^{\,\gamma}|\cdot c$, respectively, yields

$$(m_0c^2 + E_j^{\gamma} - E_{j+1}^{\gamma})^2 - (m_0c^2)^2 = (E_j^{\gamma})^2 + (E_{j+1}^{\gamma})^2 - 2E_j^{\gamma}E_{j+1}^{\gamma}\cos\phi \tag{6.109}$$

From here we obtain

$$m_0c^2E_j^{\gamma} - m_0c^2E_{j+1}^{\gamma} = E_j^{\gamma}E_{j+1}^{\gamma}(1 - \cos\phi) \tag{6.110}$$

Using the relation $E = hc/\lambda$ between a photon's energy and its wavelength, this yields Compton's equation

$$\lambda_{j+1} - \lambda_j = \frac{1}{m_0c}(1 - \cos\phi) \tag{6.111}$$

where λ_j and λ_{j+1} are the wavelengths of the captured photon and the emitted photon, respectively. We can make the same derivation for any monadic system: this shows that the EPT is consistent with Compton scattering.

Now back to the process: at the initial event, the initial state—recall that this is a superposition—transforms into a transition state of the neutron. At this event the incident photon is captured. Consequently, at any time $t \in (t_j, t_j + t_P)$ the momentum $\vec{p}$ and Hamiltonian H of the neutron in its transition state are the following:

$$\begin{cases} \vec{p} = \vec{p}_j + \vec{p}_j^{\,\gamma} = m_i^* \cdot \vec{v}_{j+1}^{\,*} \\ H = m_0 c^2 + \frac{1}{2} m_0 |\vec{v}_j|^2 + E_j^\gamma = m_i^* c^2 + \frac{1}{2} m_i^* |\vec{v}_{j+1}^{\,*}|^2 \end{cases} \tag{6.112}$$

Here $m_i^* > m_0$ is the inertial rest mass of the neutron in its transition state, and $\vec{v}_{j+1}^{\,*}$ is the velocity associated to the transition state. At time $t = t_{j+1} = t_j + t_P$, the next event takes place by which the neutron gets into an excited state at position $X = X_j + t_P \cdot \vec{v}_{j+1}^{\,*}$ with the above momentum and Hamiltonian. Immediately thereafter neutron falls back from its excited state to the next ground state. The latter, however, necessarily has the inertial mass m_0 as predetermined by the rest mass spectrum. That means that the neutron has to emit a photon at the final event: hence the Compton scattering. See Fig. 6.2 for an illustration of a process II.

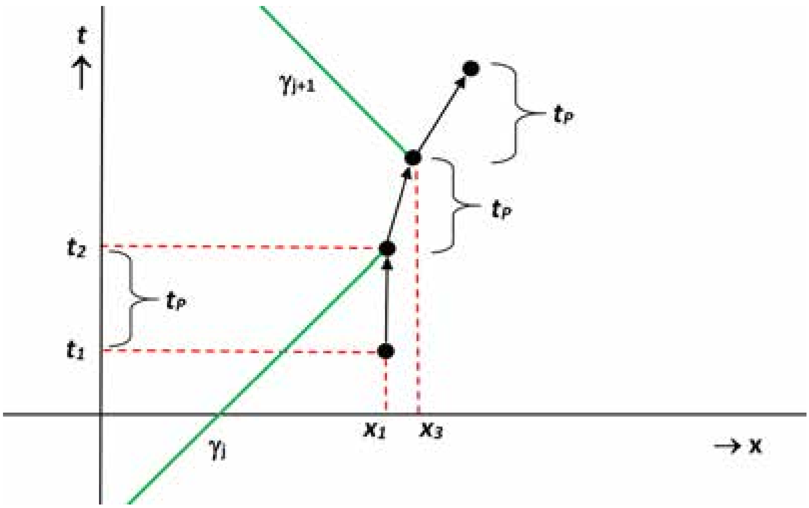


Figure 6.2: Illustration in a tx-diagram of the initial evolution of the system by successively a process I, a process II, and again a process I; horizontally the x-axis, vertically the t-axis. The four dots and the three upwards directed arrows have the sdame meaning as in Fig. 6.1. The lower and upper green line segments are the world lines of respectively the incident photon and the emitted photon (here with $\phi = \pi$).

It is emphasized that the preceding descriptions of a process I and a process II concern elementary processes in the temporal evolution of *this* one-neutron system, which is surrounded by a force-free environment as defined by Eq. (6.96). If we consider a simplest process in the evolution of a monadic system surrounded by classical fields *in general*, then the total impulse $\delta\vec{p}_{\text{int}} = (\delta p^1_{\text{int}}, \delta p^2_{\text{int}}, \delta p^3_{\text{int}})$ that the system receives due to interaction with the surrounded fields can be zero or nonzero, and the impulse $\delta\vec{p}_\gamma = (\delta p^1_\gamma, \delta p^2_\gamma, \delta p^3_\gamma)$ that the system receives due to collision with a photon can be zero or nonzero. That yields four possibilities:

(i) $\delta\vec{p}_\gamma = 0 \wedge \delta\vec{p}_{\text{int}} = 0$: a **pure inertial process** (a process I);

(ii) $\delta\vec{p}_\gamma = 0 \wedge \delta\vec{p}_{\text{int}} \neq 0$: a **pure interaction process** (a process I);

(iii) $\delta\vec{p}_\gamma \neq 0 \wedge \delta\vec{p}_{\text{int}} = 0$: a **pure scattering process** (a process II);

(iv) $\delta\vec{p}_\gamma \neq 0 \wedge \delta\vec{p}_{\text{int}} \neq 0$: a **mixed process** (a process II);

That aside, one might be inclined to believe that we might as well treat the present experiment in the framework of Newtonian mechanics. That, however, is wrong thinking. We first have to put in by hand *ad hoc* assumptions for the existence of photons, and for rules of capture and emission of photons by massive particles. We can then represent our neutron as a closed ball whose center of mass moves on a piecewise differentiable trajectory in the GRF of an observer $\mathcal{O}$:

- on the differentiable segments of the trajectory the motion of the neutron is determined by the forces exerted by the surrounding fields and Newton's laws;
- on the points where the trajectory is not differentiable, the neutron captures and/or emits a photon in accordance with our new rules.

That may reproduce the result *mathematically*, but the construct remains *conceptually incoherent*: there is, namely, no such thing as a photon in the framework of Newtonian mechanics. Ergo, if we assume that the experiment takes place in a force-free environment in which photons are present and we treat the experiment in the framework of Newtonian mechanics, then we have assumed the existence of a particle that is non-existent in the theoretical framework within which we are treating the experiment—that's conceptual incoherence.

Hidden variable

In the real world, precisely one of the following two propositions is true:

(i) the j^{th} process in the temporal evolution of the system is a process I;

(ii) the j^{th} process in the temporal evolution of the system is a process II.

We then ask this epistemologically fundamental question:

> *is there any way for the experimenter to **know** whether the j^{th} process in the evolution of the one-neutron system is going to be a process I or a process II?*

The answer to that question is: no, the experimenter cannot possibly know that because of the following "Technological No-Go":

> **Technological No-Go**: it is fundamentally impossible to create a device by which one "sees" a photon coming. (Just think about it.)

So, the experimenter can establish *that* photons are present, but the crux is thus that the experimenter cannot predict *which* photon, *if any*, hits the neutron when it exists in a ground state. Consequently, the momentum $\vec{p}_j^{\,\gamma}$ of the captured photon—we have $\vec{p}_j^{\,\gamma} = (0, 0, 0)$ for a process I—plays the role of a **hidden variable** $\lambda = (\lambda^1, \lambda^2, \lambda^3)$ which is **fundamentally unknowable** for the experimenter: for any $1 \leq j \leq b$ the transition state of the system at any $t \in (t_j, t_{j+1})$ depends, thus, on the value of λ in that process. Consequently, the momentum of the emitted photon is a second hidden variable $\mu = (\mu^1, \mu^2, \mu^3)$ which is equally unknowable.

That being said, let's look at the first process in the temporal evolution of the one-neutron system, starting at $t = t_1$. All that the experimenter knows is that at the beginning of the process, at $t = t_1$, the neutron was in a ground state at $X = X_1$, and that the neutron is again in a ground state at $t = t_2$. But the experimenter cannot possibly know the value for the hidden variable λ for this process: therefore, there is a set of positions $X_2^\lambda \in \mathbb{R}^3$, for each of which there is a **probability** that the ground state of the neutron at $t = t_2$ finds itself at that position. As the number of photons in the universe of the EPT is finite, the set F of possible values of λ is finite: therefore the set $\{X_2^\lambda\}_{\lambda \in F} \subset \mathbb{R}^3$ is finite.

Let for any $X_2^P \in \{X_2^\lambda\}_{\lambda \in F}$ a *closest neighbor* be a point $X_2^{P'} \in \{X_2^\lambda\}_{\lambda \in F}$ such that for any X_2^λ we have that $d(X_2^P, X_2^\lambda) \geq d(X_2^P, X_2^{P'})$; since the number of photons in the environment surrounding the one-neutron system is very large, we then have for any possible point $X_2^\lambda \in \mathbb{R}^3$ that the distance $d(X_2^\lambda, X_2^{\lambda'})$ to a closest neighbor $X_2^{\lambda'}$ is much smaller than the resolution of any measurement apparatus. Consequently, the probability distribution of the discrete variable X_2^λ can *for all practical purposes* be approximated by a probability density function $\Psi(t_2, X)$ of a continuous variable $X \in \mathbb{R}^3$. This function $\Psi(t_2, X)$ has a sharp peak at $X = X_1$, and it depends for a value $X = X_1 + \delta X_1 \neq X_1$ on the distance $d(X, X_1)$ such that the graph of $\Psi(t_2, X)$ as a function of $d(X, X_1)$ will be similar to the *measurable* graph of the photon density (in number of photons per m^3) at $t = t_1$ as a function of photon frequency. E.g. in outer space photon densities derive from the intensities shown in Fig. 6.3.

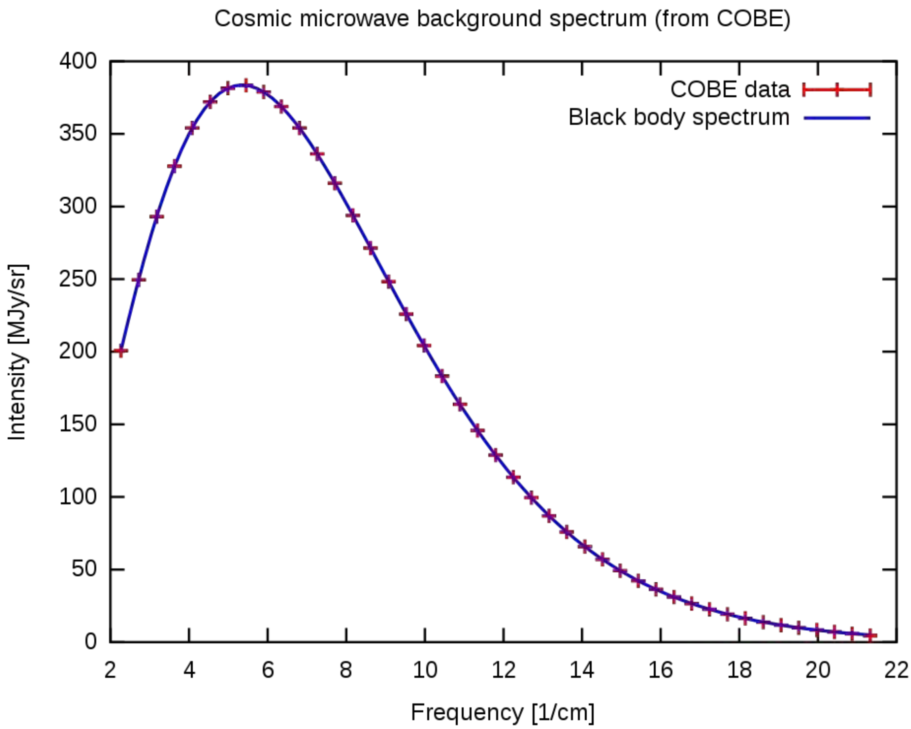


Figure 6.3: Cosmic microwave background spectrum measured by COBE (Fixsen et al., 1994). Horizontally the photon frequency, vertically the intensity in Megajansky per steradian. Source of the image: public domain.

Emergent ψ-epistemic QM as a continuous limit

Having looked at the first process, let's now look at the j^{th} process in the temporal evolution of the system. In reality there is then a finite set $\{X_{j+1}^{\lambda_1\mu_1\cdots\lambda_{j-1}\mu_{j-1}\lambda_j}\}$ of possible positions with

$$X_{j+1}^{\lambda_1\mu_1\cdots\lambda_{j-1}\mu_{j-1}\lambda_j} = X_1+\delta X_1(\lambda_1)+\ldots+\delta X_j(\lambda_1,\ldots,\lambda_{j-1},\mu_{j-1},\lambda_j) \quad (6.113)$$

For each of these positions there is thus a probability that the ground state of the neutron at $t = t_{j+1}$ will be at that position. The probability distribution of the discrete variable ranging over this finite set of possible positions can then again be approximated by a probability density function $\Psi(t_{j+1}, X)$ of a continuous variable $X \in \mathbb{R}^3$. For the present experiment, we thus obtain a sequence of continuous probability density functions $\Psi(t_2, X), \Psi(t_3, X), \Psi(t_4, X), \ldots$ and we are interested in a testable prediction of the terms of this sequence.

First we observe that on account of the Central Limit Theorem of probability theory, there is a j such that $\Psi(t_{j+1}, X)$ can be approximated by a normal distribution

$$\Psi(t_{j+1}, X) = \sqrt{\left(\frac{a}{\pi}\right)^3} e^{-ar^2} \quad (6.114)$$

where a is a constant and $r = d(X, X_1)$. Of course the smallest possible value of j is open for debate, but we have to realize that

(i) if we set the most precise atomic clock currently available at $t = t_1$ when the system was prepared, the time setting still has an uncertainty of some 10^{-15} second;

(ii) if we let the trial last for the smallest possible amount of time that technology can measure, then the trial has a duration τ of about 10^{-11} second (Diddams and O'Brian, 2004)

(iii) if we want to do a position measurement on our system when the atomic clock reads $t = t_1 + \tau$, then again there is an uncertainty of some 10^{-15} second in the time at which the measurement is done.

That is, we have to realize that more than 10^{30} elementary processes of Planck time duration have passed (!) before we can do our first possible position measurement on the system that we have prepared: the smallest value for j such that Eq. (6.114) applies is certainly smaller than 10^{30}. *So for all practical purposes*, Eq. (6.114) certainly applies at $t = t_1 + \tau$ when the first position measurement is technologically possible. (Note that the value of a in Eq. (6.114) can empirically be determined at $t = t_1 + \tau$ by repeated experiments with identically prepared systems.)

Next, impressed by the empirical success of QM, we simply accept the **meta-postulate** that for discrete times $t_k \in \{t_1, t_1 + t_P, t_1 + 2t_P, \ldots\}$ for which $t_k \geq t_1 + \tau$, QM yields an empirically adequate continuous approximation of the discrete evolution in time of the probability density function $\Psi(t_k, X)$ to $\Psi(t_{k+1}, X) = \Psi(t_k + t_P, X)$. That is, we accept that the change $\delta\Psi(t_k, X) = \Psi(t_k + t_P, X) - \Psi(t_k, X)$ in a time span $(t_k, t_k + t_P)$ described by the Schroedinger equation is empirically adequate. So, at the time $t_1 + \tau$ we associate to the microsystem an **initial** complex wave function ψ such that

$$\psi(X)\psi^*(X) = \Psi(t_1 + \tau, X) \tag{6.115}$$

where ψ^* is the complex conjugate of ψ. The real function ψ given by

$$\psi = \sqrt[4]{\left(\frac{a}{\pi}\right)^3} e^{-ar^2/2} \tag{6.116}$$

is of course the simplest function ψ that satisfies Eq. (6.115): let's use this ψ as the initial wave function with a being the value of the constant in Eq. (6.114) as measurable at $t = t_1 + \tau$. The temporal evolution of $\Psi(t, X)$, assuming spherical symmetry, is then determined by

$$i\hbar\frac{\partial\psi}{\partial t} = -\frac{\hbar^2}{2m}\frac{\partial^2\psi}{\partial r^2} \tag{6.117}$$

where m is the rest mass of the neutron. See e.g. (Griffith, 1994): at any given $t > t_1 + \tau$ we then have

$$\psi = \sqrt[4]{\left(\frac{a}{\pi}\right)^3} e^{-ar^2/2y}/\sqrt{y} \tag{6.118}$$

$$y = 1 + \frac{i\hbar a[t - (t_1 + \tau)]}{m} \tag{6.119}$$

And of course at all times t we have

$$\psi(t,X)\psi^*(t,X) = \Psi(t,X) \tag{6.120}$$

so the result is a normal distribution that widens in time. At any of the discrete times $t_k > t_1 + \tau$ that mark the end of an elementary process, for any environment $U \subset \mathbb{R}^3$ the probability $p(\mathcal{E}_k^U)$ that the event $\mathcal{E}_k^U$ occurs, being that the neutron will occur in a particle state at a position $X_k \in U$, is then

$$p(\mathcal{E}_k^U) = \int_U \psi(t_k,X)\psi^*(t_k,X)dX = \int_U \Psi(t_k,X)dX \tag{6.121}$$

Since we have (naively) assumed that our position measurement has no influence on the position of the neutron, this translates to the probability that the neutron can be found in the region U at the time $t_k = t_1 + (k-1) \cdot t_P$.

Remark 6.4.3. To get a grasp of the idea set forth in this section so far, the following macroscopic experiment can be considered as a metaphor for the experiment with the one-neutron system:

- the *initial condition* is that at time t_1, a heavy bowling ball is placed on a position X_1 on a frictionless floor in a large, blinded room;
- the *trial* is that people are allowed into the room to throw small bouncy balls at the bowling ball from any angle and with any speed, the throws being evenly separated by a time δt: every time the bowling ball is hit—note that a throw may also miss—it receives an impulse and the bouncy ball scatters off the bowling ball at an angle;
- after a large number $b \gg 1$ of throws, that is, after a time $\Omega \cdot \delta t \gg \delta t$ the experimenter enters the room: the *outcome* of the experiment is the position of the bowling ball at time $t_1 + b \cdot \delta t$—for all practical purposes, the sample space Ω is given by $\Omega = \mathbb{R}^2$;
- the event $\mathcal{E}(X)$ takes place when the outcome is X, and $p(X)$ is the probability density that the event $\mathcal{E}(X)$ takes place.

The metaphor doesn't hold up in all aspects, but the idea is that the bowling ball is the like the free neutron, and the bouncy balls are like the incident photons: if all throws during the trial miss the bowling ball, it will still be at X_1 at the end of the trial. After a certain time t^*, for which $t_1 < t^* < t_1 + b \cdot \delta t$, the probability density function is a normal distribution due to the Central Limit Theorem of probability theory. The further temporal evolution of the probability density function can then be derived from the temporal evolution of a wave function associated to the bowling ball. However, if we zoom in at the first couple of throws, which is like zooming in at Planck scale, this doesn't hold. ■

We can now generalize the results obtained so far to postulates of **emergent $\boldsymbol{\psi}$−epistemic QM**: in the framework of the EPT, this applies to non-relativistic microsystems that can be treated as spinless and that find themselves in an environment where the gravitational and electromagnetic fields can be treated as classical fields. Below, τ refers to the smallest possible time period currently measurable—about 10 picoseconds.

Postulate 6.4.4. *To a monadic system is associated a time-dependent complex-valued wave function $\psi(t, X)$ on position space with norm $\|\psi\| = 1$, provided the condition is satisfied that at least a time period τ has passed since the last time the position was known.* ■

Postulate 6.4.5. *The complex wave function $\psi(t, X)$ is nothing but a purely mathematical object that is instrumental in representing our statistical knowledge of the monadic system: if we* ***know*** *the wave function $\psi(t, X)$ at a time $t = t_k$ that the monadic system transforms into an excited state, then we* ***know*** *for every region U of position space $\mathbb{R}^3$ that the probability $p(\mathcal{E}_k^U)$ that the event $\mathcal{E}_k^U$ occurs, being that the excited state will occur at a position $X_k \in U$, is given by Eq.* (6.121). ■

Postulate 6.4.6. *The wave function $\psi(t, X)$ of a monadic system evolves continuously in time according to the Schroedinger equation*

$$i\hbar \frac{\partial \psi(t, X)}{\partial t} = \hat{H}(\Phi_G, \Phi_E, \overrightarrow{B})\psi(t, X) \tag{6.122}$$

where $\hat{H}(\Phi_G, \Phi_E, B)$ is a Hamiltonian operator that depends on the gravitational potential field Φ_G, the electric potential field Φ_E, and the magnetic field $\overrightarrow{B}$. ■

These postulates only form the contours of emergent ψ−epistemic QM: they have to be supplemented by other postulates of non-relativistic QM to get the full theory. An explicit formulation of these well-known postulates will not be given *hic et nunc*; for an overview, see e.g. Muller and Saunders (2008).

We thus have on the one hand that the EPT is **inconsistent** with orthodox QM, but on the other hand that the EPT is **consistent** with emergent $\psi-$epistemic QM. The inconsistency with orthodox QM has already been shown in Ch. 5 (see Prop. 5.4.2). It comes to expression here in the fact that the one-neutron system has countably many times a definite position during the trial: with that, the system has a property that it cannot possibly have in the framework of orthodox QM due to the Berkelian idealism regarding properties (see Sect. 1.1). The consistency with emergent $\psi-$epistemic QM lies therein that the latter yields an empirically adequate continuous approximation of the discrete temporal evolution of the continuous approximation of the probability distribution of the discrete variable ranging over possible positions of the excited state that occurs in every elementary process of the temporal evolution of a system.

It is emphasized that the adjective 'emergent' in emergent $\psi-$epistemic QM is to indicate that the theory is **not fundamental** *from the physical perspective*: this comes to expression in the condition included in Post. 6.4.4, which is absent in the State Postulate of orthodox QM. The idea is that emergent $\psi-$epistemic QM only applies in the continuous limit of a discrete microsystem: it breaks down at Planck scale where temporal evolution is discrete. This breakdown can be illustrated by the present experiment: the probability density functions $\Psi(t_1, X)$ and $\Psi(t_2, X)$ at the end of the first two processes under consideration are continuous approximations of probability distributions of discrete variables, but the change from $\Psi(t_2, X)$ to $\Psi(t_3, X)$ does not derive from the continuous temporal evolution of a wave function ψ according to Eq. (6.117).

On the other hand, $\psi-$epistemic QM is **of fundamental importance** *from an epistemic perspective.* With the EPT c.q. a model thereof we may be able to describe what really goes on in the individual processes by which the smallest massive systems evolve. But even though the individual processes in themselves are strictly deterministic, we can only statistically predict outcomes of position measurements on such systems: the wave function of a system remains an important concept.

Emergent concepts of quantum field theory

So, emergent $\psi-$epistemic QM has to be viewed as 'QM in the framework of the EPT'. Its non-fundamentalness comes with a limited area of applicability: it only applies to one-component systems that

(i) are non-relativistic;

(ii) can be treated as spinless;

(iii) are surrounded by an environment that can be treated with (non-relativistic) classical field theory.

If we lift the above restriction (i), then the durations of elementary processes are no longer the same: if we use Planck units ($t_P = \ell_P = 1$) in a Minkowskian reference frame $(R^{1,3}, \eta)$, then the duration δt of an elementary process in the temporal evolution of a monadic system in which a spatial displacement $\delta X = (\delta x, \delta y, \delta z)$ takes place satisfies

$$(\delta t)^2 = 1 + (\delta x)^2 + (\delta y)^2 + (\delta z)^2 \tag{6.123}$$

See Ch. 9. So, the possible final states of a process then no longer have the same time coordinate: if the spatiotemporal position of the initial particle state of a process is known, then the spatiotemporal positions of the possible final particle states lie on a hyperboloid in Minkowski spacetime. Applied to our experiment with the one-neutron system, that means that the idea of the probability density function $\Psi(t_2, X)$ is no longer valid: it has to be replaced by a probability density function $\Psi_2(t, X)$ whose domain is a hyperboloid in $\mathbb{R}^{1,3}$. Furthermore, let's compare the following cases:

- case #1 is that the first two processes are both a process I, so in this case the final particle state of the neutron is two times at $X = X_1$;
- case #2 is that the first two processes are both a process II, but such that the final particle states of the neutron are successively at $X = X_2 \neq X_1$ and $X = X_3 = X_1$.

In the first case, the neutron makes two spatiotemporal leaps $(\delta t_1, \delta X_1)$ and $(\delta t_2, \delta X_2)$ without spatial displacement:

$$\delta X_1 = X_2 - X_1 = \delta X_2 = X_3 - X_2 = (0, 0, 0) \tag{6.124}$$

So, using Eq. (6.123) we get that in this case the initial event of the third process—this is the state transition by which the one-neutron system changes from a ground state to a transition state—takes place at position $X = X_1 + \delta X_1 + \delta X_2 = X_1$ and at time $t = t_3 = t_1 + \delta t_1 + \delta t_2 = t_1 + 2$ (in Planck units). In the second case, on the other hand, the neutron makes two spatiotemporal leaps $(\delta t'_1, \delta X'_1)$ and $(\delta t'_2, \delta X'_2)$ with opposite spatial displacement:

$$\delta X'_1 = X'_2 - X_1 = -\delta X'_2 = -(X'_3 - X'_2) \tag{6.125}$$

So, in this second case the state transition by which the one-neutron system changes from a ground state to a transition state in the third process takes place at the same position $X = X_1 + \delta X'_1 + \delta X'_2 = X_1$ but at time

$$t'_3 = t_1 + \delta t'_1 + \delta t'_2 = t_1 + 2\sqrt{1 + (\delta x'_1)^2 + (\delta y'_1)^2 + (\delta z'_1)^2} > t_3 \tag{6.126}$$

Together that means that the transition ${}^{EP}\varphi_1^{n_3} \rightarrow {}^{NW}\varphi_1^{n_3}$ can take place with nonzero probability at position $X = X_1$ and time $t = t_3$, but also with nonzero probability at position $X = X_1$ and time $t = t'_3 > t_3$.

In addition, we have to take into account that our position measurement after the trial is not infinitely fast, and that the resolution of the position measurement device is not infinite. So instead of talking about the probability of finding the neutron at the exact position X_1 at exactly τ seconds after $t = t_1$, we can at best talk about the probability of finding the neutron at a position $X \approx X_1$ at a time $t \approx t_1 + \tau = t_\omega$, meaning that $(t, X) \in U_{(t_\omega, X_1)}$ where $U_{(t_\omega, X_1)} \subset \mathbb{R}^{1,3}$ is an environment of the spatiotemporal position (t_ω, X_1) determined by the duration of the position measurement and the resolution of the device. We get

$$U_{(t_\omega, X_1)} = (t_\omega, t_\omega + \epsilon_t) \times (x_1 - \epsilon_r, x_1 + \epsilon_r) \times (y_1 - \epsilon_r, y_1 + \epsilon_r) \times (z_1 - \epsilon_r, z_1 + \epsilon_r) \tag{6.127}$$

where ϵ_t corresponds to the duration of the position measurement and ϵ_r to the resolution of the device.

That being said, to 'find' the neutron at a position $X \approx X_1$ after the trial (i.e., at a time $t \approx t_\omega$) *means* that the neutron has travelled on a path ℓ from the initial spatiotemporal position (t_1, X_1) to a position (t, X)

for which $t \approx t_\omega$ and $X \approx X_1$ as meant above. That path ℓ consists of finitely many straight segments, and each straight segment corresponds to the 'leap' δX of the neutron in a process I or a process II in its temporal evolution. However, having detected the neutron we still do not know which path has been taken: there are finitely many possibilities $\ell_1, \ldots, \ell_N$, and each $\ell_j \in \{\ell_1, \ldots, \ell_N\}$ comes with a probability $P(\ell_j)$ that the neutron goes on that path ℓ_j from the initial spatiotemporal position (t_1, X_1) to a position $(t, X) \approx (t_\omega, X_1)$. So, the *probability* $P(X \approx X_1)$ of finding the neutron at a position $X \approx X_1$ after the trial (i.e., at a time $t \approx t_\omega$) is thus the summation of the probabilities $P(\ell_j)$ over all possible paths $\ell_j \in \{\ell_1, \ldots, \ell_N\}$. In a formula:

$$P(X \approx X_1) = \sum_{\ell_j \in \{\ell_1, \ldots, \ell_N\}} P(\ell_j) \tag{6.128}$$

A path ℓ_j can be written as the union of $n(j)$ straight segments $\delta\ell_{j,k} \subset \mathbb{R}^{1,3}$, each of which corresponds to a spatiotemporal leap $\delta X_{j,k}$ of the neutron:

$$\ell_j = \bigsqcup_{k=1}^{n(j)} \delta\ell_{j,k} \tag{6.129}$$

The probability $P(\ell_j)$ is then the product of the individual probabilities for each of these leaps:

$$P(\ell_j) = \prod_{k=1}^{n(j)} P(\delta X_{j,k}) \tag{6.130}$$

Thus speaking, the k^{th} segment $\delta\ell_{j,k}$ of the path ℓ_j has boundary points $(t_{j,k}, X_{j,k})$ and $(t_{j,k+1}, X_{j,k+1})$ in $R^{1,3}$ with

$$(t_{j,k+1}, X_{j,k+1}) - (t_{j,k}, X_{j,k}) = (\delta t_{j,k}, \delta X_{j,k}) \tag{6.131}$$

where $\delta t_{j,k}$ and $\delta X_{j,k}$ are related by Eq. (6.123). So, $P(\delta X_{j,k})$ stands for the probability that the neutron 'leaps' from $(t_{j,k}, X_{j,k})$ to $(t_{j,k+1}, X_{j,k+1})$ **under the condition that** the previous leaps on ℓ_j have been made.

Let us now zoom in at the elementary process by which the neutron makes the k^{th} 'leap' on the path ℓ_j, corresponding to the segment $\delta\ell_{j,k}$. At this point we can start thinking of the initial event of this process—this is the transition by which the incident photon (with zero spatial momentum in a process I) and the neutron in its ground state transform into the neutron in a transition state—as the annihilation of a photon with 4-momentum $(E^{in}_{j,k}, \vec{p}^{\,in}_{j,k})$ and a neutron with 4-momentum $(E_{j,k}, \vec{p}_{j,k})$, and the creation of a neutron with 4-momentum $(E^{*}_{j,k}, \vec{p}^{\,*}_{j,k}) = (E_{j,k} + E^{in}_{j,k}, \vec{p}_{j,k} + \vec{p}^{\,in}_{j,k})$. Likewise, we can think of the last two events of a process—these are two consecutive transitions by which the neutron in a transition state transforms into the neutron in its new ground state plus an emitted photon—as the annihilation of a neutron 4-momentum $(E^{*}_{j,k}, \vec{p}^{\,*}_{j,k})$ and the creation of a photon with 4-momentum $(E^{out}_{j,k+1}, \vec{p}^{\,out}_{j,k+1})$ and a neutron with 4-momentum $(E_{j,k+1}, \vec{p}_{j,k+1} + \delta\vec{p}_{j,k}) = (E^{*}_{j,k} - E^{out}_{j,k+1}, \vec{p}^{\,*}_{j,k} - \vec{p}^{\,out}_{j,k+1})$.

We can now express the probabilities $P(\delta X_{j,k})$ in probabilities of annihilations and creations. Let's start with the first factor $P(\delta X_{j,1})$ of the product on the right-hand side of Eq. (6.130): $P(\delta X_{j,1})$ stands for the probability that the neutron (in the first process of temporal evolution in the trial) 'leaps' from the spatiotemporal position $(t_{j,1}, X_{j,1}) = (t_1, X_1)$ to the spatiotemporal position $(t_{j,2}, X_{j,2})$ for which

$$(t_{j,2}, X_{j,2}) = (t_1 + \delta t_{j,1}, X_1 + \delta X_{j,1}) = (t_1, X_1) + \frac{1}{m^{*}_{j,1}}(E^{*}_{j,1}, \vec{p}^{\,*}_{j,1}) \quad (6.132)$$

where $m^{*}_{j,1} = |(E^{*}_{j,1}, \vec{p}^{\,*}_{j,1})|$. But that means that $P(\delta X_{j,1})$ is actually the probability that the neutron gets the required momentum $(E^{*}_{j,1}, \vec{p}^{\,*}_{j,1})$, which is identical to the probability that a photon with 4-momentum $(E^{in}_{j,1}, \vec{p}^{\,in}_{j,1})$ and a neutron with 4-momentum $(E_{j,1}, \vec{p}_{j,1}) = (m_0, \vec{0})$ are annihilated and a neutron with 4-momentum $(E^{*}_{j,1}, \vec{p}^{\,*}_{j,1}) = (m_0 + E^{in}_{j,1}, \vec{p}^{\,in}_{j,1})$ is created.

Proceeding, consider for $k > 1$ the case that the neutron has already made its first $k-1$ leaps on ℓ_j: the probability $P(\delta X_{j,k})$ is then, likewise, the probability that the neutron gets the required momentum $(E^{*}_{j,k}, \vec{p}^{\,*}_{j,k})$. Writing

$$(\delta E^{*}_{j,k}, \delta\vec{p}^{\,*}_{j,k}) = (E^{*}_{j,k} - E^{*}_{j,k-1}, \vec{p}^{\,*}_{j,k} - \vec{p}^{\,*}_{j,k-1}) \quad (6.133)$$

we get

$$(\delta E^{*}_{j,k}, \delta\vec{p}^{\,*}_{j,k}) = (E^{in}_{j,k} - E^{out}_{j,k-1}, \vec{p}^{\,in}_{j,k} - \vec{p}^{\,out}_{j,k-1}) \quad (6.134)$$

Thus speaking, the probability that $P(\delta X_{j,k})$ can be expressed in terms of annihilations and creations as the probability that subsequently

(i) a neutron with 4-momentum $(E^*_{j,k-1}, \vec{p}^{\,*}_{j,k-1})$ is annihilated and a photon with 4-momentum $(E^{out}_{j,k}, \vec{p}^{\,out}_{j,k})$ and a neutron with 4-momentum $(E_{j,k}, \vec{p}_{j,k})$ are created,

(ii) the newly created neutron with 4-momentum $(E_{j,k}, \vec{p}_{j,1})$ and a photon with 4-momentum $(E^{in}_{j,k}, \vec{p}^{\,in}_{j,k})$ are annihilated and a neutron with 4-momentum $(E^*_{j,k}, \vec{p}^{\,*}_{j,k})$ is created,

such that Eq. (6.134) is satisfied. There are, again, finitely many possibilities for the 4-momenta $(E^{out}_{j,k}, \vec{p}^{\,out}_{j,k})$ and $(E^{in}_{j,k}, \vec{p}^{\,in}_{j,k})$ of respectively the photon γ^{out} emitted at the end of the $(k-1)^{\text{th}}$ leap and the incident photon γ^{in} captured at the beginning of the k^{th} leap: it is just that the sum has to satisfy Eq. (6.134). So, we collect all allowable two-tuples $(\vec{p}^{\,out}_{j,k}, \vec{p}^{\,in}_{j,k})$ in a set S; then $P(\delta X_{j,k})$ is (for $k > 1$) the finite sum

$$P(\delta X_{j,k}) = \sum_{(\delta\vec{p}_1, \delta\vec{p}_2) \in S} P(\delta\vec{p}_1, \delta\vec{p}_2) \tag{6.135}$$

where $P(\delta\vec{p}_1, \delta\vec{p}_2)$ is the probability that the momenta $\vec{p}^{\,out}_{j,k}$ and $\vec{p}^{\,in}_{j,k}$ of γ^{out} and γ^{in} are $\delta\vec{p}_1$ and $\delta\vec{p}_2$, respectively—it is left as an exercise to write this out in terms of annihilations and creations, as in (i) and (ii) above.

With that in mind, we can start thinking of state vectors in a direct product $H_\gamma \otimes H_n$ of a Hilbert space H_γ for photons and a Hilbert space H_n for 'our' neutron, such that

- $|0\rangle|\vec{p}\rangle$ represents a state of zero photons and a neutron with (spatial) momentum $\vec{p}$;

- $|\vec{p}_\gamma\rangle|\vec{p}\rangle$ represents a state of a photon with momentum $\vec{p}_\gamma$ and a neutron with momentum $\vec{p}$;

- $|\vec{p}_{\gamma(1)}, \vec{p}_{\gamma(2)}\rangle|\vec{p}\rangle$ represents a state of a photon with momentum $\vec{p}_{\gamma(1)}$, a photon with momentum $\vec{p}_{\gamma(2)}$, and a neutron with momentum $\vec{p}$;

etcetera. We could also use notations $|n_1, n_2, \ldots\rangle|b_1, b_2, \ldots\rangle$ with occupation numbers $n_i \in \mathbb{N}$ and $b_j \in \{0, 1\}$ to represent the above state vectors, but the above notation is suitable since we are only interested in states of one neutron and zero, one or two photons. Next, we can start thinking of creation and annihilation operators $\hat{\gamma}^{+}_{\vec{p}}$ and $\hat{\gamma}^{-}_{\vec{p}}$ that create c.q. annihilate a photon with momentum $\vec{p}$, and of creation and annihilation operators $\hat{n}^{+}_{\vec{p}}$ and $\hat{n}^{-}_{\vec{p}}$ that create c.q. annihilate a neutron with momentum $\vec{p}$. These act on a state vector as usual; we have, for example,

$$\hat{\gamma}^{-}_{\vec{p}}\hat{n}^{-}_{\vec{q}}|\vec{p}\rangle|\vec{q}\rangle = \hat{\gamma}^{-}_{\vec{p}}|\vec{p}\rangle|0\rangle = |0\rangle|0\rangle = \hat{n}^{-}_{\vec{q}}|0\rangle|\vec{q}\rangle = \hat{n}^{-}_{\vec{q}}\hat{\gamma}^{-}_{\vec{p}}|\vec{p}\rangle|\vec{q}\rangle \tag{6.136}$$

$$\hat{\gamma}^{-}_{\vec{p}_1}\hat{n}^{-}_{\vec{q}_1}|\vec{p}_2\rangle|\vec{q}_2\rangle = 0 \text{ if } \vec{p}_1 \neq \vec{p}_2 \text{ or } \vec{q}_1 \neq \vec{q}_2 \tag{6.137}$$

$$\hat{\gamma}^{+}_{\vec{p}}\hat{n}^{+}_{\vec{q}}|0\rangle|0\rangle = \hat{n}^{+}_{\vec{q}}\hat{\gamma}^{+}_{\vec{p}}|0\rangle|0\rangle = |\vec{p}\rangle|\vec{q}\rangle \tag{6.138}$$

etcetera; here $|0\rangle|0\rangle$ is the vacuum state. We now define the capture operators $\hat{\alpha}_{\delta\vec{p}}$ and the emission operators $\hat{\epsilon}_{\delta\vec{p}}$ as follows:

$$\hat{\alpha}_{\delta\vec{p}} = \sum_{\vec{p}} \hat{n}^{+}_{\vec{p}+\delta\vec{p}}\hat{\gamma}^{-}_{\delta\vec{p}}\hat{n}^{-}_{\vec{p}} \tag{6.139}$$

$$\hat{\epsilon}_{\delta\vec{p}} = \sum_{\vec{p}} \hat{n}^{+}_{\vec{p}-\delta\vec{p}}\hat{\gamma}^{+}_{\delta\vec{p}}\hat{n}^{-}_{\vec{p}} \tag{6.140}$$

Taking the rules into considerations, these operators act as follows on state vectors:

$$\hat{\alpha}_{\delta\vec{p}}|\delta\vec{p}\rangle|\vec{p}\rangle = |0\rangle|\vec{p}+\delta\vec{p}\rangle \tag{6.141}$$

$$\hat{\alpha}_{\delta\vec{p}}|\delta\vec{q}\rangle|\vec{p}\rangle = 0 \text{ if } \delta\vec{p} \neq \delta\vec{q} \tag{6.142}$$

$$\hat{\epsilon}_{\delta\vec{q}}|\delta\vec{p}\rangle|\vec{p}\rangle = |\delta\vec{p}, \delta\vec{q}\rangle|\vec{p}-\delta\vec{q}\rangle \tag{6.143}$$

The next step is then to define the operator fields $\hat{F}_{\alpha}$ and $\hat{F}_{\epsilon}$ on $\mathbb{R}^{1,3}$:

$$\hat{F}_{\alpha} : (t, X) \mapsto \sum_{\delta\vec{p}} \xi_{\delta\vec{p}}(t, X)\hat{\alpha}_{\delta\vec{p}} \tag{6.144}$$

$$\hat{F}_{\epsilon} : (t, X) \mapsto \sum_{\delta\vec{q}} \zeta_{\delta\vec{q}}(t, X)\hat{\epsilon}_{\delta\vec{q}} \tag{6.145}$$

Here the summation is over all possible $\delta\vec{p}$ c.q. $\delta\vec{q}$, while the amplitudes $\xi_{\delta\vec{p}}(t, X)$ and $\zeta_{\delta\vec{q}}(t, X)$ are complex numbers, i.e. elements of $\mathbb{C}$.

With these definitions in place, let us go back to the first factor $P(\delta X_{j,1})$ on the right-hand side of Eq. (6.130); recall that this is the probability that, at the spatiotemporal position (t_1, X_1), a photon with 4-momentum $(E^{in}_{j,1}, \vec{p}^{\,in}_{j,1})$ and a neutron with 4-momentum $(E_{j,1}, \vec{p}_{j,1}) = (m_0, \vec{0})$ are annihilated and a neutron with 4-momentum $(E^*_{j,1}, \vec{p}^{\,*}_{j,1}) = (m_0 + E^{in}_{j,1}, \vec{p}^{\,in}_{j,1})$ is created. The initial state for the event at (t_1, X_1) is then the state of one photon with (spatial) momentum $\vec{p}^{\,in}_{j,1}$—we ignore all the other photons that don't collide with the neutron—and one neutron with (spatial) momentum $\vec{0}$: we may represent this state then by a state vector $|\vec{p}^{\,in}_{j,1}\rangle|\vec{0}\rangle \in H_\gamma \otimes H_n$. The final state for that event can likewise be represented by a state vector $|0\rangle|\vec{p}^{\,*}_{j,1}\rangle = |0\rangle|\vec{0} + \vec{p}^{\,in}_{j,1}\rangle$. Now we can express the probability $P(\delta X_{j,1})$ in terms of our new concepts, using the inner product of the Hilbert space:

$$P(\delta X_{j,1}) = |\langle \vec{p}^{\,*}_{j,1}|\langle 0|\hat{F}_\alpha|\vec{p}^{\,in}_{j,1}\rangle|\vec{0}\rangle|^2 \tag{6.146}$$

This has to be evaluated at $(t, X) = (t_1, X_1)$. Likewise, let's look at a term $P(\delta\vec{p}_1, \delta\vec{p}_2)$ on the right-hand side of Eq. (6.135); recall that this is the probability that altogether a neutron with 4-momentum $(E^*_{j,k-1}, \vec{p}^{\,*}_{j,k-1})$ and a photon with 4-momentum $(E^{in}_{j,k}, \vec{p}^{\,in}_{j,k}) = \delta\vec{p}_2$ are annihilated at the spatiotemporal position $(t_{j,k}, X_{j,k})$ with $k > 1$, and a photon with 4-momentum $(E^{out}_{j,k}, \vec{p}^{\,out}_{j,k}) = \delta\vec{p}_1$ and a neutron with 4-momentum $(E^*_{j,k}, \vec{p}^{\,*}_{j,k})$ are created, such that the condition $\delta\vec{p}_2 - \delta\vec{p}_1 = \delta\vec{p}^{\,*}_{j,k}$ is satisfied. The initial state for this event can be represented by a state vector $|\delta\vec{p}_2\rangle|\vec{p}^{\,*}_{j,k-1}\rangle$, the final state by a state vector $|\delta\vec{p}_1\rangle|\vec{p}^{\,*}_{j,k}\rangle$. We can express the probability $P(\delta\vec{p}_1, \delta\vec{p}_2)$ then as follows:

$$P(\delta\vec{p}_1, \delta\vec{p}_2) = |\langle \vec{p}^{\,*}_{j,k}|\langle \delta\vec{p}_1|\hat{F}_\alpha\hat{F}_\epsilon|\delta\vec{p}_2\rangle|\vec{p}^{\,*}_{j,k-1}\rangle|^2 \tag{6.147}$$

This has to be evaluated at $(t, X) = (t_{j,k}, X_{j,k})$. So, the probability $P(\delta X_{j,k})$ then becomes

$$P(\delta X_{j,k}) = \sum_{(\delta\vec{p}_1, \delta\vec{p}_2)\in S} |\langle \vec{p}^{\,*}_{j,k}|\langle \delta\vec{p}_1|\hat{F}_\alpha\hat{F}_\epsilon|\delta\vec{p}_2\rangle|\vec{p}^{\,*}_{j,k-1}\rangle|^2 \tag{6.148}$$

where the summation is thus over all possible pairs $(\delta\vec{p}_1, \delta\vec{p}_2)$ such that $\delta\vec{p}_2 - \delta\vec{p}_1 = \delta\vec{p}^{\,*}_{j,k}$, cf. Eq. (6.134). With that, all factors of the probability $P(\ell_j)$ as given by Eq. (6.130)—recall that $P(\ell_j)$ is the probability that the detected neutron has travelled on the path ℓ_j from the initial spatiotemporal position (t_1, X_1) to a spatiotemporal position $(t, X) \approx (t_\omega, X_1)$—have been expressed in terms of state vectors, creation operators, and annihilation operators, that is, in terms of concepts of quantum field theory.

In the foregoing we have developed a rudimentary version of a quantum field theory in the framework of the EPT for a free neutron in a force-free environment. Without a doubt, this rudimentary version is full of holes and inconsistencies. Some examples of issues with this version:

(i) when the neutron is in rest, that is, when it has the lowest possible spatial momentum $\vec{p} = \vec{0}$, it cannot emit a photon; therefore, an emission operator $\hat{\epsilon}_{\delta\vec{p}}$ should leave a state vector $|0\rangle|\vec{0}\rangle$ untouched;

(ii) the neutron can capture a photon only at the initial event of an elementary process, and can emit a photon only at the final event; therefore, an annihilation operator $\hat{n}^-_{\vec{p}}$ should leave a state vector $|0\rangle|\vec{p}\rangle$ untouched if it represented the one-neutron system in a transition state at an intermediate time between initial and final event;

(iii) the spatial momenta $\vec{p}_\gamma$ and $\vec{p}$ in the notation $|\vec{p}_\gamma\rangle|\vec{p}\rangle$ may have to be replaced by the 4-momenta, to distinguish a state vector of the neutron with spatial momentum $\vec{p}$ and rest mass m_0 from a state vector of the neutron with spatial momentum $\vec{p}$ and rest mass $m^* > m_0$.

We will not solve these issues *hic et nunc*: the main point of the present treatise is that it demonstrates the general idea of how concepts of quantum field theory emerge in the framework of the EPT when we think the experiment with the one-neutron system consequently through. It is important to understand that—in the framework of the EPT—the concepts of quantum field theory are *emergent*, as opposed to *fundamental*, from the perspective of physics: **quantum field theory is not fundamental physics**.

Things get immensely more complicated if we also lift restrictions (ii) and (iii) on p. 303: this is when we consider a relativistic system of one component with spin in an environment described by a relativistic field theory. A full quantum field theory for such a system in the framework of the EPT can only be developed *after* a relativistic field theory has been developed: this is a topic for further research—even basic considerations for such a full quantum field theory are beyond the scope of the present monograph. A relativistic quantum theory covering the possibility of a matter-antimatter repulsive gravity has already been published by Mark E. Kowitt (1996): a full quantum field theory in the framework of the EPT will have to reproduce predictions of Kowitt's theory.

Axiomatization of the EPT with a hidden variable

It is possible to adjust the language and the axioms of the EPT, such that the idea of a hidden variable set forth in this section is captured by a revised version of Ax. 5.3.10, the generalized principle of nonlocal equilibrium. First of all, this requires that we add new **abstract constants** to the set G of generators of the monoid $(M, +)$ defined in clause (ii) of Def. 5.2.5: for every $n \in Z_N$ and for every $k \in I_{z(x)}$, we add $r(n,k)$ 2×1 matrices $\begin{bmatrix} {}^{LW}\sigma_{k,j}^{n+1} \\ {}^{LW}\overline{\sigma}_{k,j}^{n+1} \end{bmatrix}$, with $j \in \{1, \ldots, r(n,k)\}$. The **Interpretation Rule** is that an abstract constant $\begin{bmatrix} {}^{LW}\sigma_{k,j}^{n+1} \\ {}^{LW}\overline{\sigma}_{k,j}^{n+1} \end{bmatrix}$ is to be interpreted as the j^{th} local wavelike subatomic occurrent emitted in the world at the $(n+1)^{\text{th}}$ degree of evolution in the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution, and the conjugated subatomic occurrent in the antiworld. For every photon (a continuant) there is then a local wavelike subatomic occurrent, such that the latter can be viewed as the life of the photon (an occurrent). An additional **Analytic Postulate** is then

$$\mathbb{E}\begin{bmatrix} {}^{LW}\varphi_k^{n+1} \\ {}^{LW}\overline{\varphi}_k^{n+1} \end{bmatrix} \Rightarrow \begin{bmatrix} {}^{LW}\varphi_k^{n+1} \\ {}^{LW}\overline{\varphi}_k^{n+1} \end{bmatrix} = \begin{bmatrix} {}^{LW}\mu_{k,1}^{n+1} + \ldots + {}^{LW}\sigma_{k,r}^{n+1} \\ {}^{LW}\overline{\sigma}_{k,1}^{n+1} + \cdots + {}^{LW}\overline{\mu}_{k,r}^{n+1} \end{bmatrix} \tag{6.149}$$

Furthermore, we let the **variable** λ range over the free semigroup G_{LW}^+ on the set G_{LW}, made up of 0 and the *upper* entries of these new abstract constants, under addition; and we let the conjugate $\overline{\lambda}$ of an element $\lambda \in G_{LW}^+$ be *that* element of the free semigroup $\overline{G}_{LW}^+$—defined analogously for the *lower* entries of these new abstract constants—*which* denotes the conjugate in the antiworld of the occurrent in the world denoted by λ. By assigning a constant value to λ, the 2×1 matrix $\begin{bmatrix} \lambda \\ \overline{\lambda} \end{bmatrix}$ thus becomes $\begin{bmatrix} 0 \\ 0 \end{bmatrix}$, or any constant $\begin{bmatrix} {}^{LW}\sigma_{k,j}^{n+1} \\ {}^{LW}\overline{\sigma}_{k,j}^{n+1} \end{bmatrix}$, or any sum thereof. The **generalized principle of nonlocal equilibrium with hidden variable** is then

$$\exists\lambda \begin{bmatrix} {}^{EP}\varphi_k^n + \lambda \\ {}^{EP}\overline{\varphi}_k^n + \overline{\lambda} \end{bmatrix} \begin{matrix} \rightarrow \\ \leftarrow \end{matrix} \begin{bmatrix} {}^{NW}\varphi_k^n \\ {}^{NW}\overline{\varphi}_k^n \end{bmatrix} \tag{6.150}$$

This is thus a revised version of Ax. 5.3.10.[55]

6.5 Objections and replies

Objection 6.5.1. "*Dear Dr. Cabbolet, Thank you for submitting your manuscript entitled "A Semi-Classical Model of the Elementary Process Theory Corresponding to Non-Relativistic Classical Mechanics". Unfortunately, following editorial evaluation, we are unable to consider it further for publication.*"—Editor-in-Chief of a respected physics journal, rejecting my submission (Cabbolet, 2022) which presents the semi-classical model of the EPT developed in Sect. 6.3 (2022) ■

Reply 6.5.2. What an editorial rejection means is that it is the opinion of the editors that the submitted result is not worthy of further consideration. But that's what it is: an opinion. To their defense, the journal is by no means obliged to publish any manuscript submitted by me or to support my writings in any other way. ■

Objection 6.5.3. "*This work presents a complex and elaborated construction (already developed by he author in previous works) that could lead to a negative gravity for antimatter. The formalism is then studied in a non-relativistic limit. The journal finds the motivations of this work too weak. The author is right in saying that we are not certain that antimatter would not fall upward, but even if the experiments indicated so, contrary to most expectations, would that justify such a radical reconstruction of basic physics? All things considered, the journal has decided not to accept the long paper, judging it too speculative and lacking sufficient motivations.*"—Two editors of a physics journal specializing in conceptual issues rejecting my submission (Cabbolet, 2022) in 2022 ■

Reply 6.5.4. The two editors, both renowned physicists, have two objections: (i) the paper is too speculative and (ii) it lacks sufficient motivation. As to objection (i), they misjudged the aim of the paper. The aim of the paper was not to justify the introduction of new physical principles to describe repulsive gravity. The aim of the paper was to show that the new physical principles, which had already been published in another journal, correspond to classical mechanics—and of course correspondence is a foundational issue. As to objection (ii), to the defense of the editors the rejection can be justified if we interpret the scope of the journal narrowly, so that only papers on foundational issues of widely accepted theories are acceptable: the submission doesn't satisfy that criterion.

Objection 6.5.5. "*We regret to inform you that arXiv's moderators have determined that your submission will not be accepted and made public on arXiv.org. Our moderators determined that your submission does not contain sufficient original or substantive scholarly research and is not of interest to arXiv.*"—The arXiv Content Management, removing my preprint (Cabbolet, 2022) three months after it had been uploaded to arxiv.org in 2022 ■

Reply 6.5.6. To the defense of the moderators: arxiv.org is a privately run enterprise and acceptance of a preprint for publication on arxiv.org is entirely to the discretion of the moderators—they can remove any uploaded preprint at will. On the other hand, the submitted paper satisfies any standard of scientific quality: it proves by mathematical modelling that the EPT agrees with classical mechanics. That shows that the decision by the moderators is based on personal dislike of the uploaded preprint. ■

Objection 6.5.7. "***I have studied your work with care****, and I regret to inform you that I'm not going to accept your manuscript for publication. Unfortunately, the content of your submission is inadequate to be considered for publication in this journal. Besides, several passages are obscure, starting from the first sentence of the abstract, which appears to be syntactically inconsistent.*" (emphasis added)—Editor of a respected physics journal, rejecting my submitted manuscript (Cabbolet, 2018e) in 2018 ■

Reply 6.5.8. To the defense of the editor, the submitted manuscript was a letter-type paper that set forth the basic idea of Sect. 6.4 *at a qualitative level*: he is justified to reject it because of its qualitative nature. The editor, however, claims to have studied my work "with care", and accuses me of having submitted a manuscript containing an inconsistency. Fact of the matter is, however, that I received his rejection *within eight minutes* (!!!) *after submission.* So to get this straight: if you take into the account the time needed to react to a pop-up that a manuscript has been submitted, going to the journal's website, downloading the paper, opening it, writing a response, uploading the response, and typing in the final decision, then you arrive at the conclusion that the editor has spent approximately 30 seconds on my submitted paper. He has not studied the work with care, as he claims: he has read the title and the abstract, and he has looked at the typography of the formulas in the paper and that's about it. ■

Objection 6.5.9. "*: The paper discusses the Elementary Process Theory (EPT) and its connections to some foundational issues such as determinism, indeterminism, and the reality of the quantum state. I am afraid that the paper is not publishable. First, the motivations are unclear. There are already deterministic models of quantum mechanics (such as Bohmian mechanics and its variants) that make the same predictions with orthodox quantum mechanics (where the latter makes precise predictions). There is no discussion about / comparisons to the Bohmian approaches.*"—referee #1 of physics journal specializing in conceptual issues, recommending rejection of my submitted paper (Cabbolet, 2019b) which is comparable to Sect. 6.4 ■

Objection 6.5.10. "*In my estimation, the paper does not make a relevant contribution to the foundations of physics. While I appreciate the author's intentions, several premises of the discussion are already false and do not reflect the current state of the art in quantum foundations. For instance, the paper states that only 'fairly recently' people 'have speculated at the metalevel about a deterministic theory underlying QM ... but so far no one has been successfully'. This is not true. In particular, Bohmian mechanics ... and the Many-Worlds theory ... are well-established deterministic quantum theories able to ground the standard textbook formalism.*"—referee #2 of that journal, recommending rejection of the same submission ■

Reply 6.5.11. Both referees did not understand the submitted paper, not even in broad lines. As both responded emotionally to the fact that Bohmian mechanics was not mentioned in the submitted manuscript, it is safe to assume that both are from the Bohmian camp. That being said, both have stated in their reports that Bohmian mechanics is a deterministic theory, *as if* that somehow means that a deterministic theory <u>underlying</u> QM since long exists—that is, *as if* that somehow refutes my statement that so far no one has successfully developed a deterministic theory underlying QM. It is true that Bohmian mechanics is a deterministic theory, but that is not relevant for the present paper: when one talks about a *deterministic theory underlying QM*, one means a *deterministic* ***non-quantum*** *theory from which QM emerges*—one doesn't mean Bohmian mechanics or any other deterministic quantum theory developed by reinterpreting the formalism of orthodox QM.

Furthermore, while Bohmian mechanics may be linked to De Broglie's original idea of the pilot wave, Many Worlds theory is absolutely not a "well-established" quantum theory, as referee #2 alleges: there is not a shred of evidence for the existence of parallel worlds. In fact, Many Worlds theory is an example of a result of poor speculative philosophy that is being marketed as theoretical physics. It has been developed by first rejecting the physical idea of orthodox QM, then *blindly* accepting the purely mathematical formalism of orthodox QM—'blindly' as in 'without a preexisting clear and distinct idea of the fundamental workings of the outside world'—and then developing a new physical idea by reinterpreting that formalism. As an endeavor to frame a coherent, logical, necessary system of ideas in terms of which every element of our experience can be interpreted, this method of theory development is poor speculative philosophy: it yields at best *cleverly invented poetry* (cf. 2 Peter 1:16). A necessary condition for obtaining true knowledge of the fundamental workings of the outside world by working on a research program is, that its hard core *must have been developed* by developing a mathematical representation of a preexisting clear and distinct idea about the outside world, not the other way around—that is, not by developing an idea about the outside world from a preexisting purely mathematical formalism. This also holds for string theory: the mathematics are undoubtedly superb, but it's poor speculative philosophy that is being marketed as theoretical physics. ■

Objection 6.5.12. "*Second, it's not clear what the author is proposing in the paper. There are no equations for a new interpretation of quantum mechanics or realist theory of quantum mechanics. Everything is at an abstract level. So it's not clear what the scientific significance of the paper is.*"—second objection of referee #1, commenting on my submitted paper (Cabbolet, 2019b) ■

Reply 6.5.13. This objection shows that the analytical skills of referee #1 are not at the level where he thinks they are: he has wrongly judged the paper as a paper on a new interpretation of QM or a realist theory of QM—topics in the research area called 'quantum foundations'. It was explicitly mentioned that "the aim of this paper is to show that the EPT is inconsistent with orthodox QM, but consistent with ψ-epistemic QM", and the method for showing that was precisely described—cf. Sect. 6.4. ■

Objection 6.5.14. "*The paper claims that 'This distinction between ψ-ontic and ψ-epistemic interpretations is of course directly related to the question whether the universe is fundamentally probabilistic or fundamentally deterministic.' But this relation is not obvious at all, and I would argue that it doesn't really exist. Both ψ-ontic and ψ-epistemic are compatible with both determinism and indeterminism. ... ψ being ontic is not the same as providing a complete description of the physical state. Indeed, it is not entirely clear to me from the discussion if the author understands the ψ-ontic/ψ-epistemic distinction correctly.*"—second objection of referee #2, commenting on my paper (Cabbolet, 2019b) ■

Reply 6.5.15. First of all, note that the last sentence quoted above is an ad hominem argument. That said, the predicate 'ψ-ontic' applies to an interpretation of QM when the wave function is viewed as a representation of a physical state, and the predicate 'ψ-epistemic' applies to an interpretation of QM when the wave function is viewed as a representation of *our knowledge of* a physical state: there is nothing more to it, and this was explicitly mentioned in the paper. So, this remark of referee #2 is out of order. Furthermore, the referee insinuated that I believe

(i) that the predicate 'ψ-ontic' only applies to interpretations of QM in which the universe is viewed as fundamentally probabilistic and the wave function as a complete representation of a physical state;

(ii) that the predicate 'ψ-epistemic' only applies to interpretations of QM in which the universe is viewed as fundamentally deterministic.

This is false: I never made any claim to that extend. What we have is that there is currently a plethora of interpretations of QM, which can roughly be dived into two groups: ψ-ontic interpretations and ψ-epistemic interpretations. This plethora of interpretations has emerged from the problems laid bare in the now historical debate of Bohr's (ψ-ontic) orthodox interpretation vs. Einstein's (ψ-epistemic) ensemble interpretation, which of course revolved around the question whether the universe is fundamentally probabilistic or fundamentally deterministic. So, the relation is there.

Of course I could have formulated that one sentence slightly differently, but this objection is nothing but nitpicking: it has nothing to do with the fundamental problem treated in the manuscript, or with the new view on that problem presented in the manuscript. ■

Objection 6.5.16. "*The paper then goes on to discuss the 'Elementary Process Theory (EPT)'. The only references provided for the EPT are by the author himself, which is, in general, a bit suspicious. And indeed, the EPT seems to be only a fairly simplistic model, and any conenction* [sic] *to quantum mechanics and its statistical predictions is merely postulated in a rather vague and ad hoc way. While more details may have been profided* [sic] *elsewhere, it seems doubtful, from the present discussion, that this probability postulate is even consistent with the proposed dynamical process.*"—third objection of referee #2, commenting on my submitted paper (Cabbolet, 2019b) ■

Reply 6.5.17. First of all, note that the second sentence quoted above is the second ad hominem argument by this referee, and that all sentences but the first have a vitriolic tone: these are tell-tale signs of pseudoskepticism (Cabbolet, 2018d). That said, three claims are made about my work:

(i) the EPT is a fairly simplistic model;

(ii) the relation between the EPT and QM is postulated in a rather vague and ad hoc way;

(iii) the probabilistic nature of the knowledge of a microsystem in the framework of the EPT is not consistent with the proposed dynamical process—this is the process of evolution of a neutron as in Sect. 6.4.

All three claims are false. As to (i), the EPT is a *theory*, not a *model*. Most probably this referee, like the majority of physicists, has no background in logic, and is unaware of the theory/model distinction—he hasn't thought about what he wrote. As to (ii), the opposite is the case: the relation between the EPT and QM is treated precisely and there is nothing *ad hoc* about it—the treatment makes systematically use of the axioms and ontology of the EPT. As to (iii), it suffices to quote Monty Python: *that's not an argument, that's just contradiction.* Any and all analysis is lacking, and nothing has been done to substantiate this claim.

Summarizing, the referee hasn't understood my work from a first superficial reading, and has blurted out whatever came first to mind in accordance with the response-in-an-outburst model on p. li. The typos indicate that his report is hastily written, which fits this picture. ■

Objection 6.5.18. "*Assuming that the EPT is consistent and bares some relation to quantum theory, the discussion provided does not even conclusively establish the central claim that it is, in fact, ψ-epistemic.*"—fourth objection of referee #2, commenting on my submitted paper (Cabbolet, 2019b) ■

Reply 6.5.19. As we proceed with the referee report, the degree of misunderstanding surfaces. Here the referee claims that the central claim of the paper is that the EPT is ψ-epistemic. But that claim is made nowhere in the paper, because it is nonsensical: the EPT is not a quantum theory, and its formal language does not contain a wave function ψ—any talk about the EPT as ψ-epistimic is as nonsensical as a talk about a defensive tactic in a game of rock-paper-scissors, or about the nature of the smell of the right to freedom of speech. ■

Objection 6.5.20. "*Third, there is no discussion of the PBR theorem regarding ψ-epistemic interpretations of quantum mechanics and how it may affect the author's approach, since the latter approximates ψ-epistemic QM at some continuous limit.*"—third objection of referee #1, commenting on my submitted paper (Cabbolet, 2019b) ■

Objection 6.5.21. "*Finally, if the EPT would be ψ-epistemic, as claimed, it remains unclear how it avoids the PBR-theorem which establishes the incompatbility* [sic] *of ψ-epistemic theories with quantum predictions under fairly mild assumptions. The paper contains only a footnote about this, but I find it neither clear nor sufficient.*"—fifth objection of referee #2, commenting on my submitted paper (Cabbolet, 2019b) ■

Reply 6.5.22. Both the submitted paper and Sect. 6.4 of this monograph present a new idea on a deterministic non-quantum theory from which QM emerges. The focus is on presenting that new idea: there is then no need to discuss every idea ever published on the topic. That being said, the theorem by Pusey, Barret, and Rudolph (2012) leans on a number of assumptions about quantum states, preparations of quantum states and measurements on quantum states. It is a research on its own to investigate whether these assumptions are valid in the framework of the deterministic semi-classical model of the EPT, where the value of the hidden variable is fundamentally unknowable and knowledge about a monadic state is fundamentally probabilistic. This is left as a topic for further research. ■

Chapter 7

A new approach to the mind-body problem

"*Not a new Einstein, but a fuck up*"—Peter Olsthoorn, "investigative journalist", commenting to the news that my PhD graduation was canceled on the widely-read forum *leugens.nl* (2008)

7.1 Preliminary: the intelligent neutron

Let us revisit the one-neutron system as described on p. 289 of Sect. 6.4, and let us consider the first process in the evolution of the system after its preparation at $t = t_1$; let this be a process I, so let there be no photon being captured at the initial event of the process. Now in Ch. 6 we have assumed that the neutron concerns inanimate matter: as a result, it is predictable that the system will evolve as described by the semi-classical model of interaction processes for a force-free environment. For that first process we can then mathematically model the initial ground state of the system, the subsequent transition state of the system, and the next ground state of the system as follows:

(i) at $t = t_1$, the initial ground state of the system can be modeled by a function $f_{t_1} : \mathbb{R}^3 \to \mathbb{R}$ representing the uniform distribution of the gravitational mass m_g over a closed ball $\overline{B}_r(X_1)$ with r being the mass radius of the neutron;

(ii) for $t \in (t_1, t_2)$, the transition state of the system can be modeled by a function $f_t : \mathbb{R}^3 \to \mathbb{R}$ representing a *time-independent* normal distribution of the gravitational mass m_g over the surrounding space $\mathbb{R}^3$, e.g. the function given by

$$f_t : X \mapsto m_g \cdot \sqrt{\pi^{-3}} e^{-r^2} \tag{7.1}$$

where $r = d(X, X_1)$, cf. Eq. (6.26);

(iii) at $t = t_2$, the next ground state of the system can be modeled by a function $f_{t_2} : \mathbb{R}^3 \to \mathbb{R}$ representing the uniform distribution of the gravitational mass m_g over a closed ball $\overline{B}_r(X_2)$: we have $X_2 = X_1$.

The above functions f_{t_1}, f_t, and f_{t_2} thus model states of (temporal parts of) phase quanta in the GRF of the experimenter.

We now drop the assumption that the neutron concerns inanimate matter: instead we assume that the neutron is an intelligent observer and that an act of free will takes place in the first process in the evolution of the system. For this alternative first process we can then model the initial ground state of the animated monadic system, its subsequent transition state, and its next ground state as follows:

(i′) at $t = t_1$, the ground state of the system is the same as above: it can be modeled by the function $f_{t_1} : \mathbb{R}^3 \to \mathbb{R}$ given under (i) above;

(ii′) for $t \in (t_1, t_2)$, the transition state of the system can be modeled by a function $f'_t : \mathbb{R}^3 \to \mathbb{R}$ representing a *time-dependent* distribution of the gravitational mass m_g over the surrounding space $\mathbb{R}^3$, e.g. the function given, for some displacement $\delta X \in \mathbb{R}^3$, by

$$f'_t : X \mapsto m_g \cdot \sqrt[3]{\pi^2} e^{-r(t)^2} \tag{7.2}$$

where $r(t) = d(X, X_t)$ with $X_t = X_1 + (t - t_1) \cdot \delta X / (t_2 - t_1)$;

(iii′) at $t = t_2$, the next ground state of the system can be modeled by a function $f'_{t_2} : \mathbb{R}^3 \to \mathbb{R}$ representing the uniform distribution of the gravitational mass m_g over a closed ball $\overline{B}_r(X'_2)$ now centered at the position $X'_2 = X_1 + \delta X$.

The functions f_{t_1}, f'_t, and f'_{t_2} thus model states of (temporal parts of) phase quanta in the GRF of the experimenter for this alternative process.

The core idea here is that an act of free will of the intelligent neutron goes hand in hand with a *variation* in the transition state of the system—a change in the distribution of the neutron's gravitational mass over space—that is **not** due to interaction with the surrounding fields. More formally, if an act of free will has taken place in this process, then

$$\exists \delta f_t : f'_t = f_t + \delta f_t \tag{7.3}$$

The variation δf_t thus causes the neutron's transition state to be $f_t + \delta f_t$ instead of f_t, which in turn causes the next ground state of the neutron to be centered at X'_2 instead of at X_2: by bringing about the variation δf_t, the neutron has thus caused a bodily action—to wit: the displacement accomplished by the transition from a particle state at a position X_1 to a particle state at a position $X_1 + \delta X$.

This is thus the physical mechanism by which an intentional thought of the intelligent neutron has an effect on the body: there is then no other possibility than that an intentional thought of the intelligent neutron is an occurrent, whose temporal part at $t \in (t_1, t_2)$ is a variation δf_t of its transition state. To say that the intelligent neutron has a free will then means that the neutron has the disposition to *autonomously* generate intentional thoughts—variations in its transition state, that is.

Of course free will is only *real*—as opposed to *illusive*—when there is a fundamental principle of choice. In the framework of the EPT, the generalized principle of choice, Ax. 5.3.13, is in place. Applied to the first process in the evolution of the system made up of the intelligent neutron, that is, the animated monadic system, this yields the following picture.

At $t = t_1$, when the neutron is in a ground state at $X = X_1$, it is determined that the neutron will be in an excited state at $t = t_2$ but it is not yet determined at which position X that excited state will be created. So, at $t = t_1$ there is a set $\theta_1^{n_2}$ of parallel possible excited states: for each possible position X of the excited state of the neutron at $t = t_2$, there is a possible excited state in $\theta_1^{n_2}$. The choice is made by the collapse of the transition state of the neutron at $t = t_2$: only then one of the possible excited states materializes, and this excited state then immediately transforms into the ground state of the neutron at $t = t_2$.

That being said, as explained in Rem. 6.3.8, at $t = t_1$ it is determined which one of the parallel possible excited states will materialize at $t = t_2$ in the process under consideration **if** the neutron concerns inanimate matter: the transition state of the system is then completely determined by the initial conditions and by the interaction with the surrounding fields—the transition state of the system can then be modeled by the function f_t of Eq. (7.1), and at $t = t_2$ it will collapse into an excited state at the spatial position $X = X_2 = X_1$. Thus speaking, this 'inanimate' transition state of the neutron corresponds to a choice function f_C on the singleton of $\theta_1^{n_2}$: the excited state that materializes at $t = t_2$ is then precisely the element $f_C(\theta_1^{n_2})$ associated to the position $X = X_2 = X_1$.

If the neutron concerns our intelligent neutron, on the other hand, then the transition state of the system in the process under consideration is not completely determined by the initial conditions and by the interaction with the surrounding fields: it depends then also on the intentional thought that the neutron has. The intermediate transition state of the system is then to be modeled by the function f'_t of Eq. (7.2), and at $t = t_2$ it will collapse into an excited state at $X = X'_2 \neq X_1$. Thus speaking, this 'living' transition state of the neutron corresponds to a choice function $f'_C \neq f_C$ on the singleton of $\theta_1^{n_2}$—the excited state that materializes at $t = t_2$ in this alternative first process is then precisely the element $f'_C(\theta_1^{n_2})$ associated to the position $X = X'_2$.

This short discussion of the intelligent neutron captures the basic idea of mental causation in the framework of the EPT. But of course, there is no such thing as an intelligent neutron in the outside world: systems made up of a single component have absolutely no intelligence c.q. free will. That is to say: the composition of a system needs to be of a certain complexity for the system to have a free will, that is, for the system to have the disposition to *autonomously* generate variations in its transition states. In the remainder of this chapter we will therefore consider an intelligent observer to be a macroscopic system made up of a multitude of components, which evolves in time by billions and billions elementary processes simultaneously. However, no attempt will be made to define a necessary and sufficient criterion for the composition of a system, such that a system has a free will if and only if that criterion is satisfied.

7.2 Introduction

Although the idea of a dualism was already proposed in Ancient Greece by Plato (427 – 347 B.C.), the mind-body problem has arisen from the now historical substance dualism of Descartes, according to which the universe is made up of two distinct kinds of matter: mental and physical. Within that Cartesian dualism, a human is a composite entity that consists of two ontologically different parts: a body, which is material, extended, and unthinking, and a mind, which is immaterial, indivisible, and thinking. Descartes, however, never succeeded in successfully answering this question: how can the mind cause a bodily action? From this failure, the mind-body problem arose—it is *the* central issue in the philosophy of mind.

A possible approach to the mind-body problem is to investigate it from a physicalist point of view: this comes down to describing at object level, *strictly using the vocabulary and assumptions of physics*, what the mind is and how, if at all, mental causation can occur. Since there is no consensus on what *the* language and assumptions of physics are, a dilemma analogous to Hempel's dilemma (1969) arises: does one have to use the vocabulary and assumptions of a *well-defined* physics paradigm, or can a physicalist approach also be based on some *ideal future* physics paradigm? To resolve this dilemma, here the following position is taken:

> *a physicalist approach to the mind-body problem is an approach from the point of view of a well-defined disciplinary matrix for the study of physical reality.*

Note that a well-defined disciplinary matrix for the study of physical reality does not necessarily have to be *widely accepted*. According to this definition, there is thus no such thing as *the* physicalist point of view: there is *a* physicalist point of view for every such well-defined disciplinary matrix. An example of a non-physicalist approach is *emergentism*: the body, in particular the brain, is then assumed to be a complex system of classical particles, but to explain the mind it is assumed in addition that complex systems can have properties that cannot be reduced to properties of the particles that make up the system. This additional assumption places it outside the framework of classical mechanics, so that emergentism cannot be called a physicalist approach.

Classical and modern physicalist approaches

Thus far, two disciplinary matrices for the study of physical reality have been used as a basis for a physicalist approach to the mind-body problem: the framework of classical mechanics and the framework of modern physics (quantum mechanics). Below, the variety of resulting approaches is illustrated by selected examples, but without the intention to give a complete overview or an in-depth review.

Despite the falsification of classical mechanics as a true physical theory, the corresponding physicalist point of view is still widely held today due to the "tremendous inertia from the philosophers of the past, philosophers of the classical world"—as Stapp put it (Kuhn, 2010). The most straightforward philosophy to fit the mind in the ontology of classical mechanics is the so-called *identity theory* that the mind simply *__is__* the brain, where the brain is a system of particles; this ontological monism was developed by Feigl (1958) and Smart (1959). Various other philosophies, simply put, reject the idea that the mind can be reduced to the brain (as in identity theory) as an oversimplification, but maintain that the mind can be explained by the brain as a complex system of classical particles; for an overview see e.g. (Kim, 2005). The common denominator is that the mind is not a substance of any sort in itself (McLaughlin, 1999)—a stance that is naturally rooted in the fact that there is no such thing as "mental substance" in the classical-mechanical universe.

Concerning mental causation, Van Inwagen has shown that the idea of free will is incompatible with a deterministic world view (1975). The various physicalist approaches to the mind-body problem solutions that are based on classical mechanics therefore all meet the general criticism that they discard free will as an illusion:

> "*the important lesson we have learned from three decades of debate [is that these approaches] run aground on the rocks of mental causation*"—Kim (2005).

Such approaches "have been generally accepted, [only] because they do not violate the closedness of World 1", that is, because they do not violate the classical-mechanical view that the world of matter-energy is completely unaffected by any non-material agency such as the mind (Eccles, 1986).

Another criticism is hereby that classical mechanics has already been falsified: how can a physicalist approach to the mind-body problem lead to a fundamental understanding of mental causation, when the physical laws that are assumed as representations of the workings of the physical world are known to be false? Apparently, mental causation uses laws of nature at a more fundamental level than classical mechanics, that is, laws of nature from which classical mechanics emerges at the macroscopic scale—it may be the case that it is hitherto unknown which laws of nature that are, but one thing is for sure: mental causation does not use the laws of classical mechanics. All physicalist approaches to the mind-body problem based on classical mechanics are therefore futile beforehand. That is, it may be true that identity theory and variations thereof such as eliminative materialism are sufficient to explain experimental data obtained from measuring brain activity, but these deterministic doctrines have nevertheless to be rejected as a definite solution of the mind-body problem. One might thus take the point of view that the denial of mental causation *__is__* the definite answer to the question of mental causation, but that point of view is then based on the false assumption that the laws of classical mechanics are universally true: the denial has, thus, been developed from a falsehood and has, thus, to be discarded.

The falsification of classical mechanics as fundamental laws of nature has in recent decades caused interest in a physicalist approach to the mind-body problem based on QM. Important for the question what the mind is from the quantum-mechanical point of view, is the framework of complementarity, which was developed by Bohr in the 1920's as a general framework for the interpretation of QM (Bohr, 1928). The aspect of complementarity relevant for the mind-body problem is the so-called wave-particle dualism, an ostensible paradox which arises when one tries to apply the classical concepts of waves and particles to atomic phenomena and

> "*[fails] to realize that such different descriptions refer not to the same object but to complementary phenomena which only together provide an unambiguous description of the nature of the objects which give rise to these phenomena*"—Folse (1985).

Shortly after inception, Bohr hinted at an application of his framework of complementarity to the subject-object problem in philosophy (Bohr, 1929).

Decades later, Pauli suggested an application of complementarity to the mind-body problem: “It would be most satisfactory if physis and psyche could be conceived as complementary aspects of the same reality” (1952).

Since then, several dual-aspect approaches to the mind-body problem have been developed within the paradigm of QM. An example is the dual-aspect monism proposed by Polkinghorne, which concerns duality of matter: “there is only one stuff in the world (not two—the material and the mental), but it can occur in two contrasting states (material and mental phases, a physicist would say) which explain our perception of the difference between mind and matter” (1994). Another example is the dual-aspect theory introduced by Stapp, which involves a duality of events (only events are real in this theory):

> “*in this [dualistic] model the thinking and the doing do not occur in tandem. The thought and the physical act that implements it are two faces of a single mind/brain event*”—Stapp (2009).

But also a Cartesian-like dualism has been formulated in the framework of QM: according to Eccles, the mind is a nonmaterial entity (1986). Eccles refers to Margenau, who stated the following: “The mind may be regarded as a field in the accepted physical sense of the term. But it is a nonmaterial field, its closest analogue is perhaps a probability field” (1984).

Concerning mental causation, several solutions have been proposed within the paradigm of QM. Of these, the mechanism published by Stapp is the most elaborate one staying strictly within the quantum paradigm; it uses the feature of the framework of QM that there are two kinds of processes (continuous and discontinuous ones). In a nutshell, Stapp assumes that the brain evolves continuously in accordance with the Schroedinger equation until a specific probing action, that is, an act that implements a thought, takes place. The quantum state of the brain then immediately reduces in a discontinuous way to a state compatible with both the state attained at the previous probing action ánd an increment of knowledge that stems from the thought. This reduction can actualize a large-scale pattern of brain activity that can cause an intended bodily action to occur (Stapp, 2009). Another dual-aspect quantum approach that “explores Pauli’s idea that mind and matter are complementary aspects of the same reality” uses two concepts of time: reality has a nonmaterial, tensed domain, which is related to a mental world, and a tenseless domain, which is related to physical objects; both domains are connected to each other in a non-classical way by entanglement Primas (2003). So this dual-aspect approach suggests a mechanism for mental causation that uses another feature of the framework of QM: entanglement. Nagel criticized all dual-aspect approaches formulated within the paradigm of QM with the remark that

> "*talk about a dual-aspect theory ... is only to say roughly where the truth might be located, not what it is*"—Nagel (1986)

This criticism, however, seems to be too general to rule out all such approaches; it is, for example, not clear how this refutes Stapp's approach. What the various quantum approaches do have in common is that they all still lack experimental support, due to the fact that measurements of brain activity necessarily involve the whole of the brain as a macroscopic object.

Motivation for a new approach

It is currently not the case that any consensus exists about a physicalist solution of the mind-body problem. That is, there is currently absolutely no agreement whatsoever about what the mind is in physical terms, nor about what the physical principles at object level are by which an intentional thought can cause a bodily action. To summarize the current state of affairs, it suffices to quote Searle: "we are nowhere remotely near having a solution" (2007). Even stronger, Norman wrote that one must face the conclusion that "the entire epistemic system of [contemporary] science is based on a faulty set of premises" if mental causation is possible (2004). Or, as Kuhn put it:

> "*explaining consciousness will require something radically new—either finding physical stuff beyond current boundaries or revealing the reality of nonphysical stuff*"—Kuhn (2010)

That being said, with the EPT a fundamentally new, well-defined disciplinary matrix for the study of physical reality has been introduced. The motivation to use this as the basis for a new physicalist approach to the mind-body problem is, as we will see, that the mind and mental causation fit more naturally in the ontology of the EPT than in the ontology of classical mechanics or the ontology of QM.

7.3 Man as trinity of body, spirit and soul

Body, spirit, and soul as aspects of a physical system

Before we can talk about macroscopic systems such as stones and human beings in the framework of the EPT, we have to define the related notion of a macroscopic occurrent: macroscopic systems can then be introduced by postulating that the state of a temporal part of a macroscopic occurrent in the reference frame of an observer can be viewed as the state of a macroscopic system. Just as in Ch. 6 we assume non-relativistic conditions, which means that we can assume that all elementary processes take place *synchronously* and have a duration of a Planck time t_P. We can then also use the notion of a GRF of an observer, introduced in Def. 6.1.4.

Definition 7.3.1 (Macroscopic occurrent).
A ***macroscopic occurrent****, designated by a constant '$\mathfrak{O}$' (a Gothic 'O') in the language of the EPT, is an occurrent made up of atomic occurrents (i.e., phase quanta) that exist in the four-dimensional world of the EPT, such that*

(i) for every open-ended Planck segment of $\mathfrak{O}$, designated by a constant $\mathfrak{O}_{[n,n+1)}$ with n being a degree of evolution, there is a (normal) particlelike part $\mathfrak{O}_n$, a wavelike part $\mathfrak{O}_{(n,n+1)}$, a permutation σ_n on the initial section $I_{z(n)}$ of the natural numbers (see Sect. 5.1), and a number $b(n) < z(n)$ such that

$$\mathfrak{O}_{[n,n+1)} = \mathfrak{O}_n + \mathfrak{O}_{(n,n+1)} \tag{7.4}$$

$$\mathfrak{O}_n = {}^{EP}\varphi^n_{\sigma_n(1)} + \ldots + {}^{EP}\varphi^n_{\sigma_n(b(n))} \tag{7.5}$$

$$\mathfrak{O}_{(n,n+1)} = {}^{NW}\varphi^n_{\sigma_n(1)} + \ldots + {}^{NW}\varphi^n_{\sigma_n(b(n))} \tag{7.6}$$

(ii) for any (inertial) observer $\mathcal{O}$, there is for any (normal) particlelike part $\mathfrak{O}_n$ a time t_n and a closed volume in space V_n in the GRF of $\mathcal{O}$ such that $\mathfrak{O}_n$ exists at t_n and is enclosed by V_n;

(iii) for any (inertial) observer $\mathcal{O}$ and for any point in time t in the time span $[t_\alpha, t_\omega]$ of $\mathfrak{O}$ in the GRF of $\mathcal{O}$, the state of the temporal part of $\mathfrak{O}$ at t can be viewed as the state of a macroscopic system.

■

A corollary of Def. 7.3.1 and Ax. 5.3.11 is that for every open-ended Planck segment $\mathfrak{O}_{[n,n+1)}$ of a macroscopic occurrent $\mathfrak{O}$, there are $\omega(n) \geq b(n)$ monadic occurrents $\psi^n_{\mathrm{M}_1}, \ldots, \psi^n_{\mathrm{M}_{\omega(n)}}$ such that

$$\mathfrak{O}_{[n,n+1)} = \psi^n_{\mathrm{M}_1} + \ldots + \psi^n_{\mathrm{M}_{\omega(n)}} \tag{7.7}$$

Furthermore, consecutive particlelike parts $\mathfrak{O}_n$ and $\mathfrak{O}_{n+1}$ need not to be composed of the same number of phase quanta. That is, in general we have $b(n) \neq b(n+1)$. If we consider the life of a growing crystal, for example, then we expect this number to be increasing over n. But if we consider the life of a stupid human being who at some point decides to amputate one of his own limbs for no particular reason, then there is an n and an $x > 0$ such that $b(n + x)$ is substantially less than $b(n)$. What we have is that the evolution of a particlelike part $\mathfrak{O}_n$ to its successor $\mathfrak{O}_{n+1}$ is governed by a macroscopic process from the n^{th} to the $(n + 1)^{\text{th}}$ degree of evolution, composed of the elementary processes taking place simultaneously, whose *input* is the particlelike part $\mathfrak{O}_n$ **plus** an "incoming mass" designated by $\mathfrak{M}^+_n$, and whose *output* is the particlelike part $\mathfrak{O}_{n+1}$ **plus** an "outgoing mass" designated by $\mathfrak{M}^-_{n+1}$. Suppose that $\mathfrak{M}^+_n$ has $x(n)$ components and that $\mathfrak{M}^-_{n+1}$ has $y(n + 1)$ components, that is, suppose that

$$\mathfrak{M}^+_n = {}^{EP}\varphi^n_{\sigma_n(b(n)+1)} + \ldots + {}^{EP}\varphi^n_{\sigma_n(b(n)+x(n))} \tag{7.8}$$

$$\mathfrak{M}^-_{n+1} = {}^{EP}\varphi^{n+1}_{\sigma_{n+1}(b(n+1)+1)} + \ldots + {}^{EP}\varphi^n_{\sigma_{n+1}(b(n+1)+y(n+1))} \tag{7.9}$$

for $x(n), y(n + 1) \in \mathbb{N}$, and let the constant $\mathfrak{O}^+_{(n,n+1)}$ be defined by

$$\mathfrak{O}^+_{(n,n+1)} = {}^{NW}\varphi^n_{\sigma_n(1)} + \ldots + {}^{NW}\varphi^n_{\sigma_n(b(n)+x(n))} \tag{7.10}$$

Then we can write

$$\mathfrak{O}^+_{(n,n+1)} : \mathfrak{O}_n + \mathfrak{M}^+_n \dashrightarrow \mathfrak{O}_{n+1} + \mathfrak{M}^-_{n+1} \tag{7.11}$$

meaning that in the macroscopic process governing the evolution of the particlelike part $\mathfrak{O}_n$ to its successor $\mathfrak{O}_{n+1}$, the wavelike occurrent $\mathfrak{O}^+_{(n,n+1)}$ effects that the particlelike occurrent $\mathfrak{O}_n + \mathfrak{M}^+_n$ is succeeded by the particlelike occurrent $\mathfrak{O}_{n+1} + \mathfrak{M}^-_{n+1}$. This corresponds to the idea of an *open macroscopic system.*[56]

However, we can also have the scenario that in the macroscopic process governing the evolution of the particlelike part $\mathfrak{O}_n$ to its successor $\mathfrak{O}_{n+1}$, incoming mass and outgoing mass are zero: $\mathfrak{M}_n^+ = \mathfrak{M}_{n+1}^- = 0$. Eq. 7.11 then reduced to

$$\mathfrak{O}_{(n,n+1)} : \mathfrak{O}_n \dashrightarrow \mathfrak{O}_{n+1} \tag{7.12}$$

This corresponds to the idea of a macroscopic system that is *closed* in the time interval $[t_n, t_{n+1})$ in the GRF of observer $\mathcal{O}$, being the time span of the open-ended Planck segment $\mathfrak{O}_{[n,n+1)}$ of the macroscopic occurrent $\mathfrak{O}$.

That being said, we will proceed with a treatise of macroscopic systems, and for the sake of simplicity we tacitly assume that the macroscopic system under consideration is closed in the time interval under consideration.

Let $\mathfrak{O}$ be a macroscopic occurrent whose open-ended Planck segment $\mathfrak{O}_{[n,n+1)}$ has a time span $[t_n, t_{n+1})$ in the GRF of observer $\mathcal{O}$, and let counting numbers be assigned to elementary processes in such a way that

$$\mathfrak{O}_n = {}^{EP}\varphi_1^n + \ldots + {}^{EP}\varphi_{b(n)}^n \tag{7.13}$$

$$\mathfrak{O}_{(n,n+1)} = {}^{NW}\varphi_1^n + \ldots + {}^{NW}\varphi_{b(n)}^n \tag{7.14}$$

$$\mathfrak{O}_{n+1} = {}^{EP}\varphi_1^{n+1} + \ldots + {}^{EP}\varphi_{b(n)}^{n+1} \tag{7.15}$$

At any $t \in [t_n, t_{n+1}]$ the state of the temporal part of $\mathfrak{O}_{[n,n+1)}$ can then be viewed as the state of a dynamical system, represented by a function $\Psi_t : \mathbb{R}^3 \to \mathbb{R}$ which can be written as a sum of $b(n)$ terms f_t^j:

$$\Psi_t = f_t^1 + \ldots + f_t^{b(n)} \tag{7.16}$$

At $t = t_n$, the sum $f_{t_n}^1 + \ldots + f_{t_n}^{b(n)}$ represents the state of the superposition in Eq. (7.5), which can be viewed as a superposition of ground states of supersmall massive systems. Each function $f_{t_n}^j$ represents an amount of gravitational mass distributed over a closed ball—cf. Eqs. (6.21)-(6.22). Likewise for $t = t_{n+1}$. At any $t \in (t_n, t_{n+1})$ the sum $f_t^1 + \ldots + f_t^{b(n)}$ represents the state of the temporal part at t of the superposition in Eq. (7.6), which can be viewed as a superposition of transition states of supersmall massive systems. Each function f_t^j then represents an amount of gravitational mass distributed over the whole space $\mathbb{R}^3$—cf. Eq. (6.26).

Remark 7.3.2 (Hyperstates).
When we talk about the "state" of a physical system, we have in mind the condition that the system is in—e.g. the condition represented by the distribution of mass over space—*at a specific time*. It would therefore be wrong to talk about the "state" of an occurrent when it has an *extended time span*. The analogous idea for an occurrent can be called a *hyperstate*, which may be defined as follows. Let n be a degree of evolution, and let $\mathfrak{O}_{[n,n+1)}$ be an open-ended Planck segment of an occurrent with time span $[t_n, t_{n+1})$ in the GRF of an observer $\mathcal{O}$, such that for any $t \in [t_n, t_{n+1})$ the state of the temporal part of $\mathfrak{O}_{[n,n+1)}$ in the GRF of $\mathcal{O}$ is represented by a function $\Psi_t : \mathbb{R}^3 \to \mathbb{R}$. Then the **hyperstate** of the open-ended Planck segment of the occurrent $\mathfrak{O}_{[n,n+1)}$ in the GRF of $\mathcal{O}$ is the fusion of the states of its temporal parts in its time span, represented by a function $\Psi_{[t_n,t_{n+1})} : \mathbb{R} \times \mathbb{R}^3 \to \mathbb{R}$ given by

$$\begin{cases} t \in [t_n, t_{n+1}) \Rightarrow \Psi_{[t_n,t_{n+1})} : (t,x,y,z) \mapsto \Psi_t(x,y,z) \\ t \notin [t_n, t_{n+1}) \Rightarrow \Psi_{[t_n,t_{n+1})} : (t,x,y,z) \mapsto 0 \end{cases} \tag{7.17}$$

This definition can easily be generalized to the hyperstate in the GRF of an observer $\mathcal{O}$ of any segment of an occurrent with a concrete time span. Only if the time span is *degenerate*, we may speak of the "state" of the occurrent. Importantly, the function representing the hyperstate takes both a time coordinate and a spatial coordinate tuple as argument. ■

That aside, let's return to our macroscopic system, and let's assume that the system is <u>inanimate</u>. We can then distinguish a 'body' and a 'spirit': the *body* is what the macroscopic system is when the constituting supersmall subsystems are in their ground states; the *spirit* is what the macroscopic system is when the constituting supersmall subsystems are in transition states. So for the macroscopic process by which the state Ψ_{t_n} evolves to the state $\Psi_{t_{n+1}}$ we have the following:

(i) at the start of the process, the system exists as a body with state Ψ_{t_n};

(ii) thereafter, the system exists as a spirit with state Ψ_t;

(iii) at the end of the process, the system exists as a body with state $\Psi_{t_{n+1}}$.

So, in the framework of the EPT an inanimate macroscopic system, such as a stone, exists alternately as a 'body' and as a 'spirit'.

Thus speaking, if a human being is *at all* able to cause a bodily action that would not have occurred if a human being would be a macroscopic system without a free will like a stone, then on account of the causal closure principle it is **not sufficient** to say that a human being is a duality of body and spirit: a human being **has to have** an additional active principle, which accounts for awareness (consciousness) and intentional thoughts. The idea is then that this active principle must not be sought in the ontological composition of the system, but rather in the properties of the system: a macroscopic system with free will has the disposition to autonomously generate a variation in the transition state of the system. This active principle can be given many names, but here it is called a 'soul'; it manifests itself in variations of the transition state of the system—as such it *subsists*.

To elaborate, let's assume that a human being is a macroscopic system with free will—as opposed to the inanimate macroscopic system considered above—and consider again the macroscopic process by which the state Ψ_{t_n} evolves to the state $\Psi_{t_{n+1}}$. We then have the following:

(i) at $t = t_n$, the system exists as a body with state Ψ_{t_n};

(ii) thereafter, at any time $t \in (t_n, t_{n+1})$ the system has the disposition to autonomously generate a variation in its state Ψ_t;

(iii) at $t = t_{n+1}$, the system exists as a body with state $\Psi_{t_{n+1}}$.

At a time $t \in (t_n, t_{n+1})$, the state Ψ_t can then be written as

$$\Psi_t = \Psi_t^0 + \delta\Psi_t \tag{7.18}$$

where the function Ψ_t^0 represents what the state of the system would have been if the system would have been without free will—it derives from the initial state Ψ_{t_n} at $t = t_n$ and the physical interaction with its environment. The variation $\delta\Psi_t$ represents the variation of the state, autonomously generated by the system, at the time t. In the framework of the EPT, soul and spirit can thus be seen as an integrated whole: as expressed by Eq. (7.18), at any time $t \in (t_n, t_{n+1})$ the state of the soul $\delta\Psi_t$ is a variation in the state of the spirit Ψ_t. This trinity of body, spirit and soul gives rise to a counterintuitive concept of motion of a human being: it is not at all the human body that moves from A to B, it is the human spirit and soul that move from a body at a position A to a body at a position B.

The mind in the framework of the EPT

Up till now, the talk has been limited to physical entities: in the universe of the EPT, 'body', 'spirit' and 'soul' are names for physical aspects of a macroscopic system with free will. Now what happens in the physical world are physical processes, but what a subject experiences are mental processes: in this picture, the concept 'mind' requires a dual-aspect approach in addition to the material substance dualism that describes the trinity of body, spirit and soul. The key is self-awareness: the idea of a mind arises because the macroscopic system with free will is self-aware.

To relate mental processes to physical processes described by the EPT, it is interesting to cite Kim's variant of McLaughlin's widely accepted correlation thesis (2001):

> "*for every type of sensation state, S, there is a type of physical state P such that it is nomologically necessary that for any organism, x, x is in S if and only if x is in P.*"—Kim (2005)

With that we get to the *psychophysical correlation*. This is not some kind of process that is different from the ones described by the EPT: rather, the psychophysical correlation is *nothing but* the continuous concurrence of a mental state and a correlated state of a temporal part of the wavelike part $\mathfrak{O}_{(n,n+1)}$ of an open-ended Planck segment $\mathfrak{O}_{[n,n+1)}$ of the life of an animate system. A mental state S_t at $t \in (t_n, t_{n+1})$ is thus nothing but an image of the physical state Ψ_t, created by self-awareness—there is nothing more to it. To put that in other words: the family of mental states indexed by (t_n, t_{n+1}), i.e. the set of states $\{S_t \mid t \in (t_n, t_{n+1})\}$ ordered in time, is nothing but the "subjective form" of the hyperstate $\Psi_{(t_n,t_{n+1})}$ of the segment of the macroscopic occurrent $\mathfrak{O}$ with time span (t_n, t_{n+1}).

The idea of a 'mind' as a continuant emerges from this family of mental states: the consecution of mental states ***is*** the mind of the self-aware subject going through time. The mind has thus absolutely no ontological connotation in the framework of the EPT: it is not a substance of any kind, that is, it is not a thing in itself in the noumenal universe (see part IV).

The psychophysical correlation works both ways, that is, holds for both perception (from the physical to the mental domain) and intention (from the mental to the physical domain). The next section elaborates on the latter.

Mental causation

Let us again focus on a macroscopic process with the duration of a Planck time t_P, by which a macroscopic system evolves from a body with state Ψ_{t_n} in the GRF of an observer $\mathcal{O}$ to a body with state $\Psi_{t_{n+1}}$ in the GRF of that observer $\mathcal{O}$; we assume that the system is closed in the corresponding time interval $[t_n, t_{n+1})$. Now obviously, the state Ψ_{t_n} depends on the spatial positions $X_n^1, \ldots, X_n^{b(n)}$ of the $b(n)$ ground states of the supersmall systems that constitute the body at $t = t_n$. Let these $b(n)$ spatial positions correspond with a coordinate tuple $\tilde{X}_n = (x_n^1, \ldots, x_n^{3b(n)}) \in \mathbb{R}^{3b(n)}$; then

$$\Psi_{t_n} = \Psi_{t_n}(x_n^1, x_n^2, \ldots, x_n^{3b(n)-1}, x_n^{3b(n)}) = \Psi_{t_n}(\tilde{X}_n) \tag{7.19}$$

At the point in time t_n, it is determined *that* the system will again exist as a body at the time t_{n+1}, but it is not yet determined *which* state the next body will be in: a distinctive feature of the universe of the EPT is that it is neither deterministic nor probabilistic, but 'volitionistic'—in concreto, the universe is the result of choices, some of which are volitional.

Applied to the present process, that means that at the point in time $t = t_n$ there is a set Π_{n+1} of possible states of the body at the point in time $t = t_{n+1}$, which can be indexed by some set F, and each of these possible states then depends on a coordinate tuple $\tilde{Y}_{n+1} \in \mathbb{R}^{3b(n)}$:

$$\Pi_{n+1} = \{\Psi^j_{t_{n+1}}(\tilde{Y}^j_{n+1})\}_{j \in F} \tag{7.20}$$

The state of the body that actually materializes at $t = t_{n+1}$—let us denote it by $\Psi^*_{t_{n+1}}(\tilde{Y}^*_{n+1})$—is thus an element of this set:

$$\Psi^*_{t_{n+1}}(\tilde{Y}^*_{n+1}) \in \Pi_{n+1} \tag{7.21}$$

We can, in fact, say that each of these possible states has a choice function. That is, for each $j \in F$ there is a choice function f_C^j such that

$$f_C^j : \Pi_{n+1} \mapsto \Psi^j_{t_{n+1}}(\tilde{Y}^j_{n+1}) \tag{7.22}$$

The crux is now that this choice is determined by the hyperstate $\Psi_{(t_n, t_{n+1})}$ of the wavelike part $\mathfrak{O}_{(t_n, t_{n+1})}$ of the open-ended Planck segment $\mathfrak{O}_{[t_n, t_{n+1})}$ of the occurrent $\mathfrak{O}$, each of whose temporal parts has a state Ψ_t in the GRF of our observer $\mathcal{O}$ that can be viewed as a state of the macroscopic system under consideration. So, in accordance with Eq. (7.12) we have

$$\Psi_{(t_n,t_{n+1})} : \Psi_{t_n} \dashrightarrow f_C^j(\Pi_{n+1}) \tag{7.23}$$

for some $j \in F$. Now if our system would be *inanimate*, like a stone or a inanimate human being, then this hyperstate $\Psi_{(t_n,t_{n+1})}$ is completely determined by the initial state Ψ_{t_n} and the system's environment, that is, the gravitational and electromagnetic fields in its environment. Suppose now that this inanimate hyperstate is represented by a function $\Psi^0_{(t_n,t_{n+1})}$; the inanimate hyperstate then corresponds to a choice function f_C^0 on $\{\Pi_{n+1}\}$, so that by this process a possible state $\Psi^0_{t_{n+1}}(\tilde{Y}^0_{n+1}) \in \Pi_{n+1}$ materializes that is the state of the inanimate body at $t = t_{n+1}$. We then have

$$\Psi^0_{(t_n,t_{n+1})} : \Psi_{t_n} \dashrightarrow \Psi^0_{t_{n+1}}(\tilde{Y}^0_{n+1}) \tag{7.24}$$

The inanimate macroscopic system thus alternately exists as a body and as a spirit, and at any $t \in (t_n, t_{n+1})$ the state of the spirit is then represented by a function $\Psi^0_t : \mathbb{R}^3 \to \mathbb{R}$ for which

$$\Psi^0_t(x^1, x^2, x^3) = \Psi^0_{(t_n,t_{n+1})}(t, x^1, x^2, x^3)) \tag{7.25}$$

The statement 'at the time t, the system exists as a spirit' is thus simply another way of saying that the system is in a transition state at time t.

Proceeding, let's now consider the case that our system is *animate*, like a living human being. In that case the macroscopic system has the disposition to autonomously generate a variation in the transition state of the system by an intentional thought. In that case the hyperstate $\Psi_{(t_n,t_{n+1})}$ of Eq. (7.23) differs from $\Psi^0_{(t_n,t_{n+1})}$, and corresponds to a different choice function f_C^j on $\{\Pi_{n+1}\}$ for some $j \neq 0$ in F. What we have is that for each choice function in the set $\{f_C^j\}_{j\in F}$ there is a physical hyperstate required for the corresponding choice to take place. Now let the function $\Psi^j_{(t_n,t_{n+1})}$ represent the hyperstate required for the choice function f_C^j on $\{\Pi_{n+1}\}$; this hyperstate can then be written as the sum of the "inanimate" hyperstate $\Psi^0_{(t_n,t_{n+1})}$ plus a variation $\delta\Psi^j_{(t_n,t_{n+1})}$:

$$\Psi^j_{(t_n,t_{n+1})} = \Psi^0_{(t_n,t_{n+1})} + \delta\Psi^j_{(t_n,t_{n+1})} \tag{7.26}$$

The idea is thus that there is a bijection between the set $\{f_C^j\}_{j\in F}$ of choice functions on $\{\Pi_{n+1}\}$ and the set of variations of the inanimate hyperstate $\Psi^0_{(t_n,t_{n+1})}$ required for the corresponding choice to take place. A variation $\delta\Psi^j_{(t_n,t_{n+1})}$ is then the physical hyperstate of an open Planck segment of an intentional thought. (We can assume that a thought lasts longer than a Planck time, so the said variation cannot be the hyperstate of the entire thought.) Thus speaking, an intentional thought of the animate macroscopic system is an occurrent that manifests itself in the process under consideration as a variation of the inanimate hyperstate $\Psi^0_{(t_n,t_{n+1})}$, and that variation causes the hyperstate $\Psi_{(t_n,t_{n+1})}$ of Eq. (7.23) in this process to be the state $\Psi^j_{(t_n,t_{n+1})}$ for some $j \in F$. So, by the intentional thought that manifests itself as the variation $\delta\Psi^j_{(t_n,t_{n+1})}$, the body with state $\Psi^j_{t_{n+1}}(\tilde{Y}^j_{n+1})$ materializes at $t = t_{n+1}$. And since

$$\tilde{Y}^j_{n+1} \neq \tilde{Y}^0_{n+1} \tag{7.27}$$

the intentional thought has caused a *physical difference*—this may be a brain activity, which ultimately leads to e.g. the motion of an arm. Importantly, that state $\Psi^j_{t_{n+1}}(\tilde{Y}^j_{n+1})$ would not have materialized without the variation $\delta\Psi^j_{(t_n,t_{n+1})}$, and therefore not without the corresponding intentional thought:

(i) *another* intentional thought would have manifested itself in this process as *another* variation of the inanimate hyperstate $\Psi^0_{(t_n,t_{n+1})}$;

(ii) by the other variation, say $\delta\Psi^k_{(t_n,t_{n+1})}$ for some $k \neq j$, another state of the body $\Psi^k_{t_{n+1}}(\tilde{Y}^k_{n+1})$ would have materialized at $t = t_{n+1}$.

So, the causal exclusion principle holds in the framework of the EPT:

> "*no single event can have more than one sufficient cause occurring at any given time, unless it is a genuine case of causal overdetermination.*"—Kim (2005)

Summarizing, the animate macroscopic system exists alternately as a body and a spirit plus soul. In the process under consideration, the states Ψ_{t_n} and $\Psi_{t_{n+1}}$ are states of the body, while a state Ψ_t at a point in time $t \in (t_n, t_{n+1})$ is a state of the integrated whole of spirit and soul.

The principle of mental causation can thus be expressed by the formula

$$\Psi^0_{(t_n,t_{n+1})} + \delta\Psi^j_{(t_n,t_{n+1})} : \Psi_{t_n} \dashrightarrow f^j_C(\Pi_{n+1}) \tag{7.28}$$

Each individual case is thus an irreducible agent causation. See Fig. 7.1 for an illustration of the mechanism of mental causation. The sense of choice of a human being is thus not *imagined* but *real*—a human being has the real ability to make choices, and thus a free will!

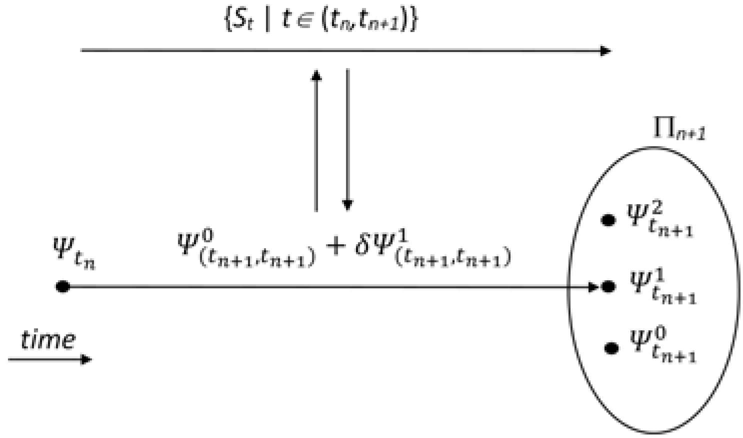


Figure 7.1: the principle of mental causation in the framework of the EPT. As indicated in the lower left corner, time increases from left to right. The lower black dot represents the state Ψ_{t_n} of an animate macroscopic system, existing as a body at $t = t_n$. The oval on the right represents the set Π_{n+1} of possible states of the system when it again exists as a body at $t = t_{n+1}$. In this example, it is at $t = t_n$ the case that there are just three states possible at $t = t_{n+1}$; we have $\Pi_{n+1} = \{\Psi^0_{t_{n+1}}, \Psi^1_{t_{n+1}}, \Psi^2_{t_{n+1}}\}$, and each of these possible states is represented by a black dot in the oval. The lower horizontal arrow represents the hyperstate $\Psi^0_{(t_n,t_{n+1})} + \delta\Psi^1_{(t_n,t_{n+1})}$ of the open Planck segment of the life of the animate system with time span (t_n, t_{n+1}): the state Ψ_t of the temporal part of this segment at any $t \in (t_n, t_{n+1})$ can be viewed as a state of the integrated whole of spirit and soul. This hyperstate causes the possible state $\Psi^1_{t_{n+1}} \in \Pi_{n+1}$ to materialize at $t = t_{n+1}$. The upper horizontal arrow is an open Planck segment of an intentional thought, which corresponds to a family of mental states $\{S_t \mid t \in (t_n, t_{n+1})\}$ of the animate system. Due to the two-way psychophysical correlation, represented by the two opposite-directed vertical arrows, this intentional thought manifests itself physically as the variation $\delta\Psi^1_{(t_n,t_{n+1})}$ in the aforementioned hyperstate: the thought therefore causes the choice $f^1_C(\Pi_{n+1}) = \Psi^1_{t_{n+1}}$ to materialize.

The intelligent neutron as toy model of an animate system

Let us treat the intelligent neutron of Sect. 7.1 as a toy model of an animate system. The life of the intelligent neutron is an occurrent $\mathfrak{O}$, and for some degree of evolution $n \in Z_N$ we thus consider an open-ended Planck segment $\mathfrak{O}_{[n,n+1)}$ of the life of the intelligent neutron; in accordance with Def. 7.3.1 we thus have

$$\mathfrak{O}_{[n,n+1)} = {}^{EP}\varphi_k^n + {}^{NW}\varphi_k^n = \psi_{\mathfrak{m}_1}^n \tag{7.29}$$

for some $k \in I_{z(n)}$, with $\mathfrak{m}_1$ being a neutronic monad. In the GRF of observer $\mathcal{O}$, the intelligent neutron exists at $t = t_n$ as a body with a state represented by a function $\Psi_{t_n} : \mathbb{R}^3 \to \mathbb{R}$ given by

$$\Psi_{t_n} : (x^1, x^2, x^3) \mapsto \rho \cdot \chi_{\overline{B}_r(X_n}(x^1, x^2, x^3) \tag{7.30}$$

for some $X_n \in \mathbb{R}^3$ and some $\rho, r \in \mathbb{R}$, with ρ being a mass density and $\chi_{\overline{B}_r(X_n} : \mathbb{R}^3 \to \{0, 1\}$ the characteristic function of the closed ball $\overline{B}_r(X_n)$ with radius r and center X_n.

Now still at $t = t_n$, there is a set Π_{n+1} of possible states in which the intelligent neutron can be at $t = t_{n+1}$ when it again exists as a body. If we do not take any restrictions into consideration, then we have

$$\Pi_{n+1} = \{\Psi_{t_{n+1}}^{\delta X} \mid \delta X \in \mathbb{R}^3\} \tag{7.31}$$

where an element $\Psi_{t_{n+1}}^{\delta X} \in \Pi_{n+1}$ is a function $\Psi_{t_{n+1}}^{\delta X} : \mathbb{R}^3 \to \mathbb{R}$ given by

$$\Psi_{t_{n+1}}^{\delta X} : (x^1, x^2, x^3) \mapsto \rho \cdot \chi_{\overline{B}_r(X_n+\delta X)}(x^1, x^2, x^3) \tag{7.32}$$

Of course there is a one-to-one corresponds between the set Π_{n+1} of possible states of the body at $t = t_{n+1}$ and the set θ_k^{n+1} of parallel possible nonextended particlelike phase quanta at the $(n+1)^{\text{th}}$ degree of evolution in the k^{th} elementary process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution. The real choice that takes place in the elementary process by which the intelligent neutron evolves from a body at $t = t_n$ to a body at $t = t_{n+1}$, is that the nonextended particlelike phase quantum ${}^{EP}\varphi_k^{n+1}$ is chosen from the set θ_k^{n+1} of parallel possibilities—the state of that nonextended particlelike phase quantum ${}^{EP}\varphi_k^{n+1}$ in the GRF of observer $\mathcal{O}$ can thus be viewed as the excited state of the intelligent neutron at $t = t_{n+1}$. That is, the existence of the intelligent neutron as a body at $t = t_{n+1}$ is actually *preceded* by the existence of the intelligent neutron in an excited state.

Proceeding, in Sect. 7.1 we have assumed that the neutron at $t = t_n$ is at rest in a force-free environment, and we have ruled out the possibility that the neutron is hit by a photon at $t = t_n$ (as in Sect. 6.4). So, if the intelligent neutron were *inanimate*, then at $t = t_{n+1}$ the state $\Psi^0_{t_{n+1}} \in \Pi_{n+1}$ would materialize (with the superscript '0' referring to $(0, 0, 0) \in \mathbb{R}^3$). In that case we would have

$$\Psi^0_{t_{n+1}} = \Psi_{t_n} \tag{7.33}$$

meaning that at $t = t_{n+1}$ the intelligent neutron would then exist as a body in the same state as the body at $t = t_n$.

Now for each $\Psi^{\delta X}_{t_{n+1}} \in \Pi_{n+1}$ there is a choice function $f^{\delta X}_C$ on Π_{n+1} such that $f^{\delta X}_C(\Pi_{n+1}) = \Psi^{\delta X}_{t_{n+1}}$, and for each choice function $f^{\delta X}_C$ there is then a hyperstate $\Psi^{\delta X}_{(t_n, t_{n+1})}$ of the wavelike part $\mathfrak{O}_{(n,n+1)} = {}^{NW}\varphi^n_k$ of the open-ended Planck segment $\mathfrak{O}_{[n,n+1)}$ of the life of the intelligent neutron, such that the hyperstate $\Psi^{\delta X}_{(t_n, t_{n+1})}$ *causes* the next body at $t = t_{n+1}$ to occur in the state $\Psi^{\delta X}_{t_{n+1}} = f^{\delta X}_C(\Pi_{n+1})$. In case the intelligent neutron were *inanimate*—of course it shouldn't be called "intelligent" then, but that's beside the point—the hyperstate corresponding to the choice function f^0_C on $\{\Pi_{n+1}\}$ would be represented by the function $\Psi^0_{(t_n, t_{n+1})} : \mathbb{R} \times \mathbb{R}^3 \to \mathbb{R}$ given by

$$\Psi^0_{(t_n, t_{n+1})} : \begin{cases} (x^0, x^1, x^2, x^3) \mapsto m_g \cdot \sqrt{\pi^{-3}} e^{-r^2} & \text{if} \quad x^0 \in (t_n, t_{n+1}) \\ (x^0, x^1, x^2, x^3) \mapsto 0 & \text{if} \quad x^0 \notin (t_n, t_{n+1}) \end{cases} \tag{7.34}$$

where $r = d(X, X_n)$ for $X = (x^1, x^2, x^3)$. So at any $t \in (t_n, t_{n+1})$, the intelligent yet inanimate neutron would then exist as a spirit in a state represented by a function $\Psi^0_t : \mathbb{R}^3 \to \mathbb{R}$ given by

$$\Psi^0_t(x^1, x^2, x^3) = \Psi^0_{t_{n+1}}(t, x^1, x^2, x^3) \tag{7.35}$$

This reproduces the function f_t of Eq. (7.1) in Sect. 7.1. But our intelligent neutron is not inanimate: it can think. So, there is a $\delta X \neq (0, 0, 0)$ such that the intermediate hyperstate corresponds to the choice function $f^{\delta X}_C$ on

$\{\Pi_{n+1}\}$ and is represented by the function $\Psi^{\delta X}_{(t_n,t_{n+1})} : \mathbb{R} \times \mathbb{R}^3 \to \mathbb{R}$ given by

$$\Psi^{\delta X}_{(t_n,t_{n+1})} : \begin{cases} (x^0, \ldots, x^3) \mapsto m_g \cdot \sqrt{\pi^{-3}} e^{-r(t)^2} & \text{if} \quad x^0 \in (t_n, t_{n+1}) \\ (x^0, \ldots, x^3) \mapsto 0 & \text{if} \quad x^0 \notin (t_n, t_{n+1}) \end{cases} \tag{7.36}$$

where $r(t) = d(X, X_t)$ for $X = (x^1, x^2, x^3)$ and $X_t = X_n + \frac{t-t_n}{\delta t}\delta X$. So at any $t \in (t_n, t_{n+1})$, the intelligent neutron exists as an integrated whole of spirit and soul in a state represented by a function $\Psi_t : \mathbb{R}^3 \to \mathbb{R}$ given by

$$\Psi_t(x^1, x^2, x^3) = \Psi^{\delta X}_{t_{n+1}}(t, x^1, x^2, x^3) = \Psi^0_t(x^1, x^2, x^3) + \delta\Psi_t(x^1, x^2, x^3) \tag{7.37}$$

This reproduces the function f_t of Eq. (7.2) in Sect. 7.1. We now write the hyperstate $\Psi^{\delta X}_{(t_n,t_{n+1})}$ of the open Planck segment $\mathfrak{O}_{(n,n+1)}$ of the life of our intelligent neutron as a sum

$$\Psi^{\delta X}_{(t_n,t_{n+1})} = \Psi^0_{(t_n,t_{n+1})} + \delta\Psi^{\delta X}_{(t_n,t_{n+1})} \tag{7.38}$$

The variation $\delta\Psi^{\delta X}_{(t_n,t_{n+1})}$ in Eq. (7.38) is then due to an intentional thought of the intelligent neutron. The open Planck segment of that intentional thought with time span (t_n, t_{n+1}) corresponds to a family of mental states $\{S_t \mid t \in (t_n, t_{n+1})\}$: the temporal part of the intentional thought at a time $t \in (t_n, t_{n+1})$ can, for the intelligent neutron, be identified with its mental state S_t. And due to the two-way psychophysical correlation between mental states and physical states this intentional thought manifests itself in the process under consideration as the variation $\delta\Psi^{\delta X}_{(t_n,t_{n+1})}$ in Eq. (7.38). It is thus *because of the intentional thought* that the intelligent neutron at $t = t_{n+1}$ exists as a body in the state

$$\Psi^{\delta X}_{t_{n+1}} \neq \Psi_{t_n} \tag{7.39}$$

meaning that at $t = t_{n+1}$ the intelligent neutron exists as a body centered at a different position than the body at $t = t_n$. It is thus *by the intentional thought* of the intelligent neutron that it has moved from X_n to $X_n + \delta X$ in a force-free environment: *without that intentional thought* it would <u>not</u> have moved, because the inanimate intelligent neutron would have existed at $t = t_{n+1}$ as a body centered at X_n as argued above.

7.4 Discussion

The present approach to the mind-body problem rests on the assumption that there is a fundamental difference between *animate* and *inanimate* macroscopic systems—the difference being that an animate macroscopic system, contrary to an inanimate one, has the disposition to autonomously generate a variation in its transition state. We have made no statement about the condition(s) a macroscopic system necessarily has to satisfy to have this disposition. We can think about a certain complexity that the system must have, but we leave this as a topic for further research. What is important now is that this disposition is absent in the constituting supersmall subsystems—there is no such thing as an "intelligent neutron". Therefore, the present approach can be called a form of *emergentism*. However, in Sect, 7.2 the present approach has been described as a physicalist approach, while emergentism has been dismissed as a non-physicalist approach: one might therefore be inclined to think that there is an inconsistency in the present text. That, however, is wrong thinking. What has been dismissed is the variety of emergentism in which the brain is assumed to be a system of classical particles: this variety of emergentism violates, namely, the "law of reducibility" of classical mechanics, being that the properties of a complex system are always reducible to the properties of the particles that make up the system. However, no such "law of reducibility" applies to the EPT due to its the degree of abstractness; therefore, in the framework of the EPT *emergent materialism* is possible, which Broad defined as follows:

> "*Put in abstract terms the emergent theory asserts that there are certain wholes, composed (say) of constituents A, B, and C in a relation R to each other; that all wholes composed of constituents of the same kind as A, B, and C in relations of the same kind as R have certain characteristic properties; that A, B, and C are capable of occurring in other kinds of complex where the relation is not of the same kind as R; and that the characteristic properties of the whole R(A, B, C) cannot, even in theory, be deduced from the most complete knowledge of the properties of A, B, and C in isolation or in other wholes which are not of the form R(A, B, C).*"—Broad (1925)

Broad argued that this would likely solve the mind-body problem.

Impossibility arguments

Ryle criticized the idea that the mind is distinct from the body: his argument against dualism, to which he referred with the term "the dogma of the ghost in the machine", is that it is completely false—he called it a "category mistake"—to assume that mental processes can be seen as something isolated from physical processes (1949). According to Stapp, "Ryle's 1949 arguments are still influential today" (2009). However, while Ryle's writing may be a valid counterargument against Cartesian dualism, it does not apply against the material substance dualism of the present view. Ryle's destructive purpose is, namely, to demonstrate the falseness of "the representation of a person as a ghost mysteriously ensconced in a machine": the subject of Ryle's attack is the immaterial ghost (i.e. Descartes' mind), but in the present view spirit and soul are material entities. Thus, Ryle's "ghost" is absolutely not the same as "spirit" or "soul" in the present view. And neither does Ryle's argument apply against the dual-aspect approach of the mind in the present view: it is, namely, not at all the case that a mental process can be seen as something occurring in itself, without any correlated physical process. The present view does, thus, not make Ryle's category mistake. Concluding, Ryle's impossibility argument does not apply to the present view of man as a trinity.

Another counterargument against dualism has been put forward by Dennet, who regarded this to be the "inescapable flaw of dualism":

> "*a fundamental principle of physics is that any change in the trajectory of a particle is an acceleration requiring the expenditure of energy ... this principle of conservation of energy ... is apparently violated by dualism.*"—Dennet (1991)

From the wording of Dennet's argument, however, it is clear that it is based entirely on the paradigm of classical mechanics, where particles move on continuous trajectories under the influence of forces: on account of Newton's laws, any change in such a continuous trajectory requires an acceleration, and thus a net force and thus energy. The present view, however, is formulated in the framework of the EPT: motion here is stepwise, so there is no such thing as a continuous trajectory, and Newton's laws are not universally valid. In other words, Dennet's "fundamental principle" is not at all fundamental in this framework: in the universe of the EPT, other laws of conservation of energy have been formulated for the individual processes that take place at supersmall scale (see Sect. 5.4). Now Dennet's argument against dualism would still have merit for the present case, if the mechanism for mental causation introduced in Sect. 7.3 would violate these laws of conservation of energy that have been formulated for the EPT. The point is, however, that this is not the case. Mental causation is realized by a variation in the transition state of a system with free will, but that does not necessarily have to imply a change in the energy of the transition state: the variation $\delta\Psi^{\delta X}_{(t_n,t_{n+1})}$ in Eq. (7.38) is a mere change in the distribution of gravitational mass over space—at any time $t \in (t_n, t_{n+1})$, we have

$$\int_{\mathbb{R}^3} \delta\Psi^{\delta X}_t(X)dX = 0 \tag{7.40}$$

where the variation $\delta\Psi^{\delta X}_t$, which models the variation in the state of the spirit plus soul at a time $t \in (t_n, t_{n+1})$ as in Eq. 7.18, is a function on $\mathbb{R}^3$ that relates to the variation $\delta\Psi_{(n,n+1)}$ in Eq. (7.38) by

$$\delta\Psi^{\delta X}_t(x^1, x^2, x^3) = \delta\Psi^{\delta X}_{(t_n,t_{n+1})}(t, x^1, x^2, x^3) \tag{7.41}$$

Concluding, Dennet's impossibility argument does not apply to the material substance dualism of the present view.

Furthermore, the experimental results reported by Libet (1983; 1985) are believed to have demonstrated that free will is an illusion. In these experiments, subjects were asked to perform a simple action such as clicking a switch, and to recall the position of a marker on a screen when the decision to click was made. The time related to the position of the marker then preceded the time of the click on average by 0.2 second. However, during the experiment the brain activity of the subjects was measured: on average an increase in brain activity was measured 0.5 second *before* the time of the click. In the present approach to the mind-body problem, intentional thought *precedes* neural activity, so there appears to be a problem with the results of Libet's experiments. However, the interpretations of the data obtained by Libet's experiments have drawn criticism, in particular by Dennet (2003). Along these lines, here we ask this question: why should the decision to click the switch be instantaneous? Can't it be just the end result of a process of, say, 300 milliseconds?

Relation with classical and modern views

In the Cartesian dualism, the mind is distinct from the body and is a nonmaterial substance. This dualistic aspect is found back: in the present view, mind and body are also distinct. However, if the Cartesian mind is compared with the mind in the present view, then an agreement between the two views is that the mind in both cases is nonmaterial, but a difference is then that in the present case it is not viewed as a substance, i.e. something that exists in itself: in the present framework, the idea of the mind as a continuant that goes through time arises from a continuous succession of mental states, which are the subjective form of successive transition states in the physical world. If, on the other hand, the Cartesian mind is compared with the integrated whole of spirit and soul in the present view, then the agreement is that in both cases it is a substance; the difference is then that in the Cartesian dualism the mind is nonmaterial, while spirit and soul are physical entities in the present philosophy. But interpreted one way or the other, the present philosophy *does* provide an answer to the question how body and mind interact—a question to which Descartes never gave a satisfactory answer.

In the dual aspect monism of Spinoza, mind and body are two concomitant aspects of a single entity: the human being. While it remains true in the present philosophy that mind and body are two aspects of a human being, there are two major differences with the view of Spinoza. The first is that from the present point of view a dual-aspect approach is insufficient to describe human beings: body and mind are not the whole story. The second major difference is about the relation between mind and body: in the present philosophy one may speak of a psychophysical parallelism as far as it concerns mental processes and the correlated physical processes, but the 'physical' part of the adjective 'psychophysical' then refers to spirit and soul, and not to the body. And there is also the issue of free will: in Spinoza's pantheistic worldview free will is an illusion, whereas in the present approach human beings really have a free will, cf. Eq. (7.28).

In the quantum-mechanical approach to the mind-body problem by Stapp, it is assumed that mental events and physical events (probing actions) are complementary aspects of a single mind/brain-event, but the point is that "the causal origin of the ... probing actions is not specified, even statistically, by the presently known laws of physics" (Stapp, 2009). In other words, in Stapp's mechanism for mental causation it is assumed *that* probing actions take place, but the paradigm of QM offers no answer to the question *why* these probing actions take place. Furthermore, in order to actualize the large-scale pattern of brain activity necessary for an intended action, not just a probing action is required: no, a *very specific* probing action is required. With respect to that, Stapp writes the following:

> "*according to the Copenhagen philosophy, there are no presently known laws that govern the choices made by the agent about how the observed system is to be probed. This choice is, in this very specific sense, a free choice.*"—Stapp (2009)

In other words, the explanation of free will is that a human being *chooses* a specific probing action by "choosing" an intentional thought—these are namely connected in a mind/brain event—but the paradigm of QM offers no answer to the question why a thought corresponds with a certain probing action: it is merely assumed that this is the case. While the present view on the mind-body problem is ontologically of course very different from Stapp's view, the comparison of the mechanisms for mental causation yield a remarkable agreement: both yield a mechanism, strictly formulated within a well-defined disciplinary matrix, for how intentional thoughts can cause the material brain to develop a large-scale pattern of neural activity, necessary to cause a certain bodily action. A difference between the two mechanisms is that Stapp's view is much coarser: the present mechanism identifies all the precise steps at the most fundamental level according to which an intentional thought leads to a certain brain activity—there are no open questions such as the above ones concerning Stapp's approach. It needs to be said, however, that it is true that Stapp's mechanism is coarser, but it is as refined as it gets in the paradigm of QM: the aforementioned open questions are inherent to the quantum paradigm. In addition, the difference may not be directly measurable: it is doubtful that experimental observations of brain activity will ever be able to decide between the two mechanism, largely because such measurements take place on macroscopic scale. To decide between the two mechanisms it is perhaps better to let the scientific method decide between the underlying physics: that, then, also decides between the mechanisms for mental causation.

Another modern approach to the mind-body problem is the Conscious Mental Field (CMF) proposed by Libet later in his career (1994). Although this is not strictly formulated in terms of fundamental laws of physics, it is highly interesting in the present context:

> "*The CMF is not a Cartesian dualistic phenomenon; it is not separable from the brain. Rather, it is proposed to be a localizable system property produced by appropriate neuronal activities, and it cannot exist without them. Again, it is not a 'ghost' in the machine. But, as a system produced by billions of nerve cell actions, it can have properties not directly predictable from these neuronal activities. It is a non-physical phenomenon, like the subjective experience that it represents. The process by which the CMF arises from its contributing elements is not describable. It must simply be regarded as a new fundamental 'given' phenomenon in nature, which is different from other fundamental 'givens', like gravity or electromagnetism.*"—Libet (2006)

At first glance, the present idea of variations in the transition state of a macroscopic system with free will seems compatible with Libet's CMF. However, further research will have to establish whether or not the comparison holds up in every detail.

Concluding remarks

Ever since the mind-body problem arose from Descartes' dualism in the 17th century, virtually every philosopher who investigated it from a physicalist point of view has searched either in the direction of explaining a duality of body and mind, or in the direction of reducing body and mind in a monism: the first conclusion is that the present approach is the first physicalist approach that views man as a trinity of body, spirit and soul in the period after Descartes. As a consequence, any duality or identity of body and mind, such as assumed in the various approaches based on classical or quantum mechanics, has to be rejected as an incomplete representation of reality from the present point of view.

A second conclusion is that a mechanism for mental causation has been formulated at object level, a mechanism which fits seamlessly in the ontology given by the EPT: this demonstrates that man has a free will, if the physical universe is indeed governed by the EPT. It is emphasized, however, that this mechanism is only about the principle of mental causation: further work in this direction is needed to derive testable predictions from this approach. But the question remains whether standard laboratory methods for brain research are at all able to decide between the present mechanism for mental causation, Henry Stapp's mechanism, which has been formulated strictly within the quantum paradigm, and identity theory, which is formulated strictly within the classical paradigm. As a method to decide between two physicalist views on the mind-body problem that are formulated within different physics paradigms, we may decide between the underlying physics: on that ground, identity theory can already be discarded.

A third conclusion is that mental causation cannot be understood in terms of fundamental interactions: the variation of a transition state correlated to an intentional thought does not arise due to electromagnetism or gravitation. At present, it is described how body, spirit, and soul interact process-wise: the EPT corresponds with the idea that the universe is best viewed in terms of processes, not interactions. It is left as a topic for further research to develop a concrete mathematical model of a variation of a transition state correlated to an intentional thought for systems beyond the intelligent neutron of Sect 7.1. Of particular interest is the extent to which a variation in the transition state of a system can change its spatiotemporal displacement: if this extent is unlimited, man could fly just by thinking about it—something this author doesn't believe in.

All in all, the present approach differs fundamentally, both qua ontology and qua mechanism for mental causation, from the various monistic and dualistic approaches to the mind-body problem on the basis of classical and quantum mechanics. The Bible, on the other hand, suggests also that man is a trinity of "spirit, soul and body" (1 Thess. 5:23), whereby soul and spirit are definitely not the same thing (Heb. 4:12). In addition, also the Vedic text indicate that the soul is to be distinguished from body and spirit (Srimad-Bhagavatam 12.5.8); according to Bhaktivedanta Swami, the Vedic texts entail that the soul is something else than the body and spirit, but all three are material entities (1988). In the present view body, spirit, and soul are names for material phenomena: further philosophical-theological research is then necessary to establish whether or not the present trinity is in agreement with the teachings of the Bible and/or the Vedic texts.

7.5 Objections and replies

All efforts to publish the present approach in a recognized journal or to give a talk about it at an academic conference turned out to be fruitless: in every single case peer review turned out to be an insurmountable obstacle. Below I treat the objections to my work in reverse order of reception.

Objection 7.5.1. "*We regret to inform you that your abstract has not been accepted ... We have received many proposals of the highest quality, so it was necessary to make some very hard decisions.*"—organisers of the Conference Free Will and Causality, held on September 26-27, 2019, in Düsseldorf (D), rejecting my proposal for a talk about free will ■

Reply 7.5.2. Although my talk was on-topic, the organization of the conference is not obliged to accept my (proposal for a) talk. What I find interesting about those who have denied me the possibility to give a talk about the human soul, is that they think they don't have one. ■

Objection 7.5.3. "*I've now had a chance to read your essay, and I'm sorry to report that we will not be accepting the paper for publication. This decision rests principally on a judgment about whether our readership is the right one for this paper. Insofar as the paper begins with difficulties in the philosophy of mind that current theories (both physicalist and non-physicalist) have been unable to resolve, there isn't a problem; but insofar as the paper draws on Elementary Process Theory, as an alternative to classical and quantum mechanics, to offer a solution, it's unclear on what basis the readers of our journal (most of whom are academic philosophers) should assess the argument. If there were a scientific consensus in favor of Elementary Process Theory, we could at least accept it on authority before turning to its philosophical implications; in the absence of such a consensus, we need to be* ***persuaded*** *that the view is sufficiently plausible to be worth considering, and I didn't find myself persuaded. ... A final question about the appropriateness of the paper for our journal arises from the fact that ... we focus on essays of special interest to philosophers who are Christians. If man is indeed a trinity of body, spirit, and soul, that's certainly of potential interest to us. But that connection is made only in the last paragraph. That's too little, too late.*"—associate editor of a philosophy journal specializing on papers of interest for Christians, rejecting my paper (Cabbolet, 2014c) ■

Reply 7.5.4. The editor has given decent reasons for the rejection of my paper. I have no quarrel with his decision, nor with the argument for his decision. ■

Objection 7.5.5. "*Thank you for submitting this paper to [our journal]. The Editors have considered it and, I am sorry to say, it has not been accepted for publication. Due to the large number of submissions received by [our journal], it is not always possible to return detailed comments. I do not have further comments-for-author on this paper.*"—editorial administrator of a top philosophy journal, rejecting my paper (Cabbolet, 2014c) ■

Reply 7.5.6. The journal is widely regarded as one of the top journals in philosophy. Of course, its editors are by no way obliged to accept my submission for publication. So just for the annals of philosophy: the mind-body problem is one of the topics covered by the journal, and I've put a new work on that topic, which no one has done before, right under their noses, but they have refused to publish it. ■

Objection 7.5.7. "***The analysis provided by the author is fundamentally flawed** and I therefor cannot recommend this paper for publication. As the problems with the paper run deep, I don't think that even a major revision of the paper will result in a publishable paper. I therefor recommend for this paper to be rejected.*

To highlight the main—but certainly not the only—problem with this paper, I will briefly review the purported solution of the mind-body problem. According to EPT, the evolution of physical reality is a discrete process in which objects, when in rest, have a body-like constitution, whereas when in motion they exhibit a wave-like pattern. Hence, physical stuff alternates between a particle-form when in rest—which the author dubs 'body'—and a wave-like form when in motion—which the author dubs 'spirit'. Hence all physical stuff has a body and a spirit.

To account for the difference between mindful beings and mindless stuff, the author ... claims that there is some active principle that is not reducible to fundamental physical interactions without giving any grounds to do so. But even if we accept this, the author needs to give an account of how this interaction between soul, body and spirit is to be understood. Despite there being a section devoted to mental causation, no such account is forthcoming. Indeed, in that section we are merely given a set of formula that allow us to *formalize the basic idea outlined in the previous sections without specifying what kind of interactions are behind these formulas. Given the fact that the author is not able to describe the interaction between body, soul and spirit it seems that notwithstanding his claims, he has not offered a solution to the mind-body problem, but merely has shown how to formulate that problem in the non-standard lingo of EPT.*" (emphasis added)—referee of a journal of philosophy and theology, rejecting of my paper (Cabbolet, 2014c) ■

Reply 7.5.8. In his opening line, this referee accuses me of having submitted a fundamentally flawed paper. What is fundamentally flawed, however, is his own analysis: this is an example of a response in an emotional outburst, as described by the model on p. li ff.

In essence he has two erroneous arguments against my paper, the first of which is that reasons should have been given as to *why* the active principle is not reducible to fundamental physical interactions (i.e., gravity and electromagnetism). Apart from the fact that this is not an argument against the mechanism for mental causation proposed in the paper, it is false: it is the very essence of the active principle that it is not reducible to fundamental interactions—there is no further 'why'. It is as Libet wrote about his Conscious Mental Field (CMF): "The process by which the CMF arises from its contributing elements is not describable. It must simply be regarded as a new fundamental 'given' phenomenon in nature, which is different from other fundamental 'givens', like gravity or electromagnetism" (2006), cf. p. 346. So, the same argument could have been used to reject Libet's paper, which shows that this is pseudoskepticism.

His second argument is in essence that the whole mechanism for mental causation is nothing but a bunch of formulas that, instead of providing an answer to the mind-body problem, merely expresses it in the framework of the EPT. This is also false. The mind-body problem is nothing but this question: how can the mind cause a bodily action? That being said, the submitted paper stated—just like Sect. 7.3 of this monograph does—what the mind is, what a bodily action is, and how the mind causes a bodily action. To summarize the key points:

- the idea of the mind as a continuant emerges from a continuous succession of mental states, which by psychophysical correlation corresponds one-to-one with a continuous succession of (physical) transition states;

- a bodily action is a transition from one state of the body to another that differs from what that state transition would have been if the body would concern inanimate matter;
- an intentional thought manifests itself as a variation in the hyperstate made up of the successive transition states correlated to mental states: the hyperstate, altered by the variation, then brings about the intended bodily action by the mechanics detailed in Sect. 7.3.

Of course this constitutes a principle answer to the mind-body problem. And of course there are open questions left; the present view does, for example, not detail where a variation of a transition state correlated to an intentional thought is mainly located. So, what is presented here is *the principle of mental causation.* Nevertheless, it is not just the mere rephrasing of the question 'how does the mind cause a bodily action?' in the framework of the EPT—that's a false assessment, and as such it is nothing but an attempt to belittle the present result. ■

Objection 7.5.9. "*I had a chance to look at your paper and I believe that there is not a good fit with the journal. As a matter of fact, [our journal] has not published articles with such an extensive formal treatment of problems since its very beginning. We also have a readership that is not at home in major parts of the literature you refer to (for example in physics and quantum theory). That is why I believe that you could better submit this type of work to another journal (for example Synthese). Since we get so many papers we have to be very selective and the journal aims for a clear profile in the field.*"—Editor of a journal specializing in papers on the philosophy of mind, rejecting in 2013 my paper (Cabbolet, 2014c) ■

Reply 7.5.10. The editor has given decent reasons as to why the submitted paper does not fit the profile of the journal. I have no quarrel with his decision, nor with the argument for his decision. ■

Objection 7.5.11. "*I tried several potential referees, including those you suggested. They either declined to review your paper or proposed to reject it right away. So I think we should agree that [our journal] is not a proper journal for its publication.*"—editor of a journal specializing in papers on the interplay of mind and matter, rejecting on July 14, 2013, my paper (Cabbolet, 2014c) which I submitted on September 21, 2011 ■

Reply 7.5.12. Despite the willingness of the editor to publish the paper, its journal publication—which never happened—has been held up for nearly two years at this journal due to the peer review practice. This shows that despite the enormous number of recognized journals that are nowadays available, it remains troublesome to publish a fundamentally new idea. Such long review times render peer review *as currently practiced* useless in science, since it takes the momentum out of a research—e.g. one cannot realistically apply for funding for further research on original results obtained in a completed research if the original results have not been published in a recognized journal. Peer review certainly has taken the momentum out of research in my case: things have taken too long and I'm no longer interested in further research on the mind-body problem. ■

Objection 7.5.13. "*'Man as Trinity of Body, Spirit, and Mind ...'* [sic] *is an ambitious attempt to use recent scientific results to make progress in the mind-body problem; specifically regarding issues surrounding mental causation and freedom of the will. The author clearly has a great depth of knowledge regarding the scientific literature relevant to these concerns. Despite these virtues, I recommend that this paper be* ***rejected without an invitation for resubmission with revision****. In what follows I will highlight the main shortcomings that have lead me to this assessment.*

(a) Objection 7.5.15

(b) Objection 7.5.17

(c) Objection 7.5.19

(d) Objection 7.5.21

(e) Objection 7.5.23

(f) Objection 7.5.25

In summary, the main deficiencies of this paper are a lack of acquaintance with the relevant philosophical literature (both in framing the problem and in answering likely objections) and a reliance on highly controversial and obscure claims about biblical texts. These difficulties are not merely ancillary and likely could not be addressed with any plausible revision" (emphasis original)—referee #1 of a philosophy journal specializing in papers of interest for catholics, rejecting a previous version of (Cabbolet, 2014c) ■

Reply 7.5.14. The referee has completely misjudged the aim of the submitted paper: its aim, which is also the aim of the present chapter, was to introduce a fundamentally new physicalist approach to the mind-body problem—its aim was not to review both the entire scientific literature *and* the entire philosophical literature on the topic. The arguments (a)-(f) that the referee provides to substantiate his judgment, which are replied to separately below, have nothing whatsoever to do with the mechanism for mental causation—the actual result of the study—presented in the paper: his arguments merely express his dislike of the submitted paper. So, here we see yet another example of how peer review nowadays is *abused* to express one's dislike of a submitted paper or research proposal, instead of being *used* to assess the scientific quality of the submission. ■

Objection 7.5.15. "***The paper gives the appearance that the author is not generally conversant with the philosophical literature regarding the mind-body problem.*** *The author's discussion of the current state of philosophical reflection on the mind-body problem is almost entirely derivative from a single text by Kim ... At times the paucity of references to other authors seriously damages the argument the author attempts to advance ... For example, ... the author raises and dismisses emergentism without ever referring to any philosopher who actually defends such a view ... I also find it telling that, though the author claims to have a contribution to make to our understanding of freedom of the will, while there are no references to any of the vast philosophical literature on that topic*" (emphasis original)—argument (a) of anonymous referee #1 of the philosophy journal specializing in papers of interest for catholics ■

Reply 7.5.16. The aim of the paper was to present a new physicalist approach to the mind-body problem: the general topic is thus the physical principle by which mental causation takes place. The introduction of the submitted paper contained an on-topic discussion c.q. review of other physicalist approaches to the mind-body problem, comparable to Sect. 7.2. There is, then, no need for an additional discussion c.q. review of the philosophical literature, because it does not contain a single suggestion for a physical principle of mental causation. Argument (a) of this referee concerns dishonest trick #29 from Schopenhauer's 1831 book *The Art of Being Right*: the diversion—see Reply 2.3.7 for a full quotation. ■

Objection 7.5.17. "***The discussion of Elementary Process Theory (EPT) is much too rushed.*** *The lynchpin of the author's argument is EPT, but the discussion of the actual 'nuts and bolts' of this theory is fairly obscure, at least to a scientific layman. The reader is introduced to EPT, but to get any real sense of how the theory works one must turn to an appendix. [This] presupposes a good deal of prior scientific understanding that I do not believe it is fair to assume many readers of [our journal] will possess, and even in the appendix little is said as to why we should take EPT to be more plausible than its competitor theories, which is absolutely essential to the argument of this paper.*" (emphasis original)—argument (b) of this anonymous referee #1 ■

Reply 7.5.18. This argument boils down to (i) the criticism that the EPT was not introduced extensively enough in the submitted paper, and (ii) the criticism that there are not enough experimental data to decide between the EPT and any of its rival theories in favor of the EPT, *as if* that is relevant for the description of the principle of mental causation in the framework of the EPT. Both points (i) and (ii) concern, again, dishonest trick #29 by Schopenhauer. To elaborate on his first point (i), in the submitted paper the EPT was discussed at the metalevel, and a reference was given to its formal introduction in *Ann. Phys.* For a journal paper, that is sufficient: one has to distinguish between a journal paper and a research monograph—one cannot help but thinking that the referee has assessed the submitted paper as a research monograph on the mind-body problem. His second point (ii) also misses the mark: the principle of mental causation in the framework of the EPT does in itself not depend on the amount of experimental support for the EPT. That is to say, the description of the principle of mental causation in the framework of the EPT is purely based on the physical principles laid down in the EPT, and not on the amount of experimental data that support the EPT. So, even if there would be sufficient experimental support for the EPT to render it generally accepted, then the description of the principle of mental causation in the framework of the EPT would still be the same. So, to describe the principle of mental causation in the framework of the EPT, one assumes that its physical principles are true and then applies these to a description of mental causation—that's how research is done. I consider it herewith demonstrated that argument (b) of the referee concerns pseudoskepticism. ■

Objection 7.5.19. "***The supposed distinction among body, spirit, and soul is never clearly drawn, and remains obscure throughout the paper.*** *The author simply assumes that these concepts are clearly distinguished in the biblical texts 1 Thessalonians and Hebrews; he or she does nothing to indicate what we should take as the meanings of these terms as intended by the biblical authors. It seems to me one could mean a lot of things by 'body', 'spirit', or 'soul', and it would take a good bit of scriptural analysis and consideration of post-biblical theological development to get to any real sense of what the right interpretation of these passages might be. The author claims ... that his or her 'view agrees with the view in the Bible—even with respect to the detail that spirit and soul not the same thing', but before we can have good reason to believe that EPT confirms the biblical distinction among 'body', 'spirit', and 'soul', we would first need to get very clear as to what that distinction is. The author does not advance us along that path at all.*" (emphasis original)—argument (c) of this anonymous referee #1 ■

Reply 7.5.20. I have to give it to the referee that he has half a point here: while the distinction between body, spirit, and soul in the framework of the EPT is clear, I wrote in the submitted version that the mere fact that man is a trinity of body, spirit, and soul in the framework of the EPT "agrees" with isolated verses in the Bible referring to a trinity *without* demonstrating that the terms in the Biblical verses have a similar distinction in meaning. What I meant to say was that the fact that man is a trinity of body, spirit, and soul in the framework of the EPT agrees with the fact that there are verses in the Bible that also refer to a trinity of body, spirit and soul: I didn't mean to imply or insinuate that it was now proven beyond doubt that the one is the same as the other.

To meet this criticism, I have deleted the statement that the present view that man is a trinity of body, spirit, and soul "agrees" with the Biblical verses in question, and I have replaced this by the statement that further research is necessary to establish whether or not the present trinity and the trinity mentioned in the Biblical verses are the same thing. Note that this is a (very) minor revision of just a few words in a paper of some 15 pages, and that it has nothing to do with the main result conveyed by the paper—the principle of mental causation in the framework of the EPT. ■

Objection 7.5.21. "***The author fails to address fairly obvious philosophical criticisms throughout the paper.*** *I will discuss two troubling examples to support this claim. ... (1) It is far from clear how the EPT rendering of qualia advances beyond standard physicalist theories ... Even on the author's account, qualia are images or experiences that would be hard to identify with anything physical. In short, all of the standard objections against non-eliminative, physicalist treatments of qualia (i.e. 'Why isn't this just property dualism by another name?') would apply straight away to the author's account, but he or she does nothing to assuage these worries. ... (2) In his or her attempt to show that freedom of the will is compatible with physicalism ... the author frequently claims that certain psychological states are 'choices', but it seems all that is meant by a 'choice' is a state that is physically indeterminate. Many philosophers argue, with good reason, that mere indeterminacy is insufficient for freedom; free will isn't random. Thus, maybe the author has shown that humans might have indeterminate psychological states under the assumption of EPT, but that is a far cry from showing that we have free will. For example, John Searle offers an argument against attempts to account for freedom of the will through quantum indeterminacy in several places*". (emphasis original)—argument (d) of this anonymous referee #1 ■

Reply 7.5.22. While ignoring that the paper had an entire section devoted to physical impossibility arguments (as in Sect. 7.4) the referee now comes up with two examples of philosophical criticism not addressed in the paper *as if* that somehow impairs the work. His example (1) is yet again an example of Schopenhauer's dishonest trick #29, the diversion: the entire discussion of qualia has no direct bearing on the topic of the paper—the physical principle by which mental causation takes place. His example (2) is based on a misinterpretation: it is simply not true that I claimed that a choice is a psychological state—quite to the contrary, a choice is a process. (I'll give a hint: mental causation is described in the framework of a process theory.) Nor is it the case that a choice is a state that is physically indeterminate. Suppose a process by which a macroscopic system with free will makes a choice lasts from $t = t_1$ to $t = t_2$; then at times $t < t_1$, so *before* the process took place, it was not yet determined what the physical state of the system would be at times $t \in [t_1, t_2]$. However, at any time $t \in [t_1, t_2]$ the state of the system is physically definite. ■

Objection 7.5.23. "*The discussion of Descartes and Spinoza generally is very rushed, and it is far from clear what role it plays in the project of the paper.*"—third point in argument (e) of anonymous referee #1 of the philosophy journal specializing in papers of interest for catholics ■

Reply 7.5.24. First a remark: argument (e) consisted of three points, the first two of which concerned subsections of the paper that are now deleted: any discussion thereof is entirely moot in the present context. The third point is the above objection, which concerns the discussion of the relation with the works of Descartes and Spinoza as now presented in Sect. 7.4.

That being said, in the reported research a new view on mental causation has been developed, and a standard thing to do is then to compare c.q. contrast it with the views of Descartes and Spinoza, which existed at the time the mind-body problem was formulated. A multitude of words is then not needed to establish that the new view is very different from these classical views. For comparison, consider the following two pictures:

(a) Picture 7.5.24-(a)

(b) Picture 7.5.24-(b)

If we would try to describe the difference between these pictures, we could, for example, say that picture 7.5.24-(a) is a picture of an outdoor landscape, while picture 7.5.24-(b) is a picture of a vehicle parked indoors. That is enough to describe that these are two really different pictures. But of course there might be someone who objects that this description is rushed. The crux, however, is this: even if we go into details, then the conclusion remains that these are two very different pictures—something that we had already established in a few words. I assume that the metaphor is clear, and also that it is clear that this objection is a non-argument. ■

Objection 7.5.25. "***The paper is too ambitious****. Part of the problems seems that the author is trying to do too much in a single paper. The author attempts to solve the problems of qualia, mental causation, and free will using EBT* [sic], *..., defend the veracity of a scriptural account of human nature, and relate all of this to the history of philosophy and natural science. It is not possible to do all of this in a single professionally competent paper.*" (emphasis original)—argument (f) of anonymous referee #1 of the philosophy journal specializing in papers of interest for catholics ■

Reply 7.5.26. This objection is based on a gross misinterpretation of the paper, and again an indication that the referee has judged it as a research monograph on the mind-body problem instead of a 15-page journal paper. The sole aim of the paper is/was to introduce a new principle for mental causation: nothing more, nothing less. Nowhere in the paper was it stated that its additional aims were to solve problems of qualia, to defend the veracity of a scriptural account of human nature, and to relate everything mentioned here to the history of philosophy and natural science: the referee made this up. Again, this is an expression of dislike of the submitted paper, rather than an assessment of the scientific quality of the reported results.■

Objection 7.5.27. "*This paper reflects broad world-view forming interests and discusses some interesting references. Unfortunately I cannot recommend it for publication in [our journal]. ... To summarize, the philosophical discussion involving free will fails to interact with the broad outlines of the longstanding discussion by ignoring a major traditional argument that seems to provide a fatal objection, the physics invoked is extremely immature and of doubtful relevance, and the theological/Biblical claims tend to be gratuitous.*"—referee #2 of the same journal, recommending rejection of a precursor of my paper (Cabbolet, 2014c) ■

Reply 7.5.28. In a report that consumed three pages of A4 size, the referee recommended rejection based on a number of non-arguments, which will be treated separately below, and one half argument along the lines of Objection 7.5.19. To summarize, the referee simply ignored that the major traditional argument that seems to provide a fatal objection against free will was discussed in the paper, he hadn't understood one iota of the relevance of the physics, and his objection to the theological/Biblical claims could have been met by a revision of just a few words—as in Reply 7.5.20. ■

Objection 7.5.29. "*The author claims to address the mind-body problem in a physicalist way, arriving at the conclusion that man involves body, spirit, and soul, allegedly the Biblical view, but with a novel physicalist conception of spirit and soul. The paper considers 3 physics paradigms: Classical Mechanics, Quantum Mechanics, and a new Elementary Process Theory. … The EPT appears to be a novel approach to physics. A paper on it was published recently by Cabbolet in Annalen der Physik, a respectable journal with moments of glory in the past. But the EPT is highly speculative, incompatible with highly successful ordinary physical theory, as-yet devoid of a mathematical model to show that it can accommodate the phenomena that ordinary physics handles successfully, and to date without any experimental results favoring it over ordinary physics—most or all of which Cabbolet there admits. … As such it might warrant another paper, or series thereof, in a physics journal open to such foundational probing. But it is unclear that one should be presently interested in its ramifications for the mind-body problem, simply because there is presently so little reason to think that the EPT is true. Furthermore, a key motivating principle of the EPT, according to Cabbolet, is that anti-matter experiences anti-gravity. That is contrary to various strong plausibility arguments linked to ordinary physics. Even if such speculation turned out to be correct, it's not at all clear how anti-matter's anti-gravity could help to solve the mind-body problem. Whatever insights the author has into the mind-body problem presumably should be consistent with ordinary physics,* ***because*** *anti-gravitating anti-matter is irrelevant to free will or other mental phenomena.*" (emhasis added)—second objection of referee #2 ■

Reply 7.5.30. This objection boils down to two arguments against the physicalist approach to the mind-body problem presented in the submitted paper:

(i) the ramifications of the EPT for the mind-body problem are not interesting as long as the EPT is not widely accepted;

(ii) apart from (i), the mind-body problem has to be treated in the framework of modern physics ("ordinary physics" in the words of the referee) **because** anti-gravitating anti-matter is irrelevant to free will.

As to argument (i), of course one can be of this opinion: 'interesting' and 'not interesting' are subjective judgments—this is not an objective argument against the submitted paper. As stated in Reply 7.5.18, the crux is that the ramifications of the EPT for the mind-body problem are *independent* of additional results that contribute to the acceptability of the EPT—the principle of mental causation in the framework of the EPT is based purely on the mathematical expression of the EPT and its physical interpretation. The question is then whether or not the journal is interested in keeping its readership up to date with the latest results from the frontiers of research. Apparently not, in this case.

As to argument (ii): this indicates that the referee has missed the entire point as to why the EPT has been used as the basis for a physicalist approach to the mind-body problem. It is true, as the referee states, that anti-gravitating anti-matter is irrelevant for mental causation. But that doesn't mean that **therefore** the mind-body problem has to be treated in the framework of modern physics: it is not a matter-antimatter repulsive gravity that helps to solve the mind-body problem, but the set of generalized process-physical principles underlying a matter-antimatter repulsive gravity—the EPT. This latter set of principles, *that* is what provides the basis for a new physicalist approach to the mind-body problem. ■

Objection 7.5.31. "*Regarding the supposed interaction problem for substance dualism in classical physics, perhaps no one has managed to solve it since Descartes set it up. But it's not clear that anyone has managed to formulate a real problem, either. If there needs to be a 'mechanism' for an immaterial person (or immaterial part of a person) to act on the body, must there be a mechanism for God to do miracles, or for angels to act on the physical world? If so, then Christian theism itself is in trouble. If not, then why are human souls different?* "—third objection of referee #2 of the philosophy journal specializing in papers of interest for catholics ■

Reply 7.5.32. Of course the mind-body problem has since long been formulated. It's formulation is this: how can the mind cause a bodily action? That aside, the above objection has been put forward *as if* shortcomings of the paper are (i) that mechanisms for God to do miracles and for angels to act on the physical world are not discussed, and (ii) that the difference between the human soul on the one hand and God and angels on the other hand are not discussed either. This objection is again a diversion, dishonest trick #29 as described by Schopenhauer (cf. Reply 2.3.7). ■

Objection 7.5.33. "*In modern physics, discussion of a physical theory usually starts with a Lagrangian density, roughly the kinetic energy per unit volume minus the potential energy per unit volume. But there is no obvious difficulty in introducing a coupling between an immaterial substance and physical fields—just write down some function of space and time that is nonzero only where minds act, and have it couple to physical fields in the Lagrangian density.* ***It's like a junior-level mechanics problem*** *with an external force. Doing so in a way that fits the facts would be a nontrivial problem, but no reason has been given to think it impossible. The result will show that energy conservation holds except insofar as the soul(s) acts on the body, just as one would expect ... of course the immaterial soul's acting on the body violates energy conservation*" (emphasis added)—fourth objection of referee #2 ■

Reply 7.5.34. This is armchair philosophy: *after having taken notice of the results in the submitted paper* the referee tries to redo the entire research himself, thereby comparing it to a junior-level mechanics problem—*as if* every freshman student could have come up with the principle of mental causation presented in Sect. 7.3. The belittling phrase is a tell-tale sign that the referee has used the peer-review report to express his dislike of the submitted paper, cf. (Cabbolet, 2018d). But not only that: he is fundamentally mistaken both in his own approach and in his conclusion.

In the first place, his own approach is the opposite of a physicalist approach: the field he created by jotting down some function of space and time does, namely, not fit in the ontology of the physical theory. The field represented by that function is simply assumed to exist *in addition to* the things assumed to exist in the physical theory: this can immediately be rejected as an *ad hoc* existential assumption—this is not the way to go in theory development. For comparison, in the present approach the 'soul' is a variation of a transition state: this *does* fit in the ontology of the EPT. (As an aside, note that the referee's talk of an 'immaterial soul' indicates a failure to notice that the 'soul' is not immaterial in the present approach.)

As to his conclusion, it may be true that in his own approach an action of a soul on a body violates energy conservation. That, however, does not imply that an act of mental causation violates energy conservation in the present approach too. In fact, an act of mental causation does not violate energy conservation in the framework of the EPT: the submitted manuscript contained a discussion that Dennet's impossibility argument is based on laws that are not valid outside the framework of classical mechanics, cf. Sect. 7.4: the referee has ignored this. That being said, we can illustrate the basic idea in detail with the intelligent neutron of Sect. 7.1. Let the following three processes, each of which is a process I as defined in Sect. 6.4, i.e. a process in which no photon is captured at the beginning, take place consecutively in the temporal evolution of the intelligent neutron, initially at rest in a force-free environment:

(i) process #0: the intelligent neutron decides to do nothing;

(ii) process #1: the intelligent neutron decides to make a move;

(iii) process #2: the intelligent neutron again decides to do nothing.

Let for $j \in \{0, 1, 2\}$, process $\#j$ in the reference frame of an observer $\mathcal{O}$ start at $t = t_j$ and end at $t = t_{j+1} = t_j + \delta t$. At discrete times t_0, t_1, t_2, and t_3 the intelligent neutron is in a ground state at position X_0, $X_1 = X_0$, $X_2 \neq X_1$, and $X_3 = X_2$, respectively; at time $t = t_i$, the ground state at $X = X_i$ can be modeled by a function $f_{t_i} : \mathbb{R}^3 \to \mathbb{R}$ representing the uniform distribution of the gravitational mass m_g over a closed ball $\overline{B}(X_i, r_m)$ with r_m being the mass radius of the neutron. At times $t \in (t_0, t_1) \cup (t_2, t_3)$, the transition state of the intelligent neutron can be modeled by a function $f_t : \mathbb{R}^3 \to \mathbb{R}$ given by Eq. (7.1):

$$f_t(X) = m_g \cdot \sqrt[3]{\pi^2} e^{-r^2} \tag{7.42}$$

where $r = d(X, X_j)$. In process #1, the transition state of the neutron at times $t \in (t_1, t_2)$ can be modeled by the function $f'_t : \mathbb{R}^3 \to \mathbb{R}$ given by Eq. (7.2), which is repeated below:

$$f'_t(X) = m_g \cdot \sqrt[3]{\pi^2} e^{-r(t)^2} \tag{7.43}$$

where $r(t) = d(X, X_t)$ with $X_t = X_1 + (t - t_1) \cdot \delta X / (t_2 - t_1)$.

Summarizing, in process #0 the intelligent neutron remains at rest at the spatial position $X = X_0$; in process #1 the intelligent neutron decides to move from the spatial position $X_1 = X_0$ to the spatial position $X_2 \neq X_1$ in a time span δt; in process #2 the neutron is again at rest, now at the spatial position $X = X_2$. Recall that the intelligent neutron is surrounded by a force-free environment: in process #0 and process #2 the intelligent neutron is thus indistinguishable from an inanimate neutron. See Fig. 7.2 for an illustration.

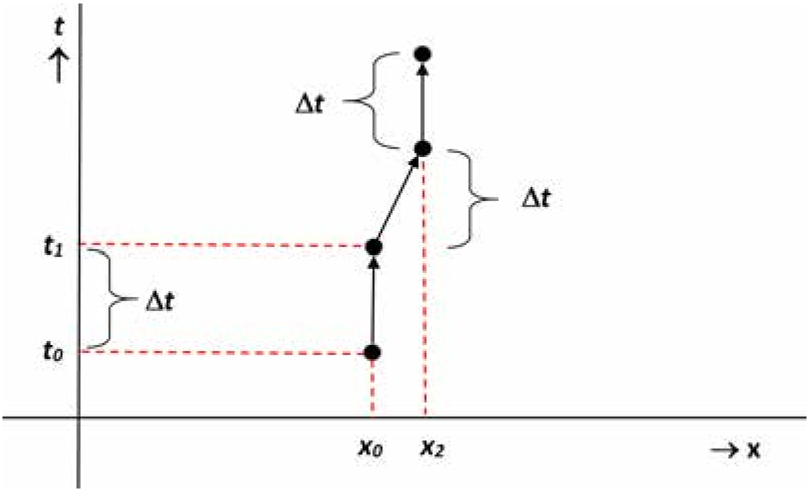


Figure 7.2: illustration of the three processes in the temporal evolution of the intelligent neutron in the reference frame of observer $\mathcal{O}$; vertically the t-axis, horizontally the x-axis. The four dots represent the positions of the ground states of the intelligent neutron modeled by the functions f_{t_0}, f_{t_1}, f_{t_2}, and f_{t_3}. The three arrows represent the spatiotemporal displacements made by the intelligent neutron in the time intervals (t_0, t_1), (t_1, t_2), and (t_2, t_3), during which it is in a transition state. In process #0 and process #2 the neutron is at rest; in process #1 the neutron moves.

We can now turn to questions of energy conservation. Obviously, at any time $t \in (t_0, t_1) \cup (t_2, t_3)$ during process #0 c.q. process #2, the kinetic energy E_k^0 c.q. E_k^2 of the neutron in its transition state is zero since the neutron is at rest in these processes. At any time $t \in (t_1, t_2)$ during process #1, however, the kinetic energy E_k^1 of the neutron in its transition state is

$$E_k^1 = \frac{1}{2} m_i^1 \frac{\delta X \cdot \delta X}{(\delta t)^2} = \frac{1}{2} m_i^1 v^2 > 0 \tag{7.44}$$

where $\delta X \cdot \delta X$ is the inner product of $\delta X = (\delta x^1, \delta x^2, \delta^3) = X_2 - X_1$ with itself, and m_i^1 is the inertial rest mass of the neutron in the transition state at time t. Being surrounded by a force-free environment, we cannot associate any potential energy to the neutron: one might therefore be inclined to think that energy conservation is violated—the kinetic energy $E_k^1 > 0$

seems to come from nowhere. That, however, is not the case. At the start of process #1 the neutron is in a ground state and as such it has energy in the form of mass: this initial energy is conserved at the first event of process #1, when the neutron transforms into a transition state. In its transition state, the neutron has kinetic energy but the total amount of energy is not changed: the kinetic energy is "borrowed" from the initial energy. Thus speaking, if we use natural units with light speed $c = 1$, then the following energy conservation law holds in process #1 for $v \ll 1$:

$$m_0^1 = m_i^1 + \frac{1}{2} m_i^1 v^2 \tag{7.45}$$

where m_0^1 is the inertial rest mass of the neutron in its ground state at the beginning of process #1. At the collapse of the transition state, the energy that had been borrowed is "returned": in its next ground state at the start of process #2, the neutron has again rest mass $m_0^2 = m_0^1$ and no kinetic energy. ■

Objection 7.5.35. "*Approaching the mind-body problem using classical physics might be a good idea because the problem, if it exists, is more difficult with classical physics than with other physics. So a solution in the classical case would likely carry over to the easier cases.*"—fifth objection of referee #2 ■

Reply 7.5.36. The armchair philosophy continues: the referee now suggests to redo the entire research in the framework of classical mechanics. Thereby, the objection against the present result is thus that not the framework of the EPT but the framework of classical mechanics should have been used for a *physicalist approach* to the mind-body problem. This is wrong thinking: any attempt to a physicalist approach to the mind-body problem in the framework of classical mechanics is futile beforehand.

The referee ignores that the laws of physics that are laid down in the framework of classical mechanics have since long been refuted, that is, have since long been shown to be not fundamental: it is thus a certainty that mental causation does not take place by the physical principles of classical mechanics, because it is a certainty that the fundamental workings of the universe are *different* from the principles of classical mechanics—if mental causation takes place at all, it therefore uses *other* principles than those of classical mechanics. This was stated in the paper as in Sect. 7.2. ■

Objection 7.5.37. "*I don't see any awareness of the difficulty of the indeterminism-implies-randomness-implies-no-free-will argument ... One can scarcely claim to have established free will by rejecting determinism, or by rejecting determinism and introducing 'choices', unless one can show free will to be compatible with indeterminism.*"—sixth objection of referee #2 ■

Reply 7.5.38. This objection boils down to the following syllogism:

(P1) rejecting determinism is embracing indeterminism;

(P2) indeterminism implies no free will;

(C) therefore, having rejected determinism, the present idea of free will cannot be true.

This reasoning is false, because it is based on a tacit assumption that is false. This will become clear by treating its two premisses, (P1) and (P2), and its conclusion, (C), in detail.

Regarding the first premise, P1, let us first agree that here 'physical determinism' is meant—the talk is not about logical determinism, theological determinism, etc. That said, let us come to an acceptable definition of physical determinism. When philosophers talk about determinism they all have the universe of classical mechanics in mind. However, the universe of Bohmian mechanics is also deterministic. The following definition then captures the common denominator:

Definition 7.5.39. *The term* ***physical determinism*** *refers to the view that absent nuclear interaction, for any closed massive system its state at a time t is* <u>*completely*</u> *determined by its state at an arbitrary earlier time $t_0 < t$ and the interactions with its surrounding environment governed by rigid laws.* ■

Of course a human being is an open system and not a closed system, but if we focus on a short enough time span the system can be considered closed. Using Van Inwagen's consequence argument, we can then show by induction that free will is an illusion from the perspective of physical determinism. For that matter, consider the first act in the lifetime of a human being believed to be an act of free will: let this first act have taken place in a time interval $[t_1, t_2]$; in this relatively short time span we can consider the system to be closed. Consider then, the state of the system at a time t_0 just before t_1: since $t_0 < t_1$, the time of the first act of free will, the human being has had no control over the state of the system at $t = t_0$. But since the system is closed and since we have physical determinism, the state system of the system at $t = t_2$, at the end of the alleged act of free will, is completely determined by its state at $t = t_0$ and the fundamental interactions. Ergo, the first act of free will is illusory. Suppose now that the n^{th} act of free will was illusory: by the same argument, the $(n+1)^{\text{th}}$ act of free will is then illusory too. By induction, all acts of free will of the human being are then illusory: hence free will is an illusion from the perspective of physical determinism.

That being said, if we merely reject physical determinism, then we indeed embrace physical indeterminism. But we have to realize that this physical indeterminism is then *negatively defined*:

Definition 7.5.40. *The term **physical indeterminism** refers to the view that absent nuclear interaction, for any closed massive system its state at a time t is <u>not necessarily</u> completely determined by its state at an arbitrary earlier time $t_0 < t$ and the interactions with its surrounding environment governed by rigid laws.* ■

There are, then, at least two *positively defined* views that satisfy the definition of physical indeterminism:

(i) quantum (probabilistic) indeterminism:
in absence of measurement the state of a quantum system at a time t is determined by its state at an arbitrarily earlier time t_0 and the Schroedinger equation, yet upon a measurement at a time $t_1 > t_0$ its state transforms by a discrete state transition into a randomly determined eigenstate as described by the Projection Postulate 1.1.3;

(ii) the non-probabilistic indeterminism in the framework of the EPT:
for a (closed) system with free will whose first act of volition takes place in a time interval $[t_1, t_2]$, its state at the time $t = t_2$ is determined by its state at an arbitrary earlier time $t_0 < t_1$ when the act of volition was not yet intended, the interactions with its surrounding environment governed by rigid laws, *and* by the act of volition.[57]

Needless to say, view (i) corresponds to the idea that the universe is *fundamentally probabilistic*, while view (ii) corresponds to the idea that the universe is *fundamentally volitionistic*—there is no place for randomness in this latter view. The crux is this: by rejecting physical determinism we indeed embrace physical indeterminism, but we do not necessarily have to embrace quantum indeterminism: we can also opt for the non-probabilistic indeterminism in the framework of the EPT.

As to the second premise of the syllogism, P2, this is what Van Inwagen called *the Mind argument*. While several versions have been published that differ only with small nuances, the following statement reflects its essence:

> "*The Mind argument proceeds by identifying indeterminism with chance and by arguing that an act that occurs by chance, if an event that occurs by chance can be called an act, cannot be under the control of its alleged agent and hence cannot have been performed freely.*"—Van Inwagen (1983)

That is to say, the indeterminism-implies-randomness-implies-no-free-will argument, which is referred to in Objection 7.5.37, fails to make the crucial distinction between negatively defined physical indeterminism and a positively defined quantum indeterminism: the one is identified with the other. Hence, the said argument applies, if at all, only to a treatment of free will in the framework of orthodox QM, in which the universe is viewed as fundamentally probabilistic.

Therefore, the conclusion of the syllogism, C, is false. The first premise P1 is true only in the sense that we embrace a negatively defined physical indeterminism if we reject physical determinism, and the second premise P2 is true only in the sense that quantum indeterminism (arguably) implies no free will: from there it does absolutely not follow that the non-probabilistic indeterminism, which is embraced in the non-deterministic framework of the EPT, also implies no free will. The error by the referee lies thus in the tacit assumption that a rejection of physical determinism goes hand in hand with an acceptance of quantum indeterminism: that assumption is false. The referee has missed the entire point of the paper. ∎

Objection 7.5.41. "*It also appears that human freedom as licensed by the EPT might differ surprisingly little from the free will of stones, which is disappointing: it suggests that whatever the EPT has achieved for free will isn't what most people discussing free will have wanted.*"—seventh objection of referee #2 ∎

Reply 7.5.42. This objection underlines that the referee has failed to understand the non-probabilistic indeterminism in the framework of the EPT as mentioned under (ii) on page p. 366. ■

Objection 7.5.43. "*The author tells us that stones, like human beings, have both body and spirit. ... A soul turns out to be 'fluctuations in the wavelike phenomenon that is identified with the spirit.' ... Even if one manages to count 3 Biblical parts of the human person—it is not as clear as the author thinks that the Bible teaches such a trichotomy—the author's concepts of spirit and soul appear to be unrelated to the Bible's.*"—eighth objection of referee #2 ■

Reply 7.5.44. See Reply 7.5.20. ■

Objection 7.5.45. "*The aim of this unusual, ambitious and at times rather technical paper is to explore the implications of the author's own Elementary Process Theory (EPT) for the mind-body problem. The author comes to the remarkable conclusion that 'man has to be a trinity of body, spirit and soul as suggested by the Bible', to quote his own words.*

In favour of this paper, I can say that it is very original, and that the author has made a commendable effort to synthesize modern philosophical ideas on the mind-body problem with biblical ideas and with EPT. Not many physicists have made such an effort to understand modern philosophy. ...

But there are also problems. The greatest is that the status of EPT is unclear to say the least. Although I cannot judge the physics myself, I notice that EPT was proposed by the author in a single publication in 2010, and so far as I can tell it appears not to be generally accepted. Bearing in mind that the readers of [our journal] are from all branches of science, it seems to me inappropriate to publish in this journal a paper linking such an avant-garde, controversial and perhaps marginal theory to the mind-body problem and Christian thought. The situation might change in the future, depending on how EPT develops."—referee #1 of an interdisciplinary journal, recommending rejection in 2011 of a precursor of my paper (Cabbolet, 2014c) ■

Reply 7.5.46. This objection has already been replied to under point (ii) of Reply 7.5.18. The objection is reasonable if the journal aims to publish papers on the interplay of <u>established</u> theories of physics and Christian belief—which might be the case for this journal. ■

Objection 7.5.47. "*I really tried to read this manuscript, as well as the [paper] published by the author in Annalen der Physik. My sole firm conclusion is that the formula presented in the [submitted] manuscript are not science. None of the symbols in the author's formulas seem to correspond to any well-defined physical or mathematical object. Physical units are an interesting question too. Is the author's energy the same as standard energy in physics with the same units? Apparently the author's 'spirit' S_x is also an energy... Is there any scientific basis to such claims? I didn't see in which way EPT (which also appears to be based on fuzzy concepts) could be relevant to the issues raised in this manuscript. Refuting the 'scientific results' of this paper would be an enormous task, as it is hard to find the first point to hold on to refute it. But it is clearly a problem that the author does not connect clearly at all his theory and concepts to the body of existing knowledge. I am sorry but I cannot recommend publication.*"—anonymous referee #2 of the same journal

Reply 7.5.48. Apart from the fact that the EPT is not based on fuzzy concepts, it is wrong to classify the material presented in this Ch. 7 as 'science'. That is, any mechanism of mental causation will always be in the realm of philosophy: details of the mechanism cannot possibly be tested, because measurements of brain activity necessarily involve the brain—a macroscopic object—as a whole.

That being said, like many responses to my work, this response is not better than the reaction of the cookie monster to fruit—see Fig. 7.3. ■

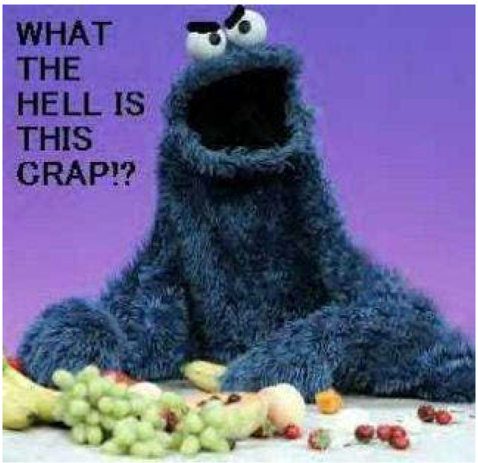


Figure 7.3: Reaction of the cookie monster to fruit. The cookie monster is a character from the children's series *Sesame Street*: his world is about eating cookies and nothing but cookies. When fruit was put in front of him, his reaction was: *What the hell is this crap*? Now take any modern scientist: his world is usually about working within a mainstream research program. When a work, which questions the assumptions of that mainstream research program, is put in front of him, he reacts, as a rule, likewise.

Objection 7.5.49. "*Thank you for sending [our journal] your manuscript ... We receive many proposals that, for one reason or another, we must decline to pursue. Yours falls in this category given our current volume of papers.*"—Editor of an interdisciplinary journal, recommending rejection of a precursor of my paper (Cabbolet, 2014c) ■

Reply 7.5.50. The journal in question is not obliged to publish any of my submitted papers. Its website states that the journal provides a forum for exploring ways to unite what in modern times has been disconnected, such as religion and science. From that perspective the submitted paper was on-topic, unless of course the journal is only interested in publishing papers on interactions between religion and established theories of physics—cf. Reply 7.5.46. ■

Part IV

Categorical models

Chapter 8

The research program on the EPT

> "*Allowing this manuscript to be defended as a PhD thesis would be a disgrace for Eindhoven University, and therefore I have to advise you strongly against it.*"—Gerard 't Hooft, Nobel laureate, commenting on my 2008 concept-dissertation (2008c)

8.1 Aim and methodology

On the one hand, the EPT is intended as a theory of the physical universe. On the other hand, however, quite some knowledge about the physical universe has already been developed. In particular, a body of knowledge has been built from the empirically successful predictions of the fundamental theories of modern physics. These are:

- Special Relativity (SR);
- General Relativity (GR);
- Quantum Electrodynamics (QED);
- Quantum Chromodynamics (QCD);
- Electroweak Theory (EW).

The natural question is then: does the EPT agree with that existing body of knowledge? If not, then of course the EPT will have to be rejected.

So, by asking this question we immediately have an aim for further research on the EPT: its aim is to prove that the EPT agrees with the body of knowledge about the physical world that derives from the empirically successful predictions of the aforementioned theories of modern physics. That, however, raises two new questions:

(i) what does it *mean* that the EPT "agrees" with existing knowledge?

(ii) how can an agreement be *proven*?

In the remainder of this section, these two questions will be addressed.

The weak correspondence principle

As to the first question (i), the golden standard by which a new theory T can be said to "agree" with the body of knowledge that derives from the empirically successful predictions of an existing theory T' is what I would like to call a 'strong correspondence'. Applying the notion of formal reduction as defined by Rosaler (2015), we can define this as follows:

Definition 8.1.1. *A new theory T* ***corresponds strongly*** *to an existing theory T' if and only if T reduces formally to T', that is, if and only if T' obtains from T by applying some limiting procedure.* ■

We may heuristically express such a formal reduction by an "equation"

$$\lim_{\zeta \to 0} T = T' \qquad \text{for a parameter } \zeta \text{ of } T \tag{8.1}$$

but we must realize that this is not a well-formed formula: although we intuitively understand what it means, neither the identity relation nor the limiting operator has ever been defined on the collection of all theories.

That being said, as Rosaler already noted, the fact whether or not a new theory T corresponds strongly to an existing theory T' can be established purely from the mathematical formulation of T and the mathematical formulation of T'. An observation is then that the EPT is an *abstract physical theory*, as explained on pp. 199 ff. in Sect. 5.1, while the theories of modern physics are formulated in a concrete set-theoretical domain: that means that the EPT, due to its higher degree of abstractness, *cannot possibly* correspond strongly to any of the theories of modern physics—there is no limiting procedure that can be applied to the EPT.

But does that mean that the EPT cannot possibly be said to "agree" with the existing body of knowledge about the physical universe? The answer to that question is: 'no'. It is a widely believed misconception that any new theory of physics that is intended to be fundamental **must** satisfy the strong correspondence principle, that is, **must** correspond strongly to established theories of physics: there is, namely, another way by which the EPT in particular can agree with the body of existing knowledge. I would like to call this the 'weak correspondence principle'. To develop this new principle, it is best to start with the definition of a concrete set-theoretic model of the EPT, which derives from the usual definition of a set-theoretic model of a first-order theory that can be found in the literature, e.g. (Shoenfield, 2001).

Definition 8.1.2. *A* ***concrete set-theoretic model*** *M of the EPT, or shorter: a* ***set-theoretic model*** *of the EPT, is a mathematically concrete structure $\langle |M|, I(R_1), I(R_2), I(R_3)\rangle$ for the EPT specified in a language $\mathcal{L}(M)$, with interpretation function $I : \mathcal{L}(EPT) \to \mathcal{L}(M)$, such that*

(i) every <u>abstract</u> constant $\Phi \in U_{EPT}$ is interpreted as a <u>concrete</u> constant $I(\Phi)$ in the universe $|M|$ of individuals of M;

(ii) the relations R_1, R_2, R_3 of the EPT are interpreted respectively as relations $I(R_1)$, $I(R_2)$, $I(R_3)$ on $|M|$ for which

$$I(R_j) \subset |M|^j \tag{8.2}$$

$$\langle \Phi_1, \ldots, \Phi_j\rangle \in R_j \Leftrightarrow \langle I(\Phi_1), \ldots, I(\Phi_j)\rangle \in I(R_j) \tag{8.3}$$

(iii) for each of the seven axioms $A^1_{EPT}, \ldots, A^7_{EPT}$ of the EPT, its interpretation $I(A^j_{EPT})$ is true in M:

$$M \models I(A^j_{EPT}) \tag{8.4}$$

■

Let an 'intra-model prediction' be a prediction that can be derived from a single model; the idea is then to reproduce successful predictions of an established theory of physics with intra-model predictions of a set-theoretical model of the EPT. However, as the following example shows, there are set-theoretic models of the EPT that are *not interesting* for physics.

Example 8.1.3. Let N be a positive integer, and $z(0), z(1), \ldots, z(N-1)$ an array of positive integers. Let then, for integers $n \in Z_N = \{0, \ldots, N-1\}$ and $k \in I_{z(n)} = \{1, \ldots, z(n)\}$, the interpretation function I for the EPT be partially given by:

- $I({}^{EP}\Phi^n_k) = \{(\sqrt[N]{2})^n + (\sqrt[z(n)]{3})^k\}$
- $I({}^{NW}\Phi^n_k) = \{(\sqrt[N]{5})^n + (\sqrt[z(n)]{7})^k\}$
- $I({}^{NP}\Phi^n_k) = \{(\sqrt[N]{11})^n + (\sqrt[z(n)]{13})^k\}$
- $I({}^{LW}\Phi^n_k) = \{(\sqrt[N]{17})^n + (\sqrt[z(n)]{19})^k\}$
- $I({}^{S}\Phi^n_k) = \{(\sqrt[N]{23})^n + (\sqrt[z(n)]{29})^k\}$
- $I(\Phi_1 + \Phi_2) = \{I(\Phi_1) + I(\Phi_2)\}$

In other words, abstract constants of the EPT referring to atomic occurrents in the physical world are interpreted as singletons containing a unique number; with some creativity the structure can then be completed to yield a concrete set-theoretic model in which the axioms of the EPT are true. There is then a concrete set-theoretic model M for each choice of integers $N, z(0), z(1), \ldots, z(N-1)$, so that the universe $|M|$ of individuals of M is the monoid generated by the numbers specified above under addition. However, *physically* this model makes no sense since these numbers do not really represent states of particles—these numerical representations don't yield any experimentally testable intra-model predictions. ■

This example establishes that if we want to reproduce the empirically successful predictions of an established theory with intra-model predictions that can be derived from a set-theoretic model of the EPT, then it is *not sufficient* to specify just any set-theoretic model of the EPT. But not only that: even specifying a set-theoretic model M of the EPT that *does* yield verifiable intra-model predictions is <u>still</u> insufficient because it cannot ever reproduce relativity.

To see that, suppose that in a set-theoretic model M of the EPT the state of a given supersmall system at the beginning of an individual process is modeled as a point particle with position X_0 and momentum $\vec{p}_0$ in the reference frame (RF) of an observer $\mathcal{O}$, and suppose that M predicts that the state of that system at the end of that process is a point particle with position X_1 and momentum $\vec{p}_1$ in the RF of $\mathcal{O}$: this is a verifiable intra-model prediction. However, for another observer $\mathcal{O}'$ the initial state of that same system will have to be modeled as a point particle with some position X_0' and momentum $\vec{p}_0'$ in the RF of $\mathcal{O}'$, and the predicted final state of the process will be a point particle with a position X_1' and a momentum $\vec{p}_1{}'$ in the RF of $\mathcal{O}'$. The one model M, however, does not contain the initial and final states of the supersmall system in the process in the RF of $\mathcal{O}'$: it only contains the initial and final state of the supersmall system in the RF of $\mathcal{O}$—for the observer $\mathcal{O}'$ *another* set-theoretic model M' of the EPT is required. Moreover, the model M is incapable of predicting what the values of the aforementioned position X_1' and momentum $\vec{p}_1{}'$ will be: a single set-theoretic model of the EPT is thus **insufficient** because it can never predict relativity of spatiotemporal characteristics of motion (time dilation, length contraction). A prediction of relativity can thus only be reproduced by an 'intermodel prediction', which derives from predictions of two set-theoretic models of the EPT.

This shows the necessity of the categorical nature of a model of the EPT: a model of the EPT has to be identified with a category, which does contain a set-theoretic model of the EPT for every observer. The notion of a categorical model of a first-order theory has already been discussed in the literature, see e.g. Halvorson (2016) and the references therein; applied to the EPT, this gives the following definition:

Definition 8.1.4. *A* ***categorical model of the EPT*** *is a (small) category $\mathscr{C}$ such that*

(i) the collection of objects of $\mathscr{C}$ is a family $\{M_i\}_{i\in F_1}$ of set-theoretic models of the EPT, so that any M_p in $\{M_i\}_{i\in F_1}$ is a structure for the EPT as in Def. 8.1.2 specified in a sublanguage $\mathcal{L}(M_p)$ of the language $\mathcal{L}(\mathscr{C})$ of $\mathscr{C}$;

(ii) the collection of arrows of $\mathscr{C}$ is a family $\{T_j\}_{j\in F_2}$ of structure isomorphisms, so that for any arrow T_k in $\{T_j\}_{j\in F_2}$ there is a domain $M_p \in \{M_i\}_{i\in F_1}$ and a codomain $M_q \in \{M_i\}_{i\in F_1}$ such that

- *T_k bijectively maps the universe $|M_p|$ to the universe $|M_q|$;*
- *$\langle T_k(\alpha_1), \ldots, T_k(\alpha_j)\rangle \in I_q(R_j) \Leftrightarrow \langle \alpha_1, \ldots, \alpha_j\rangle \in I_p(R_j)$.*

■

But what has been said earlier about set-theoretic models of the EPT remains the case for categorical models of the EPT: there are categorical models of the EPT that are *not interesting* from the point of view of physics—it's a tedious exercise, but it is not difficult to specify such an uninteresting categorical model along the lines of Ex. 8.1.3.

That said, we now have everything in place to precisely define the weak correspondence principle for the EPT; the definition below uses the term 'empirical reduction' introduced by Rosaler (2015):[58]

Definition 8.1.5. *The EPT **corresponds weakly** to a relativistic theory T in the array SR, GR, QED, QCD, EW if and only if the EPT has a categorical model $\mathscr{C}$ that reduces empirically to T, that is, a categorical model $\mathscr{C}$ that reproduces the empirically successful predictions of T.* ■

Such a weak correspondence means that if there are n empirically successful predictions of T that can be reproduced by an intra-model prediction, then for each $i \in \{1, \ldots, n\}$ there is an object M_i of $\mathscr{C}$ and a formula P_T^i that expresses a prediction of T in the language of M_i such that

$$M_i \models P_T^i \tag{8.5}$$

In addition, if there are p empirically successful relativistic relations predicted by T that can be reproduced by an inter-model prediction, then for each $j \in \{1, \ldots, p\}$ there is an object M_j of $\mathscr{C}$, an arrow A_j of $\mathscr{C}$, an intra-model prediction ϕ_j of M_j, an intra-model prediction ϕ'_j of $M'_j = A_j(M_j)$, and a relation R_T^j that expresses a relativistic relation predicted by T in the language of $\mathscr{C}$ such that the inference

$$\frac{M_j \models \phi_j \ , \ A_j(M_j) \models \phi'_j}{R_T^j} \tag{8.6}$$

obtains—here the relation R_T^j is thus the inter-model prediction.[59]

Thus speaking, if the EPT corresponds weakly to a theory T in the array SR, GR, QED, QCD, EW, then it can be said that the EPT agrees with the body of knowledge that derives from the experimentally successful predictions of T—if T is an interaction theory, then it can be said that the interaction as we know it from the experimentally successful predictions of T can take place in the processes described by the EPT.

One has to fully understand the implications of a weak correspondence of the EPT with GR: if the EPT has a categorical model $\mathscr{C}$ that reduces empirically to GR, then *any* experimental outcome that at the time of the performance of the experiment was seen as experimental support for GR, provides equally well experimental support for $\mathscr{C}$—the experimental support for $\mathscr{C}$ is then *as strong as* the experimental support for GR. Currently the experimental support for GR provides good reasons to believe that repulsive gravity is impossible, but if the EPT corresponds weakly to GR there are *equally good reasons* to believe that repulsive gravity is possible!

Proceeding, with the definition of weak correspondence in place, we can now define what it means that the EPT is a *unifying scheme* or a *grand unifying scheme*:

Definition 8.1.6. *The EPT is a* ***unifying scheme*** *if and only if the EPT corresponds weakly to both GR and QED. The EPT is a* ***grand unifying scheme*** *(GUS) if and only if the EPT corresponds weakly to GR, QED, QCD, and EW.* ■

This notion of a GUS is related to the idea of *empirical adequacy*, introduced by Van Fraassen (1980): the EPT is a GUS if and only if it has a model that is empirically adequate when applied to any inanimate system subject to the four fundamental interactions. This notion of a GUS should, thus, absolutely not be confused with the idea of a Grand Unified Theory (GUT): a GUT is a model of a single interaction that **corresponds strongly** to the three interaction theories of the Standard Model. This strong correspondence forces a GUT *qua mathematical structure* into framework of quantum field theory: for the EPT as a GUS, however, only a weak correspondence to the Standard Model is required and that puts less limits on its mathematical structure. Needless to say, if the EPT is a GUS—note that this is not claimed *hic et nunc*—then the EPT *agrees* with the entire body of knowledge that derives from the successful predictions of modern physics.

Outline of the research program

Having answered question (i) on p. 374, we can now turn to the second question (ii). Obviously, a method to prove that the EPT agrees with the entire body of existing knowledge in physics is to prove that the EPT is a GUS: if we can prove that, we're done. But that means that we not only have to specify a categorical model $\mathscr{C}$ of the EPT; we also have to prove the expression (8.5) c.q. (8.6) for each of the empirically successful predictions of GR, for each of the empirically successful predictions of QED, for each of the empirically successful predictions of QCD, and for each of the empirically successful predictions of EW. It has to be understood, however, that while the first-order notation of Eqs. (8.5) and (8.6) in Def. 8.1.5 is compact, *in concreto* these are very complicated mathematical expressions that are very hard to prove. Not only will it take a considerable team effort to prove that the weak correspondence principle is satisfied once a categorical model $\mathscr{C}$ of the EPT is specified, but it is also a tall order to at once specify a categorical model $\mathscr{C}$ of the EPT of which we can *conjecture* that it satisfies the weak correspondence principle: we will have to work our way to such a model. The answer to the question 'how?' is then: by working on the research program on the EPT. This is a fundamentally new Lakatosian research program in theoretical c.q. mathematical physics, which will be outlined below.[60]

To give an adequate outline of the research program on the EPT, it is necessary and sufficient to describe the parts that determine a Lakatosian research program. These are:

- the hard core;
- the auxiliary hypotheses;
- the *positive* and *negative* heuristics;
- the aim(s).

Below, these parts are treated one by one.

Hard core The hard core of the research program consists of

(i) the theory $\mathfrak{T}$ introduced in Ch. 4 as the mathematical foundation for the use of abstract constants in the formalism of the EPT;

(ii) the EPT in its finalized formulation as given in Ch. 5;

(iii) the examples of applications of the EPT as given in Chs. 6 and 7.

The generalized process-physical principles laid down in the EPT are then the *fundamental laws of physics* in this research program. Being the hard core means that these are immune to revision: if the EPT doesn't hold up against experimental results, the research program has to be terminated. For the theory $\mathfrak{T}$, on the other hand, there is a fall-back position: if $\mathfrak{T}$ is rendered untenable by future developments, it can be replaced by the theory outlined in Rem. 4.3.6. To complete the hard core, the theory $\mathfrak{T}$ and the EPT are supplemented by illustrative examples of applications of the EPT: altogether, the hard core then already corresponds to what Kuhn called a paradigm (disciplinary matrix) Kuhn (2010).

Auxiliary hypotheses The auxiliary hypotheses are the following:

(i) the views on the noumenal world and the phenomenal world as introduced in Sect. 8.2;

(ii) the categorical model $\mathscr{C}_0$ of the EPT as fully specified in Ch. 9.

The views on the noumenal and phenomenal worlds may be viewed as interpretations of Kantian ideas in the framework of the EPT, but it has to be understood that Kantian terminology is used to express a preexisting idea: it is not the other way around, that is, it is not the case that Kantian philosophy led to an idea of the noumenal world and the phenomenal world in the framework of the EPT. The categorical model $\mathscr{C}_0$ has to be viewed as an "initial" fully specified categorical model of the EPT, which satisfies Eqs. (8.5) and (8.6) for SR: while this rigorously proves that the EPT weakly corresponds to SR, the categorical model $\mathscr{C}_0$ is *not* empirically adequate in the area of application of GR, QED, QCD, or EW. So, further research is required to refine $\mathscr{C}_0$: the heuristics below are rules for this further research.

Heuristics The natural *negative heuristic* is to refrain from developments that are inconsistent with the hard core: such developments are *not interesting*. For example, it is not interesting to search for "deeper" principles from which the EPT emerges: within this research program, the position is that the EPT is fundamental—there are no deeper principles (such as a principle of least action) from which the generalized principles of the EPT derive. Likewise, it is not interesting to develop new interpretation rules for the formalism of the EPT, so that the EPT all of a sudden corresponds to a multiverse or a fundamentally probabilistic universe: there is only one universe, it is made up of atomic occurrents, and it is volitionistic—there is no place for randomness in this universe, nor for Laplace's demon. The same goes for the axiomatization of the EPT: the EPT has been finalised, and no more changes should be made to the axiomatization. These examples may indicate the scope of the negative heuristics.

That being said, the natural *positive heuristic* is to develop successors $\mathscr{C}_1$, $\mathscr{C}_2$, ... of $\mathscr{C}_0$ that are theoretically and empirically progressive. Lakatos has defined theoretical and empirical progression for theories (1970); these notions can be defined similarly for categorical models of the EPT:

Definition 8.1.7. *A categorical model $\mathscr{C}_{n+1}$ of the EPT is* ***theoretically progressive*** *compared to a categorical model $\mathscr{C}_n$ of the EPT when not only <u>all</u> observations, which could be expressed as predictions of $\mathscr{C}_n$, can also be expressed as predictions of $\mathscr{C}_{n+1}$ but also <u>some</u> observations, which could not be expressed as predictions of $\mathscr{C}_n$, can be expressed as predictions of $\mathscr{C}_{n+1}$. Likewise, a categorical model $\mathscr{C}_{n+1}$ of the EPT is* ***empirically progressive*** *compared to a categorical model $\mathscr{C}_n$ of the EPT when in the framework of $\mathscr{C}_{n+1}$ predictions can be formulated that are impossible in the framework of $\mathscr{C}_n$ <u>and</u> some of these predictions have been verified.* □

Given a categorical model $\mathscr{C}_n$ of the EPT, a negative result is that no categorical model exists that is theoretically and empirically progressive compared to $\mathscr{C}_n$. The research program on the EPT can then be terminated.

Aims The short-term aim is to develop a categorical model $\mathscr{C}_1$ of the EPT that reduces empirically to GR. An Ansatz is given in Ch. 10, but weak correspondence remains to be proven. That requires a team effort.

The medium-term aim is to develop a categorical model of the EPT that reduces empirically to GR *and* to QED. Although a unification of QED and GR—in the sense of a single theoretical framework in which QED and GR are both universally valid—is impossible, that would show that the EPT is a unifying scheme as meant in Def. 8.1.6: the unifying principles (the generalized process-physical principles of the EPT) are then at a higher level of abstractness.

The long-term aim is to develop a categorical model $\mathscr{C}^*$ of the EPT that *in addition* reduces empirically to QCD and EW, thus proving that the EPT is a GUS as meant in Def. 8.1.6. The idea is thus that the array $\mathscr{C}_0$, $\mathscr{C}_1$, $\mathscr{C}_2$, ... converges to $\mathscr{C}^*$. This concludes the outline of the research program on the EPT.

8.2 The noumenal/phenomenal distinction

In the research program on the EPT, a categorical model $\mathscr{C}$ of the EPT is distinct from the EPT itself: this distinction comes with a distinction between the noumenal world and the phenomenal world. On the one hand, the EPT is a theory of the *noumenal universe*, which consists of world and antiworld: the generalized process-physical principles of the EPT are formulated without reference to a coordinate system of an observer. On the other hand, a set-theoretic model of the EPT—recall from Def. 8.1.4 that this is an object of a categorical model $\mathscr{C}$—is a model of the *phenomenal world of an observer* $\mathcal{O}$: in such a model, abstract constants of the EPT that designate atomic occurrents in the noumenal world (noumena) are interpreted as functions representing observable hyperstates of atomic occurrents in the reference frame of the observer $\mathcal{O}$ (phenomena).

The terms 'noumenal world', 'noumenon', 'phenomenal world', and 'phenomenon' play a central role in Kantian philosophy, in particular in his opus magnum *Kritik der Reine Vernunft*. The distinction between noumena and phenomena that Kant introduced is rather complex: more than two centuries after publication of Kant's work, there still is debate about how this has to be interpreted. For example, there are those who argue that Kant used the term 'noumenon' as a synonym for 'thing-in-itself', while others argue that there is no such synonymity—this will be discussed below. But now these terms have been recontextualized in the research program on the EPT. In a discussion after a seminar on this topic, this recontextualization has been fiercely opposed by the Kantian camp, as the resulting new meaning deviates from the there prevailing view on what Kant had in mind when he introduced these terms. To the defense of this recontextualization, the first point is that Kantian philosophy does not have a monopoly on the usage of these terms: fact of the matter is that these terms have been used in philosophy since ancient Greece. That being said, the second point is that the present usage is in line with the historical usage: in various philosophic systems the terms 'noumenon' and 'phenomenon' have been used to contrast objects as they are in themselves, independent of perception, with objects as they appear upon perception, and to that end they are being used in the research program on the EPT—it has never been the intention to use these terms with the precise meaning they have in another context.

Proceeding, in the research program on the EPT the terms 'noumenal universe' and 'phenomenal world' have the following meaning:

(i) the **noumenal universe** is the universe as it is in itself, apart from how it is being observed;

(ii) the **phenomenal world of an observer** is the world as it is perceived by an observer—it is the world represented by the mental image produced by perception.

The view implemented in the research program on the EPT is then that noumena are *material objects* in the noumenal world—in this view, noumena are thus occurrents made up of atomic occurrents (phase quanta). From the Kantian camp the objection has been put forward that in Kant's view, noumena are *immaterial* and exist only in our thoughts.

To address this objection we must distinguish between the *material object*, i.e. that what we want to understand, and our *conception* of it. The point is, namely, that when Kantians talk about the noumenon as something *immaterial*, they have in mind the noumenon defined as a concept of the thing-in-itself, a point of reference for our reason (Vlerick, 2013). Of course, in that sense the noumenon exists only in our thoughts. In the research program on the EPT we can likewise distinguish between individual building blocks of the noumenal world and the primitive notion of a phase quantum: the latter exists, of course, only in our thoughts—we use it as a term of our language to refer to material objects. So, the phrase "phase quanta are material individuals" means: *the objects to which the term 'phase quanta' refers* are material individuals. But if we take the position that this concept is what Kant had in mind with the *noumenon*, then we must also take the position that Kant had something else in mind with the *thing-in-itself*—these cannot be synonyms then. Because according to Kant himself, if we accept the view that the thing-in-itself is immaterial too, then we also have to accept the "absurd conclusion that there can be appearance without anything that appears" (*Kritik der Reine Vernunft*, 2$^{\text{nd}}$ Ed., Bxxvi-xxvii). The use of the adjective 'absurd' here indicates that Kant himself holds the view that the thing-in-itself is a *material* thing—and thus, if one takes the view that the noumenon is *immaterial*, one proposes an interpretation of Kant's work in which the *noumenon* is distinct from the *thing-in-itself*.

Concluding, this objection stems from two different meanings given to the term 'noumenon': in the research program on the EPT it is a synonym for the thing-in-itself, which is material, but for (some) Kantians it is *our understanding of* the thing-in-itself, which is immaterial. The reply to this objection is then that as far as it concerns this aspect of the EPT, the contrast with Kant's work is only *apparent*: the bigger picture is that the view implemented in the research program on the EPT, being that the thing-in-itself is a *material* individual in the outside world, coincides with Kant's view on the thing-in-itself—there is no contradiction here.

In the research program on the EPT the individual building blocks of the noumenal world are *positively* characterized: each such noumenon is definitely one of the five types of phase quanta introduced in Sect. 5.2, and some are even further composed of matter quanta. From the Kantian camp the objection has been put forward that a positive characterization of noumena is not only *in principle impossible*, but it also makes the concept 'noumenon' *useless*.

As to the first part of this objection, Kant's view that nothing can be known of the noumena at object level stems from his assumption that man has no way to cognitively access the world outside observation. In the research program on the EPT this assumption is rejected: it is agreed with Kant that knowledge of the noumenal world cannot be obtained by sensory observation and/or reason, but the view that knowledge of the noumenal world is therefore *not at all* possible is rejected. The EPT, as a theory of the noumenal universe, has been developed from what Descartes in his Meditations called a 'clear and distinct idea'. But this clear and distinct idea did not emerge from an *act of reasoning* nor from an *act of observation* nor a combination thereof: instead, it emanated from a *mystical experience* that immediately followed upon the thought experiment of Sect 1.2.[61] The Stanford Encyclopedia of Philosophy defines a mystical experience as

> a (purportedly) super sense-perceptual or sub sense-perceptual unitive experience granting acquaintance of realities or states of affairs that are of a kind not accessible by way of sense-perception, somatosensory modalities, or standard introspection.

In the present case it is best described as *a beholding of the noumenal* *universe with the soul.* (In Dutch: *een aanschouwing van de noumenale wereld met de ziel.*) It has to be distinguished from the grasping of the world of Forms with the soul in Plato's philosophy: according to Plato the soul gets acquainted with the Forms *before birth* so that knowledge of the Forms is a matter of remembering, but a mystical experience as meant here occurs during lifetime. Other terms referring to the mystical experience are 'illumination' and 'revelation', but these have the distinct connotation that God is the ultimate source of the idea emanating from the mystical experience: in the present case it is neither claimed nor denied that God is the source of that idea.[62] So, what we have is this:

(i) just like it is objectively the truth for other contributions to the scientific discourse that they stem from observation, it is simply objectively the truth that the EPT has been developed from an idea emanating from a mystical experience;

(ii) the trustworthiness of the mystical experience as an epistemic source of knowledge about the noumenal world is testable: if experiments at CERN demonstrate that the gravitational force between massive particles and massive antiparticles is attractive, then the present idea about the fundamental workings of the universe (as laid down in the EPT) that emerged from the mystical experience is falsified—in that case we can objectively conclude that the mystical experience has zero trustworthiness as a source of knowledge of the physical universe.

That being said, the research program on the EPT thus implements the distinctively non-Kantian view that a positive characterization of elementary noumena at object level ***is*** possible, with the mystical experience as an epistemic source: this implies, thus, a rejection of the Kantian view that sensory observation and reason are the *only* epistemic sources. Correspondingly, the position is taken that a mystical experience is *necessary* to acquire true knowledge of the universal elementary laws of nature: both (strict) empiricism, i.e. the view that true knowledge can only be based on experience of the senses, and (strict) rationalism, i.e. the view that true knowledge can only be based on reasoning, are thus rejected as far as it concerns the universal elementary laws of nature. Historically, the position that a mystical experience can be a source of knowledge is known at least since Plotinus (±204 - 270), who was a proponent of the idea that such an experience is even *the only source* of knowledge. However, there is not much modern literature—'modern' as in, say, from the 17^{th} century on—on the mystical experience as a source of scientific knowledge. In his *Pensées*, Pascal expressed the view that reasoning is inferior to Divine revelation (1670): replacing 'Divine revelation' by 'mystical experience', this is in line with the present view that the most fundamental laws of nature cannot be known from reasoning alone. Schopenhauer, on the other hand, criticized the mystical experience and the assertions based on such an experience:

> "*nothing of this [i.e. the mystical experience] is communicable except the assertions that we have to accept on his word; consequently he is unable to convince*"—Arthur Schopenhauer (1844)

The EPT reflects the clear and distinct idea that emanated from the mystical experience *exactly*: one indeed has to take my word for it that this representation is *exact*. (Note also that developing an expression of the clear and distinct idea in a communicable form required additional acts of reasoning.) That being said, Schopenhauer's criticism is correct: the EPT, which essentially is a set of assertions, is by itself *unconvincing* in the sense that the mere publication of the EPT is neither meant to be convincing evidence that the EPT is superior to theories of modern physics nor meant to be convincing evidence that the EPT concerns scientific knowledge of the physical universe. To be convincing, additional theoretical results (models of the EPT) and experimental results (confirmations of predictions derived from models of the EPT) are required: that is the whole idea of the research program on the EPT outlined in Sect. 8.1. So, one should not accept the EPT as true or reject it as false *because* I claim that it has been developed from a mystical experience: one should only accept the EPT as a scientific theory c.q. reject it as a purely hypothetical construct when the research program on the EPT has yielded convincing evidence that it does c.q. doesn't concern scientific knowledge of the physical world.

As to the second part of the objection, the view of the Kantian camp that a positive characterization destroys the usefulness of the concept 'noumenon' is rejected. First of all, it has to be understood that this positive characterization is limited to the information entailed by the typography of abstract constants referring to elementary noumena: after all, *mathematically* these constants are abstract things in the category of sets and functions as laid down in Eq. (5.1). That being said, in the research program on the EPT one uses of course the terms 'extended particlelike phase quantum', 'nonlocal wavelike phase quantum', etc., to express statements about the physical universe in words—after all, the entire research program on the EPT leans on seven generalized process-physical principles that are expressed in terms of these phase quanta. But that does not render the concept 'noumenon' useless, since the distinction noumenon/phenomenon applies: as a general term, the concept 'noumenon'

(i) is useful to express a common denominator of the terms 'extended particlelike phase quantum', 'nonlocal wavelike phase quantum', being that these refer to objects as they are in themselves, independent of how they are observed;

(ii) is useful to express the contrast of phase quanta with phenomena: a phase quantum as a thing-in-itself (a noumenon) is to be contrasted with the hyperstate of that phase quantum in the phenomenal world of an observer (a phenomenon).

Thus speaking, the positive characterization of elementary noumena in the framework of the EPT does not render the concept 'noumenon' useless.

Proceeding, as remarked in (ii) above, in the research program on the EPT the view is embraced is that a 'phenomenon' is the manifestation of a noumenon in the phenomenal world of an observer: the mental image of a massive system that appears to an observer upon perception is the mental image of a state, and that state is the manifestation of a temporal part of a noumenon in the phenomenal world of the observer. From the Kantian camp the objection has been put forward that the idea of appearance as a manifestation of the thing-in-itself is distinctively non-Kantian, as it would imply that our senses interact causally with the noumenal in one way or another. This objection stems from a Babylonian confusion of tongues: it can be resolved by clarifying the difference in meaning of the terms 'phenomenon' and 'phenomenal world'.

A *noumenon* is an occurrent in the noumenal world: it is made up of the atomic occurrents, i.e. the phase quanta, that exist in the universe described by the EPT. For every observer, on the other hand, there is a *phenomenal world*: it is made up of phenomena, i.e. observable hyperstates of occurrents in the reference frame of the observer that can be described by a set-theoretic model of the EPT. So, for every noumenon and for every observer there is a *phenomenon*, such that the phenomenon is the hyperstate of the noumenon in the reference frame of the observer: this hyperstate is thus the manifestation of the noumenon in the phenomenal world of that observer. Importantly, in the framework of the EPT phenomena are *physical hyperstates* of noumena, whereas in Kantian philosophy phenomena are *mental images* of noumena. See Fig. 8.1 for an illustration.

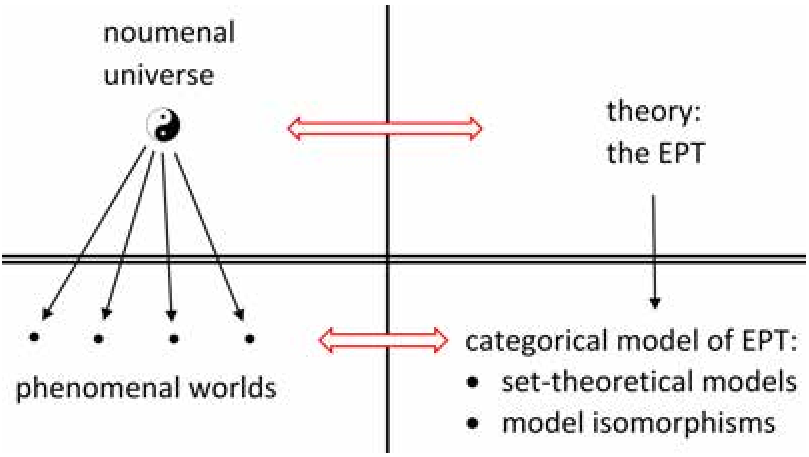


Figure 8.1: Illustration of the noumenal/phenomenal distinction in the research program of the EPT. The horizontal double line separates the noumenal from the phenomenal, and the vertical line separates *reality* from *descriptions of reality*. So, the yin-and-yang symbol in the upper left quadrant represents the noumenal universe, which consists of world and anti-world: this is described by the EPT, which finds itself in the upper right quadrant. The dots in the lower left quadrant represent phenomenal worlds of observers: each of these is a stream of states that are observable from the perspective of an observer, but we should distinguish the observable state of a thing in the phenomenal world from the thing-in-itself in the noumenal world from which it emanates. Each phenomenal world of an observer is described by a model: such a model is then a set-theoretic model of the EPT (an object in a categorical model of the EPT), and can be transformed into another model by a model isomorphism (an arrow in that category).

Furthermore, as argued in Ch. 7, an open Planck segment of the life of an observer with time span (t_1, t_2) corresponds to a succession of mental states $\{S_t \mid t \in (t_1, t_2)\}$: each mental state S_t then concurs with a physical state Ψ_t of the observer, who himself is a macroscopic system. So, if an observer at a time t sees a mental image of another macroscopic system, e.g. a nearby bicycle, then that mental image is contained in the mental state S_t at that time t. But that means that the physical state $\Phi_{t-\delta t}$ of the bicycle at an earlier time $t-\delta t$, where $\delta t > 0$ accounts for signal processing, must have had an effect on the physical state Ψ_t of the observer at the time t, which is psychophysically correlated to the mental state S_t that contains the mental image of the bicycle at time t. This yields a refined Kantian picture of observation, see Fig. 8.2 for an illustration.

So, to reply to the objection: we agree with the Kantians that the mental state S_t (in our view) has not causally interacted in any way with the state $\Phi_{t-\delta t}$ of the bicycle at the earlier time $t - \delta t$. But in the present view a 'phenomenon' does not belong to the mental realm as in Kantian philosophy: it is a *physical manifestation* of a noumenon, which upon perception produces mental images. Ergo, this objection is a non-argument.

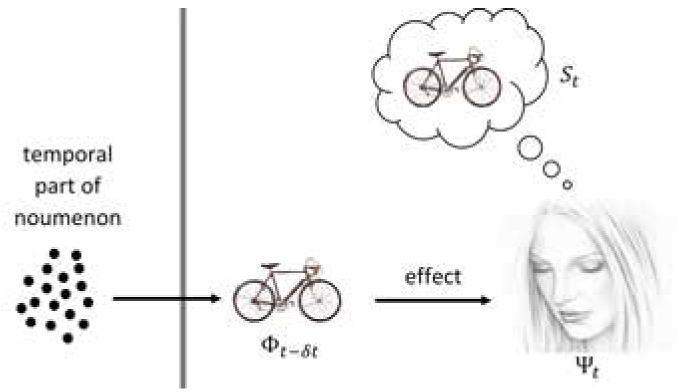


Figure 8.2: The refined Kantian picture of observation. The vertical line separates the noumenal world (left) from the phenomenal world an observer (right), depicted as a lady. The state $\Phi_{t-\delta t}$ of a bicycle in the lady's phenomenal world is depicted as having an effect on the state Ψ_t of the lady looking at it, and that state Ψ_t concurs with a mental state S_t containing a mental image of the bicycle. But the observed state of the bicycle is the state of a temporal part of an occurrent, made up of atomic occurrents: this is depicted by the dots on the left.

8.3 Objections and replies

Objection 8.3.1. "*This paper is not recommended for publication in [our journal]. It contains very little structure that would make it relevant to the readership of that journal. ... The author presents Definition 2.1 which is really just the usual definition of first-order theory with one additional axiom (his axiom (iv)) which he calls an abstract physical theory. But there doesn't seem to be anything physical about it. His additional axiom doesn't seem very well-defined and the subsequent discussion doesn't elucidate any of these concerns. There is a discussion within these remarks distinguishing between abstract and concrete sets, even though these concepts are badly defined at best.*"—referee of a journal on category theory and its applications, rejecting my paper introducing the research program on the EPT as a new application of category theory ■

Reply 8.3.2. I have no quarrel with the referee's opinion that the paper is not interesting qua structure. But as I see it, structure is nothing and interpretation is everything—*mathematica ancilla physicae*. That, however, is just a difference of opinions. What is worse are the false statements of fact that follow. First of all, the definition of the EPT as an abstract physical theory on p. 199 is not just the usual definition of a first-order theory plus the axiom (iv): the formal axioms (5.1) and (5.2), by which constants and relations of the EPT become *mathematical objects*, are namely **absent** in the usual definition—usually, constants and relations of a first-order theory are **not at all** assumed to be mathematical objects. The next false claim is that there is nothing physical about the interpretation rules, axiom (iv) on p. 199. The opposite is the case: *only* the interpretation rules give a physical meaning to the formalism—without these interpretation rules, the formal axioms of the EPT are just relations between abstract things in the universe of sets and functions.[63] This shows that the referee is not familiar with physical interpretations of formalized theories. Thirdly, it is false that the concepts of concrete and abstract constants are badly defined. A concrete constant is one that is postulated to be identical to a mathematical object that has been constructed from the empty set. E.g. the Zermelo ordinals 0, 1, 2, ... with $0 := \emptyset$ and $n + 1 := n^+$ are concrete constants. An abstract constant is one that is only postulated to be identical to an existing mathematical object. Cf. pp. 199 ff. ■

Remark 8.3.3. I have only once tried to publish the material set forth in Sect. 8.1 as a journal paper. Objection 8.3.1 is thus the only one obtained from a direct response to the material. However, further objections to this material have been obtained from responses to proposals for funding research towards a model of the EPT: the material set forth in Sect. 8.1 was the central part of these proposals. ■

Objection 8.3.4. "*The question is whether [this proposal] has research relevance in the context of new mathematics or philosophy of sciences. The EPT scenario does not seem to have much to offer in these fields either for the following reasons. The mathematical picture used in the publications of the theory is mostly just symbolic description of statements and assertions that are neither proved nor supported by scientific arguments. There is no indication of a new mathematical development with eventual overlap in some limit to the mathematics of present day physics—**after all, one needs to finally get the well-tested Einstein's equation of gravity as well as all of tested standard model physics in some limit of EPT**.*" (emphasis added)—anonymous referee, rejecting in 2016 my research proposal for developing a model of the EPT ■

Reply 8.3.5. The root cause of this objection, that is, of the emphasized comment, lies therein that it is a widely believed misconception among theoretical physicists that any new theory of physics that is intended to be fundamental **must** correspond to established theories of physics by what on p. 374 has been called a 'strong correspondence'. Of course there is nothing wrong with a theory that does satisfy the strong correspondence principle: what is wrong is the word 'must'. It has went completely unnoticed to the referee that in the submitted research proposal actually a new kind of correspondence was proposed, which is relevant in the context of new philosophy of science. Although the name 'weak correspondence' was not explicitly mentioned in the submitted research proposal, the first-order formulas (8.4) and (8.5) were there.

That being said, let us ask ourselves this question: could it perhaps be that this widely believed misconception that any new theory of physics **must** satisfy the strong correspondence principle, which keeps one 'inside the box', is one of the main reasons as to why research in the foundations of physics has revolved in the same old circles since the 1920s? ■

Objection 8.3.6. "*[Our organisation] has considered your application for a grant, with the title 'Towards a Mathematical Model of the Elementary Process Theory'. A multidisciplinary evaluation committee in the exact sciences has compared all eligible applications and has assessed these. ... With regret I have to inform you that the Board of the section Physics has decided to reject your application. Your application has received an end score of 3.5 or higher, and is therefore not eligible for funding. Of the 51 submitted applications, seven have been awarded a grant. Your application has ended at place 51. For your information I give you the numerical scores that your application has received for each of the judgment criteria (on a scale of 1=excellent to 9=poor).*

judgement criterion	***score***
quality applicant	*4.3*
scientific quality application	*6.7*
quality host institute	*6.0*
total	*5.7*

(...) At the end the total score, being the average of the three judgment criteria, is decisive."—interim director of the section Physics of a funding organisation, communicating the decision on my research proposal for developing a model of the EPT ■

Reply 8.3.7. The objection against the proposal is here expressed in the numerical scores for the judgment criteria: my application has been judged as an application by a third-rate scientist for a crackpot research project at an inferior university. This provides exemplary evidence for the conclusion that I've drawn from my collision with the establishment, being that the *quality check* of a research proposal has completely deteriorated to a mere *conformity check*—literature suggests that this has been going on in physics since the 1950s, see (Prugovecki, 1993). So, this referee is correct in his observation that the proposal is not in line with mainstream ideas on how to do physics, but wrong in his conclusion (expressed by those numerical scores) that it is a priori excluded that this leads to progress. As I see it, the takeaway point for physics from Feyerabend's *Against Method* (1975) is that as long as the foundational problem of modern physics (p. 13) is unsolved, the endeavor to achieve progress in physics should not be restricted to the methodological rules applied in the mainstream research programs. ■

Objection 8.3.8. "*I find the mathematical content underlying EPT too descriptive to be considered as new and path-breaking. The work plan of different steps outlined in the proposal is not a logically coherent description of a research plan. It is mostly, stringing together several superficially connected aspects that are not substantial enough to address the problem in hand—that of creating a new theory and paradigm to replace standard model and general relativity. Some ideas are just restatement of known concepts of emergent continuity of space from a nearly discrete space at Planck scale etc. In summary, I do not recommend this application for the award of the post-doctoral fellowship.*"—anonymous referee, rejecting in 2015 my research proposal for developing a model of the EPT ■

Reply 8.3.9. This objection boils down to three judgments about the intended research project:

(i) the method, outlined in the proposal as a sequence of steps, as a whole is logically incoherent;

(ii) the steps, identified in the proposal as necessary to successfully carry out the research project, are insufficient for the aim of the research project, which is to replace GR and the Standard Model;

(iii) ideas suggested in the proposal are just restatements of known ideas in Planck-scale physics.

As will be shown below, the above three judgments are all false statements of fact: everyone is entitled to his own opinion, but the right to freedom of speech does not include the right to make false statements of fact.

Ad (i). The aim of the research project was to develop a theory of gravity by specifying a model of the EPT that satisfies Eqs. (8.4) and (8.5). This method comes down to carrying out a number of steps. In broad lines, first a model of spacetime has to be developed; then an interpretation of phase quanta as real functions on spacetime has to be specified; thereafter, an interpretation of the process-physical principles of the EPT has to be specified. To call this "logically incoherent" does not demonstrate much familiarity with logic. But I can tell you where this is coming from. After decades of narrowing down the physics curriculum, the vast majority of theoretical physicists have had no education in logic: although there are of course individual exceptions, as a rule a theoretical physicist cannot read

Eqs. (8.4) and (8.5), and has no idea what these mean. This referee is no exception: he has not recognized a formal method, he therefore has not seen the logical coherence of the steps, and so he has simply concluded that the whole is logically incoherent. That conclusion is false: it may very well be that the research project is not to one's liking, but even then it remains the case that this is a straightforward application of a method of formal logic to physics. Cf. the response-in-an-outburst model on page li.

Ad (ii). The steps identified in the proposal were sufficient for the aim of the research project. But that aim was to develop a model of the EPT that reproduces the empirically successful predictions of GR, and not to replace GR and the Standard Model. Ergo, the referee hadn't even understood the general aim of the project.

Ad (iii). No one in physics has done the work that I have done: not one of those who are working on mainstream research programs in theoretical physics, and not one of those who are working on unorthodox ideas. With the response-in-an-outburst model on page li we can then explain how the referee has come to his comment that ideas in the project are just restatements of known concepts. First the referee became angry because the unorthodox proposal opposes his connatus. And listing angrily through the submission, the referee has not understood the nuances of the research proposal, but has noted that there are publications in the vast library of mathematics that on a first glance are close. From there the thought has popped up that ideas in the proposal are mere "restatements" of known ideas in Planck-scale physics, and without giving it a second thought he has passed that off in writing as a conclusion about the research proposal. With that, he has made false statements of fact.

For comparison, just changing names, imagine that an editor of B.G. Teubner would have replied as follows to a proposal for publishing David Hilbert's famous book in 1899:

> *Dear Dr. Hilbert,*
> *we have read your 'Grundlagen der Geometrie'. However, your ideas are just restatements of concepts of Euclidean space known since ancient Greece. Therefore, I cannot recommend this book for publication.*

Just think about it. ■

Objection 8.3.10. "*You have submitted a proposal entitled 'Towards a Mathematical Model of the Elementary Process Theory' ... In total 59 applications were submitted as interdivisional. In view of the limited budget available [for scientific research in the tropics] we decided to use the short-listing procedure. I regret to inform you that [our board] has reached its final decision to reject your grant application for the research project ... [Our board] feels your application stands less chance of competing successfully for grant funding. In comparison with other applications yours was evaluated less positively on the following criteria:*

- *quality of the researcher: publications, track record;*
- *quality of the research proposal: innovative elements, potential to make an important contribution to the advancement of science, suitability of the proposed methods;*
- *knowledge utilisations: potential contribution to solve a problem, potential to actual application of the results, ...*

I am sorry that I cannot inform you otherwise."—executive director of the Board for scientific research in the tropics, a section of a Dutch funding organisation, communicating the decision on my research proposal for developing a model of the EPT ■

Remark 8.3.11. I have no idea how my proposal for research in the foundations of physics has ended up at the desk for scientific research in the tropics, amongst proposals for innovations in food production in Africa and things like that. For me, this puts a question mark over the level of professionalism at this Dutch organisation for scientific research. ■

Reply 8.3.12. This objection is similar to Objection 8.3.6. What is interesting here, however, is that the referee is of the opinion that the proposal lacks innovative elements and that the suitability of the proposed method is questionable. While I grant the referee that one is free to believe that the intended work has no "potential to make an important contribution to the advancement of science", it does not demonstrate much understanding of the research proposal to claim that the EPT is nothing new, and that specifying a model of the EPT is not a suitable method for testing its merit. ■

Objection 8.3.13. "*During the discussion in the panel meeting the following elements were pointed out:*

- *The presentation and the discussion could not convince the panel*"

Anonymous decision of an interdisciplinary panel of a funding organisation, rejecting in 2015 my research proposal for developing a model of the EPT ■

Reply 8.3.14. On the one hand, I think that it's a very good idea to have proposals for research projects in interdisciplinary areas—such as the foundations of physics—evaluated separately to avoid false negatives in the judgment caused by an assessment from a monodisciplinary perspective. On the other hand, *all* interdisciplinary proposals had to be submitted to the same panel, resulting in an enormously broad range of topics of submitted proposals: research proposals in the foundations of physics had to compete with research proposals in areas like medical biochemistry, which are much closer to practical applications. To cope with that broad range, the expertises of the members of the panel were shattered across all of science and philosophy. So, my reply to the objection that my presentation was unconvincing is this: the interdisciplinary panel was too diverse qua background of its members, so that for most proposals most panel members are laymen on the topic of that proposal—it then becomes an impossibility to give an outline of the intended research project for the panel members that goes beyond a lecture for a laymen audience. (Try to explain to someone with a medical degree what a set-theoretic model of a first-order theory is.) ■

Objection 8.3.15. "*Your project 'A fundamentally new relativistic theory of a gravitational interaction as a model of the Elementary Process Theory' was carefully reviewed and considered for funding. Unfortunately, the Foundation has decided not to invite a full proposal for this project. Each inquiry is considered in relation to other submissions, along with the potential for innovation and outcomes that advance the Foundation's mission. We regret that we often have to decline even very promising project ideas.*"—co-worker of an international non-governmental organisation for scientific research funding, rejecting my research proposal with the mentioned title ■

Reply 8.3.16. I do not have the 'right' to a funding for my research endeavors. Likewise, funding organisations do not have the obligation to fund my research endeavors: that goes for this organisations as well as for all other organisations who have refused to fund my research.

That being said, the procedure at this organisation is better than that at other organisations: a first decision is namely made on the basis of a summarily proposal, which takes much less time to prepare than a full proposal. So, in case of a rejection, much less time is wasted on the side of the researcher—which is, I believe, a good thing. ■

Objection 8.3.17. "*Don't people then laugh in your face?*"—Tom Botte, freelance journalist, asking this question in reply to my statement that the clear and distinct idea from which I developed the EPT emerged from a mystical experience (2014) ■

Reply 8.3.18. The question implies a judgment: make no mistake, under the guise of "investigative journalism" Botte included this question in the printed article in the widely read journal *Eos* to depict my work as despicable. We can treat this as an objection to the idea that a mystical experience can be an epistemic source for a theory of physics. Now regardless whether one likes it or not, it is simply *the truth* that the idea for the EPT emerged from a mystical experience. Furthermore, the EPT is testable by refined falsificationism. So on the one hand, a refutation of the EPT goes hand in hand with a refutation of the mystical experience as an epistemic source of knowledge of the physical world. But on the other hand, if the EPT can be shown to be a (grand) unifying scheme (Def. 8.1.6) then that shows that the mystical experience, just like observation and reason, can indeed be an epistemic source of knowledge of the physical world. ■

Objection 8.3.19. "*It's a jump into the dark with the eyes closed.*"—Jos Uffink, then at Utrecht University, commenting on my work (2008) ■

Reply 8.3.20. We can take this as an objection against the whole research program on the EPT. But it's not true: the development of the EPT is based on a clear and distinct idea in the realm of physics. For comparison, in the research program on string theory physical ideas are sought to match the mathematics just developed (Witten, 1988). Or as Duff put it: "physicists are glimpsing only small corners of M-theory; the big picture is still lacking" (1998). Now thát is the blind leading the blind. ■

Chapter 9

A categorical model of the EPT incorporating SR

> "*[In] fundamental computer science, behavioral descriptions by means of discrete transitions in automata and transition systems have been extensively studied. He completely ignores this ... The entire physics developed in the next chapters is* ***therefore*** *devoid of meaning and devoid of content.*" (emphasis added)—Jos Baeten, logician and professor of computer science, commenting on my 2007 concept-dissertation (2008)

The purpose of this chapter is to demonstrate the formal method developed in Ch. 8 by fully specifying a categorical model $\mathscr{C}_{SR}$ of the EPT that reduces empirically to Special Relativity (SR). This categorical model $\mathscr{C}_{SR}$ thus consists of

(i) a collection of objects, each of which is a set-theoretic model of the EPT in the reference frame of an inertial observer;

(ii) a collection of arrows, each of which corresponds to a Lorentz transformation that transforms one set-theoretic model into another.

The specification of the category $\mathscr{C}_{SR}$ is straightforward but before we can commence with the specification we have to solve a mathematical problem: that is the topic of the first section.

9.1 Hyperreal delta functions

Motivation

For the development of a model of the EPT we are interested in mathematical objects that can model a state of a supersmall system, in which an amount of energy or mass is divided over space. Such objects may then be of general interest, because in physics we are in general interested in modeling a state of a system in which a physical quantity is distributed over space. Let's limit the discussion to one-dimensional physical systems for the sake of simplicity, and suppose then that a real amount ξ of a physical quantity (e.g. mass) is distributed over the space $\mathbb{R}$: this state can then, in general, be modeled by a function $f : \mathbb{R} \to \mathbb{R}$, satisfying $\int\limits_{-\infty}^{\infty} f(x)dx = \xi$, with the function value $f(x) \in \mathbb{R}$ at a point $x \in \mathbb{R}$ representing the *density*. However, troubles arise when the physical quantity is distributed over isolated points $x_1, x_2, \ldots, x_n$ in the space $\mathbb{R}$; for $n = 1$ we have this when we consider the distribution of energy in the excited state of a monadic system. In such cases *infinitely high densities* occur at those isolated points $x_j \in \mathbb{R}$: no real function f exists that can model such a state.

To model states of systems in which infinitely high densities occur, functions f are required that can have an infinitely large value at isolated points in space, but such that f can also be added to a (piecewise) smooth function g representing a distribution of an amount χ that physical quantity over a region of space—a sum $f + g$ then represents a distribution of an amount $\xi + \chi$ of that physical quantity over space. Analyzing, the **mathematical problem** is thus that functions f *on the real* line are required that must satisfy the following two conditions:

$$\begin{array}{ll} \text{(i)} & f : \mathbb{R} \to R \\ \text{(ii)} & \begin{cases} f(x) = 0 \Leftrightarrow x \neq r \\ \int\limits_{-\infty}^{+\infty} f(x)dx = \xi \end{cases} \end{array} \tag{9.1}$$

where $r, \xi \in \mathbb{R}$ and R is a number ring containing the reals: $R \supset \mathbb{R}$. In this section we solve this problem—note that it is defined in terms of a *Riemann integral*: the *Lebesque integral* is of no interest here—by introducing ordinary functions on the real line that satisfy Eq. (9.1).

Our attention is drawn to the Dirac delta. At its original introduction Dirac did not define it exactly, but rather characterized it heuristically as an object—denoted by the symbol δ—for which

$$\begin{cases} \delta(x) = 0 \Leftrightarrow x \neq 0 \\ \int\limits_{-\infty}^{+\infty} \delta(x)dx = 1 \end{cases} \tag{9.2}$$

where x is a real variable (Dirac, 1927). This corresponds to clause (ii) of Eq. (9.1) for $r = 0, \xi = 1$. There is no function $f : \mathbb{R} \to \mathbb{R}$ that has these properties. In fact, Von Neumann dismissed the idea of the Dirac delta as "fiction" (1955).

Since then, however, various objects that capture the idea of the Dirac delta have been rigorously defined within the framework of standard analysis; for an overview, see e.g. (Hoskins, 2009). An example is the linear functional $\delta : \mathcal{D}(\mathbb{R}) \to \mathbb{R}$ on the space of test functions on $\mathbb{R}$ called *Dirac delta distribution*, which is defined by $\langle \delta, f \rangle := f(0)$ for all $f \in \mathcal{D}(\mathbb{R})$ (Schwartz, 1950). Its definition is often written as

$$\langle \delta, f \rangle = \int_{\mathbb{R}} f(x)\delta(x)dx = f(0) \tag{9.3}$$

but the objection is then that this is an abuse of notation since the term '$\delta(x)$' in the integrand does not refer to an existing object. To meet that objection, the term $\delta(x)$ can be viewed as a weak limit of a sequence of real functions $g_n : \mathbb{R} \to \mathbb{R}$, e.g. the functions g_n given, for positive integers n, by $g_n(x) = n$ for $x \in (-\frac{1}{2n}, \frac{1}{2n})$ and $g_n(x) = 0$ else; we then get

$$\int_{\mathbb{R}} f(x)\delta(x)dx := \int_{\mathbb{R}} \lim_{n\to\infty} f(x)g_n(x)dx \tag{9.4}$$

Still, this weak limit δ does not exist in the space of all functions from $\mathbb{R}$ to $\mathbb{R}$. Another standard object that formalizes the idea of the Dirac delta is the *Dirac measure*, a real function $\delta_0 : \mathcal{B}(\mathbb{R}) \to \mathbb{R}$ on the σ-algebra of Borel sets of $\mathbb{R}$ defined, for $X \in \mathcal{B}(\mathbb{R})$, by $\delta_0(X) = 1$ if $0 \in X$ and $\delta_0(X) = 0$ else (Rudin, 1966). The Lebesgue integral of a (measurable) function $f : \mathbb{R} \to \mathbb{R}$ against the measure δ_0 then gives

$$\int_{\mathbb{R}} f(x)\delta_0(dx) = f(0) \tag{9.5}$$

So, the Dirac measure corresponds to a Dirac delta distribution as defined above in a natural way, but it has to be emphasized that the Dirac measure has no Radon derivative—that is, the Dirac measure δ_0 does not correspond to an ordinary function δ on the reals such that we have

$$\int_{\mathbb{R}} f(x)\delta_0(dx) = \int_{\mathbb{R}} f(x)\delta(x)dx \tag{9.6}$$

Other objects equivalent to the above distribution and measure have been introduced, but the point is this: although they all capture the idea of the Dirac delta, none of them actually defines a function satisfying Eq. (9.2). That is, the objects that have been defined in the framework of standard analysis to formalize the idea of the Dirac delta are useful for doing calculations, but are useless for our present purpose—which is to model the state of a system in which a physical quantity is distributed over isolated points in space by a function on $\mathbb{R}^n$.

Another development is that the real number field has been extended to the hyperreal number field ${}^*\mathbb{R}$ (Robinson, 1966). Todorov has shown that there exists a nonstandard (hyperreal) function ${}^*\delta : {}^*\mathbb{R} \to {}^*\mathbb{R}$ such that

$$\int_{{}^*\mathbb{R}} f(x){}^*\delta(x)dx = f(0) \tag{9.7}$$

for any continuous function f on $\mathbb{R}$ (1990). An example is the function ${}^*\delta : {}^*\mathbb{R} \to {}^*\mathbb{R}$ given by

$$\begin{cases} {}^*\delta(x) = 0 \Leftrightarrow x \notin [-\frac{1}{2\omega}, \frac{1}{2\omega}] \\ {}^*\delta(x) = \omega \Leftrightarrow x \in [-\frac{1}{2\omega}, \frac{1}{2\omega}] \end{cases} \tag{9.8}$$

where ω is a hyperreal number—this and more examples can be found in (Hoskins, 2009). So, this is an object defined in the framework of nonstandard analysis that captures the idea of the Dirac delta of Eq. (9.2), but again this object is not useful for our present purposes: it is a function of a hyperreal variable and not of a real variable, and thus violates condition (i) of Eq. (9.1). This is objectionable, because in physics we want to model a spatial dimension with the real numbers, not with the hyperreal numbers.

Thus speaking, we cannot but conclude that the existing objects that formalize the idea of the Dirac delta are *not suitable* for our present purposes: we will, thus, have to develop a new object.

Hyperreal delta functions of a real variable

For our present purpose we need hyperreal numbers, but we do not need *all* of the hyperreal number field. So first of all we apply Ockham's razor and we define the ordered ring of the expanded reals as the part of the ordered field of hyperreal numbers $({}^*\mathbb{R}, +\ , \ \cdot\ , >)$ that we need:

Definition 9.1.1. *The* ***ordered ring of expanded real numbers*** *is the subring* $({}^*_+\mathbb{R}, +\ , \ \cdot\ , >)$ *of the ordered field of hyperreal numbers given by*

$$ {}^*_+\mathbb{R} = \{\xi \in {}^*\mathbb{R} \mid \xi = a_1\omega^{p_1} + \ldots + a_n\omega^{p_n}, n \in \mathbb{N}^+, p_1 > \ldots > p_n \geq 0, a_j \in \mathbb{R}\} \tag{9.9}$$

In words, the set ${}^*_+\mathbb{R}$ *contains, as indicated by the subscript '+' on the left, only those hyperreal numbers that can be written as a finite sum of a real number and products of a real number and a* <u>*positive*</u> *power of the infinitely large hyperreal number* ω *with* $|\omega| = \infty$*. If we define a real number as a set by identifying it with a Dedekind cut, then an expanded real number can be defined as a set by identifying it with the graph of a real polynomial:*

$$\sum_{j=1}^{n} a_j\omega^{p_j} := \{(x, f(x)) \mid x \in \mathbb{R}\ ,\ f(x) = \sum_{j=1}^{n} a_j x^{p_j}\} \tag{9.10}$$

where $p_1 > p_2 > \ldots > p_n \geq 0$*. As a corollary, the hyperreal number* ω *is then the set*

$$\omega := \{(x, x) \mid x \in \mathbb{R}\} \tag{9.11}$$

An inequality

$$a_1\omega + a_2 \neq a_1\omega \tag{9.12}$$

is then an inequality of sets, that is, of graphs of polynomials. The ordering on the ring of expanded real numbers then coincides with the ordering on the ring $\mathbf{R}[t]$ *of real polynomials described in (Lang, 2002).* □

Agreement 9.1.2. We will henceforth take the notation $\sum_{j=1}^{n} a_j\omega^{p_j}$ for an expanded real number $x \in {}^*_+\mathbb{R}$ to *imply* that $p_1 > p_2 > \ldots > p_n \geq 0$ as in Def. 9.1.1 above. ■

Definition 9.1.3. *Let $x = \sum_{j=1}^{n} a_j \omega^{p_j}$ be an expanded real number. The* ***real part*** *of x is then the number $Re(x)$ given by*

$$\begin{cases} p_n = 0 \Rightarrow Re(x) = a_n \\ p_n > 0 \Rightarrow Re(x) = 0 \end{cases} \tag{9.13}$$

Likewise, the ***hyperreal part*** *of x is then the number $Hy(x)$ given by*

$$\begin{cases} p_n = 0 \Rightarrow Hy(x) = x - a_n \\ p_n > 0 \Rightarrow Hy(x) = x \end{cases} \tag{9.14}$$

So, for any expanded real number x we have $x = Re(x) + Hy(x)$. ■

Definition 9.1.4. *Let $f : \mathbb{R} \to {}^*_+\mathbb{R}$. Then the* ***real part of*** *f is the function $f_{Re} : \mathbb{R} \to {}^*_+\mathbb{R}$ given by*

$$f_{Re} : x \mapsto Re(f(x)) \tag{9.15}$$

Likewise the ***hyperreal part of*** *f is the function $f_{Hy} : \mathbb{R} \to {}^*_+\mathbb{R}$ given by*

$$f_{Hy} : x \mapsto Hy(f(x)) \tag{9.16}$$

■

The space of all functions $f : \mathbb{R} \to {}^*_+\mathbb{R}$ then forms a vector algebra over $\mathbb{R}$, when function addition, scalar multiplication, and function multiplication are defined naturally.[64] In particular, for any $f : \mathbb{R} \to {}^*_+\mathbb{R}$ we have $f = f_{Re} + f_{Hy}$. In this function space ${}^*_+\mathbb{R}^{\mathbb{R}}$ we now define hyperreal delta functions $\alpha\delta_\beta$ as follows:

Definition 9.1.5. *For any $\alpha, \beta \in \mathbb{R}$, the* ***hyperreal delta function*** *$\alpha\delta_\beta : \mathbb{R} \to {}^*_+\mathbb{R}$ is a function given by*

(i) $x \neq \beta \Rightarrow \alpha\delta_\beta(x) = 0$

(ii) $x = \beta \Rightarrow \alpha\delta_\beta(x) = \alpha\omega$

Note that for $f = \alpha\delta_\beta$ we have $f = f_{Hy}$. ■

Corollary 9.1.6. *Any hyperreal delta function $\alpha\delta_\beta$ is an ordinary function on the real line, ordinary in the sense that it maps every $x \in \mathbb{R}$ to precisely one $\xi \in {}^*_+\mathbb{R}$.* ■

In the framework of the theory $\mathfrak{T}$ of Ch. 4, a hyperreal delta function $\alpha\delta_\beta$ can be formalized as a function $G_{\mathbb{R}}$ with graph G given by

$$G := \{\langle x, \xi\rangle \in \mathbb{R} \times {}^*_+\mathbb{R} \mid x \neq \beta \Rightarrow \xi = 0 \wedge x = \beta \Rightarrow \xi = \alpha\omega\} \tag{9.17}$$

Our next step is that we establish which hyperreal functions $f : \mathbb{R} \to {}^*_+\mathbb{R}$ have a real-valued integral over $\mathbb{R}$.

Axiom 9.1.7. *Let $\mathcal{R}^1(\mathbb{R})$ be the set of Riemann integrable functions on $\mathbb{R}$, and let the set of all integrable expanded real functions on $\mathbb{R}$ be denoted by ${}^*_+\mathcal{R}^1(\mathbb{R})$. Let $f \in {}^*_+\mathbb{R}^{\mathbb{R}}$; then $f \in {}^*_+\mathcal{R}^1(\mathbb{R})$* ***if and only if***

$$f_{Re} \in \mathcal{R}^1(\mathbb{R}) \tag{9.18}$$

$$f_{Hy} = \sum_{n=1}^{\infty} \alpha_n \delta_{\beta_n} \tag{9.19}$$

for some convergent series $\sum_{n=1}^{\infty} \alpha_n = s \in \mathbb{R}$; if $\int_{-\infty}^{+\infty} f_{Re}(x)dx = h$ then

$$\int_{-\infty}^{+\infty} f(x)dx = \int_{-\infty}^{+\infty} f_{Re}(x)dx + \int_{-\infty}^{+\infty} f_{Hy}(x)dx := h + s \tag{9.20}$$

■

We can now prove a new mathematical result.

Theorem 9.1.8. *Writing δ_0 for $1\delta_0$, there is a number ring $R = {}^*_+\mathbb{R}$ and a function $\delta_0 : \mathbb{R} \to R$ such that δ_0 is an ordinary function on the real line that has all four essential characteristic properties of the Dirac delta identified by Lützen (1982), to wit:*

(i) $\delta_0(x) = \frac{d}{dx}H(x)$ *with $H(x)$ the Heavyside function;*

(ii) $\delta_0(x) = \lim\limits_{n\to\infty} g_n(x)$ *for suitable functions g_n;*

(iii) $\delta_0(x) = 0$ *if $x \neq 0$ and* $\int_{-\infty}^{\infty} \delta_0(x)dx = 1$, *cf. Eq.* (9.2)*;*

(iv) $\int_{-\infty}^{\infty} f(x)\delta_0(x)dx = f(0)$.

■

Proof:

(i) for any closed interval $[a, b] \subset \mathbb{R}$, we have $\int_a^b \delta_0(x)dx = H(b) - H(a)$;

(ii) consider the functions g_n of Eq. (9.4); then

$$\int_{-\infty}^{\infty} \delta_0(x) f(x) dx = \int_{-\infty}^{\infty} \lim_{n\to\infty} g_n(x) f(x) dx \tag{9.21}$$

for any $f \in C^{\infty}(\mathbb{R})$;

(iii) this follows immediately from Def. 9.1.5 and Ax. 9.1.7;

(iv) writing $h(x) = f(x)\delta_0(x)$, note that

$$f(x)\delta_0(x) = h_{Re}(x) + h_{Hy}(x) = 0 + f(0)\delta_0(x) \tag{9.22}$$

Consequently, $\int_{-\infty}^{\infty} h(x)dx = \int_{-\infty}^{\infty} f(0)\delta_0(x)dx = f(0)$.

■

Each hyperreal delta function $\alpha\delta_\beta$ is thus an ordinary function with domain $\mathbb{R}$ that satisfies both clauses of Eq. (9.1). The function δ_0 in particular is thus an ordinary function on the reals with the properties of the Dirac delta δ displayed in Eq. (9.2)—the dismissal of the Dirac delta by Von Neumann was thus premature!

Generalization and conclusion

Ax. 9.1.7 can be generalized to integrable expanded real functions on $\mathbb{R}^n$. For that matter, we need the following definition:

Definition 9.1.9. *Let S_n be the group of permutations on n letters. Let $\sigma \in S_n$. Then a* ***permutation of variables*** $\pi_\sigma : {}^*_+\mathbb{R}^{\mathbb{R}^n} \to {}^*_+\mathbb{R}^{\mathbb{R}^n}$ *is a function on the space of all functions from $\mathbb{R}^n$ to ${}^*_+\mathbb{R}$, such that the image $\pi_\sigma(f)$ of an arbitrary function $f : \mathbb{R}^n \to {}^*_+\mathbb{R}$ under π_σ is given by*

$$\pi_\sigma(f) : (x^1, x^2, \ldots, x^n) \mapsto f(x^{\sigma(1)}, x^{\sigma(2)}, \ldots, x^{\sigma(n)}) \tag{9.23}$$

■

Example 9.1.10. Let $\sigma \in S_3$ be the permutation $\begin{pmatrix} 1 & 2 & 3 \\ 2 & 3 & 1 \end{pmatrix}$, and let the function $f : \mathbb{R}^3 \to {}^*_+\mathbb{R}$ be given by $f : (x^1, x^2, x^3) \mapsto \sin(x^1 x^2)\ \delta_0(x^3)$. Then π_σ is a permutation of variables such that

$$\pi_\sigma(f) : (x^1, x^2, x^3) \mapsto \sin(x^2 x^3)\delta_0(x^1) \tag{9.24}$$

■

Furthermore, we extend Def. 9.1.4 to expanded real functions on $\mathbb{R}^n$. That is, for any function $f : \mathbb{R}^n \to {}^*_+\mathbb{R}$ the real and hyperreal parts of f are the functions f_{Re} and f_{Hy} given by

$$f_{Re} : (x^1, \dots, x^n) \mapsto Re(f(x^1, \dots, x^n)) \tag{9.25}$$

$$f_{Hy} : (x^1, \dots, x^n) \mapsto Hy(f(x^1, \dots, x^n)) \tag{9.26}$$

(Def. 9.1.4 can, of course, be extended to expanded real functions on any non-empty set X.)

Definition 9.1.11. *Let $\mathcal{R}^1(\mathbb{R}^n)$ be the set of Riemann integrable functions on $\mathbb{R}^n$, and let the set of all integrable expanded real functions on $\mathbb{R}^n$ be denoted by ${}^*_+\mathcal{R}^1(\mathbb{R}^n)$. Let, for positive integers n, a symbol $\alpha\delta^n_{(\beta_1,\dots,\beta_n)}$ denote a function $\alpha\delta^n_{(\beta_1,\dots,\beta_n)} : \mathbb{R}^n \to {}^*_+\mathbb{R}$ for which*

$$\alpha\delta^n_{(\beta_1,\dots,\beta_n)} : (x^1, \dots, x^n) \mapsto \alpha\delta_{\beta_1}(x^1)\delta_{\beta_2}(x^2)\cdots\delta_{\beta_n}(x^n) \tag{9.27}$$

Let $f : \mathbb{R}^n \to {}^*_+\mathbb{R}$; then $f \in {}^*_+\mathcal{R}^1(\mathbb{R}^n)$ ***if and only if***

$$f_{Re} \in \mathcal{R}^1(\mathbb{R}^n) \tag{9.28}$$

$$f_{Hy} = \sum_{j=1}^{\infty} \pi_{\sigma_j} g_j \tag{9.29}$$

where each π_{σ_j} is a permutation of variables and each function g_j satisfies

$$g_j : (x^1, \dots, x^n) \mapsto f_{n-k}(x^1, \dots, x^{n-k})\delta^k_{(\beta_1,\dots,\beta_k)}(x^{n-k+1}, \dots, x^n) \tag{9.30}$$

with $f_{n-k} \in \mathcal{R}^1(\mathbb{R}^{n-k})$ if $0 < n-k < n$ and $f_0 \in \mathbb{R}$ if $k = n$ and with $\delta^k_{(\beta_1,\dots,\beta_k)} = \delta^k_{(\beta_1(x^1,\dots,x^{n-k}),\dots,\beta_k(x^1,\dots,x^{n-k}))}$, ***and if*** *the sum of the integrals of* *the g_j's is finite:*

$$\sum_{j=1}^{\infty} \int_{-\infty}^{\infty} \cdots \int_{-\infty}^{\infty} g_j dx^1 \cdots dx^n = \sum_{j=1}^{\infty} s_j \in \mathbb{R} \tag{9.31}$$

■

Example 9.1.12. Let $n = 2$. Let the function $\alpha\delta^2_{(\beta_1,\beta_2)} : \mathbb{R}^2 \to {}^*_+\mathbb{R}$ be given by

$$\alpha\delta^2_{(\beta_1,\beta_2)} : (x^1, x^2) \mapsto \alpha\delta_{\beta_1}(x^1)\delta_{\beta_2}(x^2) \tag{9.32}$$

Then $\alpha\delta^2_{(\beta_1,\beta_2)}$ can be written as a tensor product: $\alpha\delta^2_{(\beta_1,\beta_2)} = \alpha\delta_{\beta_1} \otimes 1\delta_{\beta_2}$. For the integral of $\alpha\delta^2_{(\beta_1,\beta_2)}$ over $\mathbb{R}^2$ we then have

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \alpha\delta^2_{(\beta_1,\beta_2)}(x^1, x^2)dx^1dx^2 = \int_{-\infty}^{\infty} \alpha\delta^2_{\beta_1}(x^1)dx^1 \int_{-\infty}^{\infty} 1\delta_{\beta_2}(x^2)dx^2 = \alpha \tag{9.33}$$

■

Concluding, we have introduced hyperreal functions $\alpha\delta_\beta$ on the real line, and we have obtained the new mathematical result that in particular the hyperreal function δ_0 is an ordinary function on the real line that has all the properties of the Dirac delta, cf. Th. 9.1.8.[65] If we interpret the function value as a density, we can speak of *infinitely high densities* in those points where the function value is nonzero, since $|\alpha \cdot \omega| = \infty$ for any $\alpha \in \mathbb{R}$.

For the mathematical modeling of physical systems the newly introduced functions are advantageous compared to the existing objects that capture the idea of the Dirac delta: unlike these existing objects, the new functions enable one to model the state of a physical system in which infinitely high densities occur by representing the distribution of the density over space with a function on $\mathbb{R}^n$. This allows us to use them in a model of the EPT.

A true limitation of the present result is, however, that the set of integrable expanded-real functions on $\mathbb{R}$ is defined to be the set of expanded-real functions on $\mathbb{R}$ with a real-valued integral. An obvious generalization is to consider the set of expanded-real functions on $\mathbb{R}$ with a hyperreal-valued integral. A step in that direction will be suggested in Sect. 9.4, but we leave the generalization of Ax. 9.1.7 as a topic for further research.

9.2 The categorical model $\mathscr{C}_{SR}$

Pragmatic approach: pointillism

Recall from p. 399 that the aim here is to prove that the EPT agrees with SR *and nothing more than that.* This calls for a purely pragmatic approach: it is enough to specify the simplest categorical model of the EPT that reproduces SR. First of all, the definition of a reference frame of an observer can be taken from SR:

Definition 9.2.1 (IRF)**.** *The **reference frame of an inertial observer** is Minkowski space* $(\mathbb{R}^{1,3}, \eta)$ *with signature* $(-,+,+,+)$*. Such an inertial reference frame will henceforth be referred to by the acronym 'IRF'. For a point* $X = (x^0, x^1, x^2, x^3) \in \mathbb{R}^{1,3}$*, the real number* x^0 *is the time coordinate, the three real numbers* x^1, x^2, x^3 *are the spatial coordinates. **Planck units** are used: both Planck length and Planck time are scaled to 1.* ■

Def. 9.2.1 thus implies that the present categorical model of the EPT only applies for inertial observers: it is, thus, a presupposition that all observers are inertial observers. Furthermore, for the sake of simplicity we will use rectangular coordinates so that we can use the components $\eta_{\alpha\beta}$ of the metric tensor $\eta = \text{diag}(-1, 1, 1, 1)$.

Secondly, to show agreement with SR it suffices that the set-theoretic models of the EPT in the category $\mathscr{C}_{SR}$ are *pointillistic.* Originally referring to a technique in painting, the term 'pointillism' in physics is defined as

> "*the doctrine that a physical theory's fundamental quantities are defined at points of space or of spacetime, and represent intrinsic properties of such points or point-sized objects located there; so that properties of spatial or spatiotemporal regions and their material contents are determined by the point-by-point facts*—Butterfield (2006).

Thus speaking, a pointillistic model of the EPT is one in which the state of a phase quantum in the IRF of an observer at every moment of its existence is modeled as the state of a point particle. Butterfield made a case against pointillism (2006), but it is once more emphasized that we take a purely pragmatic approach in this study: the pointillistic model of the EPT is an *idealization* that is purely intended to prove agreement with SR—the model needs to be refined to have a wider area of application.

Applying the hyperreal Dirac delta functions to model hyperstates of phase quanta—see Rem. 7.3.2 for the definition of a hyperstate—we come to the following general postulate:

Postulate 9.2.2 (Pointillistic hyperstate postulate for $\mathscr{C}_{SR}$).
In the categorical model $\mathscr{C}_{SR}$ of the EPT, the hyperstate of a phase quantum with (possibly degenerate) time span $J \subset \mathbb{R}$ in the IRF of an observer $\mathcal{O}$ is represented by a function $f : \mathbb{R}^{1,3} \to {}^*_+\mathbb{R}$ for which

$$f : (t, x, y, z) \mapsto E \cdot \chi_J(t)\delta^3_{(r^1,r^2,r^3)}(x, y, z) \tag{9.34}$$

where E is an amount of energy c.q. mass and χ_J is the characteristic function of the interval J. That is, at every point of time $t \in J$, the energy c.q. mass E of the state of the temporal part of the phase quantum at t is distributed over the one point $(t, r^1(t), r^2(t), r^3(t)) \in \mathbb{R}^{1,3}$. ■

For the present categorical model of the EPT, the above hyperstate postulate is to be viewed as an equivalent of e.g. the state postulate of standard quantum mechanics, which states that a quantum state is represented by an element ψ of a Hilbert space $\mathscr{H}$ with norm $\|\psi\| = 1$—this goes back to Schrödinger's early works, e.g. (Schroedinger, 1926). Here we have that the state of a supersmall massive system at a time t^* in the IRF of an observer $\mathcal{O}$ is represented by a function $f_{t^*} : \{t^*\} \times \mathbb{R}^3 \to {}^*_+\mathbb{R}$, which is identical to the restriction of the hyperstate $f : \mathbb{R}^{1,3} \to {}^*_+\mathbb{R}$ of a phase quantum with time span $J \ni t^*$ to the "slice" $\{t^*\} \times \mathbb{R}^3$ of $\mathbb{R}^{1,3}$:

$$f_{t^*} = f \downarrow \{t^*\} \times \mathbb{R}^3 \ , \ f_{t^*}(t^*, x, y, z) = f(t^*, x, y, z) \tag{9.35}$$

Below, set-theoretic models of the EPT are specified in accordance with this pointillistic hyperstate postulate.

Last but not least, as in Ch. 6 we assume that all systems are *inanimate*. To prove that the EPT agrees with the knowledge of the outside world that derives from the successful predictions of SR, we are not concerned with the nuances that have been articulated in Ch. 7. Thus speaking, the model of the EPT specified in this chapter is *strictly deterministic*: it does not cover all aspects of the volitionistic universe of the EPT—its area of application is thus *also* limited to inanimate systems.

Objects of the category $\mathscr{C}_{SR}$

Below a *generic set-theoretic model* $M_{\mathbb{Z},\Omega,\mathcal{O}}$ of the EPT will be specified in accordance with Def. 8.1.2: this determines the objects of the category $\mathscr{C}_{SR}$, i.e., the categorical model $\mathscr{C}_{SR}$ of the EPT. In this generic set-theoretic model, the finite set Z_N of all integer-valued degrees of evolution—see Def. 5.2.1-(i) and Interpretation Rule 5.2.9—is modeled by the infinite set $\mathbb{Z}$ of all integers: we brush aside all philosophical objections since our present model is not meant to be applicable under the physical circumstances where the difference plays a role (Big Bang and Big Crunch).[66] Furthermore, the initial segments $I_{z(x)}$ of the positive integers—see Def. 5.2.1-(ii) and Interpretation Rule 5.2.10—are all interpreted as the initial segment I_Ω of positive integers up to and including Ω:

$$I_\Omega := \{1, 2, \ldots, \Omega\} \tag{9.36}$$

That means that in the world of the generic model $M_{\mathbb{Z},\Omega,\mathcal{O}}$, at every degree of evolution there are Ω elementary processes from that degree of evolution to the next. For the constant k in the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution, we thus have $k \in I_\Omega$. There is, thus, a class of concrete set-theoretic models for each value of Ω.

That being said, the specification of the generic set-theoretic model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ of the EPT consists of a number of *interpretations*, in which the pointillistic hyperstate postulate 9.2.2 is applied. These interpretations can be divided in two groups:

(i) interpretations of the abstract constants of the EPT, listed in Def. 5.2.5, as variables in the language $\mathcal{L}(\mathscr{C}_{SR})$ of the category $\mathscr{C}_{SR}$;

(ii) interpretations of the generalized process-physical principles of the EPT as true expressions in the language $\mathcal{L}(\mathscr{C}_{SR})$ of the category $\mathscr{C}_{SR}$.

A concrete set-theoretic model of the EPT—each is an object of the category $\mathscr{C}_{SR}$—is then obtained by assigning a constant value to the variables that interpret the abstract constants of the EPT in the generic set-theoretic model $M_{\mathbb{Z},\Omega,\mathcal{O}}$: in such a model, the axioms of the EPT and the universality of the speed of light are valid. The collection of objects of $\mathscr{C}_{SR}$ is then uncountably infinite. Which model applies to the physical world depends, then, on the system to be modeled.

Agreement 9.2.3. Greek indices α, β, etc. for the components of vectors and tensors can take all values from 0 to 3, but Roman indices i, j, k, etc. can only take a value from 1 to 3. So x^α can be any of the components of the 4-tuple $(x^0, ..., x^3)$, while x^j refers only to x^1, x^2, or x^3. Furthermore, $(x^0, ..., x^3)^\alpha$ denotes the α^{th} component of the 4-tuple $(x^0, ..., x^3)$. ■

Notation 9.2.4. Let $M_{\mathbb{Z},\Omega,\mathcal{O}}$ be a set-theoretic model of the EPT with interpretation function $I_{\mathbb{Z},\Omega,\mathcal{O}} : \mathcal{L}(EPT) \to \mathcal{L}(\mathscr{C}_{SR})$. For an abstract constant ϕ of the EPT, the expression

$$\phi \xrightarrow{\mathcal{O}} f \tag{9.37}$$

is then a notation for $I_{\mathbb{Z},\Omega,\mathcal{O}}(\phi) = f$. For an abstract constant ϕ referring to a phase quantum or a matter quantum, this has to be read as: 'the hyperstate of the phase quantum / matter quantum, designated by ϕ, in the IRF of the observer $\mathcal{O}$ is represented by f'. ■

Notation 9.2.4 is loosely based on a notation used by Schutz (1990). To interpret all abstract constants of the EPT, we simply start by interpreting the abstract constants $\mathfrak{m}_1, \ldots, \mathfrak{m}_\Omega$ on top of the list given by Def. 5.2.5, and then work our way down.

Interpretation 9.2.5 (Monads)**.**
For an integer $k \in I_\Omega$, the constant $\mathfrak{m}_k$ of the EPT designates the k^{th} monad. In the set-theoretic model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ of the EPT we then have

$$\mathfrak{m}_k \xrightarrow{\mathcal{O}} \{c_{\text{n}}^k, s_k\} \tag{9.38}$$

This has to be read as: 'the k^{th} monad, designated by $\mathfrak{m}_k$, is for the inertial observer $\mathcal{O}$ the pair set of the **characteristic number of normality** c_{n}^k and the **rest mass spectrum** s_k'. In the categorical model $\mathscr{C}_{SR}$, c_{n}^k is a number in the set $\{-1, 1\}$, and s_k is a constant function

$$s_k : \mathbb{Z} \to \mathbb{R}, s_k : n \mapsto m_0^k \tag{9.39}$$

that maps a degree of evolution n to the number $m_0^k > 0$, which is an inertial rest mass. ■

Note that Interpretation 9.2.5 is conform to the idea that a monad is an immaterial bundle of invariant properties, cf. Interpretation Rule 5.2.16.

Definition 9.2.6. *A* ***closed interval*** *is a subset* $[t_1, t_2] \subset \mathbb{R}$ *with* $t_1 \leq t_2$*. A* ***degenerate interval*** *is a closed interval* $[t_1, t_2]$ *with* $t_1 = t_2$*, that is, a singleton* $\{t_1\}$*. An* ***open ended interval*** *is a subset* $[t_1, t_2) \subset \mathbb{R}$ *with* $t_1 < t_2$*. An* ***open interval*** *is a subset* $(t_1, t_2) \subset \mathbb{R}$ *with* $t_1 < t_2$*. An* ***endless open interval*** *is a subset* $(t_1, \infty) \subset \mathbb{R}$*.* ■

In this categorical model of the EPT, a time span is represented by an interval, so 'a time span J' is short for 'a time span represented by the interval J'. The characteristic function of a time span J is denoted by χ_J.

Interpretation 9.2.7. The constant ${}^{EP}\mu^n_{\mathfrak{m}_k}$ of the EPT designates the extended particlelike matter quantum carrying the k^{th} monad at the n^{th} degree of evolution. In the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ we then have

$$ {}^{EP}\mu^n_{\mathfrak{m}_k} \xrightarrow{\mathcal{O}} {}^{EP}u^n_{\{c^k_{\mathrm{n}}, s_k\}} \tag{9.40}$$

$$ {}^{EP}u^n_{\{c^k_{\mathrm{n}}, s_k\}} : (t, x, y, z) \mapsto c^k_{\mathrm{n}} E^{EP}_{n,k} \chi_{\{t_{n,k}\}}(t) \delta^3_{(x_{n,k}, y_{n,k}, z_{n,k})}(x, y, z) \tag{9.41}$$

for a point $X_{n,k} = (t_{n,k}, x_{n,k}, y_{n,k}, z_{n,k}) \in \mathbb{R}^{1,3}$ and a real number $E^{EP}_{n,k} > 0$. So, the matter quantum ${}^{EP}\mu^n_{\mathfrak{m}_k}$ is modeled as the state ${}^{EP}u^n_{\{c^k_{\mathrm{n}}, s_k\}}$ of a **point particle** carrying the set of properties $\{c^k_{\mathrm{n}}, s_k\}$ at the point in time $t = t_{n,k}$ in the IRF of the observer $\mathcal{O}$. In this state, an amount of gravitational mass $c^k_{\mathrm{n}} E^{EP}_{n,k}$ is discretely distributed over the isolated point $X_{n,k}$. ■

Postulate 9.2.8. *To a state* ${}^{EP}u^n_k$ *is associated a 4-momentum* $\vec{p}^{\,EP}_{n,k}$ *with* $(\vec{p}^{\,EP}_{n,k})^0 = E^{EP}_{n,k} > 0$*, for which*

$$ \|\vec{p}^{\,EP}_{n,k}\| = \sqrt{-\eta(\vec{p}^{\,EP}_{n,k}, \vec{p}^{\,EP}_{n,k})} = s_k(n) = m^k_0 \tag{9.42}$$

with s_k *being the rest mass spectrum of the* k^{th} *monad.* ■

Interpretation 9.2.9. The constant ${}^{EP}\varphi^n_k$ of the EPT designates the extended particlelike phase quantum at the n^{th} degree of evolution in the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution. In the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ we then have

$$ {}^{EP}\varphi^n_k \xrightarrow{\mathcal{O}} {}^{EP}f^n_k \tag{9.43}$$

$$ \models {}^{EP}f^n_k = {}^{EP}u^n_{\{c^k_{\mathrm{n}}, s_k\}} \tag{9.44}$$

Here Eq. (9.44) models Analytic Postulate 5.3.8. ■

Remark 9.2.10 (Systems view, I)**.**
Alternatively, we can view the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ as a model of the universe, in which a countable number Ω of *monadic systems* (Def. 6.1.7) evolve in time by countable processes described by the EPT: the start and end times of each process can be labeled with degrees of evolution and with the counting number assigned to the monadic system. From that point of view,

(i) ${}^{EP}f_k^n$ is the *ground state* of the k^{th} monadic system in its process of temporal evolution starting at time $t = t_{n,k}$;

(ii) $\vec{p}_{n,k}^{\,EP}$ is the 4-momentum of the monadic system in the state ${}^{EP}f_k^n$.

■

Interpretation 9.2.11. The constant ${}^{NW}\varphi_k^n$ of the EPT designates the nonlocal wavelike phase quantum created at the n^{th} degree of evolution in the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution. In the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ there is then a (constant) 4-velocity $\vec{v}_{n,k}$ with $\|\vec{v}_{n,k}\| = 1$ and an open time span $J = (t_{n,k}, t_{n,k} + \delta t_{n,k})$ such that

$$
{}^{NW}\varphi_k^n \xrightarrow{\mathcal{O}} {}^{NW}f_k^n \tag{9.45}
$$

$$
{}^{NW}f_k^n : (t, x, y, z) \mapsto c_{\mathrm{n}}^k \cdot E_{n,k}^{NW}(t) \cdot \chi_J(t)\delta^3_{(r^1(t),r^2(t),r^3(t))}(x, y, z) \tag{9.46}
$$

where the energy $E_{n,k}^{NW}(t)$ can be expressed in terms of an initial energy $E_{n,k}^{NW}(t_{n,k})$ and a change $\delta E_{n,k}^{NW}$ by

$$
E_{n,k}^{NW}(t) = E_{n,k}^{NW}(t_{n,k}) + \frac{t - t_{n,k}}{\delta t_{n,k}} \delta E_{n,k}^{NW} \tag{9.47}
$$

and where the component $r^j(t)$ of the three-tuple $(r^1(t), r^2(t), r^3(t))$ in Eq. (9.46) is related to the point $X_{n,k}$ of Int. 9.2.9 by

$$
r^j(t) = (X_{n,k})^j + \frac{t - t_{n,k}}{\delta t_{n,k}} v_{n,k}^j \tag{9.48}
$$

So, the phase quantum ${}^{NW}\varphi_k^n$ is modeled as the hyperstate ${}^{NW}f_k^n$ of a **time-like string** with open time span $(t_{n,k}, t_{n,k} + \delta t_{n,k})$ and constant 4-velocity $\vec{v}_{n,k}$ in the IRF of $\mathcal{O}$. The spatiotemporal extension of this time-like string is the open line segment $\overline{\delta X}_{n,k} = \{X_{n,k} + \tau \cdot \vec{v}_{n,k} \in \mathbb{R}^{1,3} \mid \tau \in (0,1)\}$. ■

Postulate 9.2.12. *At every point t in its time span $(t_{n,k}, t_{n,k} + \delta t_{n,k})$, to the temporal part of the time-like string at t is associated a **4-momentum** $\vec{p}_{n,k}^{\,NW}(t)$ for which*

$$(\vec{p}_{n,k}^{\,NW}(t))^0 = E_{n,k}^{NW}(t) > 0 \tag{9.49}$$

$$\|\vec{p}_{n,k}^{\,NW}(t)\| = \sqrt{-\eta(\vec{p}_{n,k}^{\,NW}(t), \vec{p}_{n,k}^{\,NW}(t))} = m_{n,k}^*(t) \geq s_k(n) = m_0^k \tag{9.50}$$

with $m_{n,k}^*(t)$ being the inertial rest mass of the temporal part of the time-like string at the time $t \in (t_{n,k}, t_{n,k} + \delta t_{n,k})$, and s_k being the inertial rest mass spectrum of the k^{th} monad. ■

Remark 9.2.13 (Systems view, II).
Given the hyperreal function ${}^{NW}f_k^n : \mathbb{R}^{1,3} \to {}^*_+\mathbb{R}$ representing the hyperstate of a time-like string, we have for any $t \in (t_{n,k}, t_{n,k} + \delta t_{n,k})$ that the restriction of this function to a "slice" $\{t\} \times \mathbb{R}^3$, to be denoted ${}^{NW}f_k^n \downarrow \{t\} \times \mathbb{R}^3$, represents a state of the temporal part of the time-like string at t: this can be viewed as a transition state of a monadic system. In the language of systems theory, we then have the following:

(i) ${}^{NW}f_k^n \downarrow \{t\} \times \mathbb{R}^3$ is the *transition state* of the k^{th} monadic system at the time t in its process of temporal evolution that started at time $t = t_{n,k}$;

(ii) $\vec{v}_{n,k}$ is the constant 4-velocity of the k^{th} monadic system in its transition state throughout its lifetime, and $\vec{p}_{n,k}^{\,NW}(t)$ is its 4-momentum at the time $t \in (t_{n,k}, t_{n,k} + \delta t_{n,k})$;

(iii) $c_{\mathrm{n}}^k \cdot E_{n,k}^{NW}(t)$ is the gravitational mass of the k^{th} monadic system in its transition state at any time $t \in (t_{n,k}, t_{n,k} + \delta t_{n,k})$.

So, the transition state of the k^{th} monadic system has a lifetime $\delta t_{n,k}$: in the open time span $(t_{n,k}, t_{n,k} + \delta t_{n,k})$, the monadic system can be viewed as a *wave traveling in a straight line* with **constant** 4-velocity $(\vec{v}_{n,k})^j$. Inertial rest mass m_i and 4-momentum $\vec{p}$ are, in general, time-dependent:

$$\begin{cases} m_i = m_{n,k}^*(t) \\ \vec{p} = \vec{p}_{n,k}^{\,NW}(t) \end{cases} \tag{9.51}$$

The function ${}^{NW}f_k^n$ represents the hyperstate of the segment of the life of the k^{th} monadic system with open time span $(t_{n,k}, t_{n,k} + \delta t_{n,k})$. ■

Interpretation 9.2.14. The constant $\psi^n_{\mathfrak{m}_k}$ of the EPT designates the monadic occurrent carrying the k^{th} monad from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution. In the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ we then have

$$\psi^n_{\mathfrak{m}_k} \xrightarrow{\mathcal{O}} S^n_{\{c^k_{\text{n}}, s_k\}} \tag{9.52}$$

$$\models \; {}^{EP}u^n_{\{c^k_{\text{n}}, s_k\}} + {}^{NW}f^n_k = S^n_{\{c^k_{\text{n}}, s_k\}} \tag{9.53}$$

for a hyperreal function $S^n_{\{c^k_{\text{n}}, s_k\}} : \mathbb{R}^{1,3} \to {}^*_+\mathbb{R}$. So, the monadic occurrent $\psi^n_{\mathfrak{m}_k}$ is modeled as the hyperstate $S^n_{\{c^k_{\text{n}}, s_k\}}$ carrying the set of properties $\{c^k_{\text{n}}, s_k\}$ in the open-ended time span $[t_{n,k}, t_{n,k} + \delta t_{n,k})$ in the IRF of the observer $\mathcal{O}$. The hyperstate $S^n_{\{c^k_{\text{n}}, s_k\}}$ is thus the state ${}^{EP}u^n_{\{c^k_{\text{n}}, s_k\}}$ followed by the hyperstate ${}^{NW}f^n_k$. Thus speaking, Eq. 9.53 models the Generalized Principle of Particle/Wave Duality 5.3.11. ■

Remark 9.2.15 (Systems view, III)**.**
In the language of systems theory, the hyperstate $S^n_{\{c^k_{\text{n}}, s_k\}}$ can be viewed as the hyperstate of the segment of the life of the k^{th} monadic system with open-ended time span $[t_{n,k}, t_{n,k} + \Delta t_{n,k})$. As in Rem. 9.2.13, for any point in time $t \in (t_{n,k}, t_{n,k} + \delta t_{n,k})$ the restriction of this hyperstate to the “slice” $\{t\} \times \mathbb{R}^3 \subset \mathbb{R}^{1,3}$ can be viewed as either the ground state of the k^{th} monadic system (in which case $t = t_{n,k}$) or as a transition state of the k^{th} monadic system (in which case $t > t_{n,k}$). ■

Interpretation 9.2.16. The constant ${}^{NP}\mu^{n+1}_{\mathfrak{m}_k}$ of the EPT designates the nonextended particlelike matter quantum carrying the k^{th} monad at the $(n+1)^{\text{th}}$ degree of evolution. Let $X_{n+1,k} \in \mathbb{R}^{1,3}$ satisfy the condition $\|X_{n+1,k} - X_{n,k}\| = 1$; writing $(X_{n+1,k})^j = r^j$, in the model $M_{\mathbb{Z},\omega,\mathcal{O}}$ we then have

$${}^{NP}\mu^{n+1}_{\mathfrak{m}_k} \xrightarrow{\mathcal{O}} {}^{NP}u^{n+1}_{\{c^k_{\text{n}}, s_k\}} \tag{9.54}$$

$${}^{NP}u^{n+1}_{\{c^k_{\text{n}}, s_k\}} : (t, x, y, z) \mapsto c^k_n E^{NP}_{n+1,k} \chi_{\{t_{n+1,k}\}}(t) \delta^3_{(r^1, r^2, r^3)}(x, y, z) \tag{9.55}$$

for a hyperreal function ${}^{NP}u^{n+1}_{\{c^k_{\text{n}}, s_k\}} : \mathbb{R}^{1,3} \to {}^*_+\mathbb{R}$. So, the matter quantum ${}^{NP}\mu^{n+1}_{\mathfrak{m}_k}$ is modeled as the state ${}^{NP}u^{n+1}_{\{c^k_{\text{n}}, s_k\}}$ of a **point particle** carrying the set of properties $\{c^k_{\text{n}}, s_k\}$ at $t = t_{n+1,k}$ in the IRF of $\mathcal{O}$. In this state, an amount of gravitational mass $c^k_n \cdot E^{NP}_{n+1,k}$ is discretely distributed over the spatiotemporal position $X_{n+1,k}$. ■

Postulate 9.2.17. *To a state* ${}^{NP}u^{n+1}_{\{c^k_n, s_k\}}$ *is associated a 4-momentum* $\vec{p}^{\,NP}_{n+1,k}$ *with* $(\vec{p}^{\,NP}_{n+1,k})^0 = E^{NP}_{n+1,k}$ *for which*

$$\|\vec{p}^{\,NP}_{n+1,k}\| = \sqrt{-\eta(\vec{p}^{\,NP}_{n+1,k}, \vec{p}^{\,NP}_{n+1,k})} = m^*_{n+1,k} \geq s_k(n+1) \tag{9.56}$$

with $m^*_{n+1,k}$ *being the* ***inertial rest mass*** *of the point particle.* ■

Interpretation 9.2.18. The constant ${}^{NP}\varphi^{n+1}_k$ of the EPT designates the nonextended particlelike phase quantum at the $(n+1)^{\text{th}}$ degree of evolution in the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution. In the model $M_{\mathbb{Z},\omega,\mathcal{O}}$ we then have

$$ {}^{NP}\varphi^{n+1}_k \xrightarrow{\mathcal{O}} {}^{NP}f^{n+1}_k \tag{9.57}$$
$$ \models {}^{NP}f^{n+1}_k = {}^{NP}u^{n+1}_{\{c^k_n, s_k\}} \tag{9.58}$$

Here Eq. (9.58) models Analytic Postulate 5.3.15. ■

Remark 9.2.19 (Systems view, IV)**.**
In the language of systems theory,

(i) ${}^{NP}f^{n+1}_k$ is the *excited state* of the k^{th} monadic system in its process of temporal evolution that started at time $t = t_{n,k}$;

(ii) $\vec{p}^{\,NP}_{n+1,k}$ is the 4-momentum of the k^{th} monadic system in that excited state;

(iii) $c^k_n \cdot E^{NP}_{n+1,k}$ is its gravitational mass;

(iv) $m^*_{n+1,k}$ is its inertial rest mass.

Furthermore, Eq. (9.58) guarantees that this excited state ${}^{NP}f^{n+1}_k$ has only one component. ■

With that all the phase quanta that translate into states of a monadic system are interpreted. But it doesn't follow from the foregoing that, for example, given the position $X_{n,k}$ of the ground state of the k^{th} monadic system at time $t = t_{n,k}$, the position $X_{n+1,k}$ of its excited state at time $t = t_{n+1,k}$, and the constant 4-velocity $\vec{v}_{n,k} = dX/d\tau$ of its transition state in the time span $(t_{n,k}, t_{n+1,k})$, we have $X_{n+1,k} = X_{n,k} + 1 \cdot \vec{v}_{n,k}$. We still have to interpret the generalized principles of the EPT: only that will provide a link between the properties of the various phase quanta.

Interpretation 9.2.20. The constant ${}^{LW}\varphi_k^{n+1}$ of the EPT designates the local wavelike phase quantum created at the $(n+1)^{\text{th}}$ degree of evolution in the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution. In the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ there is then an interval $J = (t_{n+1,k}, t_{\text{end}}]$ and a null vector $\vec{v} = (1, v^1, v^2, v^3)$ with $\eta(\vec{v}, \vec{v}) = 0$ such that

$$ {}^{LW}\varphi_k^{n+1} \xrightarrow{\mathcal{O}} \gamma_k^{n+1} \tag{9.59} $$

$$ \gamma_k^{n+1} : (t, x, y, z) \mapsto E_{n+1,k}^{LW} \cdot \chi_J(t)\delta^3_{(r^1(t),r^2,t,r^3(t))}(x, y, z) \tag{9.60} $$

where the component $r^j(t)$ in the three-tuple $(r^1(t), r^2, t, r^3(t))$ in Eq. (9.60) is given by

$$ r^j(t) = (X_{n+1,k})^j + (t - t_{n+1,k}) \cdot v^j \tag{9.61} $$

Thus speaking, the phase quantum ${}^{LW}\varphi_k^{n+1}$ is modeled as the hyperstate γ_k^{n+1} of a **null string** with time span $(t_{n+1,k}, t_{\text{end}}]$ in the IRF of the observer $\mathcal{O}$. The line segment $\ell^\gamma_{n+1,k} = \{X_{n+1,k} + (t - t_{n+1,k}) \cdot \vec{v} \mid t \in (t_{n+1,k}, t_{\text{end}}]\}$ is the spatiotemporal extension of the null string. If (the temporal part of) the null string at a time $t > t_{n+1,k}$ gets captured, then t_{end} in the interval $(t_{n+1,k}, t_{\text{end}}]$ has the finite real value t; if no capture takes place, then we have $(t_{n+1,k}, t_{\text{end}}] = (t_{n+1,k}, \infty)$. ■

Postulate 9.2.21. *At every point $X(t) \in \ell^\gamma_{n+1,k}$, a **4-momentum** $\vec{p}^{\,LW}_{n+1,k}$ with $(\vec{p}^{\,LW}_{n+1,k})^0 = E^{LW}_{n+1,k}$ is associated to the null string for which*

$$ \eta(\vec{p}^{\,LW}_{n+1,k}, \vec{p}^{\,LW}_{n+1,k}) = 0 \tag{9.62} $$

■

Remark 9.2.22 (Systems view, V)**.**
Given the hyperreal function $\gamma_k^{n+1} : \mathbb{R}^{1,3} \to {}^*_+\mathbb{R}$ representing the hyperstate of a null string, we have for any $t \in (t_{n+1,k}, t_{\text{end}}]$ that the restriction of this function to a "slice" $\{t\} \times \mathbb{R}^3$, denoted by $\gamma_k^{n+1} \downarrow \{t\} \times \mathbb{R}^3$, represents a state of the temporal part of the null string at t. In the language of systems theory, we then have the following:

(i) $\gamma_k^{n+1} \downarrow \{t\} \times \mathbb{R}^3$ is the state at the time t of the photon emitted by the k^{th} monadic system in its process of temporal evolution that started at time $t = t_{n,k}$;

(ii) $\vec{p}^{\,LW}_{n+1,k}$ is the 4-momentum of the photon.

This implements a ray theory of light in this model, with the front of the ray being a photon—a massless point particle. We thus conveniently ignore that phenomena like interference and diffraction require wave theory. But recall that the aim is to show that the EPT agrees with SR: in the framework of SR, photons are massless point particles too! ■

Interpretation 9.2.23. The constant ${}^S\varphi_k^{n+1}$ designates the spatial phase quanta created at the $(n+1)^{\text{th}}$ degree of evolution in the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution. Let $0_{\mathbb{R}^{1,3}}$ be the zero function on $\mathbb{R}^{1,3}$; in the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ we then have

$$ {}^S\varphi_k^{n+1} \xrightarrow{\mathcal{O}} {}^S f_k^{n+1} \tag{9.63} $$

$$ \models \; {}^S f_k^{n+1} = 0_{\mathbb{R}^{1,3}} \tag{9.64} $$

meaning that the spatial phase quanta are nonexisting, which is consistent with SR. The Generalized Principle of Formation of Space, Ax. 5.3.18, is thus trivially true in the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ of the EPT. ■

As to the formation of space, in this model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ of the EPT we have on the one hand that local wavelike phase quanta *do* exist, but on the other hand that spatial phase quanta *do not* exist. In other words, it is assumed that no spatial phase quanta are formed from those local wavelike phase quanta that exist in this model. This assumption is perhaps best explained from the systems view. In general, the radiation emitted by a monadic system at the final event of each process in its temporal evolution is made up of a photon, which accounts for a loss in spatial momentum, and a spherically symmetric matter wave, which accounts for a loss of gravitational rest mass—see p. 267. In the present model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ of the EPT, however, we have assumed by Int. 9.2.5 that all rest mass spectra are constant functions: that means that no loss of gravitational rest mass occurs, and that means that no spherically symmetric matter waves are emitted. But the idea is that of these two components of the emitted radiation (photons and spherically symmetric matter waves), only these spherically symmetric matter waves gradually form space: we therefore have that spatial phase quanta do not exist in the present model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ of the EPT—the existing photons do not form space!

Interpretation 9.2.24. The constant Θ_k^{n+1} designates the set of parallel possible nonextended particlelike phase quanta at the $(n+1)^{\text{th}}$ degree of evolution in the k^{th} individual process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution. Let U_k^{n+1} be the set of all positions in the future lightcone of $X_{n,k}$ whose spatiotemporal separation from $X_{n,k}$ is a Planck unit:

$$U_k^{n+1} = \{U = (u^0, u^1, u^2, u^3) \mid u^0 > t_{n,k} \wedge \|U - X_{n,k}\| = 1\} \tag{9.65}$$

We then have $X_{n+1,k} \in U_k^{n+1}$ because $\|X_{n+1,k} - X_{n,k}\| = 1$ has been assumed in Int. 9.2.16. For every $U \in U_K^{n+1}$ there is then a hyperreal function $f(U)$ on $\mathbb{R}^{1,3}$ modeling the state of the nonextended particlelike phase quanta at the $(n+1)^{\text{th}}$ degree of evolution in the k^{th} individual process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution *if it would have ended up at the spatiotemporal position* U:

$$f(U) : (t, x, y, z) \mapsto c_n^k \cdot E(U) \cdot \chi_{\{u^0\}}(t) \cdot \delta^3_{(u^1,u^2,u^3)}(x, y, z) \tag{9.66}$$

where $E(U)$ is uniquely determined by U and the initial conditions of the process. Of course, $f(X_{n+1}^k) = {}^{NP}f_k^{n+1}$. Now we collect all these functions in a set $T_k^{n+1} = \{f(U) \mid U \in U_k^{n+1}\}$. In the model $M_{\mathbb{Z},\omega,\mathcal{O}}$ we then have

$$\Theta_k^{n+1} \xrightarrow{\mathcal{O}} T_k^{n+1} \tag{9.67}$$

That is, the set of parallel possible nonextended particlelike phase quanta at the $(n+1)^{\text{th}}$ degree of evolution in the k^{th} individual process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution is modeled by a set of point-particle states at positions separated by a Planck unit from $X_{n,k}$. ■

Interpretation 9.2.25. The constant $f_{(\Theta_k^{n+1})^+}$ designates the choice function on the set of parallel possible nonextended particlelike phase quanta at the $(n+1)^{\text{th}}$ degree of evolution in the k^{th} individual process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution. In the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ we then have

$$f_{(\Theta_k^{n+1})^+} \xrightarrow{\mathcal{O}} f_{(T_k^{n+1})^+} \tag{9.68}$$

$$\models f_{(T_k^{n+1})^+}(T_k^{n+1}) \in T_k^{n+1} \tag{9.69}$$

That is, the ur-function $f_{(T_k^{n+1})^+}$ "chooses" an element from the set T_k^{n+1}, i.e. the set $\{f(U) \mid U \in U_k^{n+1}\}$. ■

Remark 9.2.26 (Systems view, VI)**.**
At the moment in time $t = t_{n,k}$ when the k^{th} monadic system is in its ground state ${}^{EP}f_k^n$, we thus have that its next excited state can be any of the states $f(U) \in T_k^{n+1}$. During the process of its temporal evolution that begins with the existence of the ground state, a choice is made: the "chosen" state $f_{(T_k^{n+1})^+}(T_k^{n+1})$ is thus its next excited state ${}^{NP}f_k^{n+1}$. ■

At this point all abstract constants of the EPT of Def. 5.2.5 have been interpreted. That means that we are now ready to model the generalized process-physical principles of the EPT. We then opt for the hidden-variable formulation of the EPT, given on p. 311: we will, thus, use a constant γ from the set of functions $\{\gamma_k^{n+1} \mid n \in \mathbb{Z}, k \in I_\Omega\} \supset \{0_{\mathbb{R}^{1,3}}\}$ to formulate an expression that models Eq. (6.150), the Generalized Principle of Nonlocal Equilibrium with hidden variable, *after* the hidden variable λ has been eliminated by rule-C. Some remarks are added that treat a model of a generalized principle in the language of systems theory.

Definition 9.2.27. *All abstract constants in the set* G *of clause (ii) of Def. 5.2.5 being interpreted, let* $G_{\mathbb{Z},\Omega,\mathcal{O}}$ *be the set*

$$G_{\mathbb{Z},\Omega,\mathcal{O}} = \{{}^{EP}f_k^n,\ {}^{NW}f_k^n,\ {}^{NP}f_k^{n+1}, \gamma_k^{n+1},\ {}^{S}f_k^{n+1} \mid n \in Z,\ k \in I_\Omega\} \quad (9.70)$$

The free semigroup G^+ *on the set* G *under addition of Def. 5.2.5-(ii) is then modeled by* $\langle G_{\mathbb{Z},\Omega,\mathcal{O}}\rangle$*, which is the commutative monoid generated by the set* $G_{\mathbb{Z},\Omega,\mathcal{O}}$ *under function addition, with*

$$f + g : X \mapsto f(X) + g(X) \quad (9.71)$$

for any $f, g \in \langle G_{\mathbb{Z},\Omega,\mathcal{O}}\rangle$*. Note that* ${}^{EP}u^n_{\{c_n^k, s_k\}}, S^n_{\{c_n^k, s_k\}},\ {}^{NP}u^n_{\{c_n^k, s_k\}} \in \langle G_{\mathbb{Z},\Omega,\mathcal{O}}\rangle$ *by Eqs.* (9.44), (9.53), *and* (9.58). ■

Interpretation 9.2.28 (Generalized Existential Axiom)**.**
For integers $n \in \mathbb{Z}$ and $k \in I_\Omega$, in the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ the expression

$$\models\ \mathbb{E}\ {}^{EP}f_k^n \quad (9.72)$$

models the Generalized Existential Axiom of the EPT, Ax. 5.3.2. ■

Remark 9.2.29 (Systems view, VII).
In the language of systems theory, Eq. (9.72) means that the ground state of the k^{th} monadic system, which marks the beginning of the process of its temporal evolution that starts at time $t_{n,k}$, exists for any $k \in I_\Omega$ and at any degree of evolution $n \in \mathbb{Z}$. ■

Interpretation 9.2.30 (Generalized Exclusion Principle).
Let the variable f range over the monoid $\langle G_{\mathbb{Z},\Omega,\mathcal{O}}\rangle$ of Def. 9.2.27. In the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ the expression

$$\models \neg\mathbb{E}f + f \tag{9.73}$$

models Analytic Postulate 5.3.4, the Generalized Exclusion Principle. ■

A corollary is that for any $n \in \mathbb{Z}$ and any $k \in I_\Omega$, in the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ we have

$$\models \ {}^{EP}f_k^n \neq 0_{\mathbb{R}^{1,3}} \tag{9.74}$$

Interpretation 9.2.31 (Generalized Principle of Nonlocal Equilibrium).
For integers $n \in \mathbb{Z}$ and $k \in I_\Omega$, in the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ the expression

$$\models \ {}^{EP}f_k^n + \gamma \rightarrow {}^{NW}f_k^n \tag{9.75}$$

models the Generalized Principle of Nonlocal Equilibrium, the second of seven axioms of the EPT, in the hidden-variable formulation of p. 311. The null string $\gamma \in \{\gamma_k^{n+1} \mid n \in \mathbb{Z}, k \in I_\Omega\} \cup \{0_{\mathbb{R}^{1,3}}\}$ satisfies

$$\ell^\gamma \ni X_{n,k} \tag{9.76}$$

where ℓ^γ is, for some $p \in \mathbb{Z}$ and $q \in I_\Omega$, the spatiotemporal extension $\ell_{p,q}^\gamma$ of the null string γ as defined by Int. 9.2.20—the null string γ thus has a time span $(t_{p,q}, t_{\text{end}}]$ with $t_{\text{end}} = t_{n,k} = (X_{n,k})^0$. The (time-dependent) 4-momentum $\vec{p}_{n,k}^{\,NW}(t)$ associated to the timelike string ${}^{NW}f_k^n$ satisfies

$$\models \lim_{t \downarrow t_{n,k}} \vec{p}_{n,k}^{\,NW}(t) = \vec{p}_{n,k}^{\,NW}(t_{n,k}) = \vec{p}_{n,k}^{\,EP} + \vec{p}_{n,k}^{\,\gamma} \tag{9.77}$$

where $\vec{p}_{n,k}^{\,\gamma}$ is the (possibly zero) 4-momentum of the γ-ray captured at the initial event. ■

Remark 9.2.32 (Systems view, VIII).
In the language of systems theory, Eq. (9.75) means that, for arbitrary $k \in I_\Omega$ and $n \in \mathbb{Z}$, the first event in the process of temporal evolution of the k^{th} monadic system that starts at time $t = t_{n,k}$, is that a state transition takes place by which the k^{th} monadic system spontaneously transforms from a ground state ${}^{EP}f_k^n$, located at the spatiotemporal position $X_{n,k}$ with momentum $\vec{p}_{n,k}^{\,EP}$, to a linearly progressing transition state with lifetime $\delta t_{n,k}$ and constant 4-velocity $\vec{v}_{n,k}$. At this event, a photon with 4-momentum $\vec{p}_{n,k}^{\,\gamma}$ may be captured. If so, that is, if $\vec{p}_{n,k}^{\,\gamma} \neq \vec{0}$, then the photon ceases to exist at $t = t_{n,k}$. ■

Remark 9.2.33 (Generalized Principle of Particle/Wave Duality).
In the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ the Generalized Principle of Particle/Wave Duality, Ax. 5.3.11, has already been modeled by Eq. (9.53) of Interpretation 9.2.14, which is repeated below:

$$\models\ {}^{EP}f_k^n + {}^{NW}f_k^n = S^n_{\{c^k_{\mathrm{n}}, s_k\}} \tag{9.53}$$

■

Interpretation 9.2.34 (Generalized Principle of Nonlocal Mediation).
For integers $n \in \mathbb{Z}$ and $k \in I_\Omega$, in the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ the expression

$$\models\ {}^{NW}f_k^n :\ {}^{EP}f_k^n \dashrightarrow {}^{NP}f_k^{n+1} \tag{9.78}$$

models the Generalized Principle of Nonlocal Mediation, Ax. 5.3.12. The 4-momentum $\vec{p}_{n+1,k}^{\,NP}$ associated to the state ${}^{NP}f_k^{n+1}$ satisfies

$$\models\ \vec{p}_{n+1,k}^{\,NP} = \lim_{t \to t_{n,k} + \delta t_{n,k}} \vec{p}_{n,k}^{\,NW}(t) \tag{9.79}$$

■

Remark 9.2.35 (Systems view, IX).
In the language of systems theory Eq. (9.75) means that, for arbitrary $k \in I_\Omega$ and $n \in \mathbb{Z}$, in the process of temporal evolution of the k^{th} monadic system that starts at time $t = t_{n,k}$, the life of the k^{th} monadic system in a transition state ${}^{NW}f_k^n$ effects that its ground state ${}^{EP}f_k^n$, which is a ground state with $\|\vec{p}_{n,k}^{\,EP}\| = m_0^k$, is succeeded by the excited state ${}^{NP}f_k^{n+1}$ with $\|\vec{p}_{n+1,k}^{\,NP}\| = m^*_{n,k} \geq m_0^k$. ■

Interpretation 9.2.36 (Generalized Principle of Choice).
Let $\psi : T_k^{n+1} \to U_k^{n+1}$ be the bijection between the set of possible states T_k^{n+1} and the set of possible positions U_k^{n+1}, cf. Int. 9.2.24. Writing $\delta X_{n,k} = \lim_{\tau \to 1} \tau \cdot \vec{v}_{n,k}$, for any $n \in \mathbb{Z}$ and $k \in I_\Omega$ the expression

$$\models \ {}^{NP}f_k^{n+1} = f_{(T_k^{n+1})^+}(T_k^{n+1}) = \psi^{-1}(X_{n,k} + \delta X_{n,k}) \tag{9.80}$$

then models the Generalized Principle of Choice, Ax 5.3.13, in the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$; see Fig. 9.1 for an illustration. ■

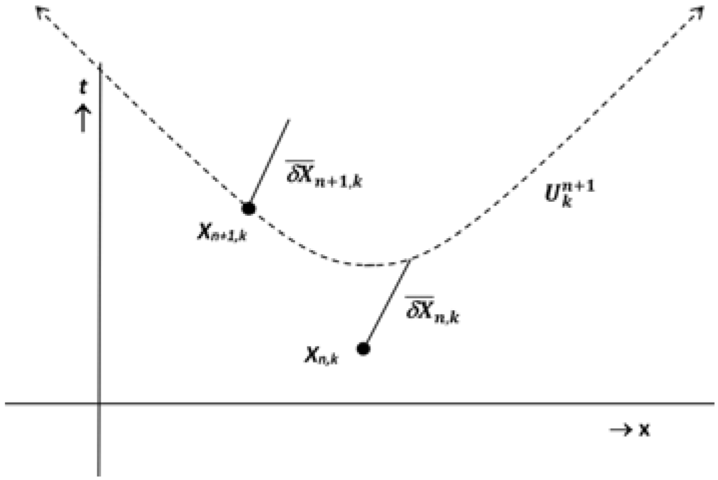


Figure 9.1: Spacetime diagram illustrating the elementary principle of choice, Eq. (9.80). The black dot in the lower middle represents the position $X_{n,k}$ of the point-particle states ${}^{EP}f_k^n$, and the adjacent diagonal line segment the spatiotemporal extension $\overline{\delta X}_{n,k}$ of the hyperstate ${}^{NW}f_k^n$ of the time-like string. The dotted hyperbola represents the set U_k^{n+1} of those positions that at $t = t_{n,k} = (X_{n,k})^0$ were possible positions for the point-particle state succeeding the hyperstate of the time-like string that succeeds the point-particle state ${}^{EP}f_k^n$. The spacetime diagram now shows a discontinuity: **without** the principle of choice there is no guarantee that $X_{n+1,k} = X_{n,k} + \delta X_{n,k}$, so the state transition from the hyperstate ${}^{NW}f_k^n$ to the point-particle state ${}^{NP}f_k^{n+1}$ at the position $X_{n+1,k}$ could then involve a discontinuity as shown in the diagram. But the principle of choice, as given by Int. 9.2.36, guarantees that we have $X_{n+1,k} = X_{n,k} + \delta X_{n,k}$ and thus that **no such discontinuity occurs**. So in the IRF of the observer $\mathcal{O}$, the particle state ${}^{NP}f_k^{n+1}$ is located at the position $X \in U_k^{n+1}$ that is the boundary point at $t = t_{n+1,k}$ of the spatiotemporal extension $\overline{\delta X}_{n,k}$ of the hyperstate ${}^{NW}f_k^n$ of the time-like string.

Interpretation 9.2.37 (Generalized Principle of Local Equilibrium).
For integers $n \in \mathbb{Z}$ and $k \in I_\Omega$, in the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ the expression

$$\models \ {}^{NP}f_k^{n+1} \to \ {}^{EP}u^{n+1}_{\{c^k_{\mathrm{n}}, s_k\}} + \gamma_k^{n+1} \tag{9.81}$$

models the Elementary Principle of Local Equilibrium, Ax. 5.3.16. The associated 4-momenta satisfy

$$\models \ \vec{p}^{\,NP}_{n+1,k} - \vec{p}^{\,LW}_{n+1,k} = \vec{p}^{\,EP}_{n+1,k} \tag{9.82}$$

$$\models \ \delta\vec{p}_{n,k} = \vec{p}^{\,\gamma}_{n,k} - \vec{p}^{\,LW}_{n+1,k} \tag{9.83}$$

where $\vec{p}^{\,\gamma}_{n,k}$ is the (possibly zero) 4-momentum of the null string captured at the initial event of the process and $\delta\vec{p}_{n,k}$ is the 4-impulse associated to the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution. ■

Remark 9.2.38 (Systems view, IX).
In the language of systems theory, Int. (9.2.37) means for arbitrary $k \in I_\Omega$ and $n \in \mathbb{Z}$ that the k^{th} monadic system receives a 4-impulse $\delta\vec{p}_{n,k}$ at time $t_{n+1,k} = (X_{n+1,k})^0$ by the 4-momentum-preserving decay of the excited state ${}^{NP}f_k^{n+1}$ into the ground state ${}^{EP}u^{n+1}_{\{c^k_{\mathrm{n}}, s_k\}}$, which is the ground state of the k^{th} massive system in its next process of temporal evolution, and a photon, whose life has a hyperstate γ_k^{n+1} in the IRF of $\mathcal{O}$. ■

Interpretation 9.2.39 (Generalized Principle of Formation of Space).
For integers $n \in \mathbb{Z}$ and $k \in I_\Omega$, in the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ the expression

$$\models \ \mathbb{E}\gamma_k^{n+1} \Leftarrow \ \neg\mathbb{E} \ {}^{S}f_k^{n+1} \tag{9.84}$$

trivially models the Generalized Principle of Formation of Space, Ax. 5.3.18.
■

Interpretation 9.2.40 (Inference Rules).
In the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$ the expressions

$$\mathbb{E}\alpha, \alpha \to \beta \models \mathbb{E}\beta \tag{9.85}$$

$$\mathbb{E}\alpha, \mathbb{E}\beta, \alpha : \beta \dashrightarrow \gamma \models \mathbb{E}\gamma \tag{9.86}$$

model the inference rules (5.18) and (5.19). ■

This completes the specification of the generic set-theoretic model of the

EPT. There is, then, a concrete set-theoretic model, i.e. an object of the category $\mathscr{C}_{SR}$, for each possible value of the constants of the generic model.

Summarizing, in view of Def. 8.1.2 a concrete set-theoretic model of the EPT with interpretation function $I_{\mathbb{Z},\Omega,\mathcal{O}} : \mathcal{L}(EPT) \to \mathcal{L}(\mathscr{C}_{SR})$ is a structure $(|M_{\mathbb{Z},\Omega,\mathcal{O}}|, I_{\mathbb{Z},\Omega,\mathcal{O}}(R_1), I_{\mathbb{Z},\Omega,\mathcal{O}}(R_2), I_{\mathbb{Z},\Omega,\mathcal{O}}(R_3))$ for which

(i) the set $|M_{\mathbb{Z},\Omega,\mathcal{O}}|$, the universe of the model, is the union of:

- the set $\{I_{\mathbb{Z},\Omega,\mathcal{O}}(\mathfrak{m}_k) \mid k \in I_\Omega\}$, whose elements represent monads as determined by Interpretation 9.2.5;
- the set $\langle G_{\mathbb{Z},\Omega,\mathcal{O}}\rangle$ of Def. 9.2.27, whose elements represent hyperstates of phase quanta c.q. matter quanta, or superpositions of such hyperstates, in the reference frame of an inertial observer;
- the set $\{I_{\mathbb{Z},\Omega,\mathcal{O}}(\Theta_k^{n+1}) \mid n \in \mathbb{Z}, k \in I_\Omega\}$, whose elements represent sets of parallel possible states of nonextended particlelike matter quanta as determined by Interpretation 9.2.24;
- the set $\{I_{\mathbb{Z},\Omega,\mathcal{O}}(f_{(\Theta_k^{n+1})^+}) \mid n \in \mathbb{Z}, k \in I_\Omega\}$, whose elements represent choice functions as determined by Interpretation 9.2.25;

(ii) the relations $I_{\mathbb{Z},\Omega,\mathcal{O}}(R_j) \subset |M_{\mathbb{Z},\Omega,\mathcal{O}}|^j$ are determined by the validity of the interpretations of the generalized process-physical principles and analytic postulates of the EPT.

The category $\mathscr{C}_{SR}$ has, thus, uncountably many objects. For any two different objects M and M', there is only an arrow $T : M \to M'$ if M and M' are models of the EPT for *the same physical situation.* For example, for a given electron and a given time interval in the reference frame of an observer, there is a model M_1 of the EPT in which the electron accelerates in that time interval and there is a model M_2 in which the electron moves uniformly in that time interval: these are different physical situations. But for each such model, e.g. M_1, there are then uncountably many other models that represent the same physical situation but in the reference frame of other observers. Thus speaking, the category $\mathscr{C}_{SR}$ has full subcategories, each of which represents a different physical situation—the objects of such a full subcategory all correspond to the same physical situation. Which model applies to a real-world problem then depends on the physical situation and the perspective of the observer.

Arrows of the category $\mathscr{C}_{SR}$

There are three kinds of basic arrows in the collection of arrows of $\mathscr{C}_{SR}$:

- **permutation arrows** that correspond to a permutation of counting numbers;
- **translation arrows** that correspond to a translation in spacetime;
- **Lorentz arrows** that correspond to a Lorentz transformation.

Below these basic arrows will be defined precisely; all other arrows are then compositions of these basic arrows. To define such a basic arrow, it suffices to define how the individuals transform that represent monads or hyperstates of phase quanta: that determines everything else.

Definition 9.2.41. *Let $M_{\mathbb{Z},\Omega,\mathcal{O}}$ be an object of $\mathscr{C}_{SR}$, and let Σ_Ω be the set of all permutations on the section of positive integers I_Ω. Then for every $\pi \in \Sigma_\Omega$ and for every function $\tau : I_\Omega \to \mathbb{Z}$, there is a* ***permutation arrow*** *$T^{\pi,\tau}_{\mathbb{Z},\Omega,\mathcal{O}}$ and an object $M_{\mathbb{Z},\Omega,\mathcal{O}'}$ of $\mathscr{C}_{SR}$ such that*

$$T^{\pi,\tau}_{\mathbb{Z},\Omega,\mathcal{O}} : M_{\mathbb{Z},\omega,\mathcal{O}} \to M_{\mathbb{Z},\Omega,\mathcal{O}'} \tag{9.87}$$

For an individual $\{s_k, c^k_{\mathrm{n}}\}$ representing the k^{th} monad in $M_{\mathbb{Z},\Omega,\mathcal{O}}$ we have

$$T^{\pi,\tau}_{\mathbb{Z},\Omega,\mathcal{O}} : \{s_k, c^k_{\mathrm{n}}\} \mapsto \{s_{\pi(k)}, c^{\pi(k)}_{\mathrm{n}}\} \tag{9.88}$$

such that the rest mass spectrum s_k and the characteristic number of normality c^k_{n} in $M_{\mathbb{Z},\Omega,\mathcal{O}}$ are the same as their images $s_{\pi(k)}$ and $c^{\pi(k)}_{\mathrm{n}}$ in $M_{\mathbb{Z},\Omega,\mathcal{O}'}$. For an individual ${}^{\alpha}f^n_k$ representing a hyperstate of a phase quantum we have

$$T^{\pi,\tau}_{\mathbb{Z},\Omega,\mathcal{O}} : \ {}^{\alpha}f^n_k \mapsto \ {}^{\alpha}f^{n+\tau(k)}_{\pi(k)} \tag{9.89}$$

such that the hyperstate ${}^{\alpha}f^n_k$ in $M_{\mathbb{Z},\Omega,\mathcal{O}}$ is the same as its image ${}^{\alpha}\varphi^{n+\tau(k)}_{\pi(k)}$ in $M_{\mathbb{Z},\Omega,\mathcal{O}'}$, with α denoting EP, NP, NW, LW, S. ∎

Loosely speaking, what in the IRF of an observer $\mathcal{O}$ is the process of evolution of the k^{th} monadic system that starts at degree of evolution n is, in the IRF of another observer $\mathcal{O}'$, the process of evolution of the $\pi(k)^{\mathrm{th}}$ monadic system that starts at degree of evolution $n + \tau(k)$.

The point is that in <u>this</u> categorical model of the EPT, $\mathscr{C}_{SR}$, it is neither important which counting number of the set I_Ω is assigned to a monadic system, nor what the numerical value is of the degree of evolution at which a process of temporal evolution of a monadic system starts. What is important is, as we will see, that the unit jump in degrees of evolution in each elementary process corresponds to a spatiotemporal separation δs of a Planck unit between the position of the ground state and the excited state: $\delta s = \|X_{n+1,k} - X_{n,k}\| = 1$.

Definition 9.2.42. *Let $M_{\mathbb{Z},\Omega,\mathcal{O}}$ be a concrete set-theoretic model of the EPT. Then for every $\Delta X \in \mathbb{R}^{1,3}$ there is a* ***translation arrow*** *$T^{\Delta X}_{\mathbb{Z},\Omega,\mathcal{O}}$ and a concrete set-theoretic model $M_{\mathbb{Z},\Omega,\mathcal{O}''}$ of the EPT such that*

$$T^{\Delta X}_{\mathbb{Z},\Omega,\mathcal{O}} : M_{\mathbb{Z},\Omega,\mathcal{O}} \to M_{\mathbb{Z},\Omega,\mathcal{O}''} \tag{9.90}$$

For an individual $\{s_k, c^k_{\mathrm{n}}\}$ representing the k^{th} monad in $M_{\mathbb{Z},\Omega,\mathcal{O}}$ we have

$$T^{\Delta X}_{\mathbb{Z},\Omega,\mathcal{O}} : \{s_k, c^k_{\mathrm{n}}\} \mapsto \{s_k, c^k_{\mathrm{n}}\} \tag{9.91}$$

For an individual ${}^\alpha f^n_k$ representing a hyperstate of a phase quantum in $M_{\mathbb{Z},\Omega,\mathcal{O}}$, with α denoting EP, NP, NW, LW, S, we have

$$T^{\Delta X}_{\mathbb{Z},\Omega,\mathcal{O}} : \ {}^\alpha f^n_k \mapsto \ {}^\alpha {f''}^n_k \tag{9.92}$$

such that ${}^\alpha {f''}^n_k(X) = \ {}^\alpha f^n_k(X - \Delta X)$. ■

Loosely speaking, for every inertial observer $\mathcal{O}$ there is an inertial observer $\mathcal{O}''$ who does not move relative to $\mathcal{O}$, such that the constituents of the IRF of $\mathcal{O}''$ are the constituents of the IRF of $\mathcal{O}$ spatiotemporally translated by ΔX. The set of monads is thus invariant under translation.

Suppose the phenomenal world of an inertial observer $\mathcal{O}$ can be transformed into the phenomenal world of an observer $\mathcal{O}'$ by means of a permutation arrow; then the 4-momentum of a monadic system in the phenomenal world of $\mathcal{O}$ and the 4-momentum of its image in the phenomenal world of $\mathcal{O}'$ are the same. This also holds in case the phenomenal world of an inertial observer $\mathcal{O}$ can be transformed into the phenomenal world of an observer $\mathcal{O}''$ by means of a translation arrow. That is to say: 4-momenta are preserved under permutation arrows and translation arrows.

Definition 9.2.43. *Let $M_{\mathbb{Z},\Omega,\mathcal{O}}$ be a concrete set-theoretic model of the EPT. Then for every Lorentz transformation Λ there is a* ***Lorentz arrow*** *$T^{\Lambda}_{\mathbb{Z},\omega,\mathcal{O}}$ and a concrete set-theoretic model $M_{\mathbb{Z},\Omega,\mathcal{O}'''}$ of the EPT such that*

$$T^{\Lambda}_{\mathbb{Z},\omega,\mathcal{O}} : M_{\mathbb{Z},\Omega,\mathcal{O}} \to M_{\mathbb{Z},\Omega,\mathcal{O}'''} \tag{9.93}$$

For an individual $\{s_k, c^k_{\mathrm{n}}\}$ representing the k^{th} monad in $M_{\mathbb{Z},\Omega,\mathcal{O}}$ we have

$$T^{\Lambda}_{\mathbb{Z},\omega,\mathcal{O}} : \{s_k, c^k_{\mathrm{n}}\} \mapsto \{s_k, c^k_{\mathrm{n}}\} \tag{9.94}$$

For an individual ${}^{\alpha}f^n_k$ representing a hyperstate of a phase quantum in $M_{\mathbb{Z},\Omega,\mathcal{O}}$, with α denoting EP, NP, NW, LW, S, we have

$$T^{\Lambda}_{\mathbb{Z},\omega,\mathcal{O}} : \ {}^{\alpha}f^n_k \mapsto \ {}^{\alpha}{f'''}^{\,n}_{k} \tag{9.95}$$

$$\text{supp}\ {}^{\alpha}{f'''}^{\,n}_{k} = \Lambda[\text{supp}\ {}^{\alpha}f^n_k] \tag{9.96}$$

$$T^{\Lambda}_{\mathbb{Z},\omega,\mathcal{O}} : \vec{p}(X) \mapsto \Lambda\vec{p}(\Lambda X) \tag{9.97}$$

where $\vec{p}(X)$ is the 4-momentum of ${}^{\alpha}f^n_k$ at position X in the IRF of $\mathcal{O}$. ■

Loosely speaking, for every inertial observer $\mathcal{O}$ there is an observer $\mathcal{O}'''$ who moves relative to $\mathcal{O}$ with constant speed, such that the origins of the IRFs of $\mathcal{O}$ and $\mathcal{O}'''$ coincide: a state of a monadic system at position X and with 4-momentum $\vec{p}$ in the IRF of $\mathcal{O}$ is then a state of a monadic system at position $\Lambda(X)$ and with 4-momentum $\Lambda(\vec{p})$ in the IRF of $\mathcal{O}'''$.

The collection of arrows of the categorical model is then generated by the basic arrows defined above under arrow composition; for any arrows $T : M \to M'$ and $T' : M' \to M''$ there is thus an arrow $T' \circ T : M \to M''$. So, once we have a concrete set-theoretic model $M_{\mathbb{Z},\omega,\mathcal{O}}$ that applies to a given system for inertial observer $\mathcal{O}$, then the arrows of $\mathscr{C}_{SR}$ transform this to **physically equivalent** models $M_{\mathbb{Z},\omega,\mathcal{O}'}, M_{\mathbb{Z},\omega,\mathcal{O}''}, \ldots$ that apply to *the same physical system* for other inertial observers $\mathcal{O}', \mathcal{O}'', \ldots$ So, inter-model predictions of the categorical model $\mathscr{C}_{SR}$ of the EPT can be derived from intra-model predictions derived from set-theoretic models of the EPT in the IRFs of observers $\mathcal{O}, \mathcal{O}', \mathcal{O}'', \ldots$ that are linked by arrows: that way it can be shown that the EPT corresponds weakly to SR—cf. Eq. (8.6) of Def. 8.1.5. This concludes the specification of the categorical model $\mathscr{C}_{SR}$.

9.3 Discussion

World view

Below we will give two descriptions of one and the same elementary process in the model $M_{\mathbb{Z},\omega,\mathcal{O}}$:

(i) a description in terms of hyperstates of atomic occurrents, that is, in terms of hyperstates of phase quanta;

(ii) a description in terms of states of a continuant, that is, in terms of states of a monadic system.

Description (ii) yields the easiest-to-grasp world view. But we will start with description (i); recall from Rem 7.3.2 that the *hyperstate* of an occurrent with a degenerate time span in the IRF of $\mathcal{O}$ can be called a *state.*

In this model $M_{\mathbb{Z},\omega,\mathcal{O}}$, the state by which the extended particlelike matter quantum carrying the monad $\mathfrak{m}_k$ at the n^{th} degree of evolution in the world manifests itself in the phenomenal world of the observer $\mathcal{O}$ is modeled as the state ${}^{EP}u^n_{\{c^k_{\text{n}},s_k\}}$ of a point particle with 4-momentum $\vec{p}^{\,EP}_{n,k}$ carrying the set of properties $\{c^k_{\text{n}}, s_k\}$ at $t = t_{n,k}$. In this state, an amount of gravitational mass $c^k_{\text{n}} \cdot E^{EP}_{n,k}$ is discretely distributed over the spatiotemporal position $X = X_{n,k}$: the property $c^k_{\text{n}} \in \{-1, +1\}$ is found back in the sign of the gravitational mass; the property $s_k : \mathbb{Z} \to \mathbb{R}$ is found back in the Minkowski measure of the 4-momentum: $\|\vec{p}^{\,EP}_{n,k}\| = m^k_0$. Thus speaking, if $\mathfrak{m}_k$ is an *electronic* monad modeled as the set of properties $\{c^k_{\text{n}}, s_k\} = \{+1, s_e\}$, then the state ${}^{EP}u^n_{\{c^k_{\text{n}},s_k\}}$ can be viewed as the ground state of an electron with identical inertial and gravitational rest mass $m^k_0 = s_e(n)$. If, on the other hand, $\mathfrak{m}_k$ is a *positronic* monad modeled as the set of properties $\{c^k_{\text{n}}, s_k\} = \{-1, s_e\}$, then the state ${}^{EP}u^n_{\{c^k_{\text{n}},s_k\}}$ can be viewed as the ground state of a positron with inertial rest mass m^k_0 and gravitational rest mass $-m^k_0$.

Furthermore, the state ${}^{EP}u^n_{\{c^k_{\text{n}},s_k\}}$ marks the beginning of an elementary process that lasts from $t = t_{n,k}$ to $t = t_{n+1,k}$. As such, the state ${}^{EP}u^n_{\{c^k_{\text{n}},s_k\}}$ is the state of an extended particlelike phase quantum—more precisely, it is the state ${}^{EP}f^n_k$ by which the extended particlelike phase quantum that marks the beginning of the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution manifests itself in the phenomenal world of $\mathcal{O}$.

At time $t = t_{n,k} = (X_{n,k})^0$, the initial event of the process takes place: by a state transition, the state ${}^{EP}f_k^n$ transforms into the hyperstate ${}^{NW}f_k^n$ of a time-like string whose spatiotemporal extension is the line segment $\overline{\delta X}_{n,k}$: in this model $M_{\mathbb{Z},\omega,\mathcal{O}}$, this is the hyperstate by which the nonlocal wavelike phase quantum occurring in the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution manifests itself in the phenomenal world of the observer $\mathcal{O}$. To this hyperstate ${}^{NW}f_k^n$ is associated a 4-velocity $\vec{v}_{n,k}$: we can therefore view it as the hyperstate of the life of a linearly progressing wave with time span (t_n, t_{n+1}) and constant 4-velocity $\vec{p}_{n,k}$ in the IRF of observer $\mathcal{O}$.

At this initial event a null string is captured if the spatiotemporal position $X_{n,k}$ of the state ${}^{EP}f_k^n$ is on its world line ℓ^γ: what we thus have is that at $t = t_{n,k}$ actually a state transition takes place by which a *superposition* ${}^{EP}f_k^n + \gamma$ of the state ${}^{EP}f_k^n$ *and* a possibly zero hyperstate γ of a null string transforms into the hyperstate ${}^{NW}f_k^n$ of the time-like string—by this state transition, the state ${}^{EP}f_k^n$ and the hyperstate γ of the null string cease to exist but their momenta are transferred to the time-like string. A 4-momentum $\vec{p}_{n,k}^{\,NW}(t)$ is associated to the state ${}^{NW}f_k^n \downarrow \{t\} \times \mathbb{R}^3$ of the temporal part of the time-like string at any time t in its time span $J = (t_{n,k}, t_{n,k} + \delta t_{n,k})$:

(i) its initial value is the sum

$$\lim_{t \downarrow t_{n,k}} \vec{p}_{n,k}^{\,NW}(t) = \vec{p}_{n,k}^{\,EP} + \vec{p}_{n,k}^{\,\gamma} \tag{9.98}$$

where $\vec{p}_{n,k}^{\,\gamma}$ is the 4-momentum associated to the null string γ;

(ii) its value at $t \in J$ is $\vec{p}_{n,k}^{\,NW}(t) = m_{n,k}^*(t) \cdot \vec{v}_{n,k}$ where $m_{n,k}^*(t) \geq m_0^k$ is the inertial rest mass, which may be increasing during the time span J due to the absorption of energy.

Proceeding, the hyperstate $S^n_{\{c_{\mathrm{n}}^k, s_k\}}$, which is the state ${}^{EP}u^n_{\{c_{\mathrm{n}}^k, s_k\}}$ followed by the hyperstate ${}^{NW}f_k^n$, is the hyperstate that carries the set of properties $\{c_{\mathrm{n}}^k, s_k\}$ in the time span $[t_{n,k}, t_{n+1,k})$: in this model $M_{\mathbb{Z},\omega,\mathcal{O}}$, the hyperstate $S^n_{\{c_{\mathrm{n}}^k, s_k\}}$ thus models the hyperstate by which the monadic occurrent $\psi^n_{\mathfrak{m}_k}$ carrying the monad $\mathfrak{m}_k$ from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution manifests itself in the phenomenal world of $\mathcal{O}$. At any $X \in \overline{\delta X}_{n,k}$, the state of the temporal part of the time-like string at $t = (X)^0$ is a state in which an amount of gravitational mass $c_{\mathrm{n}}^k \cdot E_{n,k}^{NW}(t)$ is discretely distributed over the spatiotemporal position X. The property $s_k : \mathbb{Z} \to \mathbb{R}$ with $s_k(n) = m_0^n$ is thus found back as the lowest possible value of the Minkowski measure of the 4-momentum associated to the temporal part of the time-like string at $t = (X)^0$. The property c_n^k is found back as the sign of the gravitational mass $c_\mathrm{n}^k \cdot E_{n,k}^{NW}$.

The next event is the state transition at $t = t_{n+1,k}$ by which the hyperstate ${}^{NW}f_k^n$ of the time-like string transforms into the state ${}^{NP}f_k^{n+1}$ with degenerate time span $\{t_{n+1,k}\}$, which in this model $M_{\mathbb{Z},\omega,\mathcal{O}}$ is the state by which the nonextended particlelike phase quantum at the $(n+1)^{\text{th}}$ degree of evolution in the k^{th} process from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution in the world manifests itself in the phenomenal world of the observer O. In addition, in this model $M_{\mathbb{Z},\omega,\mathcal{O}}$ the state ${}^{NP}f_k^{n+1}$ has no spatial parts, so that it is the state ${}^{NP}u_{\{c_\mathrm{n}^k, s_k\}}^{n+1}$ of a point particle carrying the set of properties $\{c_\mathrm{n}^k, s_k\}$ at $t = t_{n+1,k}$, which models the state by which the nonextended particlelike matter quantum carrying the monad $\mathfrak{m}_k$ at the $(n+1)^{\text{th}}$ degree of evolution manifests itself in the phenomenal world of $\mathcal{O}$.

At this event, 4-momentum is conserved: the hyperstate ${}^{NW}f_k^n$ with spatiotemporal extension $\overline{\delta X}_{n,k}$ and associated 4-velocity $\vec{v}_{n,k}$ thus effects that the preceding point-particle state ${}^{EP}f_k^n$ located at the *earlier* boundary point $X_{n,k}$ of $\overline{\delta X}_{n,k}$ with 4-momentum $\vec{p}_{n,k}^{\,EP}$ is succeeded by the point-particle state ${}^{NP}f_k^{n+1}$ located at the *later* boundary point $X_{n+1,k}$ of $\overline{\delta X}_{n,k}$ with 4-momentum $\vec{p}_{n+1,k}^{\,NP} = \lim\limits_{t \to t_{n+1,k}} \vec{p}_{n,k}^{\,NW}(t)$. For any $n \in Z$ and any $k \in I_\Omega$, the spatiotemporal separation δs between the positions $X_{n,k}$ and $X_{n+1,k}$ of the point-particle states ${}^{EP}f_k^n$ and ${}^{NP}f_k^{n+1}$ is always a Planck unit:

$$\delta s = \sqrt{-\eta(X_{n+1,k} - X_{n,k}, X_{n+1,k} - X_{n,k})} = 1 \tag{9.99}$$

In the state ${}^{NP}f_k^{n+1} = {}^{NP}u_{\{c_\mathrm{n}^k, s_k\}}^{n+1}$ with 4-momentum $\vec{p}_{n+1,k}^{\,NP}$, the properties c_n^k and s_k are found back in the same way as in the state of a temporal part of the time-like string (vide supra).

Furthermore, it has to be understood that a choice has taken place at this event. Just before the initial event had taken place, that is, at $t = t_{n,k}$ when the state ${}^{EP}f_k^n$ existed at the spatiotemporal position $X_{n,k}$, the next point-particle state carrying the set of properties $\{c_\mathrm{n}^k, s_k\}$ could still arise at any element U of the set U_k^{n+1} of points that are spatiotemporally separated from $X_{n,k}$ by a Planck unit. Thus speaking, prior to the initial event there is a set $T_k^{n+1} = \{f(U) \mid U \in U_k^{n+1}\}$ of parallel possible states that exist in potential, but by the state transition ${}^{NW}f_k^n \to {}^{NP}u_{\{c_{\rm n}^k, s_k\}}^{n+1}$ only the state $f(X_{n+1,k}) \in T_k^{n+1}$ at the spatiotemporal position $X_{n+1,k}$ becomes actual. This can be written as a choice using an ur-function $f_{\{T_k^{n+1}\}}$ that takes the set T_k^{n+1} as its argument: ${}^{NP}u_{\{c_{\rm n}^k, s_k\}}^{n+1} = f_{\{T_k^{n+1}\}}(T_k^{n+1})$.

Proceeding, at time $t = t_{n+1,k}$, the final event of the process takes place: by a state transition, the point-particle state ${}^{NP}f_k^{n+1}$ transforms into the point-particle state ${}^{EP}u_{\{c_{\rm n}^k, s_k\}}^{n+1}$ at the same spatiotemporal position $X_{n+1,k}$ and the (possibly zero) hyperstate γ_k^{n+1} of the life of a photon. At this event, 4-momentum is conserved: $\vec{p}_{n+1,k}^{\,NP} - \vec{p}_{n+1,k}^{\,LW} = \vec{p}_{n+1,k}^{\,EP}$. The newly created state ${}^{EP}u_{\{c_{\rm n}^k, s_k\}}^{n+1}$ is then the initial state of the next process, which lasts from $t = t_{n+1,k}$ to $t = t_{n+2,k}$: ${}^{EP}u_{\{c_{\rm n}^k, s_k\}}^{n+1} = {}^{EP}f_k^{n+1}$. This is again a "ground state", with $\|\vec{p}_{n+1,k}^{\,EP}\| = s_k(n+1) = m_0^k$.

In the language of systems theory, we consider one process in the temporal evolution of the $k^{\rm th}$ (monadic) system, whose sole component has the set of primary properties $\{c_{\rm n}^k, s_k\}$. The process under consideration starts at $t = t_{n,k}$ when the system is in the ground state ${}^{EP}f_k^n$, which is identical to the state ${}^{EP}u_{\{c_{\rm n}^k, s_k\}}^n$ of its component. This state is a *ground state* in which the 4-momentum of the system has the lowest possible Minkowski measure: $\|\vec{p}_{n,k}^{\,EP}\| = m_0^k$.

At the initial event of the process, the system transforms spontaneously from its ground state to a transition state with lifetime $\delta t_{n,k}$ and constant 4-velocity $\vec{v}_{n,k}$: the resulting hyperstate ${}^{NW}f_k^n$ of the life of the system in a transition state has spatiotemporal extension $\overline{\delta X}_{n,k}$, and has an open time span $(t_{n,k}, t_{n+1,k})$. At this initial event, a photon may be captured: if so, then the system receives a 4-impulse by the transfer of the momentum $\vec{p}_{n,k}^{\,\gamma}$ of the photon to the system: the initial value of the 4-momentum of the system in its transition state is therefore the sum $\vec{p}_{n,k}^{\,EP} + \vec{p}_{n,k}^{\,\gamma}$. Furthermore, the system may absorb energy from its environment while in a transition state. As a result, the Minkowski measure of the 4-momentum $\vec{p}_{n,k}^{\,NW}(t)$ of the system in its transition state at time $t \in (t_{n,k}, t_{n+1,k})$ may therefore be larger than that of the 4-momentum of the system in its ground state: $\|\vec{p}_{n,k}^{\,NW}(t)\| \geq m_0^k$.

At the next event at $t = t_{n+1,k}$, the system spontaneously transforms from a transition state into the excited state ${}^{NP}f_k^{n+1}$ at the spatiotemporal position $X_{n+1,k}$ with 4-momentum $\vec{p}_{n+1,k}^{\,NP}$. At this event, 4-momentum is conserved: $\vec{p}_{n+1,k}^{\,NP} = \lim\limits_{t \to t_{n+1,k}} \vec{p}_{n,k}^{\,NW}(t)$. So, the life of the system in a transition state effects that the ground state of the system at $X = X_{n,k}$ is succeeded by the excited state of the system at $X = X_{n+1,k}$. Importantly, the spatiotemporal separation between these successive particle states is always a Planck unit: $\|X_{n+1,k} - X_{n,k}\| = 1$.

This event is immediately followed by the final event, which is that the system spontaneously transforms from its excited state ${}^{NP}f_k^{n+1}$ into its next ground state ${}^{EP}f_k^{n+1}$ with 4-momentum $\vec{p}_{n+1,k}^{\,EP}$, thereby possibly emitting a photon with momentum $\vec{p}_{n+1,k}^{\,LW}$. At this final event, 4-momentum is conserved: $\vec{p}_{n+1,k}^{\,NP} - \vec{p}_{n+1,k}^{\,LW} = \vec{p}_{n+1,k}^{\,EP}$. At any point in time t during the life of the system, its gravitational mass is $c_{\mathrm{n}}^{k} \cdot (\vec{p})^0$ where $\vec{p}$ is the 4-momentum of the system at time t.

The following lemmas expand on the world view in terms of systems; the proofs are omitted.

Lemma 9.3.1. For any inertial observer $\mathcal{O}$, any massive system moves on a continuous, piecewise differentiable world line ℓ in the IRF of $\mathcal{O}$. ■

Lemma 9.3.2. For any inertial observer $\mathcal{O}$, any massive system moves piecewise unaccelerated; that is, at any point X of any massive system's world line ℓ we have for the 4-acceleration

$$\vec{a}(X) = \frac{d}{d\tau}\vec{v}(X) = (0, 0, 0, 0, 0) \tag{9.100}$$

provided ℓ is differentiable at X; here τ is the proper time. In this model $M_{\mathbb{Z},\omega,\mathcal{O}}$, every change in the 4-velocity of a system is thus a *step change*. ■

Lemma 9.3.3. For any inertial observer $\mathcal{O}$ and for any elementary process in the temporal evolution of any massive system, the spatiotemporal separation between the positions of the initial state and the final state of the system in that process is always a Planck unit—that is, there is a displacement vector $\delta X \in \mathbb{R}^{1,3}$ with

$$-\eta(\delta X, \delta X) = 1 \tag{9.101}$$

such that δX is the directed line segment from the position of the initial state to the position of the final state in the IRF of $\mathcal{O}$. ■

Proof that SR is incorporated

Lemma 9.3.4 (Principle of invariant light speed)**.**
Let an arbitrary γ-ray be represented by the function γ in a set-theoretic model M of the EPT, which corresponds to the IRF of an observer $\mathcal{O}$, and by the function γ' in a set-theoretic model M' of the EPT, which corresponds to the IRF of observer $\mathcal{O}'$, and which is physically equivalent to M. Let $X = (t, x, y, z)$ be any interior point of its world line ℓ in the IRF of $\mathcal{O}$, and let $X' = (t', x', y', z')$ be any interior point of its world line ℓ' in the IRF of $\mathcal{O}'$. Let c be the speed of light in the IRF of $\mathcal{O}$, and c' the speed of light in the IRF of $\mathcal{O}'$. We then get the following syllogism:

$$\frac{\models_M c^2 = \left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2 \ , \ \models_{M'} (c')^2 = (\frac{dx'}{dt'})^2 + (\frac{dy'}{dt'})^2 + (\frac{dz'}{dt'})^2}{c = c' = 1} \tag{9.102}$$

Ergo, in the categorical model $\mathscr{C}_{SR}$ of the EPT, the speed of light is the same for all observers. ■

Lemma 9.3.5 (Special Principle of Relativity)**.**
Let the set-theoretic models M and M' of the EPT respectively correspond to the IRFs of observers $\mathcal{O}$ and $\mathcal{O}'$. Now let the variables k and n in the language of M respectively vary over the set I_Ω of counting numbers assigned to massive systems and over the set $\mathbb{Z}$ of counting numbers assigned to elementary processes; every open formula Ψ that expresses a generalized principle of the EPT, such as Eq. (9.78) or an additional law of conservation of momentum, such as Eq. (9.77), in the model M can then be viewed as a formula $\Psi(k, n)$ that is open in k and n. If the corresponding variables in the language of M' are k' and n', then for any formula $\Psi(k, n)$ expressing a fundamental law in the model M the following deduction is true in the categorical model $\mathscr{C}_{SR}$:

$$\frac{\models_M \Psi(k, n)}{\models_{M'} [k', n'/k, n]\Psi(k, n)} \tag{9.103}$$

E.g. from Eq. (9.78) we can deduce $\models_{M'} \ {}^{NW}f_{k'}^{n'} : {}^{EP}f_{k'}^{n'} \dashrightarrow {}^{NP}f_{k'}^{n'+1}$.
Ergo, in the categorical model $\mathscr{C}_{SR}$, the laws of physics are the same for every observer. ■

Modeling some known physical processes

Definition 9.3.6 (Inertial motion in $\mathscr{C}_{SR}$).
*In the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$, the process of temporal evolution of the k^{th} massive system lasting from $t = t_{n,k}$ to $t = t_{n+1,k}$ is a process of **inertial motion** if and only if*

$$\vec{p}_{n,k}^{\;EP} = \vec{p}_{n,k}^{\;NW} = \vec{p}_{n+1,k}^{\;NP} = \vec{p}_{n+1,k}^{\;EP} \tag{9.104}$$

■

In the language of systems theory, for an inertial observer $\mathcal{O}$ a massive system exhibits inertial motion in a process of its temporal evolution if no photon is captured at the initial event or emitted at the final event, and if no 4-impulse is received due to interaction of the system with its surroundings. See Fig. 9.2 for an illustration with a spacetime diagram.

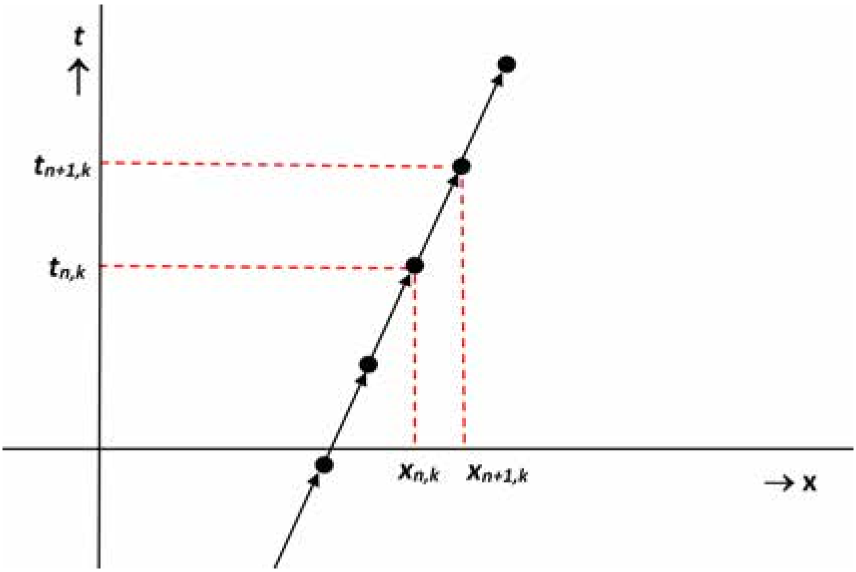


Figure 9.2: Spacetime diagram of a massive system exhibiting inertial motion. Horizontally the spatial coordinates x of the IRF of an inertial observer $\mathcal{O}$, vertically the time coordinates t. The five dots represent the spatiotemporal positions of subsequent ground states of the system, each arrow represents the spatiotemporal extension of the hyperstate of a segment of the life of the system during which it is in a transition state. Together this represents the world line ℓ of the k^{th} massive system; the constant slope of ℓ reflects the constant 4-momentum.

Definition 9.3.7 (Bremsstrahlung in $\mathscr{C}_{SR}$).
*In the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$, the process of temporal evolution of the k^{th} massive system lasting from $t = t_{n,k}$ to $t = t_{n+1,k}$ is a process with **Bremsstrahlung** if and only if (i) no photon is captured at the initial event, and (ii) a photon is emitted at the final event in the direction of motion. See Fig. 9.3 for an illustration.* ■

Note that if in a process of Bremsstrahlung a photon with 4-momentum $\vec{p}_{n+1,k}^{\,LW} = (E, p, 0, 0)$ is emitted and a ground state with 4-momentum $\vec{p}_{n+1,k}^{\,EP} = (m_0^k, 0, 0, 0)$ is produced, then the 4-momentum of the system in the excited state must have been $\vec{p}_{n,k}^{\,NW} = (m_0^k + E, p, 0, 0)$, with $\|\vec{p}_{n,k}^{\,NW}\| > m_0^k$. But the ground state of the system at the start of the process had a 4-momentum $\vec{p}_{n,k}^{\,EP} = (m_0^k + E_{\text{kinetic}}, p, 0, 0)$ for which $\|\vec{p}_{n,k}^{\,EP}\| = m_0^k$. Ergo, a (small) amount of energy must have been absorbed from the environment while the system was in a transition state.

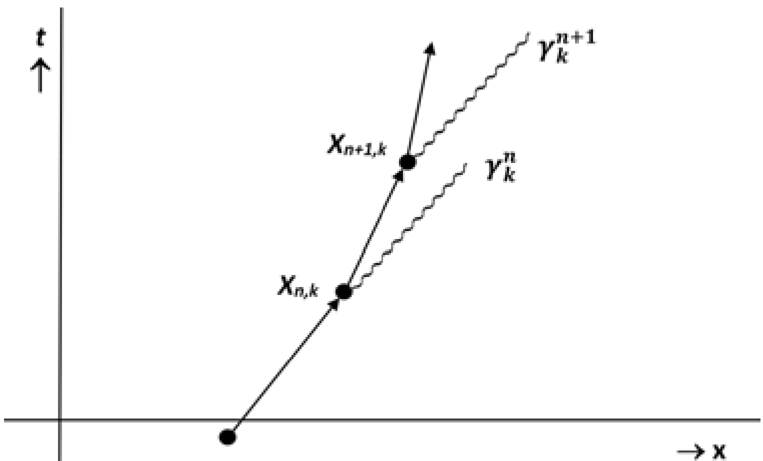


Figure 9.3: Spacetime diagram of a massive system decelerating linearly by emitting Bremsstrahlung. Horizontally the spatial coordinates x of the IRF of an inertial observer $\mathcal{O}$, vertically the time coordinates t. The three dots represent the spatiotemporal positions of ground states ${}^{EP}f_k^{n-1}$, ${}^{EP}f_k^n$ and ${}^{EP}f_k^{n+1}$ of the system, the arrows represent the spatiotemporal extensions of hyperstates ${}^{NW}f_k^{n-1}$, ${}^{NW}f_k^n$, and ${}^{NW}f_k^{n+1}$. Together these form the world line ℓ of the k^{th} massive system; the increasing slope of ℓ reflects the stepwise deceleration. The wavy lines represent the world lines of the emitted photons (Bremmstrahlung), whose lives have hyperstates γ_k^n and γ_k^{n+1} in the IRF of $\mathcal{O}$.

Definition 9.3.8 (Laser cooling in $\mathscr{C}_{SR}$).
*In the model $M_{\mathbb{Z},\Omega,\mathcal{O}}$, the process of temporal evolution of the k^{th} massive system lasting from $t = t_{n,k}$ to $t = t_{n+1,k}$ is a process of **laser cooling** if and only if the system decelerates linearly by the capture and re-emission of a photon at the initial and final event of the process. See Fig. 9.4 for an illustration.* ■

Let a system in its ground state have a spatial momentum in the x^1-direction; then in a process of laser cooling, at the initial event the system captures a photon with a spatial momentum in opposite direction. But having captured the photon, the initial 4-momentum $\vec{p}^{\,NW}_{n,k}(t_{n,k})$ of the time-like string satisfies $\|\vec{p}^{\,NW}_{n,k}(t_{n,k})\| > m_0^k$, cf. Eq. (9.77). However, the 4-momentum $\vec{p}^{\,EP}_{n+1,k}$ of the ground state ${}^{EP}u^{n+1}_{\{c^k_n, s_k\}}$ produced at the final event has to satisfy the condition $\|\vec{p}^{\,EP}_{n+1,k}\| = m_0^k$. Ergo, something has to go: in a process of laser cooling, this something is a photon that the system emits in its direction of motion.

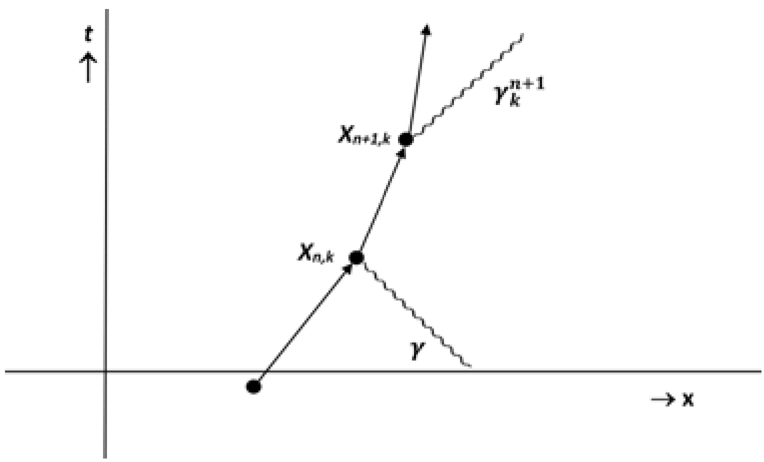


Figure 9.4: Spacetime diagram of a process of laser cooling. Horizontally the spatial coordinates x of the IRF of observer $\mathcal{O}$, vertically the time coordinates t. The three dots represent the spatiotemporal positions of the normal particles states ${}^{EP}f_k^{n-1}$, ${}^{EP}f_k^n$ and ${}^{EP}f_k^{n+1}$ of the system, the arrows represent spatiotemporal extensions of hyperstates ${}^{NW}f_k^{n-1}$, ${}^{NW}f_k^n$, and ${}^{NW}f_k^{n+1}$. Together this represents the world line ℓ of the k^{th} massive system. The wavy lines represent the world lines of the photons captured at the initial event and emitted at the final event as indicated. The increased slope of ℓ reflects the loss of spatial momentum by laser cooling.

Concluding remarks

In this chapter the category $\mathscr{C}_{SR}$, a categorical model of the EPT incorporating SR, has been fully specified, and the two Lemmas 9.3.4 and 9.3.5 show that the two postulates of SR are valid in $\mathscr{C}_{SR}$—these postulates are:

(i) the speed of light is the same for all observers;

(ii) the laws of physics are the same for all observers.

The main conclusion is then that the EPT corresponds weakly to SR: henceforth we thus *know* that the EPT is consistent with observations that can be described as predictions of SR—examples are the null result of the Michelson-Morley experiment (1887), and the observed prolonged lifetime of fast muons (Rossi and Hall, 1941).

A limitation of this pointillistic model $\mathscr{C}_{SR}$ is that it *only* demonstrates the agreement of the EPT with the empirically successful predictions of SR: it does not yield an advancement in relativity theory, nor does it demonstrate any agreement of the EPT with the knowledge of the physical world that derives from the experimentally confirmed predictions of relativistic interaction theories.

On the other hand, this model relates the stepwise motion of a massive system in the framework of the EPT to concepts of SR: for any inertial observer, the initial and final particle states of a massive system in any elementary process are always separated by a unit invariant interval Δs. That is, in any elementary process a massive system makes a 'leap' that *always* corresponds to a displacement vector $\Delta\vec{x}$ satisfying

$$\Delta s = \sqrt{-\eta(\Delta\vec{x}, \Delta\vec{x})} = 1 \tag{9.105}$$

So, this model does provide a mechanism that details *how* a moving clock ticks slower: a clock is *itself* a massive system that evolves in time by the processes described by the EPT, and the time read by a clock is nothing but a measure of the number of processes it has underwent—each process in the temporal evolution of a clock corresponds to one tick of the clock.

Last but not least: in the framework of $\mathscr{C}_{SR}$, knowledge of a massive system remains fundamentally probabilistic for the same reasons as before. See the section "Emergent concepts of quantum field theory" of Ch. 6 on pp. 303 ff. for quantum-theoretical considerations in a relativistic setting.

9.4 Objections and replies

Remark 9.4.1. Since the categorical model $\mathscr{C}_{SR}$ of the EPT has never been submitted to a journal, this section mainly addresses the objections to the Dirac delta function. The material presented in Sect. 9.1 has been published by *Axioms*, cf. (Cabbolet, 2021b), which demonstrates that there is nothing wrong with the material—at least not at first sight. Initially I tried to publish a short note, which (i) identified the problem as now described on p. 400, (ii) presented a definition of Dirac delta functions, and (iii) showed that these functions solve the problem. ■

Objection 9.4.2. "*We are sorry to inform you that the Editorial Board of [our journal] has received a quick evaluation of your note, indicating that your paper is possibly interesting and worthy of publication in a specialist journal. However, it does not quite reach the high standards of [our journal], for which we expect results with a more profound impact and with wider mathematical implications.*"—rejection of my short note on the Dirac delta function by a tier-1 mathematics journal accepting short notes ■

Objection 9.4.3. "*We have received your submission to [our journal]. However, the paper is out of the scope of this journal.*"—editor of a journal in applied mathematics, rejecting the same short note ■

Reply 9.4.4. A journal is by no means obliged to publish any submitted paper. This also holds for papers submitted by me.

Objection 9.4.5. "*As turned out, the paper contains a possibly new definition of the Dirac delta ... While the construction and the corresponding results are certainly interesting and worth of being investigated in detail, the topic is of a rather special nature and can (arguably) only be appreciated by mathematicians working in the field, for example in logic. This is why the editors decided to reject the manuscript for publication in [our journal].*"—Editor-in-Chief of a mathematics journal, rejecting my short note on the Dirac delta function

Reply 9.4.6. The previous reply also applies to this objection. What is interesting here, however, is the judgment that the paper is only interesting for logicians. But the paper doesn't contribute to logic at all. So, *even if* it would be interesting for some mathematicians, it nevertheless would not be interesting for mathematicians working in the field of logic. ■

Objection 9.4.7. "*The paper appears to be correct, but it is not novel. There have been many formalizations of the Dirac Delta within nonstandard analysis, as can readily be found by googling 'nonstandard Dirac delta,' yielding a wealth of references not cited in the present paper. Therefore, I recommend that the paper be rejected*"—anonymous referee #1 of a tier-1 mathematics journal, recommending rejection of my short note on the Dirac delta function ■

N.B. This objection was supplemented with a print screen of the result of the referee's google search on "nonstandard Dirac delta".

Reply 9.4.8. A 'note' is a type of scientific publication that focuses at the presentation of a novel result: its format is different from the IMRAD format of a regular 'article'. In particular, a note doesn't contain an introductory review of the existing literature on the topic: for the submitted note I considered it at the time sufficient to identify the problem as given by Eq. (9.2) and to describe the current state of affairs, *in casu* being that it is thus far unsolved. And I explicitly submitted the paper as a note.

That said, the above objection that the paper "is not novel" is a false statement of fact. I can tell you where this is coming from. The referee has briefly looked at the paper, after which he has done a google search on "nonstandard Dirac delta". This has returned a number of search results linked to existing definitions of the Dirac delta. Without bothering to check the facts, he has then carelessly concluded that my definition is the same as (one of) the existing definitions: right there, that's were he has passed off a figment of his imagination as a genuine finding of an investigation into the quality of my work—peer review at its worst, again. ■

Objection 9.4.9. "*For the author: Your solution of the problem of defining a delta function does not improve on the solution using so-called generalized functions formulated of Laurent Schwartz. Not surprisingly, neither your functions nor generalized functions are genuine 'ordinary integrable functions of a real variable' as your title promises. More importantly, unlike Schwartz's functions, yours cannot be used to solve differential equations for they do not seem to be differentiable. Note. Your theory does not make essential use of the hyper-real numbers. Your ω can be any symbol. It could, for example, simply be 'x'.*"—anonymous referee #2 of the same journal, recommending rejection of my short note on the Dirac delta function ■

Reply 9.4.10. This objections contains three false statements of fact:

(i) the present definition of the Dirac delta function does not improve its existing definition as a generalized function;

(ii) the Dirac delta function as defined by me is not an ordinary integrable function of a real variable;

(iii) the definition of the hyperreal delta functions does not make essential use of the hyperreal numbers.

As to (i), it was clearly stated in the note that the problem at hand is to find ordinary functions that satisfy Eq. (9.2): this purely mathematical problem has arisen from the idea that the image $I_M(\varphi)$ of an abstract constant φ of the EPT designating a phase quantum under the interpretation function $I_M : \mathcal{L}(EPT) \to \mathcal{L}(M)$ of a set-theoretic model M of the EPT should be an ordinary function on the spacetime manifold representing states of phase quanta—the problem arises when trying to interpret nonextended particlelike phase quanta. On the one hand, the generalized functions are not functions on $\mathbb{R}$, and as such they do not satisfy Eq. (9.2)—even though they may capture the idea of the Dirac delta. On the other hand, the hyperreal delta functions as presently defined are in fact ordinary functions that satisfy Eq. (9.2). So, the present definition is an improvement: contrary to the existing definition(s), it not only solves the mathematical problem identified at the beginning, cf. Sect. 9.1, but it is also applicable for the specification of a model of the EPT.

As to (ii), the submitted note contained Def. 9.1.5 of the Dirac delta function as an ordinary function on the real numbers: contrary to what is the case with existing definitions, by this definition there is a set S—*in casu* the set ${}^*_+\mathbb{R}$ of expanded real numbers—such that the Dirac delta function as a set can be identified with a relation $\delta \subset \mathbb{R} \times S = \mathbb{R} \times {}^*_+\mathbb{R}$ that is total and functional. The note also contained a definition of the value of the integral of a delta function, later expanded to Ax. 9.1.7). The referee has made a false statement of fact here.

As to (iii), it is of course not true that the hyperreal number ω in my definition of the hyperreal delta functions can be replaced by a random object x. In that case, namely, the product $\alpha \cdot x$ of x and a real number α would be undefined, sums of such products would be undefined, $|x|$ would be undefined, etc. This is peer review at its worst—again. ■

Objection 9.4.11. "*The author of this paper proposes to give an alternative analysis of the delta function ... According to his analysis, the function δ would be the function defined as follows: $\delta(x) = 0$ if $x \neq 0$ and $\delta(x) = \omega$ if $x = 0$, where ω is some fixed infinitely large hyperreal number. He then simply defines the integral of this function to be 1. It is not clear what this definition is supposed to accomplish. ... The reason it is useful to define the Dirac delta function as a generalized function is that there is a whole theory of how to use generalized functions in differential equations. But the author does not attempt to present any similar theory of how to use functions from the reals to the hyperreals. Without such a theory, it is not evident what his definition accomplishes.*"—first objection of a referee of a mathematics journal accepting short notes, recommending rejection of my short note on the Dirac delta function ■

Reply 9.4.12. In the submitted note it was clearly stated what the new definition of the Dirac delta accomplishes: it yields an ordinary function $\delta(x)$ on the reals with the properties given by Eq. (9.2). Thus far no such function had been defined, so it is simply not true that it is not evident what this definition accomplishes without a theory on how to use these hyperreal functions on the reals. In other words, *even without* a theory about how to use these functions it is evident what the new definition accomplishes. Furthermore, it is also not true that no hint was given on how to apply these functions: in the note it was mentioned explicitly that the newly defined functions can be applied as a representation of the distribution of mass in a one-dimensional system made up of point particles. ■

Objection 9.4.13. "*The author says his definition is 'unproblematic', but doesn't explain what he means by this or why it is true. ... He claims that a corollary of his definition is that certain infinite sums of multiples of shifts of the delta function are integrable, but this doesn't follow: his definition doesn't say how to integrate an arbitrary function from the reals to the hyperreals, it only assigns a value to the integral of the delta function itself (and multiples of shifts of the delta function). Perhaps his definition can be extended to cover more functions, but he has not provided such an extension that is needed to justify his claims.*"—second objection of the referee of that journal, recommending rejection of my short note on the Dirac delta function ■

Reply 9.4.14. The objection here is thus that the material in the submitted note was incomplete in the sense that a general definition of the space of all integrable functions from the reals to the hyperreals was absent. I considered this to be a valid objection, and took it to heart: consequently, I developed what now is Ax. 9.1.7. ■

Remark 9.4.15. I extended the note to a full article, albeit a short one, which I uploaded later to the arXiv—see (Cabbolet, 2018c). Qua content, the article is more or less identical to the present Sect. 9.1; I have submitted it to several journals, beginning with the above journal. ■

Objection 9.4.16. "*The author has made some changes in response to the criticisms in the last paragraph of my report on the previous version of this paper. However, those criticisms were not the most serious problem with that paper. The most serious problem was explained in the first sentence of my report to the editor, which said:* ***'I don't think there is anything of value in this manuscript.'*** *That criticism unfortunately applies to the new version as well. This paper, like the previous one, doesn't accomplish anything of interest to our readers. There is no reason to consider any further revisions.*" (emphasis added)—referee of the mathematics journal accepting short notes, rejecting the submitted paper (Cabbolet, 2018c) ■

Reply 9.4.17. This objection (in bold) reflects the referee's personal dislike of the submitted paper, rather than its objective scientific quality. So, even though the statement may be true—after all, it may actually be the case that the referee thinks that there is nothing of value in the manuscript—it is not a valid argument against my work. For comparison, imagine that a referee of the Verlag von Louis Nebert in 1879 would have commented as follows to Frege:

> *Dear Dr. Frege,*
> *Apart from your idiosyncratic notations, the most important problem of your 'Begriffsschrift' is that I don't believe that there is anything of value in this manuscript. It doesn't accomplish anything of interest. Therefore, my recommendation is to reject this manuscript for publication, and there is no reason to consider any further revisions.*

Just imagine it. ■

Objection 9.4.18. "*The present article suggests a way in which the Dirac delta function can be thought of as a genuine function, though not with values in the real numbers. It appears to be done for the sake of proving that such an interpretation is possible, rather than for any concrete use in mathematics or mathematical physics. This rather misses the point of the mathematical theories that are already in place: Riemann integration, distribution theory and measure theory are all there to ensure that there is a rigorous foundation for integration and that it is possible to give precise mathematical proofs of results rather than heuristic computations. No attempt is made in the article to develop a coherent theory of integration that could replace existing theories, nor is there any suggestion how the results of the articles may be useful for ongoing research.*"—associate editor of an open-access mega journal, recommending rejection of the submitted paper (Cabbolet, 2018c) ■

Reply 9.4.19. On its website, the journal declares the following about the peer-review process it applies:

> "*Most journals base their peer review on two separate processes. The first stage is objective and assesses the rigour of the methodology and statistics, and the validity of the conclusions. The second stage is subjective and attempts to estimate the likely impact or importance of the work. [Our journal] operates using the first stage only—objective peer review.*"

The above objection proves that this is not true: the assessment, that the definition of the Dirac delta as a genuine function is introduced "for the sake of proving that such an interpretation is possible, rather than for any concrete use in mathematics or mathematical physics", has nothing to do with an objective evaluation of the rigor of the definition or the validity of the conclusions. In addition, it is false: already in the introduction it was mentioned explicitly that "we introduce special hyperreal functions of a real variable ... that can be applied in general for the mathematical modeling of physical states in which infinitely high densities occur" (Cabbolet, 2018c). So, this objection rather misses the point of the paper: the hyperreal delta functions are introduced to ensure that there is a rigorous foundation for modeling a system made up of point particles by an ordinary function that represents the distribution of mass over space. ■

Objection 9.4.20. "*The paper contains too limited contribution to mathematical sciences to justify publication in a selective journal of applied mathematics. However, it appears more appropriate for a journal of theoretical physics.*"—anonymous referee of a tier-1 journal in mathematical modeling, recommending rejection of the submitted paper (Cabbolet, 2018c) ■

Objection 9.4.21. "*The paper is not interesting as written. The construction is ad-hoc with no clear benefit over constructions in the literature.*"—referee #1 of a journal accepting papers in nonstandard analysis, recommending rejection of the submitted paper (Cabbolet, 2018c) ■

Objection 9.4.22. "*I read the manuscript. Regretfully, I cannot recommend a publication. Here is my reasoning: 1) From mathematical point of view: There is a very little mathematical content*"—first objection of the referee of an open-access mega journal, rejecting the submitted paper (Cabbolet, 2018c) ■

Reply 9.4.23. Th. 9.1.8 is a new mathematical result that did not exist before this study. Of course one can belittle this result: as Objections 9.4.16, 9.4.18, 9.4.20, 9.4.21, 9.4.44, and 9.4.22 show, there is a plethora of pejoratives one could use for the belittling. But the point is that Dirac and Von Neumann, who are worshipped in some parts of the scientific community the same way the prophets of the Old Testament are worshipped in Christianity, failed to define the Dirac delta as an ordinary function of the reals: they couldn't do it. So if the present result doesn't mean anything, then what are Dirac and Von Neumann? A bunch of f***ing amateurs? I don't think so. The same goes for all other mathematicians who have tried to give the use of the Dirac delta a firm mathematical footing. ■

Objection 9.4.24. "*2) The fact that with the help of an integral different from the Lebesgue (or Riemann) integral you can achieve a 'Dirac delta function' which is a pointwise function from* $\mathbb{R}$ *to* $\mathbb{R}$ *is known. For example, if we replace the Lebesgue integral* $\int_{-\infty}^{\infty} f(x)\,dx$ *with the Stieltjes integral* $\int_{-\infty}^{\infty} f(x)\,dH(x)$ *(where* H *is the Heaviside step-function), the Dirac delta function* $\delta(x)$ *becomes the constant function* 1 *(i.e.* $\delta : \mathbb{R} \mapsto \mathbb{R}$ *such that* $\delta(x) = 1$ *for all* $x \in \mathbb{R}$*), because* $\int_{-\infty}^{\infty} f(x)\,dH(x) = f(0)$ *for all continuous functions* $f \in C(\mathbb{R})$*.*"—second objection of the anonymous referee of an open-access mega journal, recommending rejection of the submission (Cabbolet, 2018c) ■

Reply 9.4.25. While I do not doubt that every sentence in the above objection is true, it is not an argument against the present definition of the hyperreal delta functions: the referee digresses. He suggests that there already exists a definition of the Dirac delta as an ordinary function, namely the constant function

$$\delta : \mathbb{R} \rightarrow \mathbb{R} \ , \ \delta : x \mapsto 1$$

Now reread the problem identified in the submitted paper, which is to find a function on the reals that satisfies Eq. (9.1). Obviously, the function suggested by the referee is not a solution to the problem, nor can it be used to represent the distribution of mass in a system made up of point particles. Ergo, this objection is a non-argument. ■

Objection 9.4.26. "*3) The main philosophical argument of the author is that "in physics we want to model a spatial dimension with the real numbers, not with the hyperreal numbers" (p. 2, close to the bottom of the page). This argument is, indeed, reasonable and many physicists would easily agree. In my opinion however, it is not overly convincible: First, $\mathbb{R}$ can be replaced by any real closed field $\mathcal{R}$ (and $\mathbb{C}$ by $\mathcal{R}(i)$) in a large part of theoretical physics, in particular, the algebraic approach to quantum field theory. Second, modern theoretical physics relies not only on $\mathbb{R}^n$ as spacial space, but also on complex variables (analytic functions), discrete variables, p-adic spacial variables, and many others. To mention one example (among many), in the so called 'Constructive approach to QFT' the time is complex.*"—third and final objection of the anonymous referee of the open-access mega journal, recommending rejection of the submitted paper (Cabbolet, 2018c) ■

Reply 9.4.27. The purpose of the submitted paper—and of Sect. 9.1 of this monograph—is to introduce hyperreal delta functions that can be applied in physics: its purpose is not to defend the assumption in physics that a spatial dimension can be represented by the reals—this assumption is made in classical mechanics, relativity theory, and non-relativistic QM. Such a philosophical treatise on the nature of a spatial dimension is a completely different paper. With this objection, the referee again digresses: this is a non-argument. ■

Objection 9.4.28. "*The 'Dirac delta function' is well established in the standard analysis as a measure or as a distribution. It has also been described several times as an object in nonstandard analysis. I cannot see any novelty in this paper.*"—anonymous referee of a mathematics journal, recommending rejection of the submitted paper (Cabbolet, 2018c) ■

Reply 9.4.29. By itself, this is a repetition of Objection 9.4.7. But there is a fundamental difference: contrary to the earlier note to which Objection 9.4.7 was addressed, the paper submitted to this journal contained an overview of existing definitions of objects in standard and nonstandard analysis that capture the idea of the Dirac delta, as well as a critical discussion as to why these are not useful for the present purpose. Therefore, the above objection raises questions as to whether the referee has at all read further than title and abstract. This is yet again another example of peer review at its worst. ■

Objection 9.4.30. "*Your manuscript ... has been carefully considered by the Editors of [our journal]. From their opinion, the content does not meet the high standards of our journal and we regret for not being able to consider your manuscript for publication.*"—Managing Editor of journal of mathematical physics specialized in publishing letters, rejecting the submitted paper (Cabbolet, 2018c) ■

Reply 9.4.31. This objection is nothing but a Kafkaesque indictment: I am accused of having submitted a manuscript that does not meet the standard of quality, but without specifying *which* standards are not met and *how* they are not met. Such a bare allegation of insufficient scientific quality makes one wonder: what if the standards at this journal are so high that they are not even met by the true fundamental laws of the universe themselves? ■

Objection 9.4.32. "*I regret that we are unable to accept your paper ... for publication in [our journal] but thank you for your interest in our Journal.*"—Managing Editor of a tier-1 mathematics journal, rejecting the submitted paper (Cabbolet, 2018c) ■

Objection 9.4.33. "*the focus of your paper falls outside the scope of the journal and therefore we will not being considering it for publication*"—Editor-in-Chief of an open-access mega journal of applied mathematics, rejecting the submitted paper (Cabbolet, 2018c) ■

Objection 9.4.34. "*Thank you for your interest in [our journal]. An initial evaluation of your paper suggests that its subject matter falls somewhat far outside of the usual topics covered by the journal. We respectfully suggest that you submit it elsewhere, perhaps to a journal specializing in foundations of analysis.*"—Managing Editor of a tier-1 journal in theoretical and mathematical physics, rejecting the submitted paper (Cabbolet, 2018c) ■

Objection 9.4.35. "*I regret ... to inform you that we have decided not to consider your manuscript for publication in [our journal]. The subject of your manuscript does not belong to the centric field which we want to cultivate.*"—editorial office of a journal of analysis and its aplications, rejecting the submitted paper (Cabbolet, 2018c) ■

Objection 9.4.36. "*Thank you for your manuscript, which you submitted to [our journal]. However, it would be more suitable for a math analysis journal. Thus it cannot be accepted for publication in [our journal].*"—Managing Editor of a tier-1 journal in applied mathematics, rejecting the submitted paper (Cabbolet, 2018c) ■

Objection 9.4.37. "*The Editors have discussed your paper, but unfortunately, they feel that it is better suited to a journal specializing in aspects of measure theory. For this reason, we will not be able to publish your manuscript.*"—Managing Editor of a tier-1 journal in mechanics and analysis, rejecting the submitted paper (Cabbolet, 2018c) ■

Objection 9.4.38. "*I regret to inform you that we shall not be able to publish your paper. We are sorry that we have had to disappoint you on this occasion, but we thank you for considering publishing [in our journal].*"—rejection of the submitted paper (Cabbolet, 2018c) on behalf of the Editorial Advisory Board of a tier-1 mathematics journal ■

Objection 9.4.39. "*I regret to inform you that after careful consideration the editor has decided that your above referenced paper ... is not appropriate for publication in this journal and we must therefore decline to consider it further. We consider only papers which contain essential results in Integral Transforms And Special Functions (MSC 33/44)*"—Managing Editor of a mathematics journal specializing in integral transforms and special functions, rejecting the submitted paper (Cabbolet, 2018c) ■

Objection 9.4.40. "*The Editorial Board of [our journal] has decided that your paper is not in the scope of the journal. Therefore we have rejected this work.*"—Editor-in-Chief of a journal specializing in mathematical modeling and analysis, rejecting the submitted paper (Cabbolet, 2018c) ■

Reply 9.4.41. To the above nine objections, Reply 9.4.4 applies. As to the last two, note that the hyperreal delta functions are special functions and that these are intended to be used for mathematical modeling. ■

Objection 9.4.42. "*It is not clear to me why you have submitted this paper to a physics journal like this. This paper is largely MATHEMATICS, with no direct link to PHYSICS. Of course, it may be that this result helps to solve a genuine physical problem, but that could also be said of almost any paper published in a journal devoted to analysis. This paper should be submitted to a specialist mathematics journal and NOT to a physics journal such as this. ... I must therefore REJECT your paper.* "—editor of a tier-1 physics journal, rejecting the submitted paper (Cabbolet, 2018c) ■

Reply 9.4.43. The link to physics was clearly stated in the beginning of the submitted paper. Just reread the beginning of the motivation on p. 400: the link to physics is clearly stated.

Furthermore, writing $\delta^n_\beta(x) = (\delta_\beta(x))^n$, we could initiate further developments based on Ax. 9.1.7 by defining

$$\int_{-\infty}^{\infty} \alpha\delta^n_\beta(x)dx = \alpha\omega^{n-1} \tag{9.106}$$

so that $\int_{-\infty}^{\infty} \delta^2_0(x)dx = \omega = \delta_0(0)$. We can apply this to non-relativistic QM, where delta functions are routinely used as eigenstates of the position operator $\hat{x}$. In Dirac notation, a delta function $\delta(x - \alpha)$ with $\alpha \in \mathbb{R}$ is denoted $|\ \alpha\ \rangle$, and the inner product of two eigenfunctions of position $|\ \alpha\ \rangle$ and $|\ \beta\ \rangle$ is then

$$\langle\ \alpha\ |\ \beta\ \rangle = \int_{-\infty}^{\infty} \delta(x - \alpha)\delta(x - \beta)dx = \delta(\alpha - \beta) \tag{9.107}$$

See e.g. Griffith (1994). This equation is on shaky foundations since the right-hand side does not have a well-defined numerical value if $\alpha = \beta$.

However, if we apply our newly defined hyperreal delta functions, we obtain

$$| \ \alpha \ \rangle = \delta_\alpha(x) \tag{9.108}$$

$$\langle \ \alpha \ | \ \beta \ \rangle = \int_{-\infty}^{\infty} \delta_\alpha(x)\delta_\beta(x)dx = \delta_0(\alpha - \beta) \tag{9.109}$$

Ergo, by applying the present definition of the Dirac delta as well as Eq. (9.106), the inner product of two eigenvectors of position as in Eq. (9.107) takes a well-defined value in the expanded real numbers. This puts the use of the Dirac delta as a function on $\mathbb{R}$ in non-relativistic QM on a rigorous mathematical footing while preserving its intended interpretation as a density distribution. ■

Objection 9.4.44. "*The paper contains no proofs or theorems; I don't think a paper whose only point is to offer an alternate formalism or representation for something is sufficiently interesting to publish in a journal like [our journal] unless there is at the very least a proof that the representation solves some serious problem which the current formalism does not.*"—first objection of referee #2 of the same journal as in Obj. 9.4.21, rejecting the submitted paper (Cabbolet, 2018c) ■

Reply 9.4.45. This reply makes it questionable whether the referee has actually read the paper beyond title and abstract. In the Introduction of the paper the problem has been identified: it is not without reason that the introduction contained a sentence beginning with "Analyzing, the problem is thus that ... ". In the next section it was made clear that existing definitions of the Dirac delta did not solve the problem: it was clearly stated that "we cannot but conclude that the existing objects that formalize the idea of the Dirac delta are not suitable for our present purposes". The next section then introduces the hyperreal delta functions, explicitly stating the conclusion that these do solve the problem (so that the reader doesn't have to infer that himself). However, one may then side with the referee and maintain ad infinitum that the problem in question—i.e., the definition of the Dirac delta as an ordinary function—is not a *serious* problem. That is then a matter of personal taste: there is no objective criterion for when a problem is 'serious'. Summarizing, this objection too reflects the referee's dislike of the submitted paper, rather than its scientific quality. ■

Objection 9.4.46. "*Definition [9.1.1] is vague, and I question whether the author understands what the hyperreal field is.* ***In particular: elements of *R are not sets***" (emphasis added)—second objection of referee #2 of that journal, rejecting the submitted paper (Cabbolet, 2018c) ■

Reply 9.4.47. Rather than Def. 9.1.1 it is this objection that is vague, and I question whether the referee has understood the definition of the expanded real numbers $^*_+\mathbb{R}$. In particular, elements of $^*_+\mathbb{R}$ are defined as sets because *everything* is a set in the framework of ZF. ■

The objections against the hyperreal delta functions are herewith treated. The two objections below address the physics part of this chapter.

Objection 9.4.48. "*What bothers me most about his methods is not that he makes contestable assumptions, but that he flouts 100 years of successful science. He doesn't do anything with quantum mechanics or with general relativity, he only rebels against them.* ***Even special relativity is not compatible with this****.*" (emphasis added)—'t Hooft on my work (2015a) ■

Reply 9.4.49. The objection in bold is a false statement of fact, as proven by this chapter: the EPT is consistent with SR. To the defense of 't Hooft, the material of this chapter had not yet been developed at the time he made the statement, because the mathematical problem on p. 400 had not yet been solved. But one should not confuse 'not proven to be true' with 'proven to be not true': this objection is an elementary mistake by 't Hooft. ■

Objection 9.4.50. "*That is not much of a result.*"—'t Hooft about the news that I had proven that the EPT is consistent with SR, in a private conversation we had at the 2016 Spacetime Conference in Varna (BG) ■

Reply 9.4.51. This is nothing but a belittling of the result. For comparison, imagine that a referee of *Proc. Roy. Soc. A* would have commented as follows to Dirac's famous paper (1928):

> *Dear Dr. Dirac,*
> *I see that your quantum theory of the electron shows that QM is compatible with SR. That, however, is not much of a result. Therefore, I see no reason why your work should be published.*

Just imagine it. ■

Chapter 10

A model of a gravitational interaction process

> "*Based on the demands for dissertations at our university, the physics part of Cabbolet's work is utterly unacceptable for admission to the PhD defence.*"—Boudewijn Verhaar, professor of physics at Eindhoven University of Technology, commenting on my 2007 concept-dissertation (2008)

This chapter aims to be self-contained, and aims to develop a relativistic model of an elementary process in the temporal evolution of a massive system, by which a gravitational interaction takes place between the system and its environment. This should quantitatively explain how a massive system made up of a component of antimatter is repulsed by the gravitational field of ordinary matter. Spacetime is the arena in which this takes place, and so we will first develop a mathematical model of spacetime. For that matter, we will start out by discussing existing ideas at conceptual level. A way to do this—and that may be the standard way in physics—is to throw the mathematical formulas that represent the ideas at the readers. However, as long as the discussion is at the *conceptual* level—as opposed to the *quantitative* level—ideas can be just as effectively discussed in ordinary language when the text is illustrated with cleverly chosen pictures. The obvious advantage of the use of ordinary language is cross-disciplinary accessibility of the text. Sect. 10.1 is written with that in mind.

10.1 Philosophical considerations

On the nature of spacetime

In this section we will derive a number of propositions, which will serve as guidelines for the development of a mathematical model of spacetime. For starters, let's have a look at Newton's theory of gravity. If we know the gravitational masses m_g^1, m_g^2 of two bodies #1 and #2 as well as the distance r_{12} between them, then Newton's law of gravity allows us to calculate the gravitational force $\overrightarrow{F}_{12}$ on body #1 exerted by body #2:

$$\overrightarrow{F}_{12} = G\frac{m_g^1 m_g^2}{(r_{12})^2} \cdot \vec{e}_{12} \tag{10.1}$$

(Here $\vec{e}_{12}$ is a unit vector in the direction from body #1 to body #2.) By Newton's third law we then automatically now the gravitational force $\overrightarrow{F}_{21}$ on body #2 exerted by body #1, while Newton's second law then allows us to calculate the acceleration $\vec{a}$ of each body if we know its inertial mass m_i and if the gravitational force is the net force $\overrightarrow{F}_{\text{net}}$ on the body:

$$\overrightarrow{F}_{21} = -\overrightarrow{F}_{12} \tag{10.2}$$

$$\overrightarrow{F}_{\text{net}} = m_i \cdot \vec{a} \tag{10.3}$$

The semi-classical model of interaction processes, set forth in Sect. 6.3, describes the gravitational aspect of the interaction between a massive system that evolves in time by elementary processes described by the EPT and its environment, which is described by classical fields: this semi-classical model quantitatively reproduces the empirically successful predictions of Newtonian gravity at macroscopic scale and predicts a matter-antimatter repulsive gravity.

However, both this semi-classical model and Newtonian mechanics imply assumptions on the nature of spacetime that are inconsistent with experimental data. That is, the mathematical model of spacetime used in the semi-classical model of the EPT and in Newtonian mechanics—this is the Galilean reference frame (GRF) introduced in Def. 6.1.4—does not adequately reflect the true nature of spacetime. There are many ways to prove that, we prove it as follows:

Proposition 10.1.1. *The idea of the luminiferous ether, incorporated in the Galilean reference frame, is inconsistent with the observed prolonged lifetime of fast muons (Rossi and Hall, 1941). (Combining space and time, the life of the luminiferous ether is then spacetime.)* ■

Proof: If in the GRF of an observer $\mathcal{O}$ a motionless muon and a fast muon have lifetimes of respectively 2.2 μs and 10 μs, then in the GRF of an observer $\mathcal{O}'$ co-moving with that fast muon both muons have these same lifetimes—the underlying reason is that the rate of passing of time is assumed to be the same for all observers. But in the GRF of $\mathcal{O}'$ that fast muon is motionless, so $\mathcal{O}$ and $\mathcal{O}'$ measure radically different lifetimes of a motionless muon: if it is a law of physics that a motionless muon has a lifetime of 2.2 μs, then obviously the laws of physics are not the same for all observers in this model. See Fig 10.1 for an illustration. ■

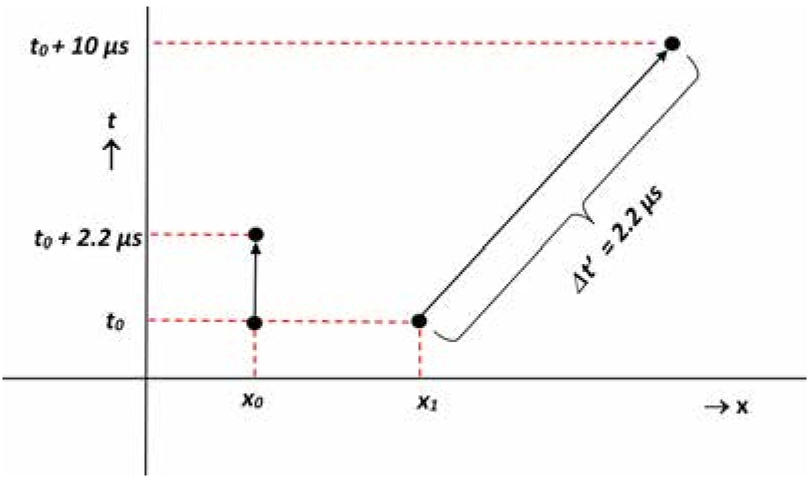


Figure 10.1: tx-diagram illustrating the prolonged lifetime of fast muons. The lower left dot represents the event that a motionless muon is produced at time $t = t_0$ at the position $x = x_0$; the event of its decay is represented by the upper left dot at the position $x = x_0$ at the time $t = t_0 + 2.2$ μs; the arrow connecting the dots is the world line of the motionless muon. The lower right dot represents the event that a fast muon is produced at time $t = t_0$ at the position $x = x_1$; the event of its decay is then at a much later time $t = t_0 + 10$ μs, as represented by the upper right dot at a position $x > x_1$; the arrow connecting the dots is the world line of the fast muon. But according to Special Relativity, the lifetime of the muon as measured by a co-moving clock is again 2.2 μs as indicated.

We might then be inclined to think that we can solve the inconsistencies of Newtonian mechanics with observed relativistic effects by recontextualizing Newton's laws in the Minkowski spacetime of Special Relativity (SR); steps in that direction have been taken in the development of *Relativistic Newtonian Dynamics* (Friedman and Steiner, 2016). We could, then, modify our semi-classical model of the EPT accordingly. However, we can prove by *reductio ad absurdum* that there is an aspect of Newtonian theory that cannot work in the framework of SR:

Proposition 10.1.2. *The gravitational potential field of a system cannot possibly be the result of an instantaneous "action at a distance".* ■

Proof: Consider two processes in the temporal evolution of a massive system in the inertial reference frame (IRF) of an observer $\mathcal{O}$:

(i) in the first process the system moves A to B, with constant 4-velocity in positive x-direction in the IRF of $\mathcal{O}$;

(ii) in the second process, the system moves from B to C, with constant 4-velocity *faster* in positive x-direction in the IRF of $\mathcal{O}$.

So, at B the system has received an instantaneous impulse, e.g. by emitting a photon as in the framework of the EPT. Furthermore consider two more IRFs of observers $\mathcal{O}'$ and $\mathcal{O}''$:

- the IRF of observer $\mathcal{O}'$ is co-moving with the massive system during the first process, such that the world line traced out by the massive system during the first process in the IRF of $\mathcal{O}'$ corresponds with a segment of the t'-axis starting at the origin;
- the IRF of observer $\mathcal{O}''$ is co-moving with the massive system during the second process, such that the world line traced out by the massive system during the second process in the IRF of $\mathcal{O}''$ corresponds with a segment of the t''-axis starting at the origin;

See Fig. 10.2 for an illustration. Now let's assume that the massive system generates a gravitational potential field Φ by an instantaneous "action at a distance". That means that when the system is located at the point A, it generates a gravitational potential $\Phi(X)$ at every point X in the co-moving

IRF of $\mathcal{O}'$ that has the same time coordinate as the point A. Thus speaking, when the system is at A, it generates a gravitational potential at every point on the x'-axis, which lies "tilted" in the tx-plane of the IRF of $\mathcal{O}$, as illustrated by Fig. 10.2. It also means that when the system is located at the point B, it generates a gravitational potential $\Phi(Z)$ at every point Z in the co-moving IRF of $\mathcal{O}''$ that has the same time coordinate as the point B. Thus speaking, when the system is at B, it generates a gravitational potential at every point on the x''-axis, which lies "tilted" in the tx-plane of the IRF of $\mathcal{O}$, as again illustrated by Fig. 10.2. But that means that there is a point D where the x'-axis and the x''-axis intersect. And that means that we can think of a point E, such that the system generates a gravitational potential at E during the **second** process, and such that points with the same spatial coordinates as E, at which the system generates a gravitational potential during the **first** process, lie in the future of E for our observer $\mathcal{O}$—see Fig. 10.2. This is absurd. Ergo, the monadic system cannot possibly generate a gravitational potential field Φ by an instantaneous "action at a distance". ∎

N.B. the above argument also holds when the massive system accelerates continuously between A and C. Importantly, it shows that the nature of spacetime is such that it forbids this "spooky" action at a distance.

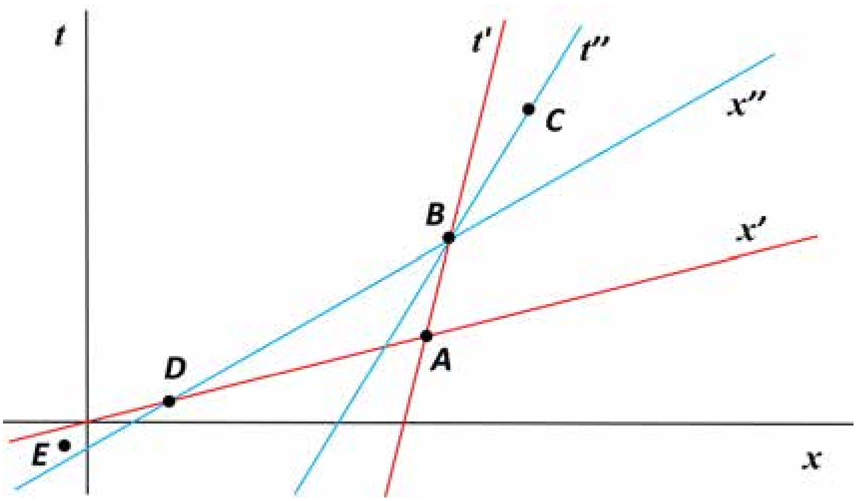


Figure 10.2: Illustration of the proof of Prop. 10.1.2.

An existing theory that is consistent with all observations on massive systems subjected to gravitation is General Relativity (GR), developed by Einstein (1916). The essence of GR is that gravitation, that is, motion of a free particle in a gravitational field, is nothing but motion on a geodesic of spacetime. It is easy to prove that spacetime is then necessarily curved; the proof below is based on an argument by Susskind (2012).

Proposition 10.1.3. ***If*** *gravitation is motion on geodesics of spacetime,* ***then*** *spacetime is necessarily curved.* ■

Proof Suppose gravitation is motion on geodesics of spacetime, and suppose a 25,000 km giant approaches earth as illustrated by Fig. 10.3. We know that the earth's gravitational field is directed towards its center, so if the particles of the giant's head and feet would be free particles they would move on curved geodesics towards earth. So, the gravitational force on the particles has a component along the giant's spine causing compression: he gets back pain. Now suppose that spacetime is not necessarily curved. The giant then calls a doctor for his back pain, and get this: the doctor prescribes him a coordinate transformation! In the new coordinate system, geodesics are straight lines in flat space as illustrated by Fig. 10.3: since gravitation is motion on geodesics, there is then no more compression of the giant's spine. So, the giant can heal his back pain by merely performing a coordinate transformation. This is absurd. Ergo, the proposition is true. ■

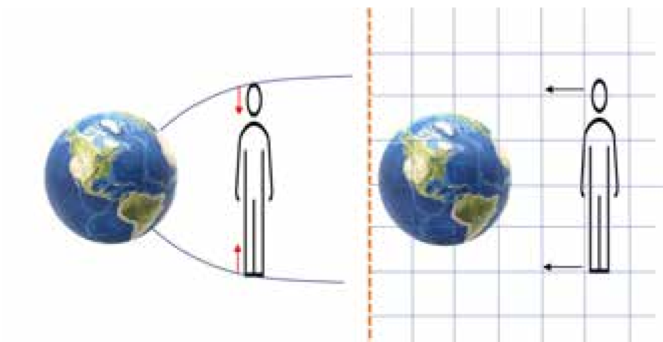


Figure 10.3: The 25,000 km giant approaching earth. On the left, two curved geodesics towards the earth's center are shown: gravitation thus leads to compression of the giant's spine as indicated by red arrows. On the right, geodesics are straight lines in flat space: compression is absent.

Prop. 10.1.3 shows that the universally accepted view that spacetime is curved leans on the assumption that gravitation is motion on geodesics of spacetime. In Sect. 2.1, however, we have argued that if a matter-antimatter repulsive gravity is a fact of nature, then gravitation *cannot be* motion on geodesics of spacetime. Thus speaking, a detection of matter-antimatter repulsive gravity would invalidate the argument for the necessity of the curvature of spacetime. We then arrive at this proposition:

Proposition 10.1.4. ***If*** *a matter-antimatter repulsive gravity is a fact of nature,* ***then*** *spacetime is not necessarily curved.* ■

One might object that the observed deflection of light by the gravitational field of the sun leaves no other conclusion than that spacetime is curved. But that is not true: the curvature of spacetime is not uniquely determined by a photon path in a coordinate system. The following corollary, namely, is an important lesson of differential geometry, illustrated by Fig. 10.4:

Corollary 10.1.5. *Let $\mathcal{M}$ be a 4-manifold, and let (U, φ) be a chart with chart region $U \subset \mathcal{M}$ and map $\varphi : U \to \mathbb{R}^4$. Now suppose we are given the coordinates γ^μ of the points in U of a curve $\gamma : \mathbb{R} \to \mathcal{M}$. Then this does* ***not*** *uniquely determine a metric g on $\mathcal{M}$ or a connection $\Gamma^\alpha_{\mu\nu}$.* ■

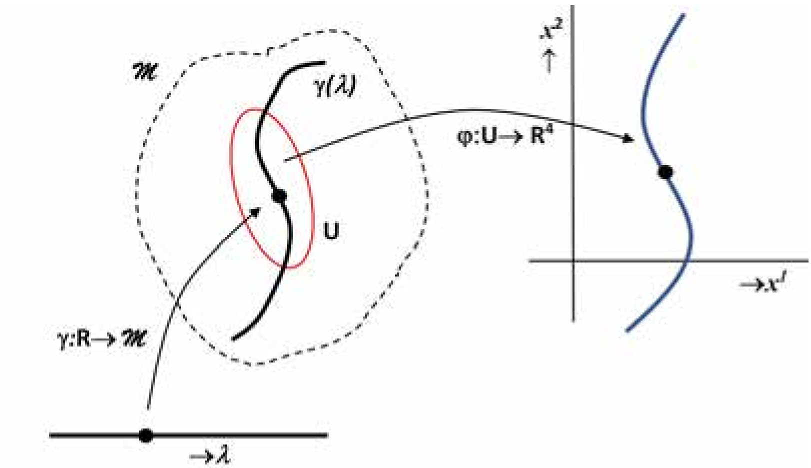


Figure 10.4: Illustration of Cor. 10.1.5. The function γ maps the real line to a curve on the manifold parameterized by λ. The map φ maps the segment of the curve in the chart region U to a curve in $\mathbb{R}^4$. Given the latter, neither the metric g nor the connection $\Gamma^\alpha_{\mu\nu}$ on $\mathcal{M}$ is determined.

Let's conclude this section with a final proposition, which also justifies the generalized principle of formation of space of the EPT (Ax. 5.3.18):

Proposition 10.1.6. ***If*** *a matter-antimatter repulsive gravity is a fact of nature,* ***then*** *spacetime is necessarily substantival.* ■

Proof: Let's assume that a matter-antimatter repulsive gravity is a fact of nature. Suppose then that we create a massive system made up of a single particle/antiparticle pair at a height h_1 $[m]$ above the earth's surface: thus costs us an energy E_1 $[J]$. We then elevate the system to a height h_2 $[m]$, with $h_2 > h_1$. Of course it costs energy to elevate the particle against the gravitational field of the earth, but on the other hand we get energy from elevating the antiparticle: therefore we can elevate the system (in principle) *adiabatically.* That means that the energy of the system at height h_2 $[m]$ is E_2 $[J]$, for which

$$E_2 = E_1 \tag{10.4}$$

Next, at height h_2 $[m]$ we convert the system into a photon by annihilation—upon annihilation we get two photons, but with intelligently placed mirrors we may merge these into a single photon. This doesn't cost energy, so the energy of the photon at height h_2 is E^2_γ $[J]$ for which

$$E^2_\gamma = E_2 \tag{10.5}$$

We now send the photon back to height h_1 $[m]$. But we know from experiment that the photon's energy *increases* when travelling down the earth's gravitational field (Pound and Rebka, 1960), so having arrived at height h_1 $[m]$ the energy of the photon is E^1_γ $[J]$ for which $E^1_\gamma > E^2_\gamma = E_1$. There is thus a small amount of energy δE $[J]$ so that we can write

$$E^1_\gamma = E_1 + \delta E \tag{10.6}$$

We have thus ended up with more energy than we started with. Now if empty space is not a substance, as in SR or GR, then this extra energy δE $[J]$ comes from nowhere: the law of conservation of energy is then violated. This is an argument against a matter-antimatter repulsive gravity, originally published by Morrison (1958). See Fig. 10.5 for an illustration.

But the argument works both ways. If a matter-antimatter repulsive gravity is a fact of nature, then there is no other possibility than that the energy δE [J] comes from the vacuum. The law of conservation of energy is then not violated: the energy contained in the vacuum has to be taken into account as well. Ergo, if a matter-antimatter repulsive gravity is a fact of nature, then spacetime is substantival. ■

Remark 10.1.7 (Principle of energy conversion)**.**
At height h_1 [m] we can "harvest" the extra energy δE [J], and use the remaining energy E_1 [J] to again create a new particle/antiparticle pair. We then actually have a cyclic process, every cycle of which *de facto* converts an amount of energy δE [J] contained in the vacuum into energy of a photon—we can "harvest" this energy in principle. This is a radically new principle of energy conversion. N.B. In the framework of the EPT this cyclic process does not yield a perpetuum mobile, because ultimately the energy contained in the vacuum is finite. ■

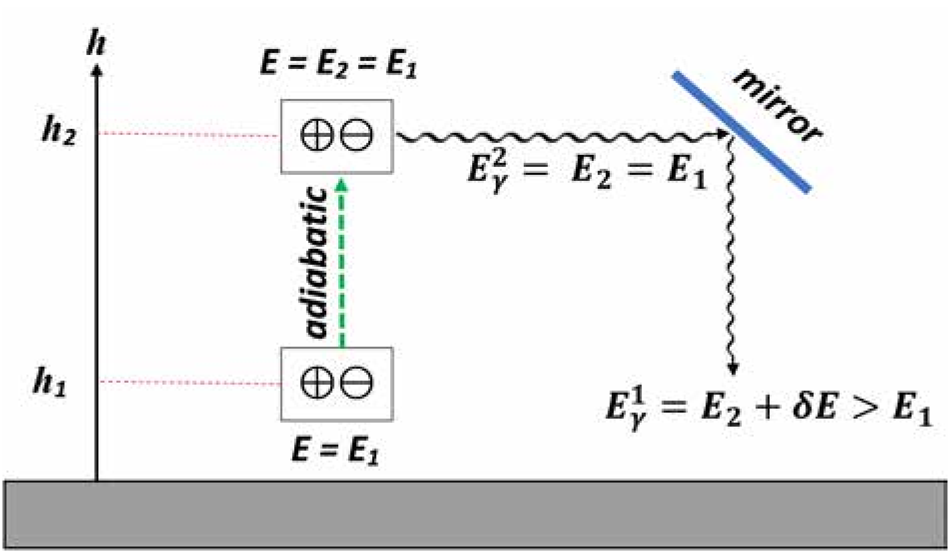


Figure 10.5: Illustration of Morrison's 1958 argument against a matter-antimatter repulsive gravity.

On the dimensionality of spacetime

Our conclusion so far is that for a relativistic theory of gravity predicting a matter-antimatter repulsion,

- we have to depart from the framework of Einstein's GR;
- we cannot go back to the framework of Newton's gravity.

Now a way to depart from the (standard) framework of GR is to consider the scenario that we live in a five-dimensional (5D) spacetime with an additional spatial dimension that is curled up (i.e. compact) and that has a very small size (e.g. Planck length): **the only reason** to pursue this far-fetched idea is to save Einstein's idea that gravity is motion on geodesics of a curved spacetime. The idea of an additional curled-up spatial dimension stems from Kaluza-Klein theory (KK theory), a theory developed by Theodor Kaluza (1921) and Otto Klein (1926) that describes both gravitation and electromagnetism. In KK theory, electric charge is identified with the direction of motion in the additional curled-up dimension. So in analogy to KK theory, we could assign a gravitational charge +1 to massive systems made up of ordinary matter and a gravitational charge of −1 to massive systems made up of antimatter, and we could consider that

(i) massive systems of ordinary matter move on geodesics with $\dot{x}^4 = +1$,

(ii) photons move on geodesics with constant x^4-coordinate,

(iii) massive systems of antimatter move on geodesics with $\dot{x}^4 = -1$,

where x^4 is the coordinate of the system on the curled-up fourth spatial dimension, and $\dot{x}^4 = dx^4/d\tau$ with τ being the proper time. So, massive systems of ordinary matter and massive systems of antimatter move in opposite direction through the curled-up dimension, while photons don't move through the curled-up dimension, cf. (Cabbolet, 2016b).

Based on that idea, equations of motions for matter, antimatter, and massless particles as well as field equations determining the curvature of 5D spacetime will have to be developed in such a way that the theory should (i) formally reduce to standard GR for massive systems of ordinary matter and for massless particles, and (ii) predict that massive systems of antimatter will accelerate away from a body of ordinary matter. This is a nontrivial exercise in differential geometry.

However, even apart from the question of whether one can get this consistent, seemingly unsolvable conceptual difficulties arise from this idea. In the 5D spacetime manifold, there is a copy of a curved 4D spacetime at every point of the curled-up dimension: that curvature must come from something. But a massive system occupies only one point of the curled-up dimension at any given point in time: only at that point in time, it is a source of the curvature of the copy of 4D spacetime attached to that point of the curled-up dimension. But an instant later, it occupies another point of the curled-up dimension: it is then no longer a source of the curvature of the copy attached to the former point. It is then conceptually different to explain how any substantial curvature arises in 5D spacetime. See Fig. 10.6 for an illustration. A way out is the cylindrical condition that all copies of 4D spacetime along the curled-up dimension are the same: that solves the problem *mathematically*, but *conceptually* it is rather ad hoc and not justified—it's an admission of cluelessness. Therefore, this whole idea of extra spatial dimensions is rejected, and therewith we abandon the idea that gravitation is motion on geodesics of a curved spacetime.

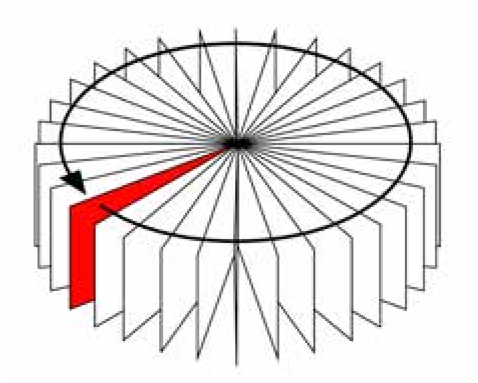


Figure 10.6: Illustration of the conceptual problem with the compact dimension. The sheets represent copies of 4D spacetime at different coordinates x^4 in the compact dimension. Suppose a massive system, say an electron, has a state S_0 in 4D spacetime at $x^4 = 0$ (represented by the colored sheet). As the electron moves through the compact dimension (as indicated by the arrow), it attains a state S_u in 4D spacetime at $x^4 = u$. But then the state S_0 in 4D spacetime at $x^4 = 0$ no longer exists: the source of curvature in the copy of 4D spacetime at $x^4 = 0$ then no longer exists. It becomes then conceptually difficult to explain any curvature in each of the copies of 4D spacetime. Drawing: Willem van Otterdijk.

10.2 A model for spacetime

Process-physical presuppositions

To maintain self-containment, we will summarize those aspects of the EPT that are needed to develop our theory of gravity in a number of propositions.

Proposition 10.2.1. *In the universe of the EPT, elementary processes are primary: all massive systems evolve in time by these processes.* ■

Luckily it's to our advantage that the elementary processes by which a massive system evolves in time are **simple** when we only consider processes by which an interaction with only gravitational and/or electromagnetic aspects takes place between the massive system and its environment:

Proposition 10.2.2. *The essence of a simple elementary process, by which an interaction with gravitational and/or electromagnetic aspects takes place between a massive system and its environment, is the following:*

(i) the process starts with the massive system in a ground state, which we may think of as a particle state;

(ii) by the first event the massive system transforms from the ground state to a transition state, which we may think of as a wave state;

(iii) the massive system absorbs energy from its environment during the time span it is in a transition state;

(iv) by the next event the massive system transforms from the transition state to an excited state, which we may think of as a particle state;

(v) by the final event the excited state decays into a new ground state plus emitted radiation;

(vi) by emitting the radiation at the final event, the massive system receives an impulse;

(vii) the massive system in the new ground state marks the beginning of a new elementary process.

Throughout a process, a massive system carries a set of invariant properties. ■

Remark 10.2.3. These elementary processes are thus a series of state transitions. The fact that these are primary then has the consequence that 'motion' is a derived concept: from the fundamental point of view there is no such thing as motion—there is only a succession of states. Only *after* we have fitted the vacuum with a coordinate system and have assigned positions to particle states, we can start talking about 'motion'. ■

Agreement 10.2.4. We will only consider the **simplest** processes, which are those by which a **monadic system**, that is, a one-component massive system, interacts with its environment. ■

We will now develop a symbolic description of such a simplest process. The key to the symbolic description is to start viewing the life of the massive system in a certain state as *one object*—note that such an object has a time span with possibly nonzero duration; cf. Sect. 3.2.

Proposition 10.2.5. *There are countably many monadic systems, so that we can assign a counting number to a monadic system. Each monadic system evolves in time by countably many elementary processes, so that we can index its evolution by real-valued degrees of evolution: we can associate consecutive integer-valued degrees of evolution to the initial events of consecutive processes in the temporal evolution of a monadic system.* ■

Proposition 10.2.6. *For any k and any n,*

(i) the life of the k^{th} monadic system in the ground state at the n^{th} degree of evolution is designated by ${}^{EP}\varphi_k^n$;

(ii) the life of the k^{th} monadic system in a transition state, created at the n^{th} degree of evolution, is designated by ${}^{NW}\varphi_k^n$;

(iii) the life of the k^{th} monadic system in the excited state at the $(n+1)^{\text{th}}$ degree of evolution is designated by ${}^{NP}\varphi_k^{n+1}$;

(iv) the life of the radiation emitted at the $(n+1)^{\text{th}}$ degree of evolution by the k^{th} monadic system is designated by ${}^{LW}\varphi_k^{n+1}$;

(v) the set of invariant properties carried by the k^{th} monadic system is designated by M_k.

■

Proposition 10.2.7. *Mathematically,*

(i) each designator $\mathfrak{S}$ that refers to an object as in clauses (i)-(iv) of Prop. 10.2.6 is assumed to be an abstract mathematical constant, meaning that it comes with a mathematical axiom

$$\exists \alpha : \alpha = \mathfrak{S} \tag{10.7}$$

saying that there is a thing α in the mathematical universe which is identical to $\mathfrak{S}$.

(ii) each designator M_k that refers to a set of properties as in clause (v) of Prop. 10.2.6 is assumed to be an abstract nonempty set, meaning that it comes with a mathematical axiom

$$\exists \alpha \exists \beta : \alpha = \mathrm{M}_k \wedge \beta \in \alpha \tag{10.8}$$

saying that there are things α and β in the mathematical universe such that α is identical to M_k and β is an element of α.

■

So, it has to be clear from the *typography* to which object a designator refers. This typography is explained in Ch. 3, but this explanation is in terms of *phase quanta*. For the simplest processes, however, it is much easier to work with Prop. 10.2.6, which uses the language of systems theory—we will have to accept, alas, that the formalism is then not an elegant fit, but still adequate. Furthermore, we will have to consider sums of constants referring to objects, like ${}^{EP}\varphi_k^n + {}^{NW}\varphi_k^n$, to formalize our process-physical presuppositions. The easiest way to do that is to use a semigroup structure.

Proposition 10.2.8. *The semigroup $(G^*, +)$ is the free semigroup on the set A of abstract constants, introduced by clauses (i)-(iv) of Prop. 10.2.6, under addition. So,*

(i) if $g \in A$, then $g \in G^*$;

(ii) if $g_1 \in G^*$ and $g_2 \in G^*$, then $g_1 + g_2 \in G^*$.

■

We will now consider a generic process: the elementary process by which the k^{th} monadic system evolves from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution. This process has already been described by Prop. 10.2.2 in the language of systems theory, but now we have all necessary definitions in place to precisely state the process-physical principles that govern this generic process—these hold, thus, for any process described by Prop. 10.2.2. Below we thus obtain a watered-down version of the EPT: it only holds for the simplest processes, but it has the enormous advantage that the physical interpretation of the formalism can be expressed in the language of systems theory—for the full version of the EPT no such interpretation exists.

Proposition 10.2.9. *The life of the k^{th} monadic system in the ground state at the n^{th} degree of evolution exists:*

$$\mathbb{E}^{EP}\varphi_k^n \tag{10.9}$$

Eq. (10.9) *can be viewed as a notation for the $\in$-relation ${}^{EP}\varphi_k^n \in R_1$ for a unary relation R_1 on G^*.* ■

Proposition 10.2.10. *By a state transition at the n^{th} degree of evolution, the life of the k^{th} monadic system in the ground state transforms into the life of the k^{th} monadic system in a transition state:*

$${}^{EP}\varphi_k^n \rightarrow {}^{NW}\varphi_k^n \tag{10.10}$$

Likewise, Eq. (10.10) *can be viewed as a notation for an $\in$-relation for a binary relation R_2 on G^*.* ■

Proposition 10.2.11. *The life of the k^{th} monadic system in a transition state, created at the n^{th} degree of evolution, effects that the life of the k^{th} monadic system in the ground state at the n^{th} degree of evolution is succeeded by the life of the k^{th} monadic system in the excited state at the $(n+1)^{\text{th}}$ degree of evolution:*

$${}^{NW}\varphi_k^n : {}^{EP}\varphi_k^n \dashrightarrow {}^{NP}\varphi_k^{n+1} \tag{10.11}$$

Eq. (10.11) *can be viewed as a notation for an $\in$-relation for a ternary relation R_3 on G^*. The dashed arrow $\dashrightarrow$ is intended to indicate that the corresponding succession does not take place by a single state transition.* ■

Proposition 10.2.12. *By a state transition at the* $(n+1)^{\text{th}}$ *degree of evolution, the life of the* k^{th} *monadic system in the excited state transforms into the life of the* k^{th} *monadic system in the ground state plus the life of radiation emitted at the* $(n+1)^{\text{th}}$ *degree of evolution by the* k^{th} *monadic system:*

$$^{NP}\varphi_k^{n+1} \;\rightarrow\; ^{EP}\varphi_k^{n+1} \;+\; ^{LW}\varphi_k^{n+1} \tag{10.12}$$

Eq. (10.10) *can be viewed as a notation for an* $\in$*-relation for the binary relation* R_2 *on* G^**.* ■

Proposition 10.2.13. *The life of the* k^{th} *monadic system in the ground state at the* n^{th} *degree of evolution followed by the life of the* k^{th} *monadic system in a transition state, created at the* n^{th} *degree of evolution, is a temporally extended object designated by* $\psi^n_{\mathrm{M}_k}$*, which is created at the* n^{th} *degree of evolution, and which carries the set of invariant properties* M_k*:*

$$^{EP}\varphi_k^{n} \;+\; ^{NW}\varphi_k^{n} \;=\; \psi^n_{\mathrm{M}_k} \tag{10.13}$$

By Prop. 10.2.8 we thus have $\psi^n_{\mathrm{M}_k} \in G^*$*.* ■

To treat the generalized principle of formation of space of the EPT, it is required that we extend the set A of generators of the semi-group $(G^*, +)$ with a new abstract constant: the next proposition introduces this constant.

Proposition 10.2.14. *The component of spacetime created at the* $(n+1)^{\text{th}}$ *degree of evolution in the process of evolution of the* k^{th} *monadic system from the* n^{th} *to the* $(n+1)^{\text{th}}$ *degree of evolution is designated by* $^{S}\varphi_k^{n+1}$*.* ■

Proposition 10.2.15. *The existence of the substantival component of spacetime designated by* $^{S}\varphi_k^{n+1}$ *requires the existence of the life of the radiation emitted at the* $(n+1)^{\text{th}}$ *degree of evolution by the* k^{th} *monadic system:*

$$\mathbb{E}^{S}\varphi_k^{n+1} \;\Rightarrow\; \mathbb{E}^{LW}\varphi_k^{n+1} \tag{10.14}$$

■

Thus speaking, we will take a substantival approach to spacetime, substantiated by Prop. 10.1.6; the essence is that a component of spacetime is generated by a special kind of radiation emitted by a monadic system. This, of course, flies in the face of the widely-held belief that experiments—in particular, the experiment by Michelson and Morley (1887)—have shown that any such approach is ruled out. But that belief is not true, it's an overstatement. What *is* true, though, is

(i) that experiments have shown that the idea of the luminiferous aether *incorporated in classical mechanics* is false;

(ii) that Einstein's theory of special relativity (SR) can explain the outcome of the Michelson-Morley experiment *without* assuming the existence of an aether.

But it has been proven that Einstein's SR is equivalent to Lorentz's aether theory: see e.g. (Ancuña, 2014) for a discussion. So, it is merely the case that historically Einstein's SR has gained widespread acceptance at the cost of Lorentz's theory because it has one assumption less. But that does not imply by any means that a substantival approach to spacetime is *a priori* ruled out: it may even be crucial for the explanation of other observations, in particular those that are now explained with the dark energy hypothesis—for a review of the latter, see e.g. (Peebles and Ratra, 2003).

Remark 10.2.16. We now have a version of the EPT—note that it is expressed without reference to the coordinate system of an observer—that can serve as a basis of our theory of gravitation, which will take the form of a model of (this version of) the EPT. However, we have omitted the generalized principle of choice of the EPT. The reason for this is that we intend to develop a *deterministic* model of the EPT. We can nevertheless give a statement of the principle for our present purpose. Since the model is deterministic, the set θ_k^{n+1} of parallel possible lives of the k^{th} monadic system in an excited state at the $(n+1)^{\text{th}}$ degree of evolution is just the singleton $\{\ {}^{NP}\varphi_k^{n+1}\ \}$. Now let's view the function f_C on the singleton of θ_k^{n+1} given by $f_C : \theta_k^{n+1} \mapsto\ {}^{NP}\varphi_k^{n+1}$ as a choice function that "chooses" ${}^{NP}\varphi_k^{n+1}$ from the set $\theta_k^{n+1} = \{\ {}^{NP}\varphi_k^{n+1}\ \}$ of possibilities; the principle of choice of the EPT is then trivially represented by

$$ {}^{NP}\varphi_k^{n+1} = f_C(\theta_k^{n+1}) \tag{10.15}$$

■

To lay out our method for the development of a theory of gravity, we still need one more notion: the notion of a *hyperstate*. We all know what is meant by a state of a system: it is a condition that a system is in *at a point of time*. So when we talk about *the life of a system*—this is an *occurrent*, that is, an object that has a possibly extended time span—it would thus be an abuse of words to talk about the "state" of the life of a system. To deal with this situation, we introduce the notion of a hyperstate as follows: the **hyperstate of the life of a system over a time span** I in the reference frame of an observer, where $I \subset \mathbb{R}$ is a (possibly degenerate) connected interval of time, is the union of the states of the system at the points in time $t \in I$ in that reference frame. It is assumed that this idea is intuitively clear—a formal definition is omitted.

That said, we will develop our theory of gravity in two steps. The first step is to develop a model of spacetime, which can be used by all observers. For that matter, an important aspect of the universe of the EPT is that a monadic system has a constant velocity during the time span it is in a wave state—although this aspect is not reflected in the generalized process-physical principles of the EPT, it is a part of the idea from which the EPT has been developed, see Ch. 3. An observer is then a "test system": it evolves in time by the processes described by the EPT but the interaction with its environment is negligible. The crux is that we can speak of a temporarily non-accelerated observer: we henceforth assume that all observers are temporarily non-accelerated.

The second step is then to model, for each kind of state that the system gets in during the generic process, the hyperstate of the life of the monadic system in that state in spacetime: this step uses our model of spacetime. Assuming only a gravitational interaction takes place between the system and its environment, this should yield

(i) a quantitative description of the effect of the gravitational field in the environment on the temporal evolution of a monadic system;

(ii) a quantitative description of the effect of a monadic system on the state of its environment.

That way we obtain a theory of gravity in the form of a model of a process of gravitational interaction between a monadic system and its environment.

Tetrad formalism: the Vierbein frame

Let's begin with a minimalist definition of the spacetime manifold. We avoid starting off with too much structure, because if we commit ourselves in great detail to a rich initial structure then we put limits on the developments of a model for spacetime right from the start: that may actually preclude that we end up with the model of spacetime that we need. So, we start off with this minimalist definition, and we will gradually develop further structure. We will use Agreement 9.2.3 about indices.

Definition 10.2.17 (Spacetime manifold)**.**
The ***spacetime manifold*** *is a structure* $(\mathcal{M}, T_{\mathcal{M}}, \mathcal{A})$ *where*

(i) $\mathcal{M}$ *is a set of (spatiotemporal)* ***points*** *that represents* ***spacetime;***

(ii) $T_{\mathcal{M}}$ *is the* ***topology*** *on* $\mathcal{M}$*, such that* $(\mathcal{M}, T_{\mathcal{M}})$ *is a second-countable Hausdorff space;*

(iii) $\mathcal{A}$ *is an* ***atlas****, which is a family of* ***charts*** *that can be indexed by some set* $\mathcal{F}$*:*

$$\mathcal{A} = \{(U_j, \varphi_j)\}_{j\in\mathcal{F}} \tag{10.16}$$

$$\bigcup_{j\in\mathcal{F}} \{U_j\} = \mathcal{M} \tag{10.17}$$

A chart $(U, \varphi) \in \mathcal{A}$ *consists of an open set* $U \in T_{\mathcal{M}}$*, the* ***chart region****, and a homeomorphism* $\varphi : U \to \mathbb{R}^4$*,* $\varphi : X \mapsto (x^0, x^1, x^2, x^3)$*, the* ***chart mapping****. The image of a point* $X \in \mathcal{M}$ *under* φ *is a* ***coordinate tuple;*** *we can also say that* X *has coordinates* (x^0, x^1, x^2, x^3)*. The* ***coordinate functions*** *are the four functions* $x^\mu : \mathcal{M} \to \mathbb{R}$ *given by* $x^\mu(X) = (\phi(X))^\mu$*, i.e. the* μ^{th} *component of the coordinate tuple* $\varphi(X)$*. The image* $\varphi[U]$ *of the chart region* U *under the chart mapping* φ *is a* ***coordinate system*** *on the open set* U*.* ■

Definition 10.2.18 (Geometric vectors)**.**
A ***geometric vector*** *in spacetime with* ***initial point*** X *and* ***terminal point*** Y *is denoted by* $\overrightarrow{XY}$*, and is represented mathematically by the ordered two-tuple* $(X, Y) \in \mathcal{M} \times \mathcal{M}$*. We may depict a geometric vector graphically as an arrow from* X *to* Y*.* ■

Definition 10.2.19 (Translations).
*For any geometric vector $\overrightarrow{XY}$ with initial point X and terminal point Y there is a **translation** $T_{\overrightarrow{XY}} : \{X\} \to \{Y\}$ that maps the initial point X to the terminal point Y. In the framework of the foundational theory $\mathfrak{T}$ of Chapter 4, this translation is an ur-function $\{(X, Y)\}_{\{X\}}$.* ■

That being said, when it comes to the coordinate systems on an environment U in spacetime, our fantasy is the only limit. But in the end, we are doing physics here. If we have a coordinate system on an open set U and two points $X, Y \in U$, then the coordinate separation between X and Y—i.e., the difference between $\varphi(X)$ and $\varphi(Y)$—must ultimately translate to spatial distances measurable with a rod and time differences measurable with a clock: else predictions about the whereabouts of monadic systems are not experimentally testable. We therefore require a definition of global units of time and spatial distance of an observer $\mathcal{O}$.

Definition 10.2.20 (Global units).
For an observer $\mathcal{O}$,

*(i) the **global unit of time**, notation: τ_G, is a precisely defined amount of time ticked off by clock co-moving with $\mathcal{O}$ in an environment where the gravitational potential is negligible.*

*(ii) the **global unit of spatial distance**, notation: ℓ_G, is a precisely defined amount of spatial distance measurable with a solid rod.*

The corresponding SI units are the second and the meter, respectively. ■

Agreement 10.2.21. If a physical quantity is expressed in global units, then the unit is displayed in square brackets. E.g. $\Delta t = 5.5\ [\tau_G]$. ■

Postulate 10.2.22 (Global chart).
*The spacetime manifold is flat, meaning that an observer O can find a global rectangular coordinate system on $\mathcal{M}$ such that every coordinate separation is a directly measurable quantity in global units. The atlas $\mathcal{A}$ therefore contains a **global chart** $(\mathcal{M}, \varphi_0)$. For any $(x^0, x^1, x^2, x^3) \in \varphi_0[\mathcal{M}]$,*

- *x^0 is the **time coordinate**;*
- *x^1, x^2, x^3 are **spatial coordinates**.*

There is no preferred global chart: there are infinitely many possibilities. ■

Corollary 10.2.23. *For any point $X \in \mathcal{M}$, there are, thus, four points $E_\mu^X \in \mathcal{M}$ such that the α^{th} coordinate of E_μ^X in $\varphi_0[\mathcal{M}]$ satisfies*

$$(\varphi_0(E_\mu^X))^\alpha = x^\alpha + \delta_\mu^\alpha \tag{10.18}$$

where δ_μ^α is the Kronecker delta. From now on, the geometric vector $\overrightarrow{XE_\mu^X}$ will be denoted by $\vec{e}_\mu^{\,X}$. ■

Postulate 10.2.24 (Torsion-freeness)**.**
*The spacetime manifold has a global chart $(\mathcal{M}, \varphi_0)$ that is torsion-free. Let, for any point $X \in \mathcal{M}$ and for any smooth curve $\gamma : [-1, 1] \to \mathcal{M}$ with $\gamma(0) = X$ and for any $\tau \in [-1, 1]$, the operator $\Omega_{0\tau}^{X,\gamma}$ map a geometric vector $\vec{e}_\mu^{\,X}$ to its **parallel image** with initial point $\gamma(\tau)$. Then we have*

$$\Omega_{0\tau}^{X,\gamma} : \vec{e}_\mu^{\,X} \mapsto \vec{e}_\mu^{\,\gamma(\tau)} \tag{10.19}$$

In terms of translations, for any $X \in \mathcal{M}$ we have

$$T_{\vec{e}_\mu^{\,Y}} \circ T_{\vec{e}_\alpha^{\,X}}(X) = T_{\vec{e}_\alpha^{\,Z}} \circ T_{\vec{e}_\mu^{\,X}}(X) \tag{10.20}$$

where $Y = E_\alpha^X$ and $Z = E_\mu^X$. See Fig. 10.7 for an illustration. ■

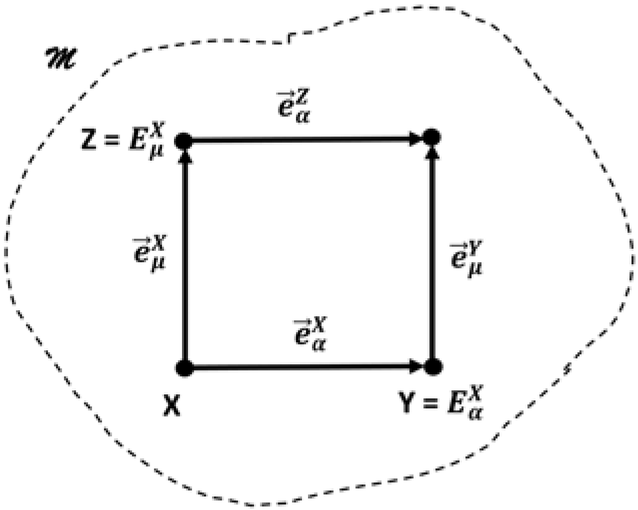


Figure 10.7: Illustration of Eq. (10.20).

Agreement 10.2.25. From now on, when we say '*let* $(\mathcal{M}, \varphi_0)$ *be a global chart*' we mean a global chart that yields a torsion-free, rectangular coordinate system on the spacetime manifold. We will call $\varphi_0[\mathcal{M}]$ the **temporarily co-moving reference frame** (TCRF) of observer $\mathcal{O}$. ■

Definition 10.2.26 (Separations in time and space)**.**
Let, for an observer $\mathcal{O}$, $(\mathcal{M}, \varphi_0)$ *be a global chart and let, for any* $X \in \mathcal{M}$ *the* ***hyperplane of simultaneity*** *of* X *be the set* $[M]_{x^0=(\varphi_0(X))^0}$ *given by*

$$[\mathcal{M}]_{x^0=(\varphi_0(X))^0} = \{Y \in \mathcal{M} \mid (\varphi_0(Y))^0 = (\varphi_0(X))^0\} \tag{10.21}$$

Then any $Y \in [M]_{x^0=(\varphi_0(X))^0}$ *is* ***separated in space*** *from* X *by a spatial distance* $\|\overrightarrow{XY}\|$ *given by*

$$\|\overrightarrow{XY}\| = \sqrt{\sum_{j=1}^{3}(y^j - x^j)^2}\ [\ell_G] \tag{10.22}$$

where the x^j*'s and* y^j*'s are coordinates in* $\varphi_0[\mathcal{M}]$*. The real function* $\|.\|$ *thus maps a geometric vector in the hyperplane of simultaneity of* X *to the spatial distance (in global units) between the initial and terminal points. Let the* ***time line*** *through* X *be the set* $[\mathcal{M}]_{x^j=(\varphi_0(X))^j}$ *given by*

$$[\mathcal{M}]_{x^j=(\varphi_0(X))^j} = \{Y \in \mathcal{M} \mid (\varphi_0(Y))^j = (\varphi_0(X))^j\} \tag{10.23}$$

Then any Y *on the time line through* X *is* ***separated in time*** *from* X *by an amount of time* $\|\overrightarrow{XY}\|$ *given by*

$$\|\overrightarrow{XY}\| = \sqrt{(y^0 - x^0)^2}\ [\tau_G] \tag{10.24}$$

So, the real function $\|.\|$ *maps a geometric vector on a time line to the time difference (in global units) between its initial and terminal points.* ■

What this accomplishes is the following. Suppose we have a chart region $U \subset \mathcal{M}$ and some weird chart mapping $\psi : U \to \mathbb{R}^4$, $\psi : X \mapsto (\xi^0, \xi^1, \xi^2, \xi^3)$, and suppose that some theory predicts that if we release a monadic system with these and these properties at coordinates $(\xi^0_1, \xi^1_1, \xi^2_1, \xi^3_1)$ in $\psi[U]$, then it can be found at coordinates $(\xi^0_2, \xi^1_2, \xi^2_2, \xi^3_2)$ in $\psi[U]$. We can then verify this prediction by using the **transition function** $\phi_0 \circ \psi^{-1} : \psi[U] \to \varphi_0[U]$, which translates the coordinates in $\psi[U]$ to coordinates in the TCRF, that is, in $\varphi_0[U]$: that way, the prediction can be verified with clocks and rods. Importantly, we don't need to define a metric tensor field for that: it suffices to have the global chart and the transition function(s).

There is, however, a fly in the ointment: there is no real clock that measures time in global units. So, the time coordinate in the TCRF of an observer $\mathcal{O}$ is a purely mathematical construct that can only be *calculated* from the time ticked off by an actual clock. In a similar vein, if we look beyond laboratory experiments then spatial distances (e.g. between heavenly bodies) cannot effectively be measured with a solid rod. So, the spatial coordinates of a monadic system in the TCRF of an observer $\mathcal{O}$ will have to be calculated from position measurements with photons. To that end, we introduce the Vierbein field. That, however, requires the prior introduction of a vector space structure to sets of geometric vectors.

Definition 10.2.27 (Geometric vectors as tangent vectors)**.**
*Let $T_X(\mathcal{M}) = \{X\} \times \mathcal{M}$ be the set of geometric vectors with initial point X, henceforth to be called: the **tangent space** at X. We define a binary operation **vector addition** $+ : T_X(\mathcal{M}) \times T_X(\mathcal{M}) \to T_X(\mathcal{M})$ on this set:*

$$\begin{cases} \forall Y \forall Z \exists P : \overrightarrow{XY} + \overrightarrow{XZ} = \overrightarrow{XP} \\ P = \varphi_0^{-1}\left(\varphi_0(Y) + \varphi_0(Z) - \varphi_0(X)\right) \end{cases} \tag{10.25}$$

*Here φ_0 is a global chart mapping. We also endow this set with a binary operation **scalar multiplication** $\cdot : \mathbb{R} \times T_X(\mathcal{M}) \to T_X(\mathcal{M})$ given by*

$$\begin{cases} \forall \alpha \forall Y \exists P : \alpha \cdot \overrightarrow{XY} = \overrightarrow{XP} \\ P = \varphi_0^{-1}\left(\varphi_0(X) + \alpha \cdot (\varphi_0(Y) - \varphi_0(X))\right) \end{cases} \tag{10.26}$$

These definitions use vector addition and scalar multiplication in $\mathbb{R}^4$. ■

Remark 10.2.28. Let the **tangent bundle** $T\mathcal{M}$ be the sum set

$$T\mathcal{M} = \bigcup \{T_X(\mathcal{M})\}_{X \in \mathcal{M}} \tag{10.27}$$

and let $\pi : T\mathcal{M} \to \mathcal{M}$ be the projection that maps a geometric vector to its initial point. Then the triple $(T\mathcal{M}, \pi, \mathcal{M})$, usually denoted $T\mathcal{M} \xrightarrow{\pi} \mathcal{M}$, is a *fibre bundle*, whose *typical fibre* is $\mathbb{R}^4$. A vector field on $\mathcal{M}$ is then called a *section of the bundle*. We will not use this language. ■

Notation 10.2.29. Given a basis $\{\vec{b}_\mu\}$ of a tangent space $T_X(\mathcal{M})$, the 4-tuple of components x^μ of a tangent vector $\vec{x} \in T_X(\mathcal{M})$ with respect to $\{\vec{b}_\mu\}$ is denoted by $\hat{X}$, so $\hat{X} = (x^0, \ldots, x^3)$. The standard basis of $\mathbb{R}^4$ is denoted by $\{\hat{E}_\alpha\}$, with $(\hat{E}_\alpha)^\beta = \delta_\alpha^\beta$ where δ_α^β is the Kronecker delta. ■

Proposition 10.2.30. *There is a one-to-one correspondence between a geometric vector $\overrightarrow{XY} \in \mathcal{M} \times \mathcal{M}$ and an equivalence class of (locally) differentiable curves on $\mathcal{M}$.* ■

Proof:
Let $(\mathcal{M}, \varphi_0)$ be a global chart, and let $\ell : I \to \mathcal{M}$ be any curve satisfying

(i) I is an interval of the real numbers $\mathbb{R}$;

(ii) $\exists \lambda_0 : \ell(\lambda_0) = X$;

(iii) $\varphi_0 \circ \ell : I \to \mathbb{R}^4$ is differentiable in a neighborhood $U \subset \mathbb{R}^4$ of $\varphi_0(X)$;

(iv) $\lim_{\delta\lambda \to 0} \ell(\lambda_0 + \delta\lambda) = T_{\delta\lambda \cdot \overrightarrow{XY}}(X)$, where $\delta\lambda \cdot \overrightarrow{XY} = (\delta\lambda \Delta x^\alpha) \cdot \vec{e}_\alpha^{\,X}$ for a geometric vector $\overrightarrow{XY} = \Delta x^\alpha \vec{e}_\alpha^{\,X}$.

For each geometric vector $\overrightarrow{XY}$, these conditions determine an equivalence class of curves. On account of condition (iii) we subsequently get

$$\lim_{\delta\lambda \to 0} \varphi_0 \circ \ell(\lambda_0 + \delta\lambda) = \varphi_0(X) + (\delta\lambda \Delta x^\alpha) \cdot \hat{E}_\alpha \tag{10.28}$$

$$\lim_{\delta\lambda \to 0} \frac{\varphi_0 \circ \ell(\lambda_0 + \delta\lambda) - \varphi_0 \circ \ell(\lambda_0)}{\delta\lambda} = \Delta x^\alpha \hat{E}_\alpha \tag{10.29}$$

$$\varphi_0^{-1}(\varphi_0(X) + \lim_{\delta\lambda \to 0} \frac{\varphi_0 \circ \ell(\lambda_0 + \delta\lambda) - \varphi_0 \circ \ell(\lambda_0)}{\delta\lambda}) = \varphi_0^{-1}[(x^\alpha + \Delta x^\alpha)\hat{E}_\alpha] \tag{10.30}$$

Hence for any curve satisfying the conditions (i)-(iii), the initial point X and the terminal point $Y = \varphi_0^{-1}[(x^\alpha + \Delta x^\alpha)\hat{E}_\alpha]$ of the geometric vector $\overrightarrow{XY}$ are in the global coordinate system separated by the tangent to the curve $\varphi_0 \circ \ell$ at $\varphi_0(X)$. Therefore, there is a one-to-one correspondence between a geometric vector $\overrightarrow{XY}$ and an equivalence class of curves. ■

In differential geometry, there are two standard interpretations of an element of a tangent space $T_X(\mathcal{M})$ at a point X in an n-dimensional smooth manifold $\mathcal{M}$. Given a chart (U, φ) with $X_0 \in U$ and a basis $\{\hat{E}_\alpha\}$ of $\mathbb{R}^n$, the standard ways to define a vector $\vec{v} = v^\alpha \vec{e}_\alpha \in T_{X_0}(\mathcal{M})$ are the following:

(i) it is identified with an equivalent class of curves in $\mathcal{M}$—any two curves $\ell_1 : I_1 \to \mathcal{M}$ and $\ell_2 : I_2 \to \mathcal{M}$ are then equivalent if

$$\ell_1(\lambda_0) = \ell_2(\mu_0) = X_0 \tag{10.31}$$

$$(\varphi \circ \ell_1)'(\lambda_0) = (\varphi \circ \ell_2)'(\mu_0) = v^\alpha \hat{E}_\alpha \tag{10.32}$$

for some $\lambda_0 \in I_1$ and $\mu_0 \in I_2$;

(ii) it is identified with the differential operator $v^\alpha \frac{\partial}{\partial x^\alpha}$ at X_0—for any smooth function $f : U \to \mathbb{R}$, we then have

$$v^\alpha \frac{\partial f(X)}{\partial x^\alpha}\bigg|_{X=X_0} = v^\alpha \frac{\partial \tilde{f}(x^0, \ldots, x^3)}{\partial x^\alpha}\bigg|_{(x^0,x^1,x^2,x^3)=\varphi(X_0)} \tag{10.33}$$

where $\tilde{f}(x^0, x^1, x^2, x^3) = f \circ \varphi^{-1}(x^0, x^1, x^2, x^3)$.

These interpretations are shown to be equivalent by showing that there is a one-to-one correspondence between an equivalence class of curves as meant above under (i) and a differential operator as meant above under (ii); see e.g. (Lee, 2003). Prop. 10.2.30 shows likewise that *for our spacetime manifold* the identification of a tangent vector with a geometric vector is equivalent to its identification with an equivalent class of curves. We will stick to this interpretation because it is *intuitively* the simplest.

Definition 10.2.31 (Standard coordinate tetrad)**.**
Let, for an observer $\mathcal{O}$, $(\mathcal{M}, \varphi_0)$ be a global chart in the atlas of the spacetime manifold, and let the four vector fields $\vec{e}_\alpha : \mathcal{M} \to T\mathcal{M}$ be given by $\vec{e}_\alpha : X \mapsto \vec{e}^{\,X}_\alpha$ where $\vec{e}^{\,X}_\alpha$ is the geometric vector $\overrightarrow{XE^X_\alpha}$ that is determined by Eq. (10.18)*. Then at any point $X \in \mathcal{M}$, the four-element set $\{\vec{e}^{\,X}_\alpha\}$ is the* ***standard coordinate tetrad****.* ■

Let τ_P and ℓ_P denote the **Planck time** and the **Planck distance**, respectively; then there are conversion factors f_τ and f_ℓ such that

$$\begin{cases} \tau_P = f_\tau\ [\tau_G] \\ \ell_P = f_\ell\ [\ell_G] \end{cases} \tag{10.34}$$

So, in SI units we have $f_\tau = 5.391247 \cdot 10^{-44}$ and $f_\ell = 1.616255 \cdot 10^{-35}$. Note that we have $f_\tau \ll 1$ and $f_\ell \ll 1$ for the above numbers f_τ and f_ℓ. The thing is namely, that the global units of time and spatial distance are supposed to be *directly observable* (if certain conditions are met). Planck time and Planck distance, however, are not directly observable: there is no solid rod with the size of just a Planck distance, and there is no clock that can tick off just one Planck time—in fact, it has been argued that no future apparatus will ever be able to measure time differences shorter than 10^{-33} $[s]$ (Wendel et al., 2020).

Definition 10.2.32 (Planck tetrad)**.**
*At any $X \in \mathcal{M}$, the **Planck tetrad** is the four-element set $\{\vec{\pi}_\alpha^X\}$ given by*

$$\vec{\pi}_0^X = f_\tau \cdot \vec{e}_0^X \ , \|\vec{\pi}_0^X\| = 1 \ [\tau_P] \tag{10.35}$$

$$\vec{\pi}_j^X = f_\ell \cdot \vec{e}_j^X \ , \|\vec{\pi}_j^X\| = 1 \ [\ell_P] \tag{10.36}$$

*At any $X \in \mathcal{M}$, τ_P and ℓ_P are then the **global Planck units**.* ■

With these definitions in place we are ready to introduce the Vierbein field. We will first define what it is, and then develop the details in a number of postulates. The Vierbein field is then key to the formulation of laws of physics.

Definition 10.2.33 (Vierbein field)**.**
*For any observer $\mathcal{O}$, the **Vierbein field** is a set of four real vector fields $\vec{g}_\alpha : \mathcal{M} \to T\mathcal{M}$, $\vec{g}_\alpha : X \mapsto \vec{g}_\alpha^X$ with*

- *$\vec{g}_0^X$ being the **local timelike basis vector** at X;*
- *$\vec{g}_j^X$ being a **local spacelike basis vector** at X, with $j \in \{1, 2, 3\}$.*

*The four-element set $\{\vec{g}_\alpha^X\}$ is the **local Vierbein**.* ■

Of course, every element $\vec{g}_\alpha^X$ of a local Vierbein is an element of the tangent space $T_X(\mathcal{M})$. And since the tangent space $T_X(\mathcal{M})$ is endowed with a vector space structure by Def. 10.2.27, there are numbers g_α^μ such that

$$\vec{g}_\alpha^X = g_\alpha^\mu \vec{e}_\mu^X \tag{10.37}$$

On the other hand, for an arbitrary geometric vector $x^\mu \vec{e}_\mu^X \in T_X(\mathcal{M})$, there are four numbers $\overline{x}^\alpha$ such that

$$x^\mu \vec{e}^{\,X}_\mu = \overline{x}^\alpha \vec{g}^{\,X}_\alpha \tag{10.38}$$

That is, we can express a geometric vector as a linear combination of the local basis vectors $\{\vec{g}^{\,X}_\alpha\}$.

Notation 10.2.34. *We will henceforth denote the components of a geometric vector $\overrightarrow{XY}$ with respect to the local Vierbein $\{\vec{g}^{\,X}_\alpha\}$ at X by a barred symbol, as in $\overrightarrow{XY} = \overline{x}^\alpha \vec{g}^{\,X}_\alpha$.* ■

Postulate 10.2.35 (Local Vierbein)**.**
The local Vierbein $\{\vec{g}^{\,X}_\alpha\}$ is uniquely determined by two fields on spacetime:

*(i) the function $\theta : \mathcal{M} \to \mathbb{R}^+_0$ is the **vacuum temperature field**, a function value $\theta(X)$ being the **vacuum temperature** at X;*[67]

*(ii) the function $\Phi : \mathcal{M} \to (-1, 1)$ is the **gravitational potential field**, a function value $\Phi(X)$ being the **gravitational potential** at X.*

The local Vierbein thereby determined is then given by

$$\vec{g}^{\,X}_0 = g^\mu_0 \vec{e}^{\,X}_\mu = \frac{1}{1 - \Phi(X)} \cdot \vec{\pi}^{\,X}_0 \tag{10.39}$$

$$\vec{g}^{\,X}_j = g^\mu_j \vec{e}^{\,X}_\mu = \theta(X) \cdot \vec{\pi}^{\,X}_j \tag{10.40}$$

where $\{\vec{\pi}^{\,X}_\alpha\}$ is the Planck tetrad at X. Both $\Phi(X)$ and $\theta(X)$ are thus dimensionless scale factors. ■

We can say that the vacuum temperature field and the gravitational potential field are *encoded* in the Vierbein field: if we know the Vierbein field, we know θ and Φ. The crux is that a Vierbein $\{\vec{g}^{\,X}_\alpha\}$ is (in principle) *measurable*: its elements have a physical interpretation, introduced by the next two postulates.

Postulate 10.2.36 (Meaning of the local timelike basis vector)**.**
For an observer $\mathcal{O}$, the local timelike basis vector at a point X, i.e. the vector $\vec{g}^{\,X}_0 \in T_X(\mathcal{M})$, is the geometric vector $\overrightarrow{XG^X_0}$ whose initial and terminal points $X, G^X_0 \in \mathcal{M}$ are occupied by the initial and final states of a co-moving monadic system in a process of temporal evolution under the condition that it takes place in an environment $U \subset \mathcal{M}$ in which the gravitational potential is $\Phi(X)$ everywhere. ■

As a corollary we thus have for a temporarily unaccelerated observer $\mathcal{O}$ that the duration, expressed in Planck time units $[\tau_P]$, of a process of evolution of a co-moving monadic system that takes place in an environment with constant gravitational potential and that starts at a point X is

$$\delta\tau\ [\tau_P] = \frac{1}{1-\Phi(X)}\ [\tau_P] \tag{10.41}$$

We will call this the **local time unit** τ_P^X, so for any $k \in \mathbb{R}$ we have

$$k\ [\tau_P^X] = \frac{k}{1-\Phi(X)}\ [\tau_P] \tag{10.42}$$

Thus speaking, in an environment $U \subset \mathcal{M}$ with a constant gravitational potential $\Phi \in (0,1)$, time passes at a slower rate compared to an environment $U' \subset \mathcal{M}$ with a constant gravitational potential $\Phi' \in (0,1)$ for which $\Phi' < \Phi$. The idea is thus that an effect of a monadic system on its environment is that it is the source of a gravitational potential field: if the system is made up of ordinary matter, which has a positive gravitational mass, then its field is positive everywhere. This is, at least qualitatively, consistent with the outcome of the Hafele-Keating experiment (1972).

Postulate 10.2.37 (Meaning of the local spacelike basis vectors)**.**
For an observer $\mathcal{O}$, a local spacelike basis vector at a point X, i.e. a vector $\vec{g}_j^X \in T_X(\mathcal{M})$, is a geometric vector $\overrightarrow{XG_j^X}$ in the hyperplane of simultaneity of X pointing in x^j-direction whose initial and terminal points $X, G_j^X \in \mathcal{M}$ are separated by the spatial distance travelled in a local time unit by a photon released at the point X in x^j-direction under the condition that it takes place in an environment $U \subset \mathcal{M}$ with constant vacuum temperature $\theta(X)$ and constant gravitational potential $\Phi(X)$. ■

As a corollary, suppose we release a photon at a point $X \in U$ in x^j-direction in an environment as in Post. 10.2.37; if the photon then after a local time unit occupies the point $Z \in U$, then for the terminal point $Y = G_j^X$ of the geometric vector $\vec{g}_j^X = \overrightarrow{XG_j^X}$ we have

$$Z = T_{\overrightarrow{YG_0^Y}} \circ T_{\overrightarrow{XY}}(X) \tag{10.43}$$

where $\overrightarrow{YG_0^Y} = \vec{g}_0^Y$. See Fig. 10.8 for an illustration.

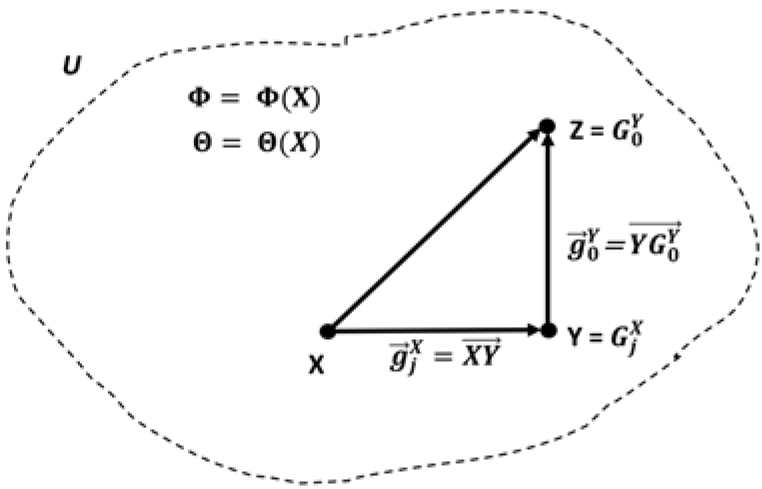


Figure 10.8: Illustration of Eq. (10.43). The area within the dotted line represents an environment $U \subset \mathcal{M}$ of a point X where $\Phi = \Phi(X)$ and $\theta = \theta(X)$. The diagonal geometric vector is the displacement vector of the photon, released at X in x^j-direction, in a local time unit. Its terminal point Z is then reached by a translation of the point X over the corresponding local spacelike basis vector at X followed by a translation of the point Y over the local timelike basis vector at Y.

Furthermore, suppose that we forge a solid rod, such that the photon released at the point $X \in U$ in x^j-direction (in this constant environment) travels precisely along the rod in N local time units. We then transport the rod to an environment U_0 where $\theta = 1$ and $\Phi = 0$, we measure the time in Planck time units $[\tau_P]$ that a photon needs to travel along that rod in that environment U_0, and divide by N: that way we obtain the **local distance unit** ℓ_P^X expressed in units of the global Planck distance; we then have

$$1\ [\ell_P^X] = \theta(X)\ [\ell_P] \tag{10.44}$$

Thus speaking, while a photon always travels a local distance unit in a local time unit in an environment with constant vacuum temperature and gravitational potential, if we look at spatial distance expressed in global units then a photon travels *further* in a local time unit in an environment with a *higher* temperature. So, we can think of the vacuum temperature as the 'light speed scaling factor'.

Definition 10.2.38 (Planck-scale patch; Planck-scale chart)**.**
A ***Planck-scale patch*** *around a point* $X \in \mathcal{M}$ *is a supersmall environment* $U_X \subset \mathcal{M}$ *of* X*, that is, an environment* $U_X \ni X$ *such that*

(i) for any $Y, Z \in U_X$ *that lie in the hyperplane of simultaneity of a point* $P \in U_X$*, the spatial distance bridged by the geometric vector* $\overrightarrow{YZ}$ *is of the order of magnitude of a local distance unit* ℓ_P^X*—that is, for any such* $Y, Z \in U_X$ *there is an upper limit* $L_\ell \in \mathbb{R}^+$ *such that*

$$\|\overrightarrow{YZ}\| < L_\ell\ [\ell_P^X] \tag{10.45}$$

(ii) for any $Y, Z \in U_X$ *that lie on the time line through a point* P *in the hyperplane of simultaneity of* X*, the time bridged by the geometric vector* $\overrightarrow{YZ}$ *is of the order of magnitude of a local time unit—that is, for any such* $Y, Z \in U_X$ *there is an upper limit* $L_\tau \in \mathbb{R}^+$ *such that*

$$\|\overrightarrow{YZ}\| < L_\tau\ [\tau_P^X] \tag{10.46}$$

(iii) for any $Y \in U_X$ *there is a point* P *in the hyperplane of simultaneity of* X *such that* Y *lies on the time line through* P*.*

For our model, $L_\ell = L_\tau = 10$*. A* ***Planck-scale chart*** *at* X *is a chart* $(U_X, \overline{\varphi}) \in \mathcal{A}$ *consisting of a supersmall environment* U_X *of* X *and a chart mapping* $\overline{\varphi} : U_X \to \mathbb{R}^4$*,* $\overline{\varphi} : X \mapsto (\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3)$*. The image* $\overline{\varphi}[U_X]$ *of the Planck-scale patch* U_X *under the chart mapping* $\overline{\varphi}$ *is a* ***Planck-scale coordinate system*** *on* U_X*. If* $\overline{\varphi}[U_X]$ *is* ***rectangular****, then for the terminal point* Y *of a geometric vector* $\overrightarrow{XY} = \overline{y}^\mu \vec{g}_\mu^X$ *with* $Y \in U_X$ *we have*

$$(\overline{\varphi}(Y))^\mu = \overline{x}^\mu + \overline{y}^\mu \tag{10.47}$$

The transition map $\varphi_0 \circ \overline{\varphi}^{-1} : \overline{\varphi}[U_X] \to \varphi_0[\mathcal{M}]$*, where* φ_0 *is the chart mapping of a global chart* $(\mathcal{M}, \varphi_0)$*, is in that case given by*

$$\varphi_0 \circ \overline{\varphi}^{-1} : \begin{pmatrix} \overline{z}^0 \\ \overline{z}^1 \\ \overline{z}^2 \\ \overline{z}^3 \end{pmatrix} \mapsto \begin{pmatrix} x^0 + f_\tau \cdot (\overline{z}^0 - \overline{x}^0)/(1 - \Phi(X)) \\ x^1 + f_\ell \cdot \theta(X) \cdot (\overline{z}^1 - \overline{x}^1) \\ x^2 + f_\ell \cdot \theta(X) \cdot (\overline{z}^2 - \overline{x}^2) \\ x^3 + f_\ell \cdot \theta(X) \cdot (\overline{z}^3 - \overline{x}^3) \end{pmatrix} \tag{10.48}$$

where f_τ *and* f_ℓ *are the conversion factors of Eq.* (10.34). ■

Agreement 10.2.39. We will henceforth refer to τ_P^X and ℓ_P^X as the **local Planck units** at the point $X \in \mathcal{M}$. ■

Thus speaking, a rectangular Planck-scale coordinate system is a coordinate system on a Planck-scale patch such that every coordinate separation is a quantity in local Planck units (of time and spatial distance). So, let $X \in \mathcal{M}$, let $U_X \ni X$ be a Planck-scale patch around X, let $(U_X, \overline{\varphi}_0)$ be a Planck-scale chart, let $\overline{\varphi}_0[U_X]$ be rectangular, and let $\overrightarrow{XY} \in \{X\} \times U_X$ be a geometric vector in $T_X(\mathcal{M})$ whose terminal point lies in U_X. If Y then lies on the time line through X, then

$$\|\overrightarrow{XY}\| = \sqrt{(\overline{y}^0 - \overline{x}^0)^2}\ [\tau_P^X] \tag{10.49}$$

And if Y then lies in the hyperplane of simultaneity of X, then

$$\|\overrightarrow{XY}\| = \sqrt{\sum_{j=1}^{3} (\overline{y}^j - \overline{x}^j)^2}\ [\ell_P^X] \tag{10.50}$$

We will describe Planck-scale physics in a rectangular Planck-scale coordinate system—note that this is determined by a choice of global units of time and spatial distance, plus a choice of spatial directions. But we're not there yet: we also need a metric tensor.

Definition 10.2.40 (Metric tensor)**.**
The ***metric tensor field*** *is a function $\overline{g}$ on $\mathcal{M}$ that maps a point X to the* ***local metric tensor*** *$\overline{g}_X$, which is a function $\overline{g}_X : T_X(\mathcal{M}) \times T_X(\mathcal{M}) \to \mathbb{R}$. Let X be a point in $\mathcal{M}$, let $\{\vec{g}_\alpha^X\}$ be the local Vierbein, and let $\overrightarrow{XY}$ and $\overrightarrow{XZ}$ be geometric vectors in $T_X(\mathcal{M})$ with $\overrightarrow{XY} = \overline{y}^\alpha \vec{g}_\alpha^X$ and $\overrightarrow{XZ} = \overline{z}^\beta \vec{g}_\beta^X$; then the function $\overline{g}_X : T_X(\mathcal{M}) \times T_X(\mathcal{M}) \to \mathbb{R}$ is given by*

$$\overline{g}_X(\overrightarrow{XY}, \overrightarrow{XZ}) = \eta_{\alpha\beta}\overline{y}^\alpha \overline{z}^\beta \tag{10.51}$$

where the numbers $\eta_{\alpha\beta}$ are components of the ***Minkowski norm squared*** *with signature $(-,+,+,+)$.* ■

So, if we use the local Vierbein at a point X as a basis of the tangent space at X, then the components of the metric tensor on the tangent space become the components of the Minkowski norm squared; the corresponding 4×4 matrix $[\eta_{\alpha\beta}]$ is just $[\eta_{\alpha\beta}] = \text{diag}(-1, 1, 1, 1)$. If we use another basis, then the components of the metric tensor change, but the number $\overline{g}_X(\overrightarrow{XY},\overrightarrow{XZ})$ remains the same.

Corollary 10.2.41. *Let $X \in \mathcal{M}$, let $U_X \ni X$ be a Planck-scale patch around X, let $(U_X, \overline{\varphi}_0)$ be a Planck-scale chart, let $\overline{\varphi}_0[U_X]$ be rectangular, and let $\overrightarrow{XY} = \delta\overline{x}^\alpha \vec{g}_\alpha^X$ be a geometric vector in $T_X(\mathcal{M})$ with $Y \in U_X$; then*

$$\overline{g}_X(\overrightarrow{XY},\overrightarrow{XY}) = -(\delta\overline{x}^0)^2 + \sum_{j=1}^{3}(\delta\overline{x}^j)^2 \tag{10.52}$$

■

Definition 10.2.42 (Local Vierbein connection: covariant derivatives)**.** *Let $P \in \mathcal{M}$, let $U_P \ni P$ be a Planck-scale patch around P, let $(U_P, \overline{\varphi}_0)$ be a Planck-scale chart, let $\overline{\varphi}_0[U_P]$ be rectangular; then the* ***local Vierbein connection*** $\overline{\nabla}$ *on U_P is defined by the action of the* ***covariant derivatives*** $\overline{\nabla}_\alpha$ *on fields and vector fields on the Planck-scale patch at any $X \in U_P$:*

(i) for any field $f : U_P \to \mathbb{R}$ we have

$$\overline{\nabla}_\alpha f = \frac{\partial f}{\partial \overline{x}^\alpha} = \frac{\partial}{\partial \overline{x}^\alpha} f \circ \overline{\varphi}_0{}^{-1}(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \tag{10.53}$$

(ii) for any vector field $V : U_P \to T\mathcal{M}$, $V : X \mapsto \overline{v}^\mu \vec{g}_\mu^X$ we have

$$\overline{\nabla}_\alpha V = (\overline{\nabla}_\alpha \overline{v}^\mu)\vec{g}_\mu^X \tag{10.54}$$

implying that

$$\overline{\nabla}_\alpha \vec{g}_\mu = \overrightarrow{0} \tag{10.55}$$

for each element $\vec{g}_\mu$ of the Vierbein field.

■

Let ∇ be the Levi-Civita connection on $\mathcal{M}$; with a global rectangular coordinate system $\varphi_0[\mathcal{M}]$ at our disposal, that is, with a TCRF at out disposal, at any $X \in \mathcal{M}$ we have $\nabla_\mu f = \frac{\partial}{\partial x^\mu} f$ for any field $f : \mathcal{M} \to \mathbb{R}$ and $\nabla_\mu \vec{e}_\alpha = \overrightarrow{0}$ for any element $\vec{e}_\alpha$ of the standard coordinate basis $\{\vec{e}_\alpha\}$. By Eqs. (10.53) and (10.54) the local Vierbein connection $\overline{\nabla}$ on a Planck-scale patch thus (locally) mimics the Levi-Civita connection ∇ on the manifold $\mathcal{M}$.

It seems, however, that there is something fishy going on. Let $U \subset M$ be an environment where the vacuum temperature θ and the gravitational potential Φ vary from point to point; then, since the local Vierbein at a point X depends on the local value of the vacuum temperature and the gravitational potential, for any element $\vec{g}_\mu$ of the Vierbein field $\{\vec{g}_\mu\}$ with $\vec{g}_\mu : X \to g^\nu_\mu \vec{e}^X_\nu$ we have

$$\nabla_\alpha \vec{g}_\mu = (\nabla_\alpha g^\nu_\mu)\vec{e}^X_\nu \neq \overrightarrow{0} \tag{10.56}$$

when ∇ is the global Levi-Civita connection. This stands in stark contrast with Eq. (10.55).

In terms of translations, let $U \subset M$ be an environment as above, let $X \in U$, and let $Y, Z \in U$ be the points G^X_0 of Post. 10.2.36 and G^X_j (for some j) of Post. 10.2.37; then in general

$$T_{\vec{g}^Y_0} \circ T_{\vec{g}^X_j}(X) = Q \neq P = T_{\vec{g}^Z_j} \circ T_{\vec{g}^X_0}(X) \tag{10.57}$$

See Fig. 10.9 for an illustration. This stands in stark contrast with Eq. (10.20) and Fig. 10.7.

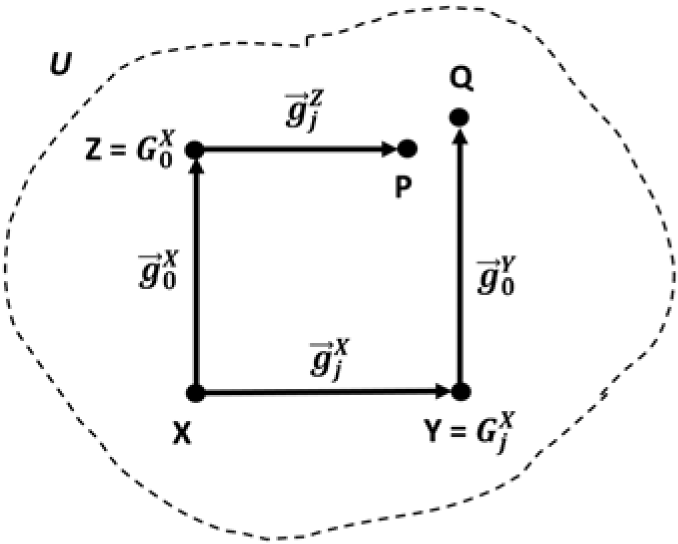


Figure 10.9: Illustration of Eq. (10.57) for an environment U in which $1 > \Phi(Y) > \Phi(X) > 0$ and $0 < \theta(Z) < \theta(X)$.

And so we have to conclude that the whole idea of a rectangular Planck-scale coordinate system $\overline{\varphi}_0(U_X)$ on a Planck-scale patch U_X, such that every coordinate separation is a quantity in local Planck units, seems to be ill-conceived. After all, just look at Fig. 10.9: if we translate the point X over a local unit of spatial distance ℓ_P^X in the $\overline{x}^j$-direction, we end up at the point Y; but if we then translate the point Y over a <u>local</u> unit of time τ_P^Y in the $\overline{x}^0$-direction, then we end up at the point Q—the time difference between Y and Q is then a local Planck unit of time at Y, τ_P^Y, which in general is different from the local Planck unit of time at X: $\tau_P^Y \neq \tau_P^X$. The coordinate difference in the Planck-scale coordinate system $\overline{\varphi}_0[U_X]$, on the other hand, is a quantity in local Planck units **at $\boldsymbol{X}$**. But if we translate the point Y over a local unit of time τ_P^X in the (upward) time-direction, then we end up at **another** point $Q' \neq Q$: the time difference between Q' and Y is then **not** a local unit of time τ_P^Y.

The crux of the matter is that it is true from *a mathematical perspective* that the Vierbein field is a non-coordinate basis, but we are doing *physics* and not *mathematics*: relative to the Planck scale, the local Planck units τ_P^X and ℓ_P^X vary only significantly at an astronomical scale. On a Planck-scale patch, their values can be considered constant: at Planck scale, a monadic system localized at a point $X \in \mathcal{M}$ "sees" a flat spacetime $T_X(\mathcal{M})$ spanned by the local Vierbein $\{\vec{g}_\mu^X\}$. That is, if

$$\begin{cases} \overrightarrow{XY} = \vec{g}_\mu^X \\ \overrightarrow{YQ} = \vec{g}_\nu^Y \\ \overrightarrow{XZ} = \vec{g}_\nu^X \\ \overrightarrow{ZP} = \vec{g}_\mu^Z \end{cases} \tag{10.58}$$

then the value of the Minkowski squared norm δs^2 given by

$$\delta s^2 = \overline{g}_P(\overrightarrow{PQ}, \overrightarrow{PQ}) \tag{10.59}$$

is so small that it plays no role in the mathematical formulation of the laws of Planck-scale physics: $|\delta s^2| \ll 1$. (See Fig. 10.9 above for an illustration showing the points P and Q for $\mu = j$ for some $j \in \{1, 2, 3\}$ and $\nu = 0$.)

We can now introduce a notion of 'approximate identity'. Any mathematician will for sure object to such a notion. But again, we are doing *physics* here: we can precisely define the notion for physics.

Definition 10.2.43 (Approximate identity in physics).
Let Q be a physical quantity, let q be a unit thereof, let ΔQ $[q]$ be an amount measurable by a real device, and let A_Q $[q]$ be the accuracy of the most accurate device thinkable for measuring Q. Then a number ΔP is ***approximately equal to*** *ΔQ, notation*

$$\Delta P \approx \Delta Q \tag{10.60}$$

if and only if the difference with ΔQ is smaller than A_Q:

$$|\Delta Q - \Delta P| < A_Q \tag{10.61}$$

■

The idea is now that we chop up the world line of the center-of-mass of a monadic system in supersmall segments that fit on a Planck-scale patch, such that each supersmall segment corresponds to the spatiotemporal displacement of the monadic system during one elementary process in its temporal evolution: a model of an elementary process in a rectangular Planck-scale coordinate system then yields a quantitative prediction for the spatiotemporal displacement in that process, and the sum of all these displacements is then approximately equal to the real displacement.

More precisely, let $\ell : [0, \Delta\tau] \to \mathcal{M}$ with $\ell(0) = A$ and $\ell(\Delta\tau) = B$ be the world line of the center-of-mass of a monadic system from A to B, where A coincides with the initial event of an elementary process #1 in the temporal evolution of the system and B with the final event of an elementary process $\#n$; let ℓ be parameterized by the proper time (in global units) elapsed since passing through A, and let $\Delta\tau$ $[\tau_G]$ be calculable from the time ticked off by a co-moving real clock. For the first process, we use a Planck-scale chart $(U_A, \overline{\varphi}_1)$ with rectangular coordinate system $\overline{\varphi}_1[U_A]$: the spatiotemporal displacement of the center-of-mass of the monadic system is then to be modeled by a curve $\ell'_1 : [0,1] \to \overline{\varphi}_1[U_A]$ parameterized by proper time in local units, such that $\ell'_1(0) = \overline{\varphi}_1(A)$ and

$$\int_0^1 \sqrt{-\eta_{\alpha\beta}v^\alpha v^\beta}\,d\tau = 1 \tag{10.62}$$

where $v^\mu = dx^\mu/d\tau$. The value $\ell'_1(1)$ is then the coordinate tuple of the center-of-mass at the end of the first process, which corresponds to a position X_1 in spacetime. See Fig. 10.10 for an illustration.

By the same token, for the j^{th} process, we use a Planck-scale patch $U_{X_{j-1}}$ around the point X_{j-1} and a Planck-scale chart $(U_{X_{j-1}}, \overline{\varphi}_j)$ with rectangular coordinate system $\overline{\varphi}_j[U_{X_{j-1}}]$: the displacement of the center-of-mass of the monadic system in the j^{th} process is then to be modeled by a curve $\ell'_j : [j-1, j] \to \overline{\varphi}_j[U_{X_{j-1}}]$, such that $\ell'_j(0) = \overline{\varphi}_j(X_{j-1})$ and

$$\int_{j-1}^{j} \sqrt{-\eta_{\alpha\beta}v^\alpha v^\beta}\, d\tau = 1 \tag{10.63}$$

where again $v^\mu = dx^\mu/d\tau$. The value $\ell'_j(j)$ is then the coordinate tuple of the center-of-mass at the end of the j^{th} process, which corresponds to a position X_j in spacetime.

Mathematically the points $X_1, \ldots, X_n$ may then not lie *exactly* on the world line $\ell[0, \Delta\tau]$, but from the physical perspective the deviation is negligible. That is, the idea is that this procedure yields a prediction X_n for the point B for which

$$\sum_{j=1}^{n} \frac{f_\tau}{1 - \Phi(X_j)} \approx \Delta\tau \tag{10.64}$$

where f_τ is the conversion factor of Eq. (10.34).

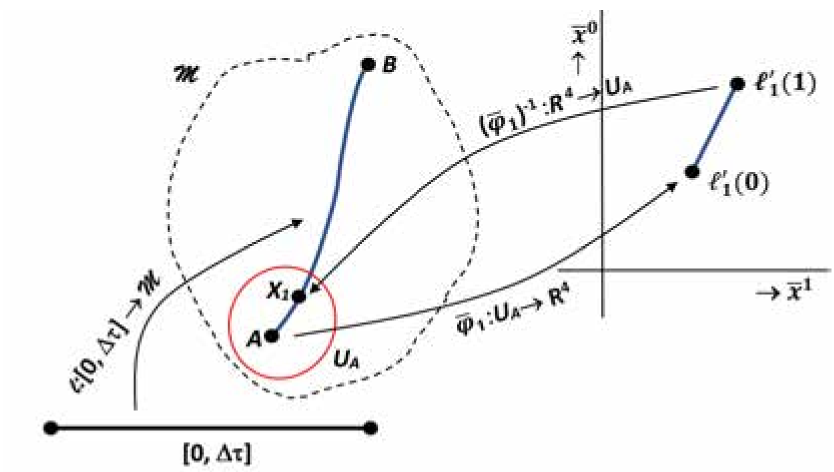


Figure 10.10: Illustration of the Planck-scale model of the first process.

Thus speaking, the idea is to approximate the world line of the center-of-mass of a monadic system by a series of displacement curves, such that the proper time along each displacement curve is always a local Planck unit of time. One may object that it is then beforehand a certainty that the model is not exactly correct, which leads to this question: why should we at all pursue this idea any further from here?

First of all, what we are after is *empirical adequateness* as meant by Van Fraassen, not *correctness* as meant by Einstein—see p. 54 for a definition of these terms. So, if the approximation yields an empirically adequate model, then it is not important that the model is not exactly correct.

Secondly, the approach that we take by ignoring variations of the Vierbein field on a Planck-scale patch yields an enormous simplification. Of course we can develop a more refined model in which variations of the Vierbein field on a Planck-scale patch are taken into consideration. Such a refined model will be much more complicated—one has to use a spin connection instead of the local Vierbein connection—but it won't yield theoretical progression since the differences in predictions are not measurable. Moreover, the principle of gravitational interaction remains the same: hence our choice for the simpler model.

Definition 10.2.44 (Directional derivatives; divergence)**.**
Let, for an observer $\mathcal{O}$, X be a point in spacetime, let $U_X \ni X$ be a Planck-scale patch around X, let $(U_X, \overline{\varphi}_0)$ be a Planck-scale chart, let $\overline{\varphi}_0[U_X]$ be rectangular, let $\overline{\nabla}$ be the local Vierbein connection on U_X; then for any geometric vector $\overrightarrow{XY} = \overline{v}^\mu \vec{g}^X_\mu \in T_X(\mathcal{M})$ the ***directional derivative*** *$\overline{\nabla}_{\overrightarrow{XY}}$ is defined as*

$$\overline{\nabla}_{\overrightarrow{XY}} = \overline{v}^\mu \overline{\nabla}_\mu \tag{10.65}$$

where $\overline{\nabla}_\mu$ is the covariant derivative given by Def. 10.2.42. Furthermore, given a vector field $\vec{w} : \mathcal{M} \to T\mathcal{M}$, the ***local divergence*** *of $\vec{w}$ is a field $\overline{\text{div}}\ \vec{w} : \mathcal{M} \to \mathbb{R}$ given by*

$$\overline{\text{div}}\ \vec{w}(X) = \overline{\nabla}_\mu \overline{w}^\mu \tag{10.66}$$

where the functions $\overline{w}^\mu$ are the components of $\overrightarrow{W}(X)$ with respect to the local Vierbein $\{\vec{g}^X_\mu\}$, as in $\overrightarrow{W}(X) = \overline{w}^\mu \vec{g}^X_\mu$. ■

Now all necessary definitions are in place for an introduction of the Vierbein frame: this adds additional structure, which we developed in this section, to the minimal definition of the spacetime manifold (Def. 10.2.17).

Definition 10.2.45 (Vierbein frame).
*For any temporarily unaccelerated observer $\mathcal{O}$, a **Vierbein frame** is a structure $(\mathcal{M}, T_{\mathcal{M}}, \mathcal{A}, \{\vec{g}_\alpha\}, \overline{g}, \overline{\nabla})$ for which*

(i) $\mathcal{M}$ is a set of (spatiotemporal) points that represents spacetime;

(ii) $T_{\mathcal{M}}$ is the topology on $\mathcal{M}$, such that $(\mathcal{M}, T_{\mathcal{M}})$ is a second-countable Hausdorff space;

(iii) $\mathcal{A}$ is an atlas, which contains a global chart $(\mathcal{M}, \varphi_0)$ that yields a rectangular, torsion-free coordinate system $\varphi_0[\mathcal{M}]$ on $\mathcal{M}$ called the TCRF of $\mathcal{O}$;

(iv) $\{\vec{g}_\alpha\}$ is the Vierbein field, a set of four vector fields $\vec{g}_\alpha : \mathcal{M} \to T\mathcal{M}$, $\vec{g}_\alpha : X \mapsto \vec{g}^X_\alpha$ with the four-element set $\{\vec{g}^X_\alpha\}$ being the local Vierbein, of which

- *$\vec{g}^X_0 = \frac{1}{1-\Phi(X)} \cdot \vec{\pi}^X_0$ is the local timelike basis vector at X,*
- *$\vec{g}^X_j = \theta(X) \cdot \vec{\pi}^X_j$ is a local spacelike basis vector at X for any index number $j \in \{1, 2, 3\}$,*

where $\theta : \mathcal{M} \to \mathbb{R}^+_0$ is the vacuum temperature field, $\Phi : \mathcal{M} \to (-1, 1)$ is the gravitational potential field, and $\{\vec{\pi}^X_\alpha\}$ the Planck tetrad at X, obtained by rescaling the standard coordinate tetrad $\{\vec{e}^X_\alpha\}$ determined by the TCRF of $\mathcal{O}$;

(v) $\overline{g}$ is the metric tensor field, $\overline{g} : X \mapsto \overline{g}_X$, given by

$$\overline{g}_X(\overline{x}^\alpha \vec{g}^X_\alpha, \overline{y}^\beta \vec{g}^X_\beta) = \eta_{\alpha\beta}\overline{x}^\alpha \overline{y}^\beta \tag{10.67}$$

(vi) $\overline{\nabla}$ is the local Vierbein connection on Planck-scale patches, with

$$\overline{\nabla}_\alpha \vec{g}^X_\beta = \overrightarrow{0} \tag{10.68}$$

From now on we will use the acronym 'VF' for Vierbein frame. ■

That concludes this section on a model of spacetime: we now have one—the VF of an observer $\mathcal{O}$ will be used as a model of spacetime.

10.3 Relativistic Planck-scale physics

Planck units

Because local Planck units and global Planck units are not necessarily the same at a point X in spacetime, it is not completely straightforward to introduce Planck units. In this section we state some very simple laws of nature in the form of postulates: these will lead us to Planck units.

Postulate 10.3.1 (Planck mass).
In the VF of any observer $\mathcal{O}$, the inertial rest mass of a monadic system does not depend on its position. ■

That means that there is a global Planck unit of mass, to be denoted by m_P, which can be used as the unit of mass at every point X. Later on we will express m_P in SI units.

Postulate 10.3.2 (Universality of light speed).
In the VF of any observer $\mathcal{O}$, the numerical value of the speed of light at any point X in spacetime is always one in local Planck units:

$$c = 1\ [\ell_P^X/\tau_P^X] \tag{10.69}$$

■

Using Eqs. (10.42) and (10.44), at the point X we then obtain

$$c = \theta\ [\ell_P/\tau_P^X] = \theta(1-\Phi)\ [\ell_P/\tau_P] \tag{10.70}$$

for the speed of light in global Planck distances per local Planck time and in global Planck distances per global Planck time, respectively.

Postulate 10.3.3 (Rest energy).
In the VF of any observer $\mathcal{O}$, Einstein's relation between the rest energy E_0 of a monadic system and its inertial rest mass m_0 is the same everywhere in local Planck units:

$$E_0\ [E_P^X] = m_0\ \left[m_P\left(\frac{\ell_P^X}{\tau_P^X}\right)^2\right] \tag{10.71}$$

where E_P^X is the local Planck unit of energy. ■

Postulate 10.3.4 (Planck-Einstein relation).
We set the value of Planck's constant $\mathfrak{h}$ *to the dimensionless number one:*

$$\mathfrak{h} \equiv 1 \ [1] \tag{10.72}$$

In the VF of any observer $\mathcal{O}$*, the Planck-Einstein relation is then the same everywhere in local Planck units:*

$$E \cdot \tau = \mathfrak{h} = 1 \tag{10.73}$$

where E *is the photon's energy and* τ *its period.* ■

The local Planck unit of energy E_P^X is then

$$1 \ [E_P^X] = 1 \ [1/\tau_P^X] \tag{10.74}$$

The local Planck unit of energy is thus the energy of a photon whose period is a local Planck time. In SI units, at a point X in an environment of spacetime where $\theta = 1$ and $\Phi = 0$ so that $\ell_P^X = \ell_P$ and $\tau_P^X = \tau_P$, we get

$$1 \ [E_P^X] = 1.2290 \cdot 10^{10} \ [J] \tag{10.75}$$

This Planck unit of energy differs from the 'usual' one by a factor 2π, because we've set the Planck constant to one and not the *reduced* Planck constant. The Planck unit of mass is thus equal to the inertial rest mass of a monadic system whose rest energy is a Planck unit of energy. Using the above value in an environment U of spacetime where $\ell_P^X = \ell_P$ and $\tau_P^X = \tau_P$, we get in SI units that

$$1 \ [m_P] = 1.3674 \cdot 10^{-7} \ [kg] \tag{10.76}$$

So, if we know that a loss of mass is emitted as a photon, then the photon's energy derives from Eq. (10.71) and its frequency from Eq. (10.73). As an example, the energy released upon the annihilation of an electron-positron pair is the same everywhere in local units of energy.

Agreement 10.3.5. We will express spatial distance in local Planck time units: a local Planck time unit of spatial distance is then the spatial distance travelled by a photon in a local Planck time unit, so $c = 1$ [1]. ■

The spatiotemporal flow

By Ax. 5.3.18 c.q. Prop. 10.2.15, spacetime is not a void but an occurrent: it's the life of a fluid. It's described by its *flow*, defined as follows:

Definition 10.3.6 (Flow)**.**
In the VF of an observer $\mathcal{O}$, the ***flow*** *is a function $\mathcal{F} : \mathbb{R} \times \mathcal{M} \to \mathcal{M}$, $\mathcal{F}(\tau, X) \mapsto \mathcal{F}^\tau(X)$. For any $X \in \mathcal{M}$, the* ***orbit of* $\mathbf{X}$** *is the set $O^+(X) \subset \mathcal{M}$ given by*

$$O^+(X) = \{\mathcal{F}^\tau(X) \ : \ \tau \geq 0\} \tag{10.77}$$

An infinitesimally nearby point $\mathcal{F}^{d\tau}(X) \in O^+(X)$ is ***the same point*** *as X but $d\tau$ $[\tau_P^X]$ local Planck units of time later as registered by a clock that "goes with the flow", that is, that moves on the orbit of X.*

The flow is generated by the ***4-velocity field*** *$\vec{u} : \mathcal{M} \to T\mathcal{M}$, its value $\vec{u}(X) = \overline{u}^\alpha \vec{g}_\alpha^X$ at a point $X \in \mathcal{M}$ being the* ***flow 4-velocity****; for any $X \in \mathcal{M}$ we have*

$$\overline{g}_X(\vec{u}(X), \vec{u}(X)) = \eta_{\alpha\beta}\overline{u}^\alpha\overline{u}^\beta = -1 \tag{10.78}$$

$$\lim_{\delta\tau \to 0} \mathcal{F}^{\delta\tau}(X) = T_{\delta\tau \cdot \vec{u}(X)}(X) \tag{10.79}$$

■

As a corollary, let X_0 be a point in spacetime at which an elementary process starts in the temporal evolution of a monadic system that "goes with the flow", and let $X_1, \ldots, X_n$ be n points on $O^+(X_0)$ that coincide with starting points of subsequent elementary processes in the temporal evolution of that monadic system; then for any two points $X_j, X_{j+1} \in \{X_0, \ldots, X_n\}$ we have

$$X_{j+1} = \mathcal{F}^1(X_j) \tag{10.80}$$

Furthermore, for large enough n the world line from X_0 to X_n can be approximated by the subsequent geometric vectors $\vec{u}(X_j)$. Suppose that the proper time difference between X_0 and X_n is $\Delta\tau$ $[\tau_G]$, then we have

$$\sum_{j=0}^{n-1} \frac{f_\tau}{1 - \Phi(X_j)} \sqrt{-\overline{g}_{X_j}(\vec{u}(X_j), \vec{u}(X_j))} \approx \Delta\tau \tag{10.81}$$

That aside, if we view spacetime as the life of a fluid then we need to describe the flow in order to describe the dynamics of the fluid, and we now know from Def. 10.3.6 that in order to describe the flow we need to describe the 4-velocity field. That can be done in a couple of postulates.

Postulate 10.3.7 (Cooling off of the vacuum)**.**
In the VF of any observer $\mathcal{O}$, let X be any point in spacetime, let the vacuum temperature field θ be smooth in a Planck-scale patch U_X around X, and let $\vec{u}(X) = \overline{u}^\mu \vec{g}_\mu^X$ be the flow 4-velocity at X; then

$$\overline{\nabla}_{\vec{u}(X)}\theta = \overline{u}^\mu \overline{\nabla}_\mu \theta = -\Lambda\theta(X)\ [1/\tau_P^X] \tag{10.82}$$

where $\Lambda > 0$ is a universal constant, which is the ***cosmological constant*** *in this framework.* ■

Postulate 10.3.8 (Continuity equation)**.**
In the VF of an observer $\mathcal{O}$, let X be any point in spacetime, let the vacuum temperature field θ and the flow 4-velocity field $\vec{u}$ be smooth in a Planck-scale patch U_X around X with rectangular coordinate system $\overline{\varphi}_0(U_X)$, let the universal constant ε being the ***thermal capacity*** *of the vacuum, and let the 4-vector $\vec{\jmath}(X) = \overline{\jmath}^\mu \vec{g}_\mu^X = \varepsilon \cdot \theta(X) \cdot \vec{u}(X)$ be the* ***flow 4-momentum****, whose components $\overline{\jmath}^\mu$ have the following interpretation:*

(i) $\overline{\jmath}^0$ is the ***degenerated mass density*** *in Planck units of mass per local Planck time unit of spatial distance unit cubed;*

(ii) $\overline{\jmath}^k$ is the ***degenerated mass flux density*** *in $\overline{x}^k$-direction in Planck units of mass per local Planck time unit of spatial distance unit squared per local Planck time unit.*

Then in absence of a source of the vacuum temperature field θ, the divergence of the flow 4-momentum $\vec{\jmath}(X) = \overline{\jmath}^\mu \vec{g}_\mu^X$ is zero:

$$\overline{\nabla}_\mu \overline{\jmath}^\mu = 0 \tag{10.83}$$

■

Remark 10.3.9. The above two postulates are generally covariant, which is to say that the mathematical form of the physical laws expressed by Eqs. (10.82) and (10.83) is invariant under arbitrary differential coordinate transformations on the Planck-scale patch U_X around X. ■

Remark 10.3.10 (Dark energy)**.**
To illustrate the physical implications of the above two postulates, let us make some simplifying assumptions and do some calculations. Let's assume

(i) that all observers are inertial observers;

(ii) that the gravitational potential is negligible everywhere, so that at any point X in spacetime the local Planck unit of time τ_P^X is identical to the global Planck unit of time τ_P, and the local timelike basis vector $\vec{g}_0^X$ is identical to the element $\vec{\pi}_0^X$ of the Planck tetrad $\{\vec{\pi}_\mu^X\}$:

$$\begin{cases} \tau_P^X = \tau_P \\ \vec{g}_0^X = \vec{\pi}_0^X = f_\tau \vec{e}_0^X \end{cases} \tag{10.84}$$

(iii) that relativistic effects are negligible, that is, that

- for any two observers, the time difference between any two events is the same;
- for any two observers, the spatial distance between any two simultaneous events is the same;
- for any observer, the speed of any object is much smaller than light speed;

(iv) that the vacuum temperature field is smooth;

(v) that for an observer $\mathcal{O}$, the hyperplanes of simultaneity are *isothermal*, meaning that for any two points X and Y in spacetime that have the same time coordinate in the global chart $(\mathcal{M}, \varphi_0)$, we have

$$\theta(X) = \theta(Y) \tag{10.85}$$

(vi) that every monadic system is a 'dust system': it 'goes with the flow' and its interactions with its environment are negligible.

Furthermore, let's agree to use the notation

$$\dot{\theta} \equiv \frac{\partial}{\partial x^0}\theta \tag{10.86}$$

in the TCRF of an observer $\mathcal{O}$.

Under these assumptions we can approximate Eqs. (10.82) and (10.83) by the following equations, respectively:

$$\dot{\theta} = -\Lambda\theta \tag{10.87}$$

$$\Lambda = \nabla_j u^j \tag{10.88}$$

where the u^j's are the spatial components of the flow 4-velocity with respect to the standard coordinate tetrad, in global units of spatial distance per global time unit. Note, however, that the cosmological constant Λ is expressed here per global time unit: $\Lambda = \Lambda\ [1/\tau_G]$.

Since our dust systems all go with the flow, the 3-tuple of their spatial coordinate velocities is just (u^1, u^2, u^3) which depends on spatiotemporal position. In the TCRF of an observer $\mathcal{O}$, who himself travels on the time line through the origin with zero spatial velocity, we then retrieve Hubble's law (at least qualitatively). Namely, if we model distant stars as dust systems in that TCRF, then from the above equations we get

$$v_r = H \cdot r \tag{10.89}$$

where v_r is the radial velocity of a dust system away from the observer, H is a constant, and r is the spatial distance between the dust system and the observer; see Fig. 10.11 for an illustration. The vacuum temperature field thus plays the role of 'dark energy': the vacuum expands by cooling off. Note that we have yet to postulate how the θ-field is generated. ■

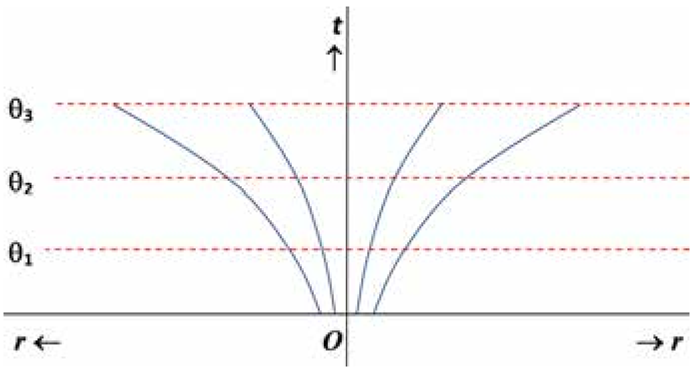


Figure 10.11: Illustration sketching some world lines of dust systems in spacetime in which the vacuum cools off: $\theta_1 > \theta_2 > \theta_3$.

Planck-scale model of a gravitational interaction process

Below we will develop a generic model M_{GR} of the version of EPT set forth in Sect. 10.2—this model describes an elementary process in the temporal evolution of a monadic system, by which a gravitational interaction takes place between the system and its environment—in four steps:

(i) the first step is to model the environment: this comes down to describing a Planck-scale patch around the spatiotemporal position of the center-of-mass of the system at the beginning of the process;

(ii) the second step is to model the properties of the monadic system: these are the invariant properties (rest mass spectrum, characteristic number of normality) and the initial properties (position, momentum, etc.) of the system at the start of the process;

(iii) the third step is to model the effect of the environment on the system in a process of its temporal evolution: since its internal structure is irrelevant for gravity we'll take a pointillistic approach as in Ch. 9;

(iv) the fourth step is to model the effect of the system on its environment: this will make clear how the vacuum temperature field and the gravitational potential field are generated.

In this model we will then incorporate the idea of a gravitational interaction set forth in Ch. 6. To develop the model, we need a couple of additional definitions:

Definition 10.3.11 (Reciprocal basis)**.**
*Let $\{\vec{b}_\mu^X\}$ be an arbitrary basis of $T_X(\mathcal{M})$ with $\vec{b}_\mu^X = b_\mu^\alpha \vec{g}_\alpha^X$; then the **reciprocal basis** at X is the four-element set $\{\vec{b}_X^\nu\} \subset T_X(\mathcal{M})$ satisfying*

$$g_{\mu\nu}\vec{b}_X^{\,\nu} = \vec{b}_\mu^X \tag{10.90}$$

*where $g_{\mu\nu} = \eta(\vec{b}_\mu^X, \vec{b}_\nu^X) = b_\mu^\alpha b_\nu^\beta \eta_{\alpha\beta}$. So, for the local Vierbein $\{\vec{g}_\mu^X\}$ at X, the **reciprocal Vierbein** is the four-element set $\{\vec{g}_X^{\,\nu}\} \subset T_X(\mathcal{M})$ satisfying*

$$\eta_{\mu\nu}\vec{g}_X^{\,\nu} = \vec{g}_\mu^X \tag{10.91}$$

■

Remark 10.3.12. Importantly, the reciprocal Vierbein $\{\vec{g}_X^{\,\nu}\}$ should not be confused with the **dual Vierbein** $\{\tilde{g}_X^{\nu}\}$ in the dual space $T_X^*(\mathcal{M})$, which consists of four linear functionals on the tangent space $T_X(\mathcal{M})$ given by

$$\tilde{g}_X^{\nu}(\vec{g}_\mu^{X}) = \delta_\mu^\nu \tag{10.92}$$

■

Definition 10.3.13 (Gradient)**.**
*Let $f : \mathcal{M} \to \mathbb{R}$ be a field on $\mathcal{M}$ that is smooth around X; the **gradient** of f at X in the Planck-scale patch around X is then the vector*

$$\vec{\overline{\nabla}} f = \overline{\nabla}_\mu f \cdot \vec{g}_X^{\,\mu} \tag{10.93}$$

*where the dot represents scalar multiplication of a vector. The **contravariant components** $\overline{\nabla}^\alpha f$ of the gradient of f with respect to the local vierbein $\{\vec{g}_\alpha^{X}\}$ at X are given by*

$$\overline{\nabla}^\alpha f \cdot \vec{g}_\alpha^{X} = \overline{\nabla}_\mu f \cdot \vec{g}_X^{\,\mu} \tag{10.94}$$

■

Definition 10.3.14 (4-velocity of a monadic system relative to the flow)**.**
*Let the flow 4-velocity at a point X be $\vec{u} = \overline{u}^\alpha \vec{g}_\alpha^{X}$ with $(\hat{U})^0 = \gamma_U$ and $\eta_{\alpha\beta}\overline{u}^\alpha\overline{u}^\beta = -1$, and let the center-of-mass of a monadic system at X have a 4-velocity of $\vec{v} = \overline{v}^\alpha \vec{g}_\alpha^{X}$ with $(\hat{V})^0 = \gamma_V$ and $\eta_{\alpha\beta}\overline{v}^\alpha\overline{v}^\beta = -1$; then the system's **4-velocity relative to the flow** is the 4-velocity $\vec{w}' = \overline{w}^{\alpha'} \vec{g}_{\alpha'}^{X}$, expressed in the local Vierbein $\{\vec{g}_{\alpha'}^{X}\}$ of a frame momentarily co-moving with the flow at X, such that $\vec{v} = (\hat{W}' \circ \hat{U})^\mu \vec{g}_\mu^{X}$, where the operation $\circ : \mathbb{R}^4 \times \mathbb{R}^4 \to \mathbb{R}^4$ is the law of 4-velocity addition, which in standard configuration (with $c = 1$) is given by*

$$\frac{(\hat{W}' \circ \hat{U})^k}{(\hat{W}' \circ \hat{U})^0} = \frac{1}{1 + \eta_{ii'}\overline{u}^i\overline{w}^{i'}/\overline{u}^0\overline{w}^{0'}} \left[\frac{\delta^k_{k'}\overline{w}^{k'}}{\gamma_U \overline{w}^{0'}} + \frac{\overline{u}^k}{\overline{u}^0} + \frac{\eta_{ii'}\overline{u}^i\overline{w}^{i'}}{\overline{u}^0\overline{w}^{0'}} \frac{\gamma_U}{1+\gamma_U} \frac{\overline{u}^k}{\overline{u}^0} \right] \tag{10.95}$$

$$\eta_{\alpha'\beta'}\overline{w}^{\alpha'}\overline{w}^{\beta'} = -1 \tag{10.96}$$

The notation $\hat{W}' \circ \hat{U}$, which stands for the addition of $\vec{w}$ to $\vec{U}$, is based on a publication by Sexl and Urbantke (2000). ■

Step (i).
We assume that, in the VF of an arbitrary observer $\mathcal{O}$, the center-of-mass of the monadic system at the beginning of the process is located at a position X_n in spacetime; let $U_n \subset \mathcal{M}$ be a Planck-scale patch around X_n, and let $(U_n, \overline{\varphi}_n)$ be a Planck-scale chart with rectangular coordinate system $\overline{\varphi}_n[U_n]$ as in Def. 10.2.38 and with $\overline{\varphi}_n(X_n) = (\overline{x}_n^0, \overline{x}_n^1, \overline{x}_n^2, \overline{x}_n^3)$.

For starters, the gradient of the gravitational potential field in the rectangular coordinate system $\overline{\varphi}_n[U_n]$ will be modeled as a uniform component-vector field $(\tilde{\nabla}\Phi^0, \tilde{\nabla}\Phi^1, \tilde{\nabla}\Phi^2, \tilde{\nabla}\Phi^3)$. At $X = X_n$ we define

$$\overrightarrow{\nabla}\Phi = \overline{\nabla}_\mu\Phi \cdot \vec{g}_X^{\ \mu} \equiv \tilde{\nabla}\Phi^\alpha(\overline{x}_n^0, \overline{x}_n^1, \overline{x}_n^2, \overline{x}_n^3) \cdot \vec{g}_\alpha^X \tag{10.97}$$

For the gradient field on the Planck-scale coordinate system, at an arbitrary coordinate tuple $(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \in \overline{\varphi}_n[U_n]$ we then have

$$\tilde{\nabla}\Phi^\alpha(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) = \tilde{\nabla}\Phi^\alpha(\overline{x}_n^0, \overline{x}_n^1, \overline{x}_n^2, \overline{x}_n^3)\ [1/\tau_P^X] \tag{10.98}$$

In other words, for an arbitrary coordinate tuple $(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \in \overline{\varphi}_n[U_n]$, we have for the α^{th} component that

$$\tilde{\nabla}\Phi^\alpha(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) = \eta^{\alpha\beta}\overline{\nabla}_\beta\Phi\Big|_{X=X_n}\ [1/\tau_P^X] \tag{10.99}$$

where $\eta^{\alpha\beta}\eta_{\beta\gamma} = \delta^\alpha_\gamma$.

Remark 10.3.15. Eq. (10.98) models the gravitational field as a uniform field on the Planck-scale coordinate system $\overline{\varphi}_n[U_n]$. The idea is that second-order derivatives of the gravitational field play no role at Planck scale. Consider, for example, the gradient of the gravitational potential field at a position 100 $[m]$ above the surface of the earth. From the *mathematical* perspective, the gradient will not remain constant if we move to a position located a Planck distance higher. But from the *physical* perspective, the variation of the gradient on a Planck-scale patch is negligible. ∎

Proceeding, let the function $\tilde{\Phi} : \overline{\varphi}_n[U_n] \to \mathbb{R}$ model the gravitational potential field in the Planck-scale coordinate system; denoting an arbitrary coordinate tuple $(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \in \overline{\varphi}_n[U_n]$ by $(\overline{x}_n^\mu + \Delta\overline{x}_n^\mu)$ we then have

$$\tilde{\Phi}(\overline{x}_n^\mu + \Delta\overline{x}_n^\mu) = \Phi(X_n) + \Delta\overline{x}_n^\alpha\overline{\nabla}_\alpha\Phi\Big|_{X=X_n}\ [1] \tag{10.100}$$

Remark 10.3.16. On the one hand, Eq. (10.100) models the gravitational potential field by a function on the Planck-scale coordinate system that depends on position. But on the other hand, the rate of passing of time is assumed to be constant on a Planck-scale patch by Def. 10.2.38. So, our approach is thus that it is true that the gravitational potential varies slightly on a Planck-scale patch, but this variation is so small that it has no significant effect on the rate of passing of time. Consider, for example, the gravitational potential at a position 100 $[m]$ above the surface of the earth. From the *mathematical* perspective, the rate of passing of time will change if we move to a position located a Planck distance higher. But from the *physical* perspective, the change in the rate of passing of time on a Planck-scale patch is negligible: it plays no role in Planck-scale physics. ■

The vacuum temperature field is modeled by a function $\tilde{\theta} : \overline{\varphi}_n[U_n] \to \mathbb{R}$ on the Planck-scale coordinate system, while the 4-velocity $\vec{u}(X)$ of an infinitesimal fluid parcel at a point X with coordinates $(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3)$ is modeled by four functions $\{\tilde{u}^\alpha\}$, such that $\tilde{u}^\alpha : \overline{\varphi}_n[U_n] \to \mathbb{R}$ models the coordinate velocity of the fluid parcel in the $\overline{x}^\alpha$-direction. Let X_{n-1} c.q. X_{n+1} be the position of the center-of-mass of the monadic system at the start of the previous c.q. the next process in its temporal evolution, let $L^+(X_{n-1}), L^+(X_n), L^+(X_{n-1})$ be the future light cones of the points X_{n-1}, X_n, and X_{n+1}, and let $\overline{L}^+_j$ be the image of the part of the future light cone $L^+(X_j)$ of the point $X_j \in \{X_{n-1}, X_n, X_{n+1}\}$ in the Planck-scale patch U_n under the Planck-scale chart mapping $\overline{\varphi}_n$, given by

$$\overline{L}^+_j = \{(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \mid \overline{x}^0 > \overline{x}^0_j \wedge \eta_{\alpha\beta}(\overline{x}^\alpha - \overline{x}^\alpha_j)(\overline{x}^\beta - \overline{x}^\beta_j) = 0\} \quad (10.101)$$

for $(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \in \overline{\varphi}_n[U_n]$. We then assume the following:

(i) at coordinates $(\overline{x}^0_n, \overline{x}^1_n, \overline{x}^2_n, \overline{x}^3_n)$, the function values of $\tilde{\theta}$ and $\tilde{u}^\alpha$ satisfy

$$\tilde{\theta}(\overline{x}^0_n, \overline{x}^1_n, \overline{x}^2_n, \overline{x}^3_n) = \theta(X_n) \quad (10.102)$$

$$\tilde{u}^\alpha(\overline{x}^0_n, \overline{x}^1_n, \overline{x}^2_n, \overline{x}^3_n) \cdot \vec{g}^X_\alpha = \vec{u}(X_n) \quad (10.103)$$

(ii) for $j \in \{n, n+1\}$, the functions $\tilde{\theta}$ and $\tilde{u}^\alpha$ are smooth on the intersection of the interior of $\overline{L}^+_{j-1}$ and the exterior of $\overline{L}^+_j$.

Eqs. (10.82) and (10.83) apply for $\tilde{\theta}$ and $\tilde{u}^\alpha$ in areas where they're smooth.

Remark 10.3.17. Again, on the one hand we model the vacuum temperature field by a function on the Planck-scale coordinate system that depends on position, while on the other hand the speed with which light travels through space, which by Post. 10.2.37 depends on the vacuum temperature when expressed in global units of spatial distance per global unit of time, is assumed to be constant on a Planck-scale patch by Def. 10.2.38. So, our approach is thus that it is true that the vacuum temperature varies on a Planck-scale patch, but this variation is so small that it has no significant effect on the speed of light:

$$\tilde{\theta}(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \approx \theta(X_n) \tag{10.104}$$

for any coordinate tuple $(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \in \overline{\varphi}_n[U_n]$. ■

Step (ii).
We begin with the set of invariant properties that our monadic system by Prop. 10.2.2 is postulated to be carrying throughout this process. In Prop. 10.2.6-(v) this set is designated by M_k, but since we consider only a single process we will drop the subscript 'k'' and use M instead. The invariant properties are the following:

(i) the characteristic number of normality c_{n};

(ii) the rest mass spectrum s;

(iii) the electric charge Q.

So, M can be interpreted as the set

$$\mathrm{M} = \{c_{\mathrm{n}}, s, Q\} \tag{10.105}$$

While the electric charge $Q \in \{-1, 0, +1\}$ needs no elaboration, the characteristic number of normality is just a number $c_{\mathrm{n}} \in \{-1, +1\}$. It has the value $+1$ if the monadic system is made up of a component of ordinary matter, and the value -1 if the monadic system is made up of a component of antimatter. The rest mass spectrum s is a real function on the set of integer-valued degrees of evolution, which maps a degree of evolution n to the inertial rest mass of the system at the beginning of the elementary process starting at that degree of evolution: the idea is that the inertial rest mass of a monadic system is not necessarily constant, and that its change is predetermined. Assuming that our monadic system by the current process evolves from the n^{th} to the $(n+1)^{\text{th}}$ degree of evolution, there are positive real numbers $m_n, m_{n+1}, \delta m$ and a number $q \in \{-1, 0, +1\}$ such that

$$s(n)\ [m_p] = m_n\ [m_p] \tag{10.106}$$

$$c_{\mathrm{n}} \cdot s(n+1)\ [m_p] = c_{\mathrm{n}} \cdot m_{n+1}\ [m_p] = c_{\mathrm{n}} \cdot m_n - q \cdot \delta m\ [m_p] \tag{10.107}$$

Here $c_{\mathrm{n}} \cdot s(n+1)\ [m_p]$ is the gravitational rest mass of the system at the beginning of the elementary process starting at the $(n+1)^{\text{th}}$ degree of evolution and δm a universal small unit of mass: the number q is then an emergent charge that stands for the loss of gravitational rest mass in units of $\delta m\ [m_P]$ per process in the temporal evolution of the monadic system. It would be interesting if $q = Q$, since electric charge is then a secondary property; we will, however, not make that assumption.

Proceeding, the initial properties of the system are the properties the system has when it is in its ground state at the beginning of the process. Assuming that spatial distance is expressed in local Planck time units in accordance with Agr. 10.3.5, these are the following:

(i) its center-of-mass has spatiotemporal coordinates $(\overline{x}_n^0, \overline{x}_n^1, \overline{x}_n^2, \overline{x}_n^3)$;

(ii) its spatial momentum in $\overline{x}^j$-direction is $\overline{p}_n^j\ [m_P]$;

(iii) its temporal momentum is $\overline{p}_n^0\ [m_P]$ with

$$\overline{p}_n^0 = \sqrt{(m_n \cdot c)^2 + \sum_j (\overline{p}_n^j)^2} = \sqrt{(m_n)^2 + \sum_j (\overline{p}_n^j)^2} \tag{10.108}$$

(iv) its energy is $E_n\ [E_P^X]$ with $E_n = \overline{p}_n^0 \cdot c$;

(v) its relativistic gravitational mass is $m_g\ [m_P]$, with $m_g = c_{\mathrm{n}} \cdot \overline{p}_n^0 / c$;

(vi) its 4-velocity is $\vec{v}_n$ with $\hat{V}_n = (\overline{v}_n^0, \overline{v}_n^1, \overline{v}_n^2, \overline{v}_n^3)$ given by

$$\hat{V}_n = \frac{1}{m_n} \hat{P}_n \tag{10.109}$$

(vii) its 4-velocity relative to the flow is $\vec{w}_n'$ with $\hat{W}_n' = (\overline{w}_n^{0'}, \overline{w}_n^{1'}, \overline{w}_n^{2'}, \overline{w}_n^{3'})$.

We will treat the monadic system as spinless.

Step (iii).
In this step we will apply hyperreal delta functions: for $\alpha, \beta_1, \ldots, \beta_n \in \mathbb{R}$ the hyperreal delta function $\alpha\delta_{(\beta_1,\ldots,\beta_n)} : \mathbb{R}^n \to {}^*_+\mathbb{R}$, where ${}^*_+\mathbb{R} \supset \mathbb{R}$ is the set of hyperreal numbers, is an ordinary function on $\mathbb{R}^n$ that satisfies

$$\alpha\delta_{(\beta_1,\ldots,\beta_n)}(x^1, \ldots x^n) = 0 \Leftrightarrow (x^1, \ldots x^n) \neq (\beta_1, \ldots, \beta_n) \tag{10.110}$$

$$\int_{-\infty}^{\infty} \ldots \int_{-\infty}^{\infty} \alpha\delta_{(\beta_1,\ldots,\beta_n)}(x^1, \ldots x^n)dx^1 \ldots dx^n = \alpha \tag{10.111}$$

The above two equations reflect the properties that we will use to develop our model. For a rigorous introduction, see Sect. 9.1 or (Cabbolet, 2021b).

Now recall from Prop. 10.2.2 that our monadic system goes through cycles of ground state, transition state, and excited state as it evolves in time by the elementary processes described by the EPT. In any of these states, the only property of the system that matters for the process of gravitational interaction between the system and its environment is its gravitational mass: it is not important *how* this gravitational mass is distributed over space. So if we want to model the hyperstate of the life of the system in one of these states, we might as well view the state of the system at any point in time as a state in which its gravitational mass is located at the position of its center-of-mass. That brings us to the following pointillistic postulate for the hyperstate of the life of a monadic system in a particular state (meaning either ground state, transition state, or excited state):

Postulate 10.3.18 (Pointillistic hyperstate postulate for M_{GR})**.**
Let $\overline{\varphi}[U_n]$ be a rectangular coordinate system on the Planck-scale patch U_n around the point X_n as in step (i); then in the generic model M_{GR} of the EPT, the hyperstate of the life of the monadic system in a particular state with (possibly degenerate) time span $I \subset \mathbb{R}$ in the elementary process under consideration is represented by a function $f : \overline{\varphi}_n[U_n] \to {}^*_+\mathbb{R}$ for which

$$f : (\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \mapsto m_g \cdot \chi_I(\overline{x}^0)\delta^3_{(\overline{r}^1(\overline{x}^0), \overline{r}^2(\overline{x}^0), \overline{r}^3(\overline{x}^0))}(\overline{x}^1, \overline{x}^2, \overline{x}^3) \tag{10.112}$$

where m_g is the (possibly time dependent) gravitational mass and χ_I is the characteristic function of the interval I. That is, at every point of time $\overline{x}^0 \in I$, the gravitational mass m_g of the system at $\overline{x}^0$ is distributed over the one point with coordinates $(\overline{x}^0, \overline{r}^1(\overline{x}^0), \overline{r}^2(\overline{x}^0), \overline{r}^3(\overline{x}^0)) \in \overline{\varphi}_n[U_n]$. ■

Before proceeding, let's first give an overview of the simplest process that we are going to model. Emphasizing that 'the monadic system' can mean 'the center-of-mass of the monadic system', we have that

(i) the process starts with the existence of the monadic system in the ground state with the following properties as described in step (ii):

- its position is X_n;
- its 4-velocity is $\vec{v}_n$;
- its 4-momentum is $\vec{p}_n = m_n \cdot \vec{v}_n$;
- its 4-velocity relative to the flow is $\vec{w}'_n$ with $\hat{V}_n = \hat{W}'_n \circ \hat{U}(X_n)$;
- its 4-momentum relative to the flow is $\vec{p}_n{}'$ with

$$\hat{P}'_n \circ \hat{U}(X_n) = (m_n \cdot \hat{W}'_n) \circ \hat{U}(X_n) = m_n \cdot (\hat{W}'_n \circ \hat{U}(X_n)) \quad (10.113)$$

(ii) the first event of the process is then the state transition by which the monadic system transforms from its ground state to a transition state;

(iii) the proper lifetime of the transition state is a local Planck time, during which the 4-velocity $\vec{w}'$ of the monadic system relative to the flow remains constant: $(\hat{W}') = \hat{W}'_n$;

(iv) there are two effects during the time span of the transition state:

- the system absorbs degenerated mass (implying energy) from its environment, so that its 4-momentum relative to the flow changes from $\vec{p}_n{}'$ to $\vec{p}^{*\prime}_{n+1}$ with $\hat{P}^{*\prime}_{n+1} = m^*_{n+1} \cdot \hat{W}'_n$ where $m^*_{n+1} > m_n$;
- the flow 4-velocity at the point where the system is located changes from $\vec{u}(X_n)$ to $\vec{u}(X_{n+1})$, so that the 4-momentum of the system changes from $\vec{p}_n$ to $\vec{p}^*_{n+1}$ with $\hat{P}^*_{n+1} = m^*_{n+1} \cdot \hat{W}'_n \circ \hat{U}(X_{n+1})$;

(v) at the next event, the system gets by a state transition into an excited state at the point X_{n+1} with that same 4-momentum $\vec{p}^*_{n+1}$;

(vi) the final event is the emission of radiation, by which the system falls back from its excited state to a new ground state at the point X_{n+1} with a 4-momentum $\vec{p}_{n+1}$ with $\hat{P}_{n+1} = m_{n+1} \cdot \hat{W}'_{n+1} \circ \hat{U}(X_{n+1})$.

Gravitation is then the change in spatial momentum relative to the flow.

Remark 10.3.19. In its own VF, the center-of-mass of the monadic system is always located at the origin of the spatial flow, which is to say that if the monadic system in its own VF is located at the point X, then the flow 4-velocity at X is just $\vec{u}(X) = \vec{g}_0^X$. So, in its own VF the system does not accelerate while it is in the transition state: in the rectangular Planck-scale coordinate system on the Planck-scale patch U_n, we then have

$$\hat{V}^*_{n+1} = \frac{1}{m^*_{n+1}}\hat{P}^*_{n+1} = \hat{W}'_n \circ \hat{U}(X_{n+1}) = \hat{W}'_n \circ \hat{U}(X_n) = \hat{V}_n = \hat{E}_0 \quad (10.114)$$

Let's assume, for the sake of simplicity, that the emergent charge q of the system is zero, meaning that the system does not lose gravitational rest mass; in that case, at the final event only a photon is emitted. In its own VF, it then is determined at the first event of the process what the gravitational 4-impulse $\delta\vec{p}_g$ will be will be that the system receives at the final event of this process due to emission of a photon with 4-momentum $\delta\vec{p}_\gamma$: we have

$$\delta\vec{p}_g = -\delta\vec{p}_\gamma \quad (10.115)$$

For an arbitrary (temporarily non-accelerated) observer $\mathcal{O}$, there are then two Lorentz transformations Λ_n and Λ_{n+1} such that in the VF of $\mathcal{O}$ the gravitational 4-impulse determined at the initial event is $\Lambda_n(\delta\vec{p}_g)$ and the 4-momentum of the photon emitted at the final event is $\Lambda_{n+1}(\delta\vec{p}_\gamma)$, but in general we will have

$$\Lambda_n(\delta\vec{p}_g) \neq -\Lambda_{n+1}(\delta\vec{p}_\gamma) \quad (10.116)$$

The reason is that in the VF of $\mathcal{O}$ the system accelerates while it is in the transition state: the photon it emits at the final event is then additionally blueshifted c.q. redshifted. ∎

Proceeding, in step (ii) we have already written down the properties of the system in its ground state at the beginning of this process. So, for starters we can model the hyperstate of the life of the monadic system in its ground state by a function $f_{[\overline{x}^0_n,\overline{x}^0_n]} : \overline{\varphi}_n[U_n] \to {}^*_+\mathbb{R}$ given by

$$f_{[\overline{x}^0_n,\overline{x}^0_n]} : (\overline{x}^0,\overline{x}^1,\overline{x}^2,\overline{x}^3) \mapsto m_g \cdot \chi_{[\overline{x}^0_n,\overline{x}^0_n]}(\overline{x}^0)\delta^3_{(\overline{x}^1_n,\overline{x}^2_n,\overline{x}^3_n)}(\overline{x}^1,\overline{x}^2,\overline{x}^3) \quad (10.117)$$

where $[\overline{x}^0_n, \overline{x}^0_n] \subset \mathbb{R}$ is the degenerate closed interval from $\overline{x}^0_n$ to $\overline{x}^0_n$—that is, $[\overline{x}^0_n, \overline{x}^0_n]$ is the singleton of $\overline{x}^0_n$. Thus speaking, the life of the monadic system in its ground state is modeled as a point particle that exists only at a single point in spacetime, to wit: the point with coordinates $\overline{x}^\alpha_n$.

At the first event of the process—this is the state transition by which the system transforms from its ground state into a transition state—the gravitational 4-impulse $\delta\hat{P}_g = (\delta\overline{p}^0_g, \delta\overline{p}^1_g, \delta\overline{p}^2_g, \delta\overline{p}^3_g)$ is determined; we have

$$\delta\overline{p}^j_g = m_g \cdot \tilde{\nabla}\Phi^j(\overline{x}^0_n, \overline{x}^1_n, \overline{x}^2_n, \overline{x}^3_n) \cdot \tau^X_P \tag{10.118}$$

$$\delta\overline{p}^0_g = -\sqrt{\sum_j (\delta\overline{p}^j_n)^2} \tag{10.119}$$

so that $(\tilde{\nabla}\Phi^j)$ can be viewed as a gravitational field. As a corollary,

$$\eta_{\alpha\beta}\delta\overline{p}^\alpha_g\delta\overline{p}^\beta_g = 0 \tag{10.120}$$

There is thus a Lorentz transformation Λ with components $\Lambda^{\mu'}_\mu$ such that the gravitational 4-impulse $\delta\hat{P}'_g$ in the reference frame co-moving with the flow at X_n has components $\delta\overline{p}_g{}^{\mu\prime} = \Lambda^{\mu'}_\mu \delta\overline{p}_g{}^\mu$. At the final event, the system will thus emit a photon, which in the reference frame co-moving with the flow at X_{n+1} has 4-momentum $\delta\hat{P}'_\gamma = -\delta\hat{P}'_g$; since the flow 4-velocity at X_{n+1} is $\vec{u}(X_{n+1})$ there is then a second Lorentz transformation Υ such that the components of the 4-momentum $\delta\hat{P}_\gamma$ of the emitted photon in the VF of our observer $\mathcal{O}$ satisfy

$$\delta\overline{p}^\alpha_\gamma = \Upsilon^\alpha_{\alpha'}\delta\overline{p}^{\alpha\prime}_\gamma \tag{10.121}$$

Note that in case $\vec{u}(X_{n+1}) = \vec{u}(X_n)$, we have $\Upsilon = \Lambda^{-1}$. That being said, what happens is that the system absorbs degenerated mass from its environment during the time span of its life in the transition state. Now the proper lifetime $\delta\tau$ of the transition state is always a local Planck time:

$$\delta\tau = 1\ [\tau^X_P] \tag{10.122}$$

During that lifetime the system's center-of-mass has a constant 4-velocity relative to the flow, which it inherited from the previous ground state: at any time we have $\hat{W}' = \hat{W}'_n$. Consequently, due to the absorption of degenerated mass from the environment during the time span of the life of the system in the transition state, the 4-momentum relative to the flow changes from $m_n \cdot \hat{W}'_n$ to $m^*_{n+1} \cdot \hat{W}'_n$ such that

$$m^*_{n+1} \cdot \overline{w}^{0\prime}_n = m_n \cdot \overline{w}^{0\prime}_n + \delta\overline{p}^{0\prime}_\gamma \tag{10.123}$$

where $\delta\overline{p}^{0\prime}_\gamma$ is the temporal momentum of the to-be-emitted photon in the reference frame co-moving with the flow. In the Planck-scale coordinate system of observer $\mathcal{O}$, the 4-momentum $\hat{P}(\tau)$ of the center-of-mass of the system in a transition state after an elapsed proper time $\tau \in (0, 1)$ is then

$$\hat{P}(\tau) = \left[m_n + \tau(m^*_{n+1} - m_n)\right] \cdot \hat{W}'_n \circ \hat{U}(\tau) \tag{10.124}$$

where $\hat{U}(\tau)$ denotes the 4-tuple $(\tilde{u}^0, \ldots, \tilde{u}^3)$ at the coordinates $(\overline{x}^0, \ldots, \overline{x}^3)$ of the center-of-mass after an elapsed proper time τ, with components $\tilde{u}^\alpha$ as in step (i). The relativistic gravitational mass $m_g(\tau)$ of the system is

$$m_g(\tau) = c_{\mathrm{n}} \cdot p^0(\tau)/c = c_{\mathrm{n}} \cdot p^0(\tau)\ [m_P] \tag{10.125}$$

During the time span of the life of the system in a transition state, its center-of-mass traces out a displacement curve in spacetime which we model by a function $\ell : (0, 1) \to \overline{\varphi}_n[U_n]$ of elapsed proper time, $\ell : \tau \mapsto (\overline{\ell}^0, \ldots, \overline{\ell}^3)$ where $\overline{\ell}^\alpha = \overline{\ell}^\alpha(\tau)$, satisfying

$$\frac{d\overline{\ell}^\alpha}{d\tau} = \left(\hat{W}'_n \circ \hat{U}(\tau)\right)^\alpha \tag{10.126}$$

$$\int_\ell -\eta_{\alpha\beta} \left(\hat{W}'_n \circ \hat{U}(\tau)\right)^\alpha \left(\hat{W}'_n \circ \hat{U}(\tau)\right)^\beta d\tau = 1 \tag{10.127}$$

So, the center-of-mass of the system traces out a displacement curve in the Planck-scale coordinate system with the size of one local Planck time unit.

The time span of the life of the system in the transition state is the open interval $(\overline{x}^0_n, \overline{x}^0_{n+1}) = (\lim_{\tau\to 0} \overline{\ell}^0(\tau), \lim_{\tau\to 1} \overline{\ell}^0(\tau))$. Now let the three real functions $\overline{r}^j : (\overline{x}^0_n, \overline{x}^0_{n+1}) \to \mathbb{R}$ be given by

$$\overline{r}^j(\overline{x}^0) = \overline{\ell}^j(\tau(\overline{x}^0)) \tag{10.128}$$

So, the function $\overline{r}^j$ maps a time coordinate $\overline{x}^0$ in the time span of the transition state to the j^{th} spatial coordinate of the center-of-mass of the monadic system after a proper time $\tau(\overline{x}^0)$ has elapsed since the first event. We can then model the hyperstate of the life of the monadic system in its transition state by a hyperreal function $f_{(\overline{x}^0_n,\overline{x}^0_{n+1})} : \overline{\varphi}_n[U_n] \to {}^*_+\mathbb{R}$ given by

$$f_{(\overline{x}^0_n,\overline{x}^0_{n+1})} : (\overline{x}^0,\ldots,\overline{x}^3) \mapsto m_g(\overline{x}^0)\cdot\chi_{(\overline{x}^0_n,\overline{x}^0_{n+1})}(\overline{x}^0)\delta^3_{(\overline{r}^1(\overline{x}^0),\overline{r}^2(\overline{x}^0),\overline{r}^3(\overline{x}^0))}(\overline{x}^1,\overline{x}^2,\overline{x}^3) \tag{10.129}$$

for $\overline{x}^0 \in (\overline{x}^0_n,\overline{x}^0_{n+1})$ and $f_{(\overline{x}^0_n,\overline{x}^0_{n+1})} : (\overline{x}^0,\overline{x}^1,\overline{x}^2,\overline{x}^3) \mapsto 0$ else.

The process-physical principle, that the system at the first event of the process transforms from its ground state to a transition state, is then simply represented by the expression

$$f_{[\overline{x}^0_n,\overline{x}^0_n]} \to f_{(\overline{x}^0_n,\overline{x}^0_{n+1})} \tag{10.130}$$

which, as remarked in Sect. 10.2, can be viewed mathematically as a notation for an $\in$-relation $(f_{[\overline{x}^0_n,\overline{x}^0_n]}, f_{(\overline{x}^0_n,\overline{x}^0_{n+1})}) \in R_2$. And the interpretation of Eq. (10.130) is thus that the life of the monadic system in its ground state is succeeded by the life of the system in a transition state.

At the end of the lifetime of the transition state, the intermediate event of the process takes place: by a state transition, the monadic system then transforms from a transition state to its excited state. In that excited state, the monadic system has inertial rest mass m^*_{n+1} while its center-of-mass is located at coordinates $(\overline{x}^0_{n+1},\overline{x}^1_{n+1},\overline{x}^2_{n+1},\overline{x}^3_{n+1}) = \lim_{\tau\to 1} \ell(\tau)$. In addition, its 4-momentum is $\hat{P}^*_{n+1} = m^*_{n+1}\cdot \hat{W}'_n \circ \hat{U}(\overline{x}^0_{n+1},\overline{x}^1_{n+1},\overline{x}^2_{n+1},\overline{x}^3_{n+1})$, which is inherited from the preceding transition state. So, we can model the hyperstate of the life of the monadic system in its excited state by a function $f^*_{[\overline{x}^0_{n+1},\overline{x}^0_{n+1}]} : \overline{\varphi}_n[U_n] \to {}^*_+\mathbb{R}$ given by

$$f^*_{[\overline{x}^0_{n+1},\overline{x}^0_{n+1}]} : (\overline{x}^0,\overline{x}^1,\overline{x}^2,\overline{x}^3) \mapsto m_g\cdot\chi_{[\overline{x}^0_{n+1},\overline{x}^0_{n+1}]}(\overline{x}^0)\delta^3_{(\overline{x}^1_{n+1},\overline{x}^2_{n+1},\overline{x}^3_{n+1})}(\overline{x}^1,\overline{x}^2,\overline{x}^3) \tag{10.131}$$

where $m_g = c_{\text{n}}(\hat{P}^*_{n+1})^0_n/c$ is the relativistic gravitational mass, and as before $[\overline{x}^0_{n+1},\overline{x}^0_{n+1}]$ is the degenerate closed interval from $\overline{x}^0_{n+1}$ to $\overline{x}^0_{n+1}$. So, the life of the monadic system in its excited state is modeled as a point particle that exists only at the point X_{n+1} in spacetime with coordinates $\overline{x}^\alpha_{n+1}$.

The process-physical principle that corresponds with this intermediate event is then represented by the expression

$$f_{(\overline{x}^0_n,\overline{x}^0_{n+1})} : f_{[\overline{x}^0_n,\overline{x}^0_n]} \dashrightarrow f^*_{[\overline{x}^0_{n+1},\overline{x}^0_{n+1}]} \tag{10.132}$$

which, as remarked in Sect. 10.2, can be viewed mathematically as a notation for an $\in$-relation $(f_{(\overline{x}^0_n,\overline{x}^0_{n+1})}, f_{[\overline{x}^0_n,\overline{x}^0_n]}, f^*_{[\overline{x}^0_{n+1},\overline{x}^0_{n+1}]}) \in R_3$. The interpretation of Eq. (10.132) is thus that the life of the monadic system in a transition state effects that the life of the system in its ground state is succeeded by the life of the system in its excited state.

We have then arrived at the final event of the process, at which the system falls back from its excited state to its new ground state, thereby emitting radiation. The easiest part is the new ground state:

(i) its coordinates are $(\overline{x}^0_{n+1}, \overline{x}^1_{n+1}, \overline{x}^2_{n+1}, \overline{x}^3_{n+1})$;

(ii) its 4-velocity is $\hat{V}_{n+1}$, which will be determined below;

(iii) its inertial rest mass is m_{n+1} $[m_P]$ with $m_{n+1} = s(n+1)$;

(iv) its 4-momentum is $\hat{P}_{n+1} = m_{n+1} \cdot \hat{V}_{n+1}$.

So, we can model the hyperstate of the life of the monadic system in its new ground state by a function $f_{[\overline{x}^0_{n+1},\overline{x}^0_{n+1}]} : \overline{\varphi}_n[U_n] \to {}^*_+\mathbb{R}$ given by

$$f_{[\overline{x}^0_{n+1},\overline{x}^0_{n+1}]} : (\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \mapsto m_g \cdot \chi_{[\overline{x}^0_{n+1},\overline{x}^0_{n+1}]}(\overline{x}^0)\delta^3_{(\overline{x}^1_{n+1},\overline{x}^2_{n+1},\overline{x}^3_{n+1})}(\overline{x}^1, \overline{x}^2, \overline{x}^3) \tag{10.133}$$

where $m_g = c_\text{n} m_{n+1} \overline{v}^0_{n+1}$ is the relativistic gravitational mass, which differs from that of the excited state. So, the life of the monadic system in its new ground state is modeled as a point particle that exists only at the one point with coordinates $\overline{x}^\alpha_{n+1}$ in the Planck-scale coordinate system.

The radiation emitted by the system at the final event consists of a photon with 4-momentum $\delta\hat{P}_\gamma = (\delta\overline{p}^0_\gamma, \delta\overline{p}^1_\gamma, \delta\overline{p}^2_\gamma, \delta\overline{p}^3_\gamma)$, and an additional spherical wave if the emergent charge $q \neq 0$, cf. Eq. (10.107). Let $\delta\hat{P}_g$ be the gravitational 4-impulse determined at the first event, Λ^{-1} the Lorentz transformation that maps $\delta\hat{P}_g$ to the gravitational 4-impulse $\delta\hat{P}'_g$ in the reference frame co-moving with the flow at coordinates $(\overline{x}^0_n, \overline{x}^1_n, \overline{x}^2_n, \overline{x}^3_n)$, and Υ the Lorentz transformation that transforms the 4-momentum $\delta\hat{P}'_\gamma$ of the emitted photon in the reference frame co-moving with the flow at coordinates $(\overline{x}^0_{n+1}, \overline{x}^1_{n+1}, \overline{x}^2_{n+1}, \overline{x}^3_{n+1})$ to the 4-momentum $\delta\hat{P}_\gamma$ of the photon in the Planck-scale coordinate system of our observer $\mathcal{O}$, then the 4-momentum of the photon upon emission is given by

$$\delta\hat{P}_\gamma = -\Upsilon \circ \Lambda^{-1}(\delta\hat{P}_g) \tag{10.134}$$

As a law of conservation of momentum we have

$$\hat{P}^*_{n+1} - \delta\hat{P}_\gamma = m_n \cdot \hat{V}_{n+1} \tag{10.135}$$

So, the emission of the photon takes the 4-momentum of the system from $\hat{P}^*_{n+1}$, which is the 4-momentum of the monadic system in its excited state, to $m_n \cdot \hat{V}_{n+1}$, which is an intermediate value if the emergent charge $q \neq 0$: the emission of the spherical wave then takes the 4-momentum of the monadic system from the intermediate value $m_n \cdot \hat{V}_{n+1}$ to $m_{n+1} \cdot \hat{V}_{n+1} = \hat{P}_{n+1}$, which is the 4-momentum of the monadic system in its new ground state. The spherical wave concerns this conservation of 4-momentum:

$$m_n \cdot \hat{V}_{n+1} = m_{n+1} \cdot \hat{V}_{n+1} + c_{\rm n} q \delta m \cdot \hat{V}_{n+1} \tag{10.136}$$

The 4-momentum $c_{\rm n} q \delta m \cdot \hat{V}_{n+1}$ is conserved in the emitted spherical wave, and then transferred to the vacuum: this generates the θ-field.

Suppose we can model the hyperstates of the first Planck-time segments of the lives of the emitted photon and of the emitted spherical wave by yet-to-be-defined functions f_γ and f_w on the rectangular Planck-scale coordinate system $\overline{\varphi}_n[U_n]$, respectively; then the process-physical principle corresponding to the final event can be represented by an expression

$$f^*_{[\overline{x}^0_{n+1}, \overline{x}^0_{n+1}]} \to f_{[\overline{x}^0_n, \overline{x}^0_n]} + f_\gamma + f_w \tag{10.137}$$

which, as remarked in Sect. 10.2, can be viewed mathematically as a notation for an $\in$-relation $(f^*_{[\overline{x}^0_{n+1}, \overline{x}^0_{n+1}]}, f_{[\overline{x}^0_n, \overline{x}^0_n]} + f_\gamma + f_w) \in R_2$. The interpretation of Eq. (10.137) is thus that the life of the monadic system in its excited state is succeeded by the superposition—i.e., the sum—of the life of the system in its next normal state, the life of the emitted photon, and the life of the emitted spherical wave.

As to the emitted photon, it moves on a world line ℓ_γ in the rectangular Planck-scale coordinate system $\overline{\varphi}_n[U_n]$, which can be parameterized by the time (in local Planck time units) that has elapsed since emission as registered by a clock that moves on the time line through the point of emission, i.e. the point with coordinates $(\overline{x}^0_{n+1}, \overline{x}^1_{n+1}, \overline{x}^2_{n+1}, \overline{x}^3_{n+1})$. We will model ℓ_γ in the rectangular Planck-scale coordinate system as a straight line: although it has been observed, first by Dyson, Eddington and Davidson (1920), that the world line of a photon in the gravitational field of a material body is curved, we take the position that its curvature is negligible on a Planck-scale patch. An equation for ℓ_γ is then the following:

$$\ell_\gamma : \begin{pmatrix} \overline{\ell}^0 \\ \overline{\ell}^1 \\ \overline{\ell}^2 \\ \overline{\ell}^3 \end{pmatrix} = \begin{pmatrix} \overline{x}^0_{n+1} \\ \overline{x}^1_{n+1} \\ \overline{x}^2_{n+1} \\ \overline{x}^3_{n+1} \end{pmatrix} + \lambda \cdot \begin{pmatrix} 1 \\ \delta\overline{p}^1_\gamma / \delta\overline{p}^0_\gamma \\ \delta\overline{p}^2_\gamma / \delta\overline{p}^0_\gamma \\ \delta\overline{p}^3_\gamma / \delta\overline{p}^0_\gamma \end{pmatrix} \tag{10.138}$$

where $\lambda > 0$ is bounded to a suitable range so that ℓ_γ remains within the coordinate system on the Planck-scale patch U_n.

Furthermore, the temporal momentum $\overline{p}^0$ of the photon is a function of its coordinates. Writing $(\overline{x}^\mu)$ for $(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3)$, initially we have

$$\lim_{(\overline{\ell}^\mu) \to (\overline{x}^\mu_{n+1})} \overline{p}^0(\overline{\ell}^\mu) = \delta\overline{p}^0_\gamma \tag{10.139}$$

where $\delta\overline{p}^0_\gamma = (\delta\hat{P}_\gamma)^0$ is the temporal momentum determined in Eq. (10.134). But from the observation of the cosmic microwave background by Penzias and Wilson (1965) we already know that the wavelength of a photon increases by the expansion of space. We will incorporate this experimental fact in our theory by postulating a dependence of the temporal momentum of a photon on the vacuum temperature: if only the vacuum temperature changes in the Planck-scale patch U_n, then the temporal momentum $\overline{p}^0(\overline{\ell}^\mu)$ of the photon at coordinates $(\overline{\ell}^\mu)$ is

$$\overline{p}^0(\overline{\ell}^\mu) = \frac{\tilde{\theta}(\overline{\ell}^\mu)}{\tilde{\theta}(\overline{x}^\mu_{n+1})} \delta\overline{p}^0_\gamma \tag{10.140}$$

In addition, from the observation of gravitational redshift by Pound and Rebka (1960) we already know that the frequency of a photon decreases as it travels away from a material body. We will incorporate this experimental fact in our theory by postulating a dependence of the temporal momentum of a photon on the gravitational potential: if only the gravitational potential changes in the Planck-scale patch U_n, then the temporal momentum $\overline{p}^0(\overline{\ell}^\mu)$ of the photon at coordinates $(\overline{\ell}^\mu)$ on ℓ_γ is

$$\overline{p}^0(\overline{\ell}^\mu) = \frac{1 - \tilde{\Phi}(\overline{x}^\mu_{n+1})}{1 - \tilde{\Phi}(\overline{\ell}^\mu)} \delta \overline{p}^0_\gamma \tag{10.141}$$

That being said, we can model the hyperstate of the first Planck-time segment of the life of the emitted photon by a function $f_\gamma : \overline{\varphi}_n[U_n] \to \mathbb{R}$ given by

$$f_\gamma : (\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \mapsto \overline{p}^0(\overline{x}^0) \cdot \chi_{\ell_\gamma}(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \tag{10.142}$$

where χ_{ℓ_γ} is the characteristic function of the world line ℓ_γ and where $\overline{p}^0(\overline{x}^0)$ is the photon's temporal momentum at time coordinate $\overline{x}^0$, for which

$$\frac{\partial \overline{p}^0}{\partial \overline{x}^0} = \frac{\partial \overline{p}^0}{\partial \tilde{\theta}} \frac{\partial \tilde{\theta}}{\partial \overline{\ell}^\mu} \frac{\partial \overline{\ell}^\mu}{\partial \overline{x}^0} + \frac{\partial \overline{p}^0}{\partial \tilde{\Phi}} \frac{\partial \tilde{\Phi}}{\partial \overline{\ell}^\mu} \frac{\partial \overline{\ell}^\mu}{\partial \overline{x}^0} \tag{10.143}$$

with $\overline{\ell}^\mu(\overline{x}^0)$ being the coordinates of the photon at time coordinate $\overline{x}^0$. Note that the right-hand side of this equation is completely determined by the dependencies given by Eqs. (10.140) and (10.141), by the vacuum temperature field $\tilde{\theta}$ and the gravitational potential field $\tilde{\Phi}$ on the Planck-scale coordinate system, and by Eq. (10.138) for ℓ_γ.

Importantly, a loss (or gain) of temporal momentum of a photon is absorbed by (or from) the vacuum. That means that in that case, an extra term has to be added to the continuity equation (10.83), which is only valid in an environment where there is no source of the θ-field. We then get

$$\overline{\nabla}_\mu \overline{\jmath}^\mu = \overline{\nabla}_0 \overline{p}^0 \tag{10.144}$$

where $\overline{p}^0$ is the temporal momentum of the photon at X.

We still have to incorporate the observed deflection of photons by the gravitational field of material bodies in our model, so let's get to it. If we want to derive the said deflection by applying a principle of least action, then the crux is to find a Lagrangian. The idea is thus that if the photon travels on a world line ℓ from A to B (with $A, B \in \mathcal{M}$) parameterized by $\lambda \in [\lambda(A), \lambda(B)]$, and if L is our Lagrangian, then the action S given by

$$S = \int_{\ell} L d\lambda = \int\limits_{\lambda(A)}^{\lambda(B)} L d\lambda \tag{10.145}$$

is a minimum value. That means that if we would consider another possible world line ℓ' of the photon from A to a point B'—we can construct ℓ' from ℓ by holding fixed its initial point A and the spatial coordinates of its end point B and then "wiggling" it a little—then the integral of the Lagrangian over ℓ' should yield a value S' of the action that exceeds S:

$$S' = \int_{\ell'} L d\lambda' = \int\limits_{\lambda'(A)}^{\lambda'(B')} L d\lambda' > S \tag{10.146}$$

What doesn't work is defining the Lagrangian as

$$L = \overline{g}_X(\frac{d\vec{x}}{d\lambda}, \frac{d\vec{x}}{d\lambda}) = \eta_{\alpha\beta} d\overline{x}^{\alpha} d\overline{x}^{\beta} \tag{10.147}$$

(or variants thereof) where $d\vec{x} = d\overline{x}^{\mu} \vec{g}_{\mu}^{X}$ is an infinitesimal displacement vector on the world line of the photon. The point is, namely, that L is always zero, so that the integral in Eq. (10.145) is then always zero too. But not only that: if we "wiggle" the world line a little, thereby creating a new possible world line ℓ', then the integral of L over ℓ' is zero too: $S' = S$. So, we are not optimizing anything then—S is then not a <u>least</u> action.

Thus speaking, for a principle of least action for photons we have to find a radically different Lagrangian. For that matter, we have to take a closer look at the world of a photon. First of all, we notice that the world line of the photon emitted in our process at the point X_{n+1} is the future half of a null curve through the point X_{n+1}, which we define as follows.

Definition 10.3.20 (Null curve; future half).
*In the VF of $\mathcal{O}$, a **null curve** through a point P is a curve $\ell_0 \ni P$ whose tangent $\vec{v} = \overline{v}^{\mu} \vec{g}_{\mu}^{X}$ at any $X \in \ell_0$ satisfies $\overline{g}_X(\vec{v}, \vec{v}) = \eta_{\alpha\beta} \overline{v}^{\alpha} \overline{v}^{\beta} = 0$. The **future half** of a null curve ℓ_0 through P consists of all points $X \in \ell_0$ that have a higher time coordinate than P in the global coordinate system.* ■

Secondly, we notice that a nonzero observer-independent action of the photon between two points A, B on its world line ℓ_0 is simply the number n of oscillations the photon makes between A and B. If we can consider the period τ of the oscillation constant on a Planck-scale patch U_P around a point $P \in \ell_0$, then for two nearby points $P, Q \in U_P$ on ℓ_0 the number n is just the difference in time coordinate between P and Q divided by τ. Thus speaking, if a photon travels on a null curve ℓ_0 from A to B, then we can cut up the curve in N little geometric vectors $\delta\vec{x}_i$ such that for the i^{th} geometric vector the photon makes $n_i = n_i(\delta\vec{x}_i)$ oscillations between the initial and terminal points. The total number n_{AB} of oscillations that the photon that makes between A and B is then

$$n_{AB} = \sum_{i=1}^{N} n_i(\delta\vec{x}_i) \tag{10.148}$$

If we consider the limit $N \to \infty$, then for a null curve $\ell_0 : [\lambda(A), \lambda(B)] \to \mathcal{M}$ this becomes

$$n_{AB} = \int_{\lambda(A)}^{\lambda(B)} \dot{n} d\lambda \tag{10.149}$$

where $\dot{n} = dn/d\lambda$. Now let λ be the coordinate time in the global coordinate system, and define the Lagrangian function $L(X)$ on a point $X \in \ell_0$ with coordinates (t, x^j) in the rectangular global coordinate system $\varphi_0[\mathcal{M}]$ by

$$L = L(x^j, \dot{x}^j, t) = \dot{n} \tag{10.150}$$

We then arrive at this postulate:

Postulate 10.3.21 (Principle of least action for photons)**.**
The ***principle of least action for photons*** *is that a photon travels on a null curve ℓ_0 from A to B in the least amount of oscillations: if the photon would travel on any other null curve $\ell_0' \ni A$ to a point B' on the time line though B, then that would require more action of the photon.* ■

Given the global coordinate system $\varphi_0[\mathcal{M}]$ on spacetime, given the optimal null curve ℓ_0 from A to B, and given the action n_{AB} of a photon travelling on ℓ_0, we thus hold fix the starting point A and the spatial coordinates

$(\varphi_0(B))^j$ of the end point B, and we then "wiggle" ℓ_0 a little bit to create a new null curve ℓ'_0 with an end point B' that has the same spatial coordinates as B. If the photon then would travel on ℓ'_0 it may arrive a little earlier or a little later at the end point B' of ℓ'_0, but in any case its action $n_{AB'}$ would me more: $n_{AB'} > n_{AB}$. Thus speaking, we obtain this result:

In the TCRF of an arbitrary (temporarily non-accelerated) observer $\mathcal{O}$, the equations of motion for a photon are

$$\frac{d}{dt}\frac{\partial \dot{n}}{\partial \dot{x}^j} = \frac{\partial \dot{n}}{\partial x^j} \tag{10.151}$$

It is true that the Lagrangian $L = \dot{n}$ is not an invariant. However, the equations (10.151) have the same form in the TCRF of any (temporarily non-accelerated) observer, because L is a derivative with respect to time and its integral over time (10.149) yields an observer-independent number.

Remark 10.3.22 (Check against existing knowledge)**.**
With the equations of motion (10.151) we should be able to reproduce the observed deflection of photons by the gravitational field of the sun as first reported by (Dyson et al., 1920). This is a research project on its own: we leave this as a topic for further research. To work out the equations, consider an infinitesimal geometric vector $d\vec{x} = dx^\mu \vec{e}^{\,X}_\mu$ along ℓ_0, where $\{\vec{e}^{\,X}_\mu\}$ is the standard coordinate tetrad; writing $dt = dx^0$ we then have

$$(1-\Phi)^2 dt^2 = \frac{\eta_{ij}dx^i dx^j}{(\theta c_{01})^2} = \frac{(dx^1)^2 + (dx^2)^2 + (dx^3)^2}{(\theta c_{01})^2} \tag{10.152}$$

where c_{01} $[\ell_G/\tau_G]$ is the speed of light in global units in an environment where $\Phi = 0$ and $\theta = 1$. The number of oscillations dn that the photon makes during its motion from the initial to the terminal point of the geometric vector $d\vec{x}$ is $dn = dt/\tau$ where $\tau = \tau(X)$ is the period of the oscillation. This gives

$$\dot{n} = \frac{\sqrt{\eta_{ij}d\dot{x}^i d\dot{x}^j}}{(1-\Phi)\theta c_{01}\tau} = \frac{f(\dot{x}^j)}{g(x^j)} \tag{10.153}$$

This can be used in Eqs. (10.151). ■

Having treated the photon, what remains to be modeled is the emitted spherical wave. In the rectangular Planck-scale coordinate system $\overline{\varphi}_n[U_n]$ it travels on the image $\overline{\varphi}_n[L^+(X_{n+1}) \cap U_n] = \overline{L}^+_{n+1}$ of the part the future light cone $L^+(X_{n+1})$ of the point X_{n+1} in the Planck-scale patch U_n under the Planck-scale chart mapping $\overline{\varphi}_n$, given by

$$\overline{L}^+_{n+1} = \{(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \mid \overline{x}^0 > \overline{x}^0_n \wedge \eta_{\alpha\beta}(\overline{x}^\alpha - \overline{x}^\alpha_n)(\overline{x}^\beta - \overline{x}^\beta_n) = 0\} \quad (10.154)$$

for $(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \in \overline{\varphi}_n[U_n]$. Let c_n and q be respectively the characteristic number of normality and the emergent charge of the monadic system as described in step (i), let δm be the unit of mass of Eq. (10.106), and let the quaternion $h_{n+1} \in \mathbb{H}$ be given by

$$c_\text{n} \cdot h_{n+1} = q\delta m v^0_{n+1} + q\delta m v^1_{n+1} \cdot i + q\delta m v^2_{n+1} \cdot j + q\delta m v^3_{n+1} \cdot k \quad (10.155)$$

where the real numbers $q\delta m v^\alpha_{n+1}$ are given by Eq. (10.136); then we can model the hyperstate of the first Planck-time segment of the life of the emitted spherical wave by a function $f_w : \overline{\varphi}_n[U_n] \to \mathbb{H}$ given by

$$f_w : (\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \mapsto h(h_{n+1}, \overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \cdot \chi_{\overline{L}^+_{n+1}}(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3) \quad (10.156)$$

where $\chi_{\overline{L}^+_{n+1}}$ is the characteristic function of $\overline{L}^+_{n+1}$ and $h(h_{n+1}, \overline{x}^\mu) \in \mathbb{H}$ the amplitude. The spherical wave transfers the momentum it carries to the vacuum: the idea is then that we get the quaternion h_{n+1} back when we integrate the loss of amplitude $\dot{h}$ over the entire spatiotemporal extension $L^+_{n+1}(X_{n+1})$ of the life of the spherical wave. So,

$$\int_{L^+_{n+1}} -\dot{h} dV = h_{n+1} \quad (10.157)$$

where $\dot{h}$ and h_{n+1} are expressed in global units. As a toy model, consider that the spherical wave is emitted at $t = 0$ in a special spacetime, in which it has a radius r at time t for which $r = t$; setting $h = h_0 e^{-t}$ we then get

$$\int_0^{2\pi} \int_0^{\pi} \int_0^{\infty} h_0 e^{-t} r^2 sin\theta dr d\theta d\varphi = 8\pi h_0 = h_{n+1} \quad (10.158)$$

yielding $h_0 = h_{n+1}/8\pi$. This reflects the basic idea for the function f_w.

Step (iv).
One of the effects of the monadic system on its environment is that the monadic system generates a gravitational potential field Φ. Prop. 10.1.2 has shown that it cannot be generated by instantaneous action at a distance. The only other possibility is that a monadic system continuously emits *gravitational waves.* In the language of the EPT, the life of such a gravitational wave is not a phase quantum to which the existence predicate applies. Rather, such a gravitational wave is a *wave of changes to the state of the environment* travelling on a light cone. That is, the generation of the gravitational potential field of a monadic system is a wavelike effect of the system on its environment.

Now back to the Planck-scale patch U_n and the rectangular coordinate system $\overline{\varphi}_n[U_n]$. Again denoting a coordinate tuple $(\overline{x}^0, \overline{x}^1, \overline{x}^2, \overline{x}^3)$ by $(\overline{x}^\mu)$, let $\ell : [0,1] \to \overline{\varphi}_n[U_n]$ be the world line of the center-of-mass of the monadic system in this process, with $\ell(0) = (\overline{x}^\mu_n)$ and $\ell(1) = (\overline{x}^\mu_{n+1})$, and let the future light cone $\overline{L}^+(\overline{\ell}^\mu)$ of a coordinate tuple $(\overline{\ell}^\mu) \in \ell[0,1]$ in $\overline{\varphi}_n[U_n]$ be defined in analogy with Eq. (10.154); then the gravitational potential $\delta\tilde{\Phi}(\overline{x}^\mu)$ generated by the monadic system at coordinates $(\overline{x}^\mu)$ on the future light cone $\overline{L}^+(\overline{\ell}^\mu)$ of $(\overline{\ell}^\mu) \in \ell[0,1]$ is modeled by

$$\delta\tilde{\Phi}(\overline{x}^\mu) = \frac{m_g(\overline{\ell}^\mu)}{\sqrt{r^2+1}} \tag{10.159}$$

where $r^2 = (\overline{x}^0 - \overline{\ell}^0)^2 = \eta_{ij}(\overline{x}^i - \overline{\ell}^i)(\overline{x}^j - \overline{\ell}^j)$ and $m_g(\overline{\ell}^\mu)$ is the relativistic gravitational mass at the coordinate tuple $(\overline{\ell}^\mu)$, which at the boundary points $\ell(0)$ and $\ell(1)$ of $\ell[0,1]$ is the relativistic gravitational mass of the ground state. The change in the state of the vacuum is the transition

$$\tilde{\Phi}(\overline{x}^\mu) \to \tilde{\Phi}(\overline{x}^\mu) + \delta\tilde{\Phi}(\overline{x}^\mu) \tag{10.160}$$

Remark 10.3.23 (Gravitational potential at Planck distance)**.**
There are no experimental data about the gravitational field of a massive system at less than a Planck distance. In Eq. (10.159) we have purely pragmatically chosen to avoid infinities at less than a Planck distance by formulating the denominator in such a way that the generated gravitational potential is always less than $m_g(\overline{\ell}^\mu)$. If future experimental data suggest otherwise, Eq. (10.159) has to be revised. ■

Remark 10.3.24 (Newtonian limit for a stationary source).
Suppose we have an environment U in outer space that can be modeled by Minkowski spacetime, and suppose a monadic system with constant inertial rest mass m (e.g. a neutron) is at rest in that environment. Then for large enough r, the gravitational potential $\delta\Phi$ generated by the monadic system at a distance r from the center-of-mass is approximately identical to the Newtonian potential: $\delta\Phi \approx \frac{m}{r}$ ■

Thus speaking, the gravitational waves that the monadic system emits in the elementary process under consideration generate a gravitational potential field in an area $U_{\tilde{\Phi}} \subset \overline{\varphi}_n[U_n]$ made up of

(i) the future light cones $\overline{L}^+(\overline{x}^\mu_n)$ of $(\overline{x}^\mu_n)$ and $\overline{L}^+(\overline{x}^\mu_{n+1})$ of $(\overline{x}^\mu_{n+1})$;

(ii) the intersection of the interior of $\overline{L}^+(\overline{x}^\mu_n)$ and the exterior of $\overline{L}^+(\overline{x}^\mu_{n+1})$.

See Fig. 10.12 for an illustration.

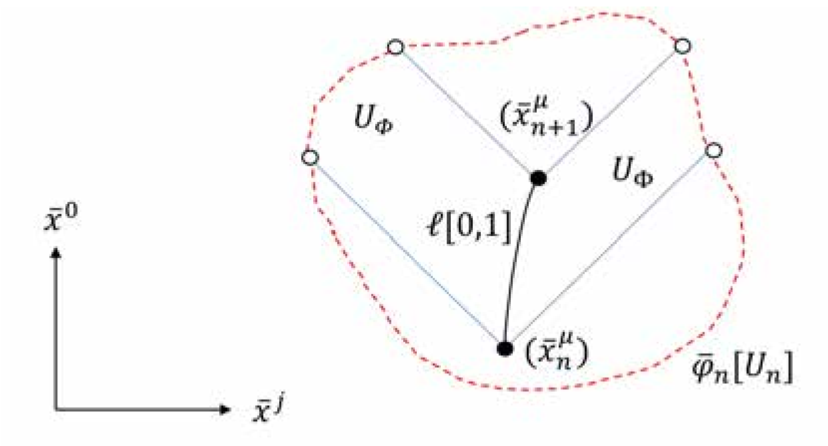


Figure 10.12: Illustration of the area of the generated gravitational potential field in the Planck-scale coordinate system. Vertically the time coordinate $\overline{x}^0$, horizontally a spatial coordinate $\overline{x}^j$. The dotted red line encloses the coordinate system $\overline{\varphi}_n[U_n]$ on the Planck-scale patch U_n. The black curve together with the two black dots represents the world line $\ell[0,1]$ traced out by the center-of-mass of the monadic system during this process. The two V-shaped blue lines are the light cones $\overline{L}^+(\overline{x}^\mu_n)$ and $\overline{L}^+(\overline{x}^\mu_{n+1})$ as indicated. The open dots are the points were the light cones "fall off" the coordinate system. The area where the potential is generated is then the V-shaped area U_Φ enclosed by the two light cones and the dotted red line.

Remark 10.3.25 (No self-gravitation)**.**
Given Eq. (10.159), we have

$$\overline{\nabla}_j \delta\tilde{\Phi}\Big|_{(\overline{x}^\mu)=(\overline{\ell}^\mu)} = 0 \tag{10.161}$$

That is, at the position of the center-of-mass of the monadic system, the gradient of the gravitational potential field generated by the system itself is zero. That means that the monadic system doesn't "see" its own field when interacting with its environment. ■

Of course the gravitational waves emitted by our system travel further beyond the Planck-scale coordinate system. Omitting a formal definition of the future light cone $L^+(X) \subset \mathcal{M}$ of a point $X \in \mathcal{M}$, its interior, and its exterior, the gravitational waves emitted by a monadic system that moves from X_n to X_{n+1} in an elementary process of its temporal evolution trace out an area $U \subset \mathcal{M}$ made up of

(i) the future light cone $L^+(X_n)$ of the point X_n;

(ii) the future light cone $L^+(X_{n+1})$ of the point X_{n+1};

(iii) the intersection of the interior of $L^+(X_n)$ and the exterior of $L^+(X_{n+1})$.

Let $\ell : [0,1] \to \mathcal{M}$, $\ell(0) = X_n$, $\ell(1) = X_{n+1}$, be the displacement curve of the center-of-mass of the monadic system during this process; then for every point $X \in U$ for which there is a point $P \in \ell[0,1]$ such that $X \in L^+(P)$ the gravitational potential $\delta\Phi$ generated by the system at X is

$$\delta\Phi(X) = G\frac{m_g(P)}{\sqrt{r^2+1}} \tag{10.162}$$

for a suitably defined spatial distance r and gravitational constant G. If there are a total of N monadic systems such that each of these generate a gravitational potential at a position X, then the value $\Phi(X)$ of the gravitational potential field Φ at X is

$$\Phi(X) = \sum_{j=1}^{N} \delta\Phi_j(X) \tag{10.163}$$

where $\delta\Phi_j(X)$ is the gravitational potential generated at X by the j^{th} of N monadic systems.

The second effect of the monadic system on its environment is the transfer of the 4-momentum carried by the emitted spherical wave to the vacuum. Let, at coordinates $(\overline{x}^\mu)$ in the Planck-scale coordinate system $\overline{\varphi}_n[U_n]$ on the Planck-scale patch U_n, the emitted spherical wave have a quaternion amplitude $h(\overline{x}^\mu) = h^0 + h^1 \cdot i + h^2 \cdot j + h^3 \cdot k$, and let the flow 4-momentum $(\jmath^\alpha)$ *before the transfer of 4-momentum* have a value

$$\jmath^\alpha = \epsilon\tilde{\theta}(\overline{x}^\mu)\overline{u}^\alpha(\overline{x}^\mu) \tag{10.164}$$

Then the transfer of 4-momentum at coordinates $(\overline{x}^\mu)$ is the transition

$$\jmath^\alpha \to \jmath^\alpha + h^\alpha \tag{10.165}$$

which gives rise to a new flow 4-momentum at coordinates $(\overline{x}^\mu)$, which we will denote by $(\jmath^\alpha_+)$ with the subscript '+' referring to the state *after* the transition. For $(\jmath^\alpha_+)$ we have

$$\jmath^\alpha_+ = \epsilon\tilde{\theta}_+\overline{u}^\alpha_+ \tag{10.166}$$

where $(\overline{u}^\alpha_+)$ is the new flow 4-velocity with

$$\eta_{\alpha\beta}\overline{u}^\alpha_+\overline{u}^\beta_+ = -1 \tag{10.167}$$

In the simplest case where $(\overline{u}^\alpha) = \hat{E}_0$ and $h = h^0$ (so $h^m = 0$) we have

$$\epsilon\tilde{\theta}_+ = \epsilon\tilde{\theta} + h^0 \tag{10.168}$$

meaning that the spherical wave changes the vacuum temperature. And if the monadic system *loses* (inertial) rest mass, that means that the spherical wave *increases* the vacuum temperature—a loss of rest mass is thus ultimately a source of the vacuum temperature field.

Remark 10.3.26 (Speculation on the weak nuclear interaction)**.**
Consider a composite system made up of an atomic nucleus of ordinary matter, and suppose that the electric charge Q of the nucleons is a secondary property that numerically is the same as their emergent charge q defined by Eq. (10.106): for a nucleon, having positive electric charge then means that it loses (gravitational) rest mass. But that means that the

spherical waves, emitted by the system at the final events of the elementary processes of its temporal evolution, increase the vacuum temperature around the center-of-mass of the system: in its own frame of reference, by the principle of formation of space this leads to an increased outward-directed flow. But that means that the nucleons that make up the atomic nucleus have the tendency to drift apart by "going with the flow": we may speculate that this is the principle of the weak nuclear interaction. That is, we speculate that the weak nuclear force is the outward-directed force that components of a nucleus experience due to the formation of space around its center-of-mass, which in turn is due to the loss of rest mass of its positively charged nucleons. This speculation is at least at a qualitative level consistent with the observation that if we have a stable isotope ${}^{n}_{z}A$ of element A (with n its mass number and z its atomic number), then there is a positive integer p such that the isotope ${}^{n+p}_{z+p}Z$ of element Z is radioactive and emits α-radiation. The idea is thus that the addition of protons increases the weak nuclear force to such a degree that the nucleus becomes instable. We leave this as a topic for further research; the interaction between the system and its environment then becomes a "gravitoweak" interaction. ■

Remark 10.3.27 (Speculation on the Planck-era genesis of spacetime)**.** For starters, the initial state of the physical world is nothing but an initial massive system in an excited state in an otherwise empty environment. We can assign the counting number '1' to this initial massive system, and we can index its evolution by the degree of evolution '0'. In the formal language of the EPT (Prop. 10.2.6) we then have

$$\mathbb{E}\ {}^{NP}\varphi_1^0 \tag{10.169}$$

This reads as follows: the life of the 1st massive system in its excited state at the 0th degree of evolution exists.

Then the first event takes place: by a state transition at $t = 0$, the life of the initial massive system in the excited state is succeeded by the life of the initial massive system in a normal state plus the life of emitted radiation:

$${}^{NP}\varphi_1^0 \rightarrow {}^{EP}\varphi_1^0 + {}^{LW}\varphi_1^0 \tag{10.170}$$

Eq. (10.170) is an instance of Prop. (10.12). As a corollary, the life of the first system in its ground state and the life of the emitted radiation exist:

$$\begin{cases} \mathbb{E}\ {}^{EP}\varphi_1^0 \\ \mathbb{E}\ {}^{LW}\varphi_1^0 \end{cases} \tag{10.171}$$

The emitted radiation is a spherically symmetric wave: consequently, in the Planck era we obtain the following instance of the generalized principle of formation of space (Prop. 10.2.15):

$$\mathbb{E}^S\varphi_1^0 \ \Rightarrow \ \mathbb{E}^{LW}\varphi_1^0 \tag{10.172}$$

Its interpretation is thus that the existence of the component of spacetime designated by ${}^{S}\varphi_1^0$ *requires* the existence of the life of the spherical wave designated by ${}^{LW}\varphi_1^0$: the latter *generates* the former.

Proceeding, immediately after the initial event the next event takes place: by a state transition, the life of the initial massive system in its ground state is succeeded by the life of the initial massive system in a transition state. As an instance of Prop. 10.10, we have

$${}^{EP}\varphi_1^0 \rightarrow \ {}^{NW}\varphi_1^0 \tag{10.173}$$

As a corollary, the life of the massive system in its transition state exists:

$$\mathbb{E}\ {}^{NW}\varphi_1^0 \tag{10.174}$$

The idea is now that the initial massive system *decays* during the time span of its transition state: not due to any interaction, it is <u>predetermined</u> that the life of the initial massive system in a transition state effects that the life of the initial massive system in the ground state is succeeded by the life of a <u>new</u> massive system in an excited state, which has multiple components. In the formal language of the EPT we have (Prop. 10.2.11)

$${}^{NW}\varphi_1^0 : \ {}^{EP}\varphi_1^0 \ \dashrightarrow \ {}^{NP}\varphi_1^1 \tag{10.175}$$

$${}^{NP}\varphi_1^1 = \ {}^{NP}\mu_1^1 \ + \ {}^{NP}\mu_2^1 \ + \ \ldots \ + \ {}^{NP}\mu_{z(1)}^1 \tag{10.176}$$

where $z(1) \in \mathbb{N}$ is the number of components of the new massive system and ${}^{NP}\mu_j^1$ designates (the life of) the j^{th} component of the new massive system in an excited state, cf. Analytic Post. 5.3.15.

We now have described how the first massive system goes through a cycle of excited state $\rightarrow$ ground state $\rightarrow$ transition state $\rightarrow$ excited state. The idea is then that spacetime has already come into existence in that very first cycle. So, let's speculate some more about the genesis of spacetime.

First of all, the idea is that the first massive system suffers an enormous loss of temporal momentum at the first event, described by Eq. (10.170), by which it falls back from the excited state to the ground state. It's hard to put a number on it, but the loss may have been e.g. 30% of its temporal momentum. This loss of temporal momentum is conserved in the emitted spherical wave, whose life is denoted by ${}^{LW}\varphi_1^0$. Now the spatiotemporal extension of the initial excited state is just a point: let's denote this by O, to be called: the origin of spacetime. The emitted spherical wave then moves on the future light cone $L^+(O)$ of O: after a proper time $\tau > 0$ has elapsed in the life of the initial system since the first event, we can speak of the interior of the future light cone $L^+(O)$ of O and the exterior of the future light cone $L^+(O)$ of O at that point in time τ. At any such time τ, the gravitational potential field and the vacuum temperature field are zero at any point X in the exterior of the initial light cone:

$$\theta(X) = \Phi(X) = 0 \tag{10.177}$$

By the transfer of 4-momentum along the lines of Eq. (10.165), the spherical wave generates a nonzero vacuum temperature field on points in its interior, that is, on points in the interior of the initial light cone $L^+(O)$. So, at any point in time during the first process (in the reference frame co-moving with the first massive system) the space enclosed by the light cone has a positive temperature, and expands due to the cooling off of the vacuum. In the meantime, the gravitational waves emitted by the massive system generate a gravitational potential field in the interior of the initial light cone. This speaking, during the first process we have at any point X in the interior of the initial light cone that[68]

$$\theta(X) > 0 \wedge \Phi(X) > 0 \tag{10.178}$$

The initial light cone thus separates its "hot" interior from its "cold" exterior. We leave it at that: a more quantitative model of the Planck era is left as a topic for further research. ■

Guidelines for developing a categorical model

By the steps (i)-(iv) in the foregoing, we have developed a mathematical model of a process of gravitational interaction in the framework of the EPT. But we have not yet specified a *categorical model of the EPT*, which is a "model" in the sense of mathematical logic. Since that is what we are ultimately after, let's have a look at the work that remains to be done for specifying a categorical model of the EPT. For starters, our intended categorical model of the EPT is a category $\mathscr{C}_{GR}$ such that

(i) the *objects* of $\mathscr{C}_{GR}$ are set-theoretical models of the EPT, each of which corresponds to a model of a process of gravitational interaction in a rectangular Planck-scale coordinate system on a Planck-scale patch in the VF of an observer;

(ii) the *arrows* of $\mathscr{C}_{GR}$ are model isomorphisms, each of which transforms the model of one observer into the model of another observer.

Cf. Def. 8.1.4. So, the first question is how to specify a set-theoretical model; the second question is how to specify a model isomorphism. To keep it simple, we can consider a categorical model of the version of the EPT introduced in Sect. 10.2, pertaining to the simplest elementary processes.

As to the first question, to specify a set-theoretical model we need to specify an interpretation function I that maps the abstract sets designating occurrents to functions on the Planck-scale coordinate system, such that the generalized principles of the EPT and the equations additionally postulated in step (i)-(iv) are valid in the model. Using the functions developed in the foregoing, we could specify the interpretation function as follows:

$$I({}^{EP}\varphi_k^n) = f_{[\overline{x}_n^0, \overline{x}_n^0]} \tag{10.179}$$

$$I({}^{NW}\varphi_k^n) = f_{(\overline{x}_n^0, \overline{x}_{n+1}^0)} \tag{10.180}$$

$$I({}^{NP}\varphi_k^{n+1}) = f^*_{[\overline{x}_{n+1}^0, \overline{x}_{n+1}^0]} \tag{10.181}$$

$$I({}^{EP}\varphi_k^{n+1}) = f_{[\overline{x}_{n+1}^0, \overline{x}_{n+1}^0]} \tag{10.182}$$

$$I({}^{LW}\varphi_k^{n+1}) = f_\gamma + f_w \tag{10.183}$$

This will have to be extended with an interpretation $I({}^{S}\varphi_k^{n+1}) = f_S$ to model the principle of formation of space (Prop. 10.2.15); here f_S is a function on the coordinate system that so far has not been discussed.

Importantly, all these functions have to be **mathematical constants**—e.g. the transition state of the monadic system may vary *physically* from time to time, but the hyperstate of the life of the system over the corresponding time span is *mathematically* a constant. So, in the framework of a set-theoretical model, the following are all mathematical constants:

(i) the vacuum temperature field and the gravitational potential field;

(ii) the properties of the system;

(iii) for each kind of state that the system can be in, the hyperstate of the life of the system in that state;

(iv) the hyperstate of the life of the emitted radiation;

(v) the hyperstate of the life of the space generated by the emitted spherical wave.

The mathematical model developed in steps (i)-(iv) is defined in terms of generic constants $(\overline{\varphi}_n[U_n], \tilde{\theta}, \tilde{\Phi}, c_{\mathrm{n}}, s, \overline{x}_n^\alpha, \overline{p}_n^\alpha, \ldots)$, and there is a set-theoretic model for each possible value of these constants for which the generalized principles of the EPT and the additional equations remain valid. Thus speaking, the number of objects in our category $\mathscr{C}_{GR}$ is uncountably infinite.

As to the second question, we have to realize that the model isomorphisms are not simply Lorentz transformations. Let's assume that all observers are *inert observers*: their interactions with their environments are negligible and they all "go with the flow". An observational frame of reference is then one in which the inert observer $\mathcal{O}$ is located at the origin of the radial flow: $\mathcal{O}$ is unaccelerated during one elementary process of $\mathcal{O}$'s temporal evolution, yet any other inert observer $\mathcal{O}'$ is observed as accelerating away from $\mathcal{O}$ due to the expansion of space.

Thus speaking, a model isomorphism is a Lorentz transformation only in the case that the acceleration of observer $\mathcal{O}'$ in the observational reference frame of $\mathcal{O}$ can be considered negligible. In all other cases, the model isomorphism become more complicated functions. But in any model, a photon always travels precisely one local Planck unit of spatial distance in a local Planck unit of time.

For now we are content with what we have: we leave the explicit formulation of a function prescription for a general model isomorphism as a topic for further research. That concludes this treatise on Planck-scale physics.

10.4 Discussion

Repulsive gravity (on earth)

By Def. 10.3.13, the contravariant components $\tilde{\nabla}\Phi^\mu$ of the gradient of the gravitational potential field are given by

$$\tilde{\nabla}\Phi^\mu = \eta^{\mu\nu}\overline{\nabla}_\nu\Phi \tag{10.184}$$

In step (i), we have modeled the gradient of the gravitational potential field by a uniform contravariant component vector on a Planck-scale coordinate system, the uniform value being its value at the coordinates of the system's center-of-mass at the first event of the process–cf. Eq. (10.98). Now let's consider a Planck-scale patch U above the earth's surface together with a Planck-scale chart $(U, \overline{\varphi})$ such that $\overline{\varphi}[U]$ is a rectangular coordinate system on U, and let's assume that we have

$$(\tilde{\nabla}\Phi^0, \tilde{\nabla}\Phi^1, \tilde{\nabla}\Phi^2, \tilde{\nabla}\Phi^3) = (0, 0, 0, \tilde{\nabla}\Phi^z) \tag{10.185}$$

meaning that we assume that the gravitational field is along the z-direction, which we identify with the direction of increasing height above the earth's surface.

In step (ii) we have assumed that the (relativistic) gravitational mass of our monadic system is m_g $[m_P]$, with

$$m_g = c_{\rm n} \cdot \overline{p}_n^0 / c \tag{10.186}$$

Thus speaking, for a monadic system made up of a component of ordinary matter ($c_{\rm n} = +1$) we have $m_g > 0$, while for a monadic system made up of a component of antimatter ($c_{\rm n} = -1$) we have $m_g < 0$.

In step (iii) we have assumed that the spatial components $\delta\overline{p}_g^j$ of the gravitational 4-impulse $\delta\overline{p}_g^\alpha$, which our monadic system receives in the process under consideration, are given by

$$\delta\overline{p}_g^j = m_g \cdot \tilde{\nabla}\Phi^j(\overline{x}_n^0, \overline{x}_n^1, \overline{x}_n^2, \overline{x}_n^3) \cdot \tau_P^X \tag{10.187}$$

where $(\overline{x}_n^\mu)$ are the coordinates of the system's center-of-mass at the first event of the process.

Now let's substitute Eqs. (10.185) and (10.186) in Eq. (10.187); this gives the following expression for the gravitational 3-impulse, that is, the spatial components of the gravitational 4-impulse:

$$\begin{cases} \delta\overline{p}_g^1 = \delta\overline{p}_g^2 = 0 \\ \delta\overline{p}_g^z = c_\mathrm{n} \cdot \overline{p}_n^0 \cdot \tilde{\nabla}\Phi^z(\overline{x}_n^0, \overline{x}_n^1, \overline{x}_n^2, \overline{x}_n^3) \cdot \tau_P^X / c \end{cases} \tag{10.188}$$

Thus speaking, if we compare the gravitational 3-impulse that a monadic system made up of ordinary matter ($c_\mathrm{n} = +1$) receives in this process with the gravitational 3-impulse that a monadic system made up of antimatter ($c_\mathrm{n} = -1$) receives in this process, then we get

$$\delta\overline{p}_g^z(c_\mathrm{n} = -1) = -\delta\overline{p}_g^z(c_\mathrm{n} = +1) \tag{10.189}$$

assuming identical temporal momenta at the beginning of the process. Thus speaking, the model predicts that a system made up of a component of antimatter will "fall up" on earth. See Fig. 10.13 for an illustration.

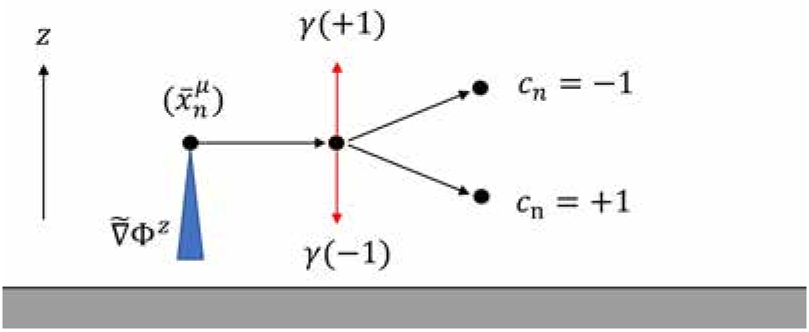


Figure 10.13: Illustration of a gravitational interaction. At the bottom, the earth's surface; vertically, the height above it. Let's assume a system has a horizontal displacement curve (horizontal black arrow) between its initial position (left black dot) and its final position (middle black dot) in an elementary process. At the initial event, it "sees" the gravitational field (blue triangle). This determines the gravitational impulse, which the system will receive at the final event by emitting a photon—upwards directed for ordinary matter (red arrow labeled $\gamma(+1)$), and downward directed for antimatter (red arrow labeled $\gamma(-1)$). So, in the next process the displacement curve of the system is towards earth if it's made up of ordinary matter (downwards black arrow labeled $c_\mathrm{n} = +1$, but away from earth if it's made up of antimatter (upwards black arrow labeled $c_\mathrm{n} = -1$).

Formal reduction to the semi-classical model

We can show that our relativistic Planck-scale model of a gravitational interaction *reduces formally* to the semi-classical model of a process of gravitational interaction introduced in Ch. 6. Since the latter corresponds to Newtonian gravity (Rem. 6.3.9), this means that our relativistic model can (in principle) reproduce the successful predictions of Newtonian gravity.

We can think of an environment U, e.g. the earth's atmosphere, where the gravitational potential at any point $X \in U$ satisfies $\Phi(X) \ll 1$. We may neglect the cooling off of the vacuum in this environment, and we may "choose the gauge" by setting $\theta(X) = 1$ at any $X \in U$; we then have

$$\vec{g}_\mu^X = \vec{\pi}_\mu^X \tag{10.190}$$

$$\vec{u}(X) = \vec{g}_0^X \tag{10.191}$$

where $\vec{u}(X)$ is the flow 4-velocity. For an inertial observer $\mathcal{O}$, the whole environment U—not just a Planck-scale patch U_X around a point $X \in U$—can then be fitted with a coordinate system that is a subset of Minkowski space. Our task is now to show that under these conditions, the relativistic model reduces to the semi-classical model if we apply it to a non-relativistic monadic system with constant mass ($q = 0$). What we have is the following:

(i) the expressions for the gravitational 3-impulse determined at the first event, Eq. (6.59) of the semi-classical model and Eq. (10.118) of the relativistic model, give the same predictions;

(ii) the spatial momentum of the photon, emitted at the final event, is in both cases *the opposite* of that gravitational 3-impulse;

(iii) the energy of the to-be-emitted photon is *in both cases* absorbed from the environment during the time span of the life of the system in a transition state, in which it has a constant spatial velocity;

(iv) the expressions for the difference in spatial momenta of two consecutive ground states of the system are the same—in the semi-classical model we have Eq. (6.58), and in the relativistic model we can deduce (under the above conditions) that $(m_n \cdot \hat{V}_{n+1})^j = (m_n \cdot \hat{V}_n)^j - (\delta\hat{P}_\gamma)^j$.

Having omitted details, this outlines how the relativistic Planck-scale model reduces formally to the semi-classical model in a limit case.

Weakness and limitations of the present model

By design, the present model of an elementary process by which a gravitational interaction takes place between a monadic system and its environment has one major weakness and three main limitations. Below these will be discussed.

First and foremost, by endowing the spacetime manifold with local Vierbein connections (Def. 10.2.42) it is assumed that variations of the Vierbein field $\vec{g}_\mu$ are negligible over a Planck-scale patch U_X around a point $X \in \mathcal{M}$. This assumption is both a strength and a major weakness. The strength lies in the simplicity of our model for spacetime that we thereby obtain: the local Vierbein $\vec{g}_\mu^X$ at a point X then becomes an orthonormal basis for a rectangular coordinate system on a Planck-scale patch U_X around X, and the local Vierbein connection on the Planck-scale patch then mimics the Levi-Civita connection on Minkowski space. The major weakness, however, is that by neglecting these variations of the Vierbein field, we **know** that our model is not 100% accurate. As a result, our model certainly does not apply to the Planck era, because the Vierbein field cannot be viewed as uniform on a Planck-scale patch around the origin of spacetime. To take these variations into account, we would have to endow the spacetime manifold with a spin connection. Our model of spacetime would then become (much, much) more complex, while on the other hand the physics that take place in spacetime would remain the same—the monadic system still goes through a cycle of ground state, transition state, excited state, and back to ground state, it still sees a gradient of the gravitational potential field at the first event of the process, it still emits radiation at the final event, etc. We therefore leave the development of a model for spacetime with a spin connection as a topic for further research.

The first main limitation is that the bounded size of a Planck-scale patch puts a high-energy limit on the area of application of the model. By our definition of a Planck-scale patch, Def. 10.2.38, any two points on a coordinate curve in a rectangular coordinate system on a Planck-scale patch are separated by less than ten local Planck units. But in our model of a process of gravitational interaction, it is tacitly assumed that the initial ground state and the excited state of the monadic system are **both** located in a Planck-scale patch around the spatiotemporal position of the initial ground state. That automatically implies that the duration of the process has to be less than ten local Planck units of time. More specifically, if the initial ground state and the excited state of the system are located at coordinates $(\overline{x}^\mu_n)$ and $(\overline{x}^\mu_{n+1})$, respectively, then it has to be the case that

$$\overline{x}^0_{n+1} - \overline{x}^0_n < 10 \tag{10.192}$$

Thus speaking, since the duration of an elementary process in the temporal evolution of a monadic system is **always** one Planck unit in the observational reference frame of the system, there is an upper limit of 10 to the Lorentz factor $\gamma = \frac{d\overline{x}^0}{d\tau}$ for the system—and hence an upper limit for the energy of the system—or else its displacement curve doesn't fit on the Planck-scale patch. An easy way out is, of course, to raise the upper limits L_ℓ and L_τ that determine the maximum size of a Planck-scale patch in Def. 10.2.38. However, on the one hand there is (theoretically) no upper limit to the value of the Lorentz factor, while on the other hand the maximum size of a Planck-scale patch cannot be increased indefinitely: the assumption that variations of the Vierbein field are negligible on a Planck-scale patch must remain valid. E.g. the spatiotemporal extension of our galaxy with a time span of 10^5 years is not a Planck-scale patch. So regardless which values we assign to the upper limits L_ℓ and L_τ, there is always a high-energy upper limit on the model's area of application. To do away with that limit, we will have to endow our model of spacetime with a spin connection (instead of the local Vierbein connections) and replace the notion of a Planck-scale patch by the notion of a differential patch (which is infinitesimal). The process of gravitational interaction then takes place in an environment that is a union of uncountably many differential patches: that severely complicates its mathematical description, but the physical principles remain the same. We leave this as a topic for further research.

The second main limitation is that the range of the quantitative model of the effect of the monadic system on its environment is limited to a Planck-scale patch. During the process of interaction with its environment, the monadic system emits gravitational waves and material radiation: these have been quantitatively modeled as functions on the rectangular coordinate system $\overline{\varphi}_n[U_n]$ on the Planck-scale patch U_n around the position X_n of its initial ground state. But the lives of the gravitational waves and of the material radiation extend beyond the Planck-scale patch. And while a general equation of motion for photons has been given, Eq. (10.151), no such general equation of motion has been given for the future light cone $L^+(X)$ of an arbitrary point $X \in \mathcal{M}$ in the $TCRF$ of an observer $\mathcal{O}$. So for now we will have to be content with what we have—after all, it is not the case that the effect of the system on its environment has not been modeled at all—and we will have to leave this as a topic for further research.

The third main limitation is that the process-physical presuppositions (Sect. 10.2) do not allow photon capture at the first event of the process. By Prop. 10.2.10, we have assumed that at the first event the monadic system transforms from its initial ground state to a transition state as in

$$^{EP}\varphi_k^n \to {}^{NW}\varphi_k^n \tag{10.10}$$

That means that if we label the 4-momentum $(\overline{p}^\alpha)$ that the system has at any point in the time span of the process by a right subscript representing the elapsed proper time $\tau \in [0, 1]$, then we get

$$\lim_{\tau \downarrow 0} \overline{p}_\tau^\alpha = \overline{p}_0^\alpha \tag{10.193}$$

meaning that the 4-momentum of the system in a transition state becomes the 4-momentum of the system in its initial ground state in the limit where τ nears zero. To allow photon capture, Eq. (10.10) has to be replaced by

$$\exists \lambda \ : \ ^{EP}\varphi_k^n + \lambda \to {}^{NW}\varphi_k^n \tag{10.194}$$

where λ ranges over the lives of photons, cf. Eq. (6.150) on p. 311. In that case, Eq. (10.193) is no longer valid: it becomes

$$\lim_{\tau \downarrow 0} \overline{p}_\tau^\alpha = \overline{p}_0^\alpha + \overline{p}_\gamma^\alpha \tag{10.195}$$

where $(\overline{p}_\gamma^\alpha)$ is the 4-momentum of the captured photon (which is zero if $\lambda = 0$). But as argued in Sect. 6.4, while $(\overline{p}_\gamma^\alpha)$ has a definite value, an observer $\mathcal{O}$ **cannot possibly know** what that value is—the 4-momentum of the captured photon is a *hidden variable*. Thus speaking, if we allow photon capture, we will have to take a quantum-theoretical approach to our model of a process of gravitational interaction. We leave this approach to a quantum theory of gravity as a topic for further research.

Weird physics in the framework of the present model

We have already encountered weird physics in Sect. 10.1: we can, at least in principle, make a box that (on earth) constantly produces energy by converting the energy contained in the vacuum. Inside the box, a particle/antiparticle pair is created at a height h_1 above the earth's surface, elevated to a height $h_2 > h_1$, and annihilated, whereupon the photon obtained by annihilation is sent back to the original height h_1: there we can harvest a part of the photon's energy, and use the rest for a new cycle. See Fig. 10.14 for an illustration.

But there is more weird physics. By Post. 10.2.35 and Eq. (10.159) we have assumed that the local timelike basis vector $\vec{g}_0^X$ at the position X of

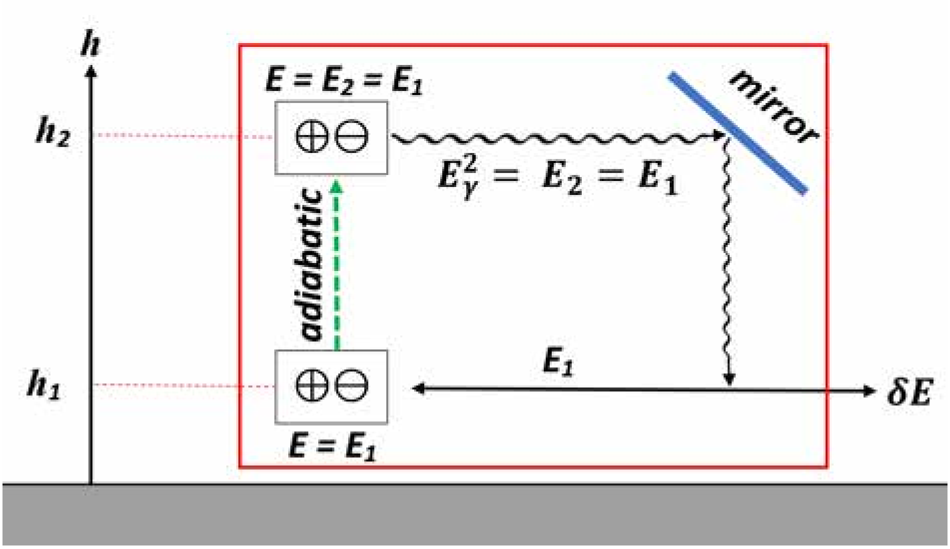


Figure 10.14: Illustration of the energy-converting box. At the bottom, the earth's surface; vertically, the height h above the surface. The red square is the box. Inside, at height h_1 a particle/antiparticle pair is produced with energy E_1. This is adiabatically elevated to a height h_2, where it is converted into a photon with energy $E_\gamma^2 = E_1$ by annihilation. The photon is then sent back to height h_1, whereby its energy increases to $E_\gamma^1 = E_1 + \delta E$. At height h_1 the energy δE, which has been absorbed from the vacuum, is harvested, and the remaining energy E_1 is used for a new cycle. For an observer on the outside, this is just a box that produces energy.

the center-of-mass of a system with gravitational mass m_g $[m_P]$ is

$$\vec{g}_0^X = \frac{1}{1 - m_g} \cdot \vec{\pi}_0^X \tag{10.196}$$

assuming that only the system contributes to the gravitational potential. In principle that means that it would take an infinitely long time to accelerate e.g. an electron to the point that we have $m_g = 1$ $[m_P]$. But suppose that by bombardment with ultrahigh-energy photons, we succeed in creating an electron with $m_g > 1$ $[m_P]$; then there is a number $\epsilon > 0$ such that

$$\vec{g}_0^X = \frac{1}{1 - m_g} \cdot \vec{\pi}_0^X = -\epsilon \cdot \vec{\pi}_0^X \tag{10.197}$$

meaning that the local timelike basis vector then points **in opposite time direction**, that is, in the direction opposite to the direction of increasing coordinate time. Then we get weird physics: exploiting it, we could organize a tourist trip back to the dinosaur era, although every tourist ages as usual during the trip. In our model this is excluded: by Post. 10.2.35 we have assumed that $\Phi(X) < 1$. Ergo, incorporating the possibility that $\Phi(X) > 1$ requires a fundamental revision of the model of spacetime.[69]

More weird physics is obtained if we consider a device that consists of a circular storage ring, in which antimatter circulates in an electromagnetic field, and a control room inside for manipulating the electromagnetic field in the storage ring—see Fig. 10.15 for an illustration. We can assume that the device consists of N components (supersmall massive systems), so that its total gravitational mass M_g is the sum of the gravitational masses $m_g(1), m_g(2), \ldots, m_g(N)$ of the N components:

$$M_g = \sum_{k=1}^{N} m_g(k) \tag{10.198}$$

Now by manipulating the electromagnetic field, we can let the antimatter circulate *faster* in the storage ring: its gravitational mass then becomes *more negative*, and consequently the gravitational mass of the device then *decreases*. So in general the gravitational mass of the device is a function of the frequency ν by which the antimatter circulates through the storage ring: $M_g = M_g(\nu)$. Since there is no upper limit, there is a frequency ν_0

such that for every $\nu > \nu_0$ we get

$$M_g(\nu) < 0 \tag{10.199}$$

meaning that the total gravitational mass of the device becomes *negative*. Consequently, by manipulating the electromagnetic field in the storage ring we can let the device take off from the surface of the earth without any use of fossil fuel—we merely use the repulsion of massive systems of antimatter by the earth's gravitational field. But note that we still can't travel anywhere: the device only goes up and down—to move horizontally (i.e. parallel to the earth's surface), additional features have to be added.

Now let's try to think a million years or so ahead—why not? If all the above by then has been technologically realised—that's not just a big 'if': it may be the biggest 'if' ever—then we have a futuristic society that looks radically different from ours. We don't have to fight wars for oil or to "bring democracy" to countries that happen to have large oil reserves, we have four-dimensional travel (as we can move through the time dimension the same way that we can move through a spatial dimension), and we have planes that cannot possibly crash because they fall up. But *hic et nunc* this is just science fiction: from the perspective of contemporary society, it is hard to imagine that any of this will ever be realised!

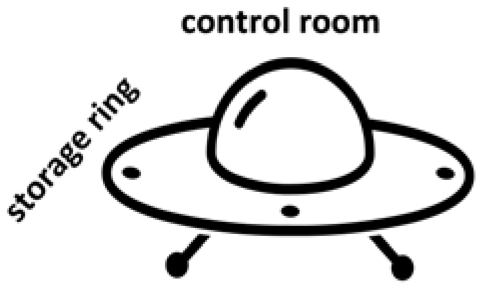


Figure 10.15: Illustration of the device. On the outside, the storage ring in which antimatter circulates in an electromagnetic field; on the inside, the control room where the electromagnetic field can be manipulated. Source of the image: public domain.

Open issues

The main open issue is that it remains to be proven that our Planck-scale model of a process of gravitational interaction *reduces empirically* to GR, that is, that our Planck-scale model can reproduce the empirically successful predictions of GR. Such a proof would demonstrate that the EPT corresponds weakly to GR, cf. Def. 8.1.5.

To show that our Planck-scale model reduces empirically to GR, *at the very least* it needs to be shown that the following crucial observations can be described as predictions of our Planck-scale model:

(i) the perihelion precession of Mercury;

(ii) the deflection of photons by the gravitational field of the sun;

(iii) the time dilation observed in the Hafele-Keating experiment.

It is interesting that the perihelion precession of Mercury has already been accurately described as a prediction of Relativistic Newtonian Dynamics (Friedman and Steiner, 2016). So, a method to show that this observation is predicted by our Planck-scale model is showing that our model reduces formally to Relativistic Newtonian Dynamics in a limit case. For that matter, we can consider the reference frame of the sun, and we can assume that the sun is the only source of the gravitational potential field. Neglecting the cooling off of the vacuum, we then have to model Mercury as a massive system and show that it behaves in accordance with the observations.

That same reference frame of the sun can be used to reproduce the observed deflections of photons by the sun. For that matter, it has to be shown that the empirical data follow from the principle of least action for photons developed in this chapter, Eq. (10.151).

To reproduce the observed gravitational time dilation we can use the same method as above for reproducing the observations concerning Mercury. That is, we can consider the reference frame of the earth, with the earth as the only source of the gravitational potential field. Neglecting the cooling off of the vacuum, we then have to model the plane as a massive system and show that it behaves in accordance with the observations.

All in all, solving these open issues cannot be done on the back of an envelop: it requires a team effort. A detection of repulsive gravity is then a compelling argument for spending resources on that effort.

Conclusions and perspectives for future research

The main conclusion is that we have henceforth a model at our disposal, which is an interpretation in concrete mathematical language of a simplest elementary process, abstractly described by the EPT, as a process of gravitational interaction taking place at Planck-scale. This model has not been subjected to peer review: without an experimental confirmation of the hypothesis on repulsive gravity on which the EPT leans, there is hardly any point in spending the resources that such a peer review requires. So, the present model is not intended as a replacement of GR, but rather as a starting point for a scientific discourse on principles of gravitation in the eventuality that repulsive gravity is detected. Such a discourse may reveal that minor details of the model have to be revised, but its general thrust will remain the same. In words, that general thrust is this:

(i) in each elementary process of its temporal evolution, any massive system goes through a cycle of initial ground state, transition state, excited state, and back to a new ground state;

(ii) its environment is described by a Vierbein field, in which a gravitational potential field and a vacuum temperature field are encoded;

(iii) at the first event of the process, when the system transforms from its initial ground state to a transition state, the gravitational impulse is determined;

(iv) while the system is in a transition state, it absorbs the energy that the gravitational impulse requires from its environment;

(v) at the final event of the process, when the system falls back from the excited state to a new ground state by emitting radiation, the system receives a gravitational impulse by emitting a photon;

(vi) a massive systems made up antimatter emits a photon in a different spatiotemporal direction than a massive system of ordinary matter in the same environment, and thereby receives an impulse due to gravitation in the opposite spatial direction.

Thus speaking, the present model offers the perspective that a detection of repulsive gravity doesn't necessitate a search for first principles: instead, research can then be focussed on developing improvements to this model.

On the downside, a second conclusion is that the present model serves currently no other purpose than to showcase the mathematical-physical principles of a gravitational interaction between a massive system and its environment that takes place in a process with a duration of a (proper) Planck time. To apply the present model to real-world problems, which inevitably involve measurements on systems at macroscopic or even astronomic scale, mind-boggling numbers of elementary processes will have to be modeled: this exceeds the capacity of any computer—even of any system of computers. For example, if we want to prove that the present model reduces empirically to GR, then precisely that has to be done: it must be proven that the observations discussed on p. 535, which all involve measurements on macroscopic or astronomic systems, can be described as predictions of the Planck-scale model. So, although it is known how to prove empirical reduction to GR, it is quite a laborious task to actually produce an adequate proof that astronomical observations are predicted by Planck-scale physics. It might even be necessary to solve (some of) the issues with the present model—in particular, if we want to specify the Vierbein field in the reference frame of the sun or the earth, we need to have a precise function prescription for the effect of a massive system on its environment *beyond a Planck-scale patch*. Thus speaking, it might be necessary to develop (minor) revisions of the present model that solve its issues before it can be applied quantitatively to real-world problems.

Provided the present model or a revised version thereof withstands the test against GR, there are several lines of further research thinkable:

(i) specifying a categorical model of the EPT that reduces empirically to GR, along the lines set forth at the end of Sect. 10.3;

(ii) developing a (categorical) model of the EPT that reduces empirically to GR and classical electromagnetism;

(iii) developing a relativistic quantum theory of interaction;

(iv) developing a model of a process of a "gravitoweak" interaction.

Regarding (i), a successful execution of the research project yields a categorical model $\mathscr{C}_{GR}$, which in the research program on the EPT then serves as a successor of the categorical model $\mathscr{C}_{SR}$ introduced in Ch. 9 that is theoretically and empirically progressive compared to $\mathscr{C}_{SR}$ (Def. 8.1.7).

Regarding (ii), the main challenge seems to be the conceptual problem that it needs to be defined what "electromagnetism" actually is in the framework of (a model of) the EPT. We have the gravitational potential field, the vacuum temperature field, the flow 4-momentum, and the system in a transition state, which can be viewed as a wave state in which the system interacts with its environment: that's it—we will have to do with that. It seems worth a try to identify the electromagnetic 4-potential A^μ with the (components of the) flow 4-momentum $\jmath^\mu$, but that may yield blatant contradictions with observations. We may view the spherical waves emitted by a charged system at final events of elementary processes as the source of its electromagnetic field, but the question remains what that field is and how such a (piecewise) continuous field can be generated by (spherical) waves emitted at discrete times. However, while this line of research faces a difficult conceptual challenge, the reward is great: if executed successfully, the project yields a model of a single interaction with gravitational and electromagnetic aspects—this is a crucial step towards proving that the EPT is a *unifying scheme* as meant in Def. 8.1.6.

Regarding (iii) and (iv), for these topics we have to model other processes than the simplest processes described at the beginning of Sect. 10.2. For a relativistic quantum theory of interaction, we have to include photon capture at the first event of the process as in Eq. (10.194). The aim is then for a quantum theory of interaction that reduces empirically to GR and QED. For a model of a "gravitoweak" or even a "gravitoelectroweak" interaction we will have to model the full version of the EPT, which allows a multi-component system to evolve into two new systems. While we have speculated in Rem. 10.3.26 what the weak force actually is in the framework of the EPT, research on this topic is best started last, when the EPT has already been shown to be a unifying scheme.

The bottom line is that we have a quantitative model of the Planck-scale world, which yields concrete answers to the fundamental questions asked in the Preface—a world with repulsive gravity: what would it be made up of, and how would it function? We might find the present model unsatisfactory because the corresponding world view is limited to a Planck-scale patch, but we have to think in terms of research programs: regardless how much we dislike the present model, it gives us something to hold on to in the eventuality that repulsive gravity is detected at CERN.

10.5 Objections and replies

Objection 10.5.1. "*Dear Marcoen Cabbolet, I regret to inform you that your abstract was not chosen as one of the abstracts to be presented at Foundations2018. We have received many more abstracts than we could possibly accept. Although we are very thankful for all the received work, the sheer number of abstracts has forced us to make some tough choices.*"—organising committee of the 19$^{\text{th}}$ European Conference on Foundations of Physics, held in 2018 from July 10 to July 13 at Utrecht University (NL), rejecting my proposal for a lecture on a relativistic theory of a process of gravitational interaction ■

Reply 10.5.2. The organisation is by no means obliged to let me have a talk at their conference. The rejection doesn't really contain an argument, though. ■

Objection 10.5.3. "*There is not nearly enough here, additional to what the author has already said in Annalen der Physik articles of 2010 to 2016.*"—anonymous referee for the 20$^{\text{th}}$ European Conference on Foundations of Physics, held in 2021 from October 28 to October 30 at Université Paris 1 (F), recommending rejection of my proposal for a lecture on a relativistic theory of a process of gravitational interaction ■

Reply 10.5.4. The referee's assessment is false: my intention was not to merely talk about the theory presented in *Ann. Phys.*, but instead to focus on the less abstract model of that theory, presented in this chapter, which goes beyond the papers in *Ann. Phys.* ■

Objection 10.5.5. "*I do not believe that this abstract meets the epistemic standards of the disciplines involved in this meeting, and so I strongly advise rejecting it.*"—second anonymous referee for the 20$^{\text{th}}$ European Conference on Foundations of Physics, held in 2021 from October 28 to October 30 at Université Paris 1 (F), recommending rejection of my proposal for a lecture on a relativistic theory of a process of gravitational interaction ■

Reply 10.5.6. This objection is straight from Monty Python's "Argument Clinic": that's not an argument, that's just contradiction. It is obvious from the choice of words that the referee doesn't think much of me, but rest assured that the feeling is mutual. ■

Remark 10.5.7. Before publishing this monograph as a non-peer-reviewed open access work, I did try to publish it with a A-rated book publisher. But I gave up on that when not even a befriended acquisition editor, himself a (senior) mathematical physicist, could convince his superiors to publish this work. Below are the objections against publication that I received. ■

Objection 10.5.8. "*I am sorry to inform you that the decision of people who are responsible for publication by [us] is fully negative. I did not see this coming. Nothing depends on me. I did what I could, you know*"—acquisition editor of an A-rated academic book publisher, and friend of mine, informing me in 2018 about the rejection of the book proposal for the current monograph despite the fact that he recommended it ■

Objection 10.5.9. "*This does not sound like the type of book that we would be interested in ... due to its unconventional and controversial nature*"—acquisition editor of an A*-rated academic book publisher, rejecting in 2017 the book proposal for the current monograph ■

Objection 10.5.10. "*[For now] I'm afraid I don't see any possibility to publish your work [with us] as a book. I will definitely be glad to take up our correspondence again when repulsive gravity is reliable detected*"—acquisition editor of an A-rated academic book publisher, rejecting in 2016 the book proposal for the current monograph ■

Reply 10.5.11. No book publisher is by any means obliged to publish my work. But the rejections I received are nothing but objections against the unconventional nature of the material, as explicitly expressed by Obj. 10.5.9. ■

Remark 10.5.12. I have made no other efforts to publish the material in this chapter. Below I'll treat some general objections to my work. ■

Objection 10.5.13. "*If I were you, I would have ...*"—opening phrase used by several physicists telling me how they would have done everything differently ■

Reply 10.5.14. To quote Mike Tyson, the former boxing champ:

> "*If they were in my shoes, they would cry like a baby.*"

■

Objection 10.5.15. "*It is sad. Marcoen Cabbolet has worked for more than ten years on his dissertation. And not just any dissertation, but one that was supposed to shake the scientific world to its foundations. I can image the talk in a pub. Without a doubt, Cabbolet has had to explain his theory countless times in a pub. And without a doubt, all his friends were very interested. After all, it could be that they were sitting across a future Nobel laureate, and in that case everybody wants to be able to say 'I was there'. But that dream doesn't seem to come true, because if the top brass in Eindhoven says 'no', then the top brass in Stockholm will be hard to convince. I can imagine the friends saying 'I also thought it was far-fetched'.*"—Bram van Gestel on the cancellation of my PhD graduation by Eindhoven University of Technology (2008) ■

Reply 10.5.16. This is not a case of projection, that is, it is not the case that Van Gestel *himself* has been explaining his work countless times in a pub. No, what we have here, finally, is someone who sees right through me! I admit: I've been working on the foundations of a world with repulsive gravity for more than 25 years for no other reason than to brag about it in a pub. Oh what joy it is to be surrounded by drunk people, the sound of slurred speech, and the fresh smell of vomit! ■

Objection 10.5.17. "*I immediately had the impression that this is the work of a charlatan*—Andries Brouwer on the 2007 concept-dissertation (2008a) ■

Objection 10.5.18. "*The entire physics developed in [this dissertation] is ... devoid of meaning and devoid of content.*"—Jos Baeten commenting on my 2007 concept-dissertation (2008) ■

Objection 10.5.19. "*Not a new Einstein, but a fuck up*"—Peter Olsthoorn, "investigative journalist", commenting to the news that my PhD graduation was canceled on the widely-read forum *leugens.nl* (2008) ■

Objection 10.5.20. "*To the defense of our Flemish friends, the following. When Cabbolet signed up in Brussels, they first made him follow courses and do exams for two years (in philosophy, I assume). After that, they told him that his entire physics is utter nonsense*"—Jan Willem Nienhuys, secretary of the organized skeptical movement *Stichting Skepsis*, fabricating facts about my PhD studies at the VUB (2015) ■

Objection 10.5.21. "*An unbelievable crackpot PhD graduation*"—Wouter van Joolingen, professor of science and mathematics education, commenting on the news that I obtained a PhD in Belgium (2011a) ■

Objection 10.5.22. "*Cabbolet is simply one of these typical pseudoscientists. In Belgium they fell for it, but at a philosophy department not at a physics department. Telling.*"—Casper Hulshof, lecturer at Utrecht University, commenting on the news that I obtained my PhD in Belgium (2011) ■

Objection 10.5.23. "*Calm but clear, devastating criticism of the fake PhD graduation of Cabbolet*"—MSc physics and science journalist Bruno van Wayenburg (2011), twittering his praise for the hostile opinion piece by Van Joolingen (2011c) ■

Objection 10.5.24. "*There has been a case where a PhD graduation was cancelled at the very last moment due to nonsense content: Marcoen Cabbolet*"—Pepijn van Erp, board member of the organized skeptical movement *Stichting Skepsis*, answering the question whether a PhD defense had ever ended in the candidate not obtaining the PhD degree (2015) ■

Objection 10.5.25. "*Just keep trying. Eventually even Marcoen Cabbolet succeeded. And even on a nonsense hypothesis.*"—Tjerk Muller, supporting someone who had a hard time during his PhD studies (2015) ■

Objection 10.5.26. "*Marcoen Cabbolet mentions Brian Martin's work on dissenting views. Me: One person's dissident is another person's crank*"—Matt Hodgkinson, head of research integrity at Hindawi (2017) ■

Reply 10.5.27. When I read these objections, I think: 30,000 years after the Neanderthal, this is where we are. ■

Remark 10.5.28. There is not a shadow of doubt in my mind that my opponents will practice *historical revisionism* in the event that repulsive gravity is detected: they will claim that they had good arguments to reject my work. They hadn't, but they have already committed themselves in great detail to the position that I'm a crackpot who doesn't know the first thing about mathematics or physics: any backtracking will come with such a loss of face that they will instantly become the laughing stock for generations to come. Don't let them deceive you. ■

Notes

[1]This does not hold for the approach to the mind-body problem on the basis of the EPT: a substantial amount of additional research on that topic has been done. But that is irrelevant in the present context: the controversy was about the physics part of my work, not about my approach to the mind-body problem.

[2]In the Netherlands, one can become a PhD candidate at a university without formally having done one's PhD research at that university, that is, without having been a PhD student at that university. Such a PhD candidate is called an *external* PhD candidate—basically, anyone can knock on the door of a university and ask if he can obtain a PhD on the basis of a manuscript.

[3]The sentences in bold are outright fabrications by Kees van Hee.

[4]The pamphlets that Van Hee subsequently obtained from Brouwer and Baeten are outside any and all PhD regulations, and I have never signed any confidentiality agreement regarding these pamphlets.

[5]Baeten's judgment that I'm a crackpot who knows nothing does not come to expression in the quote on page xxxiv. But it does come to expression in the opening quote of Ch. 10, and in the fact that he—by means of another letter that remained behind closed doors—urged the university administration to take punitive action against the then supervisor of the PhD project.

[6]Interestingly, when it was announced just before Christmas 2007 that I was scheduled to defend my PhD thesis at the Faculty of Mathematics and Computer Science of the TU/e at January 16, I was called by phone by one of the coworkers of the TU/e: he warned me to watch out for "that snake Kees van Hee". So apparently Van Hee had already built a reputation for himself.

[7]To all those crusaders against pseudoscience who now want to accuse me of having compared myself to Einstein: this comparison is not to compare myself to Einstein, but to give a clear-cut example showing that *not being an advancement in pure mathematics* does not imply *being of insufficient mathematical quality*.

[8]The pamphlet that Van Hee subsequently obtained from 't Hooft is outside any and all PhD regulations, and I have never signed any confidentiality agreement regarding this pamphlet.

[9]This excerpt from the comments by 't Hooft was preceded by the two sentences mentioned below in Rem. V. The ellipsis in line 3 of the excerpt indicates the omission of a one-liner by which 't Hooft judged the mathematics in the concept-dissertation: this one-liner is discussed in Example X on page lii. This excerpt was succeeded by a paragraph in which 't Hooft expressed his anger about the fact that I hadn't contacted his research group and that he didn't know my mentor, Sannikov; see Objection 3.5.22. This paragraph was then succeeded by a concluding sentence, which is the opening quote of Ch. 8. And that is all 't Hooft had to say.

[10]The pamphlet that Van Hee subsequently obtained from Verhaar is outside any and all PhD regulations, and I have never signed any confidentiality agreement regarding this pamphlet.

[11]In the pamphlet written by Verhaar, the excerpt of Verhaar's comments on page xxxviii was succeed by the one-liner that is the opening quote of Ch. 11. That was all of the initial verdict by Verhaar. Later, when everything had already been decided, he sent in a second pamphlet with comments that, *both* regarding the relevance of the comments to the content of the concept-dissertation *and* regarding the depth of the comments, can be summarized with *yadda yadda yadda*.

[12]There were those who claimed that 't Hooft is such an excellent expert that he **can** see within three hours that my theory, the EPT, is bogus. (One of them was Carlo Beenakker, who was asked by the LOWI to evaluate my work: "In my opinion, three hours are not enough to get an understanding of the contents of this manuscript. But I consider it [i.e. three hours] more than enough to judge whether the manuscript is acceptable as a PhD thesis, certainly for an expert such as 't Hooft.") That may be true if the theory under consideration is a *quantum theory* formulated in the language that 't Hooft has been working with for decades in a row. But that's not true in the present case: the EPT is not a quantum theory, and the definition of the axiomatic system is simply too voluminous to be mastered in three hours. Compare Tolstoy's *War and Piece*: no matter how excellent an expert one is in linguistics, it cannot be read comprehensively in three hours.

[13]That is, by blindly following the new trend set by 't Hooft to publicly discredit my work as despicable, my opponents proved that there exists a predilection among mainstream scientists to blindly follow fashions dictated by self-appointed leaders regardless of the intrinsic merit of the theories they were advancing (in casu the "theory" that I'm a crackpot who doesn't know physics and that my work is illucid). The definition of the pack effect is taken from (Prugovecki, 2002).

[14]Wikipedia is a failed project in the sense that it has become a forum for the 'tyranny of the prevailing opinion'—so called by the philosopher John Stuart Mill. This comes to expression by several lemmas on Wikipedia which *de facto* are smear campaigns against individuals who challenge any widespread belief—all under the guise of 'objectivity', of course.

[15]To get this straight: with that last sentence Beijerinck wants to say that the members of the PhD committee have been sleeping because they approved the concept-dissertation without noticing that it was at crackpot level.

[16]To his defense, rumor was that he acted that way out of fear for a conflict with 't Hooft. If so, then I do understand his action, but I nevertheless hold it against him that he has let himself be led by his emotion (in casu: fear)—as the Dutch proverb says: "fear is a bad advisor".

[17]To make this absolutely clear: where I state that my opponents committed a stupidity, I'm making a judgment about *behavior*, not about *persons*.

[18]Of all branches of science, mathematics has the unique feature that in case of a dispute one can simply *calculate* who is right. In this case, if you do the calculation then you'll find out that the mathematics in the concept-dissertation satisfy all criteria of rigor and that the claim by 't Hooft as quoted is fallacious.

[19]This generalized model applies at least to the way senior physicists have responded to

my criticism of the collective delusion that the results of experimental projects aimed at proving the existence of ultrashort-lived unstable particles can be called "observations" of these particles—see the section 'Objections and Replies' of Ch. 2.

[20]The term 'cult-of-narrowness' mindset is an allusion to Karl Popper, who called the physics community a "Cult of Narrowness" (1982). We can, thus, say that someone has a 'cult-of-narrowness' mindset if he responds to a dissenting piece as predicted by the response-in-an-outburst model. And vice versa: if someone has a 'cult-of-narrowness' mindset, then the response-in-an-outburst model applies—that is, then he'll respond to a dissenting piece as predicted by the response-in-an-outburst model.

[21]Specialization in science has also been mentioned as a cause of resistance by scientists to discovery in (Barber, 1961).

[22]The use of operators as representations of observable properties has been criticized in (Daumer et al., 1997); however, this section is about OQM, so with observable properties represented by operators.

[23]The SPP, in particular the "only if" part, has been criticized (Muller, 2014). However, the SPP as formulated is essential to OQM: if we remove the "only if" part then we *depart* from the framework of OQM. This section is about OQM, so with the SPP as stated.

[24]Some quantum physicists have asserted that in certain cases a quantum system that is in an indeterminate state (a superposition of different eigenstates) can get into an eigenstate by temporal evolution: these special cases are excluded by the condition 'absent special preparations' in Th. 1.1.1.

[25]Currently no axiomatization of QED exists. Recently, however, Andrei Rodin espoused the idea that a theory is a set of rules (2016); so, viewing QED as a countable set of rules as in Def. 1.1.6 may yield a new approach to an axiomatization. Such an axiomatization will be, then, in the framework of category theory.

[26]The rules in Def. 1.1.6 merely represent the logical structure of QED, and have nothing to do with the Feynman rules.

[27]The idea to use the H-atom to illustrate the incompatibility of continuous motion with the discreteness of the microcosmos stems came from reading (Folse, 1985), in which the discreteness of the emission spectrum of hydrogen is discussed in the context of the historical developments that led to the formulation of quantum mechanics.

[28]From the measurements of the charge-to-mass ratios for protons and antiprotons reported in (Borchert, M. J. *et al.*, 2022), the conclusion has been drawn that antimatter falls down on earth—see e.g. (Johnston, 2022). This conclusion, however, leans on tacit assumptions: these are summarized by Eq. (4) in the paper and the text around it. To arrive at the said conclusion it has been assumed that all these tacit assumptions are true: the truth value of the conclusion thus depends on the truth value of the tacit assumptions. It is, however, an enterprise on its own to investigate whether all these tacit assumptions hold up. The crux is this: because the said conclusion leans on tacit assumptions, the measurements in question cannot be viewed as a substitute for a direct measurement of the gravitational acceleration of antihydrogen on earth, aimed at by the various experimental projects described in Sect. 1.2.

[29]It is, thus, too much of an oversimplification to only talk about "negative mass" of antimatter, as Van Joolingen did in his hostile opinion piece (2011c)

[30]The fact that spacetime has a definite metric on it at every spatiotemporal position doesn't make it an 'absolute' spacetime. For an observer $\mathcal{O}$, the metric at $(\vec{x}, t)$ is g, and for an observer $\mathcal{O}'$, the metric at $(\vec{x}', t')$—with $(\vec{x}, t)$ and $(\vec{x}', t')$ referring to the same event—is g'. But we not necessarily have $g = g'$, so spacetime is not absolute.

[31]Note that if we reject the SPP by deleting it altogether from the collection of postulates of QM, we end up with a smaller collection of postulates that no longer relates the outcome of a measurement to a property of a quantum system. That means, for example, that we can no longer relate a discernable spot on a surface to a value of the position of a particle. We are, then, outside the framework of orthodox QM: in that framework, the value of an observable property of a quantum system can be measured—in the light of the BIRP, the measurement 'produces' a quantitative value of the property of the particle!

[32]Its basis is the isodual real number field $(\mathbb{R}, +, \cdot^d)$, for which the binary operation multiplication '$\cdot^d$' is given by

$$x \cdot^d y = -xy$$

This yields the claim by Santilli (1999) that the multiplicative unit -1 of the isodual real number field is *negative*. It is a well-known corollary of modern mathematics that the only possible ordering of the real number field is the natural ordering, in which the multiplicative unit is *positive*: the isodual real numbers with its *negative* multiplicative unit thus seem to yield spectacular new mathematics. That, however, is not the case: the adjective 'negative' in 'negative multiplicative unit' comes from ordering the isodual real numbers as a *set*, not as a *field*. The isodual real number field is, in fact, isomorphic to the real number field; at best, this yields a new notation 'x^d' for the isodual image of a real number x, with $x^d = -x$.

[33]However, even in a situation in which repulsive gravity has already been observed there will undoubtedly be physicists who will come up with ideas of "new physics" so that the new experimental data can be incorporated in a mainstream research program with the Standard Model as its hard core. But for me, any idea that proclaims new physics to accommodate repulsive gravity in the framework of the Standard Model, which denies its very existence, is mediocre at best, and as unnecessary as maintaining that the Standard Model is correct in a situation where it is clearly falsified.

[34]There have been philosophers before Kant (e.g. Locke) who have used the same basic picture, but this picture is so inseparable from Kant's work that the name is justified.

[35]Berkeley's 1710 book *preceded* Kant's Critique of Pure Reason, so there is no causal relation with Kant's work. However, John Locke also used what I refer to as the 'Kantian picture of observation', and Berkeley's work seems to be a reaction to Locke's work.

[36]Of course animals can observe too, but we are in the context of science here.

[37]Here 'broader acquaintance' refers to finding out more about the object. This is to separate *directly observed objects* from *illusions*. E.g. one can distinguish seeing an object on a table from a mere illusion created by a spot on one's glasses by changing the

angle of view.

[38]If an object is directly observed, then it is the object itself that is observed, not some phenomena caused by it. E.g. if we directly see an aeroplane in the sky, then we see the aeroplane *itself* and not merely its vapor trail.

[39]Throughout this section the term 'particle' refers to individuals in the ontology of the Standard Model: the term 'particle' is thus **not** used in the classical sense as a small massive object with definite position and momentum. E.g. the Higgs boson is a quantum excitation of the Higgs field, but is referred to as an ultrashort-lived unstable 'particle'. The crux is that these things come in units: that justifies the term 'particle'.

[40]As a matter of fact, certainly up until 2013 this 5σ-convention had only been voiced orally at particle physics conferences. So you get the interesting situation that the biggest claims in physics of the past decades are based on a convention that has *never* been published in the peer-reviewed literature and that has *never* been critically discussed!

[41]The EPT is thus formulated in terms of designators that refer to four-dimensionalistic objects *because* that yields a particularly simple formulation of the most fundamental laws of physics.

[42]Those who have a profound dislike of the term 'phase quantum' can replace it everywhere by the term 'atomic occurrent'.

[43]We should not confuse the idea of the luminiferous ether with the idea of spatial phase quanta: the luminiferous ether is a substance that 'fills' the void between co-existing tangible objects, but a temporal part of a spatial phase quantum 'is' the void between co-existing tangible objects—without spatial phase quanta, there would be no spatial distance between co-existing tangible objects.

[44]At first glance this might resemble a Higgs-like mechanism, but one should resist the temptation to jump to the conclusion that the introduction of spatial phase quanta has been motivated by the Higgs mechanism: that is not the case, that is, it is not the case that the spatial phase quanta have been introduced *ad hoc* to "give mass" to electrons, positrons, etc. The introduction of spatial phase quanta is based on nothing but the clear and distinct idea about the fundamental workings of the universe that followed the thought experiment described in Ch. 1.

[45]The name 'matter quantum' is to indicate that the object is a smallest possible amount of matter. Anyone who doesn't like the sound of it can replace it by 'subatomic occurrent'.

[46]To emphasize it: in Eq. (3.19), '$\mathfrak{S}$' (a Gothic 'S') is a metavariable that stands for an element of the formal language.

[47]Let's think a moment about the ethics involved. Let's assume that 'lezer69' is not 't Hooft. It is a certainty that at that time the only copy of my unpublished work in Utrecht was with 't Hooft. So, 't Hooft must have passed on this copy, which was given to him for a review, to a colleague. This is already a questionable practice. But it gets worse: this colleague publishes a very negative review of the unpublished work, of which he knew that it was in 't Hooft's possession for review, in the mass media. With co-workers like that, integrity at Utrecht University would improve if it would be turned into a brothel. We arrive at the same conclusion if 'lezer69' is actually 't Hooft himself.

[48]It was not the controversy about my work that made me change my mind, but some remarks of philosophers. So to state this explicitly: I didn't change my mind because of anything that 't Hooft or any of his colleagues at Utrecht University had said or written.

[49]There is a third possibility for a mathematical foundation for the EPT, namely the **weakest possible**. Given that the universe of the EPT is finite (see Ch. 5), we might think of this weakest possible foundation as the smallest collection of set-theoretical axioms that

(i) has a finite universe of sets as a model;

(ii) allows the ontological modeling of all constants of the EPT as sets.

The axioms of such a **finitary set theory** seem to include

- the extensionality axiom for sets;
- the empty set axiom;
- the regularity axiom;
- separation axioms;
- a set union axiom, stating that for any two sets X and Y there is a set Z that contains the elements of X and Y.

A precise axiomatization of such a finitary set theory is left as a topic for further research; it may then also be interesting to look at the finitist set theory developed by Styrman and Halko (2018).

[50]We thus get that SUM-F being true means that every instance (4.47) of SUM-F obtained by Nonstandard Universal Elimination is true; that an instance (4.47) of SUM-F being true means that for any variable $\hat{\mathbf{f}}_{\alpha^+}$ ranging over a family of ur-functions indexed in $\hat{\mathbf{X}}$, formula (4.49) is true; and that a nonstandard formula (4.49) with an occurrence of a variable $\hat{\mathbf{f}}_{\alpha^+}$ being true means that, after applying Rule-C, the scheme of standard formulas (4.53) obtained by Conjunctive Operator Elimination is true—one true standard formula obtains for every ur-function $\hat{\mathbf{u}}_{\hat{\boldsymbol{\alpha}}^+}$ in the range of the variable $\hat{\mathbf{f}}_{\alpha^+}$.

[51]Note that the **collection** of formulas $\{[I(\alpha)\backslash\alpha]\Psi(\alpha)\}_{I(\alpha)\in\hat{\mathbf{X}}}$ in Eq. (4.61) is itself not a well-formed formula of the language $L_{\mathfrak{T}}$, but each of the formulas in the collection is.

[52]In fact, *as long as one stays strictly within the framework of modern physics*, one can have a successful career in theoretical physics without ever having studied philosophy: it doesn't require any philosophical background to derive new predictions from the accepted theories, to explain observed phenomena with the accepted ontology, or to formulate new theories within the accepted paradigm. Even stronger yet: in the currently dominating 'Shut-up-and-calculate!' school of theoretical physics—which has its roots in the Manhattan Project (Prugovecki, 1993)—philosophy is dismissed as irrelevant. And so it is not without reason that philosophy, which traditionally includes logic, has been deleted from the standard physics curriculum at most universities.

[53]That said, I did look into transition systems and they may be applicable for calculating predictions of a deterministic model of the EPT. So back in 2008, I did make an appointment to meet just after my planned PhD defense with Jos Baeten, then professor

at the TU/e, to discuss these possibilities. But when my PhD defense got cancelled, with involvement of Baeten, I cancelled the appointment: as far as I am concerned, the affair at the TU/e has excluded any future collaboration.

[54]The quoted statement has been taken from the lemma "Planck units" on Wikipedia

[55]The 'old' version of Ax. 5.3.10 as given in Ch. 5 emphasizes that (in the world) it is in principle the extended particlelike phase quantum that spontaneously transforms into a nonlocal wavelike phase quantum: this property of spontaneously transforming is independent of whether the extended particlelike phase quantum fuses with a local wavelike subatomic occurrent or not.

[56]Eq. 7.11 can be viewed as a notation for an $\in$-relation, in the line of Def. 5.2.7 and Notation 5.2.8.

[57]So, Laplace's demon cannot predict the state of the system at $t = t_2$ even though he knows all positions and all momenta of all particles at $t_0 < t_1$!

[58]As to the priority of the idea of 'empirical reduction', the following. In the paper (Cabbolet, 2010), I wrote that the correspondence between the EPT and physical reality could be shown by developing a mathematical model M of the EPT such that

(i) the axioms of the EPT, translated in the language of M, are valid in M;

(ii) the hypothesis on repulsive gravity, captured in a well-formed formula H in the language of M, is valid in M;

(iii) a number n of empirical premisses, captured in well-formed formulas $P_1, \ldots, P_n$ in the language of M, are valid in M.

If these formulas $P_1, \ldots, P_n$ reflect the empirically successful predictions of a theory T, then this shows that M reduces empirically to T as meant by Rosaler. However, I never used the term 'empirical reduction', and I didn't talk about correspondence between (a model of) the EPT and a theory T but rather about correspondence between the EPT and physical reality. Thus speaking, the idea of 'empirical reduction' as a general intertheory relation is entirely Rosaler's.

[59]Note that T does not have to be an axiomatized theory: Def. 8.1.5 holds for a theory in the pluralistic sense of the word as described in Sect. 5.1—in that sense, e.g. QED is a theory although it is not axiomatized.

[60]By 'mathematical physics' I mean theoretical physics in a rigorous mathematical framework.

[61]This is, then, the first time in modern history that someone has called on the mystical experience as an epistemic source of a contribution to the scientific discourse on the fundamental laws of the physical world.

[62]To get this absolutely clear: regardless whether God is the source of the idea or not, the EPT is my work, my word—it is not the word of God, as is immediately obvious from the many times I had to revise the EPT.

[63]. E.g. the formula $\vec{F} = m \cdot \vec{a}$ only becomes Newton's second law after if $\vec{F}, m$, and $\vec{a}$ are interpreted as the net force on a body, the mass of the body, and the acceleration of the body: without this interpretation, it is just an identity between vectors with no relation to physical reality whatsoever.

[64]The natural definition of function addition, scalar multiplication, and function multiplication is

$$\begin{cases} (f+g)(x) = f(x) + g(x) \\ (\alpha \cdot f)(x) = \alpha f(x) \\ (f \cdot g)(x) = f(x)g(x) \end{cases}$$

[65]Expanded real functions $\alpha\delta^n_{(\beta_1,\ldots,\beta_n)} : \mathbb{R}^n \to {}^*_+\mathbb{R}$, which can be written as a tensor product of n hyperreal delta functions just like the function $\alpha\delta^2_{(\beta_1,\beta_2)}$ in Ex. 9.1.12, can henceforth all be called **hyperreal delta functions**. The special case δ_0 (short for $1\delta_0$) can be called the **Dirac delta function**, as opposed to the Dirac delta **distribution**, defined according to Eq. (9.3).

[66]Those who find it hard to swallow that the finite set Z_N is "interpreted" as the infinite set $\mathbb{Z}$ may view the present model as a model of the EPT in which

(a) Def. 5.2.1 is amended by replacing the finite abelian group $(Z_N, +)$ under addition modulo N in clause (i) by the *countable group* $(\mathcal{G}, +)$ under addition, and by replacing the initial segments $I_{z(x)}$ by *countable sets* of integers;

(b) Def. 5.2.5 is amended by assuming countably many constants referring to monads.

By this amendment the present model is a model of the EPT. However, it was a deliberate choice to introduce the EPT with a finite universe: this is an essential aspect of the clear and distinct idea from which the EPT has been developed.

[67]The vacuum temperature at a point X of spacetime, $\theta(X)$, has nothing whatsoever to do with the average temperature of massive systems in outer space: it is a property of *spacetime itself*.

[68]For our model of the process of gravitational interaction, we have assumed on p. 503 that it is not important how the gravitational mass of a system is distributed over space. Under that assumption, we obtain $\Phi(X) > 1$ if we assume that the (gravitational) mass of the initial system exceeds one Planck mass, given Eq. (10.159) of our model. A way out is to assume that **in the Planck era** it does matter how the mass is distributed.

[69]I myself am highly skeptical about the possibility of time travel, because it inevitably raises uncomfortable questions about backward causation. That, however, should not prohibit us from thinking about it. So, I have mentioned it here as a (weird) consequence of the postulated formula for the local temporal basis vector if the gravitational potential in the denominator gets a value $\Phi > 1$.

Bibliography

AEGIS collaboration (2008). Proposed antimatter gravity measurement with an antihydrogen beam. *Nuclear Instrum. and Methods in Phys. Research B*, 266(3):351–356.

ALPHA collaboration (2011). Confinement of antihydrogen for 1,000 seconds. *Nature Phys.*, 7:558–564.

ALPHA collaboration (2013). Description and first application of a new technique to measure the gravitational mass of antihydrogen. *Nature Commun.*, 4:1785.

Alves, D. S. M., Jankowiak, M., and Saraswat, P. (2009). Experimental constraints on the free fall acceleration of antimatter. Preprint. arXiv:0907.4110 [hep-ph].

Amelino-Camelia, G. (2015). Ace in the river. Talk presented at the Planck Scale II conference held from at 9-7-2015 to 9-11-2015 at Wroclaw University (PL). Online available at https://www.youtube.com/watch?v=dYVWtjy9gSE.

Ancuña, P. (2014). On the empirical equivalence between special relativity and Lorentz's ether theory. *Stud. Hist. Phil. Mod. Phys. B*, 46:282–306.

Antognini, A. *et al.* (2013). Proton structure from the measurement of 2S-2P transition frequencies of muonic hydrogen. *Science*, 339(6118):417–420.

Armstrong, D. M. (1973). *Belief, Truth and Knowledge.* Cambridge University Press, Cambridge (UK).

ATLAS Collaboration (2012). Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC. *Phys. Lett. B*, 716(1):1–29.

Aubert, J. J. *et al.* (1974). Experimental Observation of a Heavy Particle *J*. *Phys. Rev. Lett.*, 33:1404–1406.

Baeten, J. C. M. (2008). Cabbolet. Unpublished pamphlet. (In Dutch).

Bagaria, J., Koelner, P., and Hugh Woodin, W. (2019). Large cardinals beyond choice. *Bull. Symb. Logic*, 25:283–318.

Barber, B. (1961). Resistance by scientists to scientific discovery. *Science*, 134(3479):596–602.

Barrett, T. W. and Halvorson, H. (2015). Glymour and Quine on Theoretical Equivalence. Preprint. http://philsci-archive.pitt.edu/11341/.

Barton, N., Caicedo, A. E., Fuchs, G., Hamkins, J. D., Reitz, J., and Schindler, R. (2020). Inner-Model Reflection Principles. *Studia Logica*, 108:573–595.

Beijerinck, H. (2008). *Cursor*, 50(18):4.

Bell, J. L. (2016). Infinitary logic. In Zalta, E. N., editor, *The Stanford Encyclopedia of Philosophy*. Winter 2016 Edition.

Benoit-Lévy, A. and Chardin, G. (2012). Introducing the Dirac-Milne universe. *Astron. Astrophys.*, 537:A78.

Bernays, P. (1968). *Axiomatic Set Theory*. Dover Publications Inc., Mineola.

Bhaktivedanta Swami, A. C. (1988). *De wetenschap der zelfrealisatie. 2e druk*. The Bhaktivedanta Book Trust, Amsterdam (NL). in Dutch.

Birkhoff, G. and Von Neumann, J. (1936). *Ann. Math.* 2nd *series*, 37(4):823–843.

Bochvar, D. A. (1939). On a 3-valued logic calculus and its application to the analysis of contradictions. *Mat. Sb.*, 4:287–308.

Bohm, D. (1952a). A Suggested Interpretation of the Quantum Theory in Terms of "Hidden" Variables I. *Phys. Rev.*, 85:166–179.

Bohm, D. (1952b). A Suggested Interpretation of the Quantum Theory in Terms of "Hidden" Variables II. *Phys. Rev.*, 85:180–193.

Bohr, N. (1928). The quantum postulate and the recent development of atomic theory. *Nature*, 121:580–590.

Bohr, N. (1929). Wirkungsquantum und Naturbeschreibung. *Naturwiss.*, 17:483–486. Trans. into English as 'The quantum of action and the description of nature' in: *Atomic Theory and the Description of Nature* (Cambridge University Press, Cambridge, 1934), pp. 92-101.

Bokhove, C. (2011). twitter.com. October 31.

Bondi, H. (1957). Negative Mass in General Relativity. *Rev. Mod. Phys.*, 29(3):423–428.

Borchert, M. J. *et al.* (2022). A 16-parts-per-trillion measurement of the antiproton-to-proton charge–mass ratio. *Nature*, 601:53–57.

Botte, T. (2014). Buitenbeentjes: Marcoen Cabbolet. (*Mavericks: Marcoen Cabbolet.*). *Eos*, 31(11):990–994. (In Dutch).

Brawer, R. (1996). Inflationary Cosmology and the Horizon and Flatness Problems: The Mutual Constitution of Explanation and Questions. Masters Thesis, MIT.

Broad, C. D. (1925). *The Mind and Its Place in Nature.* Kegan Paul, London (UK).

Brouwer, A. E. (2008a). Circular. (In Dutch).

Brouwer, A. E. (2008b). Cabbolet. Unpublished pamphlet. (In Dutch).

Butterfield, J. (2006). Against Pointillisme about Mechanics. *Br. J. Philos. Sci.*, 57(4):709–753.

Cabbolet, M. J. T. F. (2008a). Open brief aan prof.dr.ir. C.J. van Duijn (*Open letter to prof.dr.ir. C.J. van Duijn*). *Cursor*, 50(17):4. (In Dutch).

Cabbolet, M. J. T. F. (2008b). Open brief aan Rector Frank van der Duyn Schouten (*Open letter to Rector Frank van der Duyn Schouten*). *Univers online*, Edition September 18. (In Dutch).

Cabbolet, M. J. T. F. (2010). Elementary Process Theory: a formal axiomatic system with a potential application as a foundational framework for physics supporting gravitational repulsion of matter and antimatter. *Ann. Phys.*, 522(10):699–738.

Cabbolet, M. J. T. F. (2011a). Addendum to the Elementary Process Theory. *Ann. Phys.*, 523(12):990–994.

Cabbolet, M. J. T. F. (2011b). *Elementary Process Theory: axiomatic introduction and applications*. PhD thesis, Vrije Universiteit Brussel.

Cabbolet, M. J. T. F. (2011c). Even voor de goede orde *Just for the record*. *Cursor*, 54(4):11. (In Dutch).

Cabbolet, M. J. T. F. (2012). Comment to a paper of M. Villata on antigravity. *Astrophys. Space Sci.*, 337(1):5–7.

Cabbolet, M. J. T. F. (2014a). Finitely Axiomatized Set Theory: a nonstandard first-order theory implying ZF. Preprint. arXiv:1402.1017 (withdrawn).

Cabbolet, M. J. T. F. (2014b). Incompatibility of QED/QCD and repulsive gravity, and implications for some recent approaches to dark energy. *Astrophys. Space Sci.*, 350(2):777–780.

Cabbolet, M. J. T. F. (2014c). Man as trinity of body, spirit and soul. Preprint. https://philpapers.org/rec/CABMAT-2.

Cabbolet, M. J. T. F. (2014d). Scientific Misconduct: Three Forms that Directly Harm Others as the Modus Operandi of Mill's Tyranny of the Prevailing Opinion. *Sci. Eng. Ethics*, 14(1):41–54.

Cabbolet, M. J. T. F. (2015a). Berkelian Idealism Regarding Properties in Orthodox Quantum Mechanics, and Implications for Quantum Gravity. Paper presented at the Planck Scale II conference, held from 9-7-2015 to 9-12-2015 at Wroclaw University (Poland). arXiv:1506.08056.

Cabbolet, M. J. T. F. (2015b). The Importance of Developing a Foundation for Naive Category Theory. *Thought*, 4(4):237–242.

Cabbolet, M. J. T. F. (2015c). Unobservability of short-lived particles: ground for skepticism about observational claims in elementary particle physics. Paper presented at the 7$^{\text{th}}$ conference of the Dutch-Flemish Association for Analytic Philosophy, held from 1-28-2015 to 1-30-2015 at Erasmus University Rotterdam (the Netherlands). https://philpapers.org/rec/CABAEC.

Cabbolet, M. J. T. F. (2016a). Corrigendum to the Elementary Process Theory. *Ann. Phys.*, 528(7-8):626–627.

Cabbolet, M. J. T. F. (2016b). On the nature of space-time: Special Relativity in five dimensions. Paper presented at the Fourth International Conference on the Nature and Ontology of Spacetime, Varna (BG). (Unpublished).

Cabbolet, M. J. T. F. (2018a). A category mistake in observational claims regarding ultrashort-lived unstable particles. *Mod. Phys. Lett. A*, 33(38):1850227.

Cabbolet, M. J. T. F. (2018b). A marriage of category theory and set theory: a finitely axiomatized nonstandard first-order theory implying ZF. Paper presented at the CLPS meeting on April 10, 2019, at the Free University of Brussels (B). arXiv:1806.05538.

Cabbolet, M. J. T. F. (2018c). Hyperreal delta functions as a new general tool for modeling physical states with infinitely high densities. Preprint. arXiv:1804.05674.

Cabbolet, M. J. T. F. (2018d). Tell-Tale Signs of Pseudoskepticism (Bogus Skepticism). Preprint. https://philpapers.org/rec/CABTSO-3.

Cabbolet, M. J. T. F. (2018e). Towards $\psi-$epistemic Quantum Gravity. Preprint. https://philpapers.org/rec/CABTEQ.

Cabbolet, M. J. T. F. (2019a). A pluralist view on theories. Preprint. https://philpapers.org/rec/CABAPV.

Cabbolet, M. J. T. F. (2019b). On the fundamentally probabilistic nature of the knowledge of a microsystem in the framework of the Elementary Process Theory. Preprint. arXiv:1911.10897.

Cabbolet, M. J. T. F. (2021a). A Finitely Axiomatized Non-Classical First-Order Theory Incorporating Category Theory and Axiomatic Set Theory. *Axioms*, 10(2):119.

Cabbolet, M. J. T. F. (2021b). Hyperreal Delta Functions as a New General Tool for Modeling Systems with Infinitely High Densities. *Axioms*, 10(4):244.

Cabbolet, M. J. T. F. (2022). A semi-classical model of the Elementary Process Theory corresponding to non-relativistic classical mechanics. Preprint. https://philpapers.org/rec/CABASM-2.

Cabbolet, M. J. T. F. and De Swart, H. C. M. (2013). Weigeren promotie blunder TU/e *Cancellation PhD graduation blooper TU/e*. *Eindhovens Dagblad*, Edition October 30:12–13. (In Dutch).

Cabbolet, M. J. T. F. and De Swart, H. C. M. (2014). Set Matrix Theory as a Physically Motivated Generalization of Zermelo-Fraenkel Set Theory. *Log. Anal.*, 225(1):59–82.

Cantor, G. L. F. P. (1874). Uber eine Eigenschaft des Inbegriffes aller reellen algebraischen Zahlen. *J. Reine Angew. Math.*, 77(77):258–262.

Carnap, R. (1923). Ueber die Aufgabe der Physik und die Anwendung des Grundsatzes der Einfachstheit. *Kant Studien*, 28:90–107.

CERN press release (1983a). A major step forward in physics: the discovery of the W vector boson. CERN-PR-83-03-EN, January 25.

CERN press release (1983b). Yet another major discovery at CERN : The Z0 intermediate Boson. CERN-PR-83-10-EN, May 31.

CERN press release (1983c). Z0 discovery confirmed. CERN-PR-83-13-EN, July 22.

CERN press release (2013). New results indicate that particle discovered at CERN is a Higgs boson. CERN-PR-2013-03-EN, March 14.

Chalmers, M. (2012). Coming to terms with the Higgs. *Nature*, 490(7419):S10–S11.

Cheyne, C. (1998). Existence claims and causality. *Australas. J. Philos.*, 76:34–47.

Cho, A. (2012). The discovery of the higgs boson. *Science*, 338(6114):1524–1525.

CMS Collaboration (2012). Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC. *Phys. Lett. B*, 716(1):30–61.

Cobb Jr., J. B. (1990). Whitehead. Unpublished essay.

Compton, A. H. (1923). A Quantum Theory of the Scattering of X-Rays by Light Elements. *Phys. Rev.*, 21(5):483–502.

Craver, C. F. (2002). Structures of Scientific Theories. In Machamer, P. and Silberstein, M., editors, *The Blackwell Guide to the Philosophy of Science*, pages 55–79. Blackwell Publishers Inc., Oxford (UK).

Cross, D. J. (2011). Response to "CPT symmetry and antimatter gravity in general relativity". Preprint. arXiv:1108.5117.

Curie, M. P. and Curie, S. (1898). Sur une nouvelle substance fortement radio-active, contenue dans la pechblende. *C. R. Acad. Sci.*, 127:175–178.

Curtis, L. J. (2003). *Atomic Structure and Lifetimes: A Conceptual Approach*. Cambridge University Press, Cambridge (UK).

Cyranoski, D., Gilbert, N., Ledford, H., Nayar, A., and Yahia, M. (2011). *Nature*, 472:276–279.

Dauben, J. (1993). Georg Cantor and the Battle for Transfinite Set Theory. Proceedings of the 9^{th} ACMS Conference (Westmont College, Santa Barbara, CA).

Daumer, M., Duerr, D., Goldstein, S., and Zanghi, N. (1997). Naive realism about operators. *Erkenntnis*, 45:379–397.

De Swart, H. C. M. (2012). Over de promotie van Marcoen Cabbolet (*About the PhD graduation of Marcoen Cabbolet*). *Twijfel*, 3:41–43. (In Dutch).

Dennet, D. C. (1991). *Consciousness Explained*. Little, Brown and Company, Boston.

Dennet, D. C. (2003). The Self as a Responding—and Responsible—Artefact. *Ann. N.Y. Acad. Sci*, 1001:39–50.

Diddams, S. and O'Brian, T. (2004). What is the fastest event (shortest time duration) that can be measured with today's technology, and how is this done? *ScientificAmerican.com.* December 27.

Dirac, P. A. M. (1927). The physical interpretation of the quantum dynamics. *Proc. Roy. Soc. A*, 113(765):621–641.

Dirac, P. A. M. (1928). The Quantum Theory of the Electron. *Proc. Roy. Soc. A*, 117(778):610–624.

Dirac, P. A. M. (1947). *Principles of Quantum Mechanics,* 3$^{\mathrm{rd}}$ *Ed.* Oxford University Press, Oxford (UK).

DØ Collaboration (2008). Observation of the Doubly Strange b Baryon Ω-b. *Phys. Rev. Lett.*, 101:232002.

Duff, M. J. (1998). The Theory Formerly Known as Strings. *Scientific American*, 278(2):54–59.

Dummett, M. A. E. (1991). *The Logical Basis of Metaphysics.* Harvard University Press, Cambridge, MA.

Dyson, F. W., Eddington, A. S., and Davidson, C. R. (1920). *Philos. Trans. R. Soc. Lond. A*, 220:291–333.

Dzikanowice, B. (2012). Tweemaal gebuisd in Nederland, doctoraat in België. (*Flunked two times in the Netherlands, doctorate in Belgium.*). *De Morgen*, Edition December 21:9. (In Dutch).

E288 Collaboration (1977). Observation of a Dimuon Resonance at 9.5 GeV in 400-GeV Proton-Nucleus Collisions. *Phys. Rev. Lett.*, 39:252–255.

Ebbinghaus, H. D. (2007). *Ernst Zermelo: An Approach to His Life and Work.* Springer, Berlin (D).

Eccles, J. C. (1986). Do mental events cause neural events analogously to the probability fields of quantum mechanics? *Proc. Roy. Soc. London B*, 227:411–428.

Einstein, A. (1905). Zur Elektrodynamik bewegter Körper. *Ann. Phys. (Leipzig)*, 17:891–921.

Einstein, A. (1907). Ueber das Relativitätsprinzip und die aus demselben gezogene Folgerungen. *Jahrbuch der Radioaktivitaet und Elektronik*, 4:411–462.

Einstein, A. (1916). Die Grundlage der allgemeinen Relativitätstheorie. *Ann. Phys. (Leipzig)*, 49:769–822.

Einstein, A., Podolsky, B., and Rosen, N. (1935). Can Quantum-Mechanical Description of Physical Reality Be Considered Complete? *Phys. Rev.*, 47(10):777–780.

Feigl, H. (1958). The 'Mental' and the 'Physical'. In Feigl, H., Scriven, M., and Maxwell, G., editors, *Minnesota Studies in the Philosophy of Science, Vol. II, Concepts, Theories, and the Mind-Body Problem*, pages 340–497. University of Minnesota Press, Minneapolis.

Fermi, E. (1934). Versuch einer Theorie der β-Strahlen. I. *Z. Physik*, 88:161–171.

Feyerabend, P. K. (1975). *Against Method: Outline of an Anarchistic Theory of Knowledge*. New Left Books, London (UK).

Feynman, R. P. (1949). The Theory of Positrons. *Phys. Rev.*, 96:749–759.

Feynman, R. P. (2011). *The Feynman Lectures on Physics, The Millenium Edition, vol 1*. Basic Books, New York, NY.

Fixsen, D. J., Cheng, E. S., Cottingham, D. A., Eplee, R. E. J., Isaacman, R. B.; Mather, J. C., Meyer, S. S., Noerdlinger, P. D., Shafer, R. A., Weiss, R.; Wright, E. L., Bennett, C. L., Boggess, N. W., Kelsall, T., Moseley, S. H., Silverberg, R. F., Smoot, G. F., and Wilkinson, D. T. (1994). Cosmic microwave background dipole spectrum measured by the COBE FIRAS instrument. *Astrophys. J.*, 420(2):445–449.

Folse, H. J. (1985). *The philosophy of Niels Bohr*. North-Holland Physics Publishing, Amsterdam (NL).

Fox, T. (2009). Why quarks are unobservable. *Philosophia Scientiae*, 13(2):167–189.

Friedman, Y. and Steiner, J. M. (2016). Predicting Mercury's precession using simple relativistic Newtonian dynamics. *Eur. Phys. Lett.*, 113:39001.

Frigg, R. (2014). Models and Theories in Science. In Pritchard, D., editor, *Oxford Bibliographies*. Oxford University Press, New York (US).

Galileo (1954). *Dialogues Concerning Two New Sciences*. Dover Books on Physics. Dover Publications, New York. Reprint edition.

Galton, A. (2016). The Ontology of Time and Process. Paper presented at the Third Interdisciplinary School on Applied Ontology, held from 6-27-2016 to 7-1-2016 at Bolzano (Italy).

Gamut, L. T. F. (1991). *Logic, Language and Meaning*, volume 1. Chicago UP, Chicago.

GBAR collaboration (2012). GBAR: gravitational acceleration of antihydrogen at rest. *Hyperfine Interact.*, 212(1-3):51–59.

Ghirardi, G. C., Rimini, A., and Weber, T. (1986). Unified dynamics for microscopic and macroscopic systems. *Phys. Rev. D*, 34(2):470–491.

Gitman, V., Hamkins, J. D., Holy, P., Schlicht, P., and Williams, K. (2020). The exact strength of the class forcing theorem. *J. Symb. Logic*, 85:869–905.

Griffith, D. J. (1994). *Introduction to quantum mechanics*. Prentice Hall, Englewood Cliffs, NJ.

Guth, A. H. (1981). Inflationary universe: A possible solution to the horizon and flatness problems. *Phys. Rev. D*, 23(2):347–356.

Hab, H. (2018). Harry Hab says. crackpotwatch.wordpress.com.

Habermas, J. (1991). *Erlauterungen zur Diskursethik*. Suhrkamp Verlag, Frankfurt a.M. (D). (In German).

Hafele, J. C. and Keating, R. E. (1972). Around-the-World Atomic Clocks: Predicted Relativistic Time Gains. *Science*, 177(4044):166–168.

Hajdukovic, D. S. (2011). Is dark matter an illusion created by the gravitational polarization of the quantum vacuum? *Astrophys. Space Sci.*, 334(2):215–218.

Halvorson, H. (2012). What Scientific Theories Could Not Be. *Phil. Sci.*, 79(2):183–206.

Halvorson, H. (2016). Scientific Theories. In Humphries, P., editor, *The Oxford Handbook of Philosophy of Science*, pages 585–608. Oxford University Press, Oxford (UK).

Hardeman, E. (2008). Iets heel erg uit de rails gelopen. (*Something seriously derailed.*). *Ublad*, 16(39):12. (In Dutch).

Hartmann, S. (2007). Unpublished referee report. (In Dutch).

Hawking, S. and Mlodinow, L. (2010). *The Grand Design.* Bantam Books, London (UK).

Heilprin, J. and Borenstein, S. (2012). Higgs boson: Cern researchers to announce evidence of 'god particle'. *The Toronto Star*, Edition July 2.

Heisenberg, W. (2007). *Physics and Philosophy, Modern Classics Edition.* HarperCollins Publishers, New York.

Hempel, C. G. (1969). Reduction: Ontological and Linguistic Facets. In Morgenbesser, S., Suppes, P., and White, M., editors, *Philosophy, Science and Method. Essays in Honor of Ernest Nagel*, pages 179–199. St. Martin's Press, New York.

Hilbert, D. (1902). Mathematical problems. *Bull. Amer. Math. Soc.*, 8(10):437–479.

Hilbert, D. (1926). Über das Unendliche. *Math. Ann.*, 95:161–190.

Hodgkinson, M. (2017). twitter.com.

Hoskins, R. F. (2009). *Delta Functions: Introduction to Generalised Functions.* Woodhead Publishing Limited, Cambridge (UK), 2nd edition.

Hover, M. (2008a). Omstreden promotie op TU/e krijgt staartje (*WE have not seen the end of the Controversial PhD graduation*). *Eindhovens Dagblad*, Edition February 1:27. (In Dutch).

Hover, M. (2008b). Promotie TU/e gaat niet door (*PhD graduation TU/e cancelled*). *Eindhovens Dagblad*, Edition January 18:30. (In Dutch).

Hulshof, C. (2011). Die Cabbolet is gewoon zo'n typische pseudowetenschapper. In Belgie trapten ze erin, bij filosofie en niet natuurkunde. Tekenend. (*Cabbolet is simply a typical pseudo-scientist. In Belgium they fell for it, at philosophy and not at physics. Typical.*). twitter.com.

Johnston, H. (2022). CERN sets stringent limits on antiprotons. *Physics World*, 35(2):5.

Kaluza, T. (1921). Zum Unitätsproblem in der Physik. *Sitzungsber. Preuss. Akad. Wiss. Berlin. (Math. Phys.)*, pages 966–972.

Kim, J. (2005). *Physicalism, or Something Near Enough.* Princeton University Press, Princeton.

Klein, O. (1926). Quantentheorie und fünfdimensionale Relativitätstheorie. *ZS f. Physik*, (37):895–906.

Konings, J. L. (2008a). Fysicus ‘t Hooft steunt opschorting promotie (*Physicist ‘t Hooft supports decision to postpone PhD graduation*). *Cursor*, 50(17):3. (In Dutch).

Konings, J. L. (2008b). Topdrukte bij lezing ’t Hooft aan TU/e (*Lecture of ’t Hooft draws a crowd at TU/e*). *Cursor*, 51(9):5. (In Dutch).

Konings, J. L. (2008c). Vetrouwenscommissie: promotiereglement geschonden in kwestie Cabbolet (*Committee for Scientific Integrity: PhD regulations violated in Cabbolet affair*). *Cursor*, 51(1):3. (In Dutch).

Konings, J. L. (2013). Cabbolet publiceert wiskundig deel omstreden proefschrift (*Cabbolet publishes mathematical part contested dissertation*). *Cursor Online*. (In Dutch).

Kowitt, M. E. (1996). Gravitational repulsion and Dirac antimatter. *Int. J. Theor. Phys.*, 35(3):605–631.

Kuhn, R. L. (2010). Solutions to the Mind-Body Problem. Science and Religion Today. *Science and Religion Today*, June 3.

Kuipers, T. A. F. (2008). Unpublished referee report. (In Dutch).

Lakatos, I. (1970). Falsification and the methodology of scientific research programmes. In Lakatos, I. Musgrave, A., editor, *Criticism and the Growth of Knowledge*, pages 91–195. Cambridge University Press, Cambridge (UK).

Lamb, W. E. and Retherford, R. C. (1947). Fine Structure of the Hydrogen Atom by a Microwave Method. *Phys. Rev.*, 72:241–243.

Lambert, F. (2008). Addition to the lemma “Marcoen Cabbolet” in Wikipedia, January 18. (In Dutch).

Landry, E. W. (1999). Category Theory: The Language of Mathematics. *Philos. Sci.*, 66:S14–S27. Supplement Issue.

Lang, S. (2002). *Algebra*. Springer Verlag, New York (USA), 3rd edition.

Lawvere, F. W. (1964). An elementary theory of the category of sets. *Proc. Natl. Acad. Sci. USA*, 52:1506–1511.

Lawvere, F. W. (1966). The Category of Categories as a Foundation of Mathematics. In Eilenberg, S., Harrison, D. K., Roehrl, H., and Maclane, S., editors, *Proceedings of the Conference on Categorical Algebra, held June 7-12, 1965, in La Jolla*, pages 1–20. Springer Verlag, Berlin (D).

Lederman, L. M. and Teresi, D. (1993). *The God Particle: If the Universe Is the Answer, What Is the Question?* Dell Publishing, New York (US).

Lee, J. M. (2003). *Introduction to Smooth Manifolds*. Springer Verlag, Berlin (D).

Levy, A. (1979). *Basic Set Theory*. Springer Verlag, Berlin (D).

Lezer69 (2008). *nujij.nl and leugens.nl*, January 18.

LHCb Collaboration (2014). Observation of the Resonant Character of the $Z(4430)$-State. *Phys. Rev. Lett.*, 112:222002.

Libet, B. (1985). Unconscious Cerebral Initiative and the Role of Conscious Will in Voluntary Action. *Behav. Brain Sci.*, 8(4):529–566.

Libet, B. (1994). A testable theory of mind-brain interaction. *J. Conscious. Stud.*, 1(1):119–126.

Libet, B. (2006). Reflections on the Interaction of the Mind and Brain. *Prog. Neurobiol.*, 78(3-5):322–326.

Libet, B., Gleason, C. A., Wright, E. W., and Pearl, D. K. (1983). Time of Conscious Intention to Act in Relation to Onset of Cerebral Activity (Readiness-Potential)—The Unconscious Initiation of a Freely Voluntary Act. *Brain*, 106(3):623–642.

LIGO and Virgo Collaborations (2016). Observation of Gravitational Waves from a Binary Black Hole Merger. *Phys. Rev. Lett.*, 116:061102.

Loewenheim, L. (1915). "Über Möglichkeiten im Relativkalkül". *Math. Ann.*, 76(4):447–470.

Luetzen, R. (1982). *The Prehistory of the Theory of Distributions.* Springer Verlag, New York (USA).

MAGE collaboration (2018). Studying antimatter gravity with muonium. *Atoms*, 6(2):17.

Margenau, H. (1984). *The Miracle of Existence.* Ox Bow Press, Woodbridge (CT).

Martin, B. (1998). Advice for the dissident scholar. *Thought & Action*, 14(1):119–130.

Mayberry, J. (1994). What is required of a foundation for mathematics? *Philos. Math.*, 3(2):16–35.

McLaughlin, B. P. (1999). philosophy of mind. In *The Cambridge Dictionary of Philosophy*, pages 684–692. Cambridge University Press, Cambridge (UK), 2 edition.

McLaughlin, B. P. (2001). In Defense of a New Wave Materialism: a Response to Horgan and Tienson. In Gillet, C. and Loewer, B., editors, *Physicalism and Its Discontent* , pages 319–331. Cambridge University Press, Cambridge (UK).

Mendelson, E. (1997). *An Introduction to Mathematical Logic.* Chapman & Hall, London (UK), 4 edition.

Michelson, A. A. and Morley, E. W. (1887). "On the Relative Motion of the Earth and the Luminiferous Ether". *Am. J. Sci.*, 34:333–345.

Migdal, A. A. and Polyakov, A. M. (1967). Spontaneous Breakdown of Strong Interaction Symmetry and the Absence of Massless Particles. *J. Exp. Theor. Phys.*, 24(1):91–98. (English Version).

Misner, C. W. (1969). The Mixmaster Universe. *Phys. Rev. Lett.*, 22(20):1071–1074.

Montague, R. (1957). *Contributions to the Axiomatic Foundations of Set Theory*. PhD thesis, University of California, Berkeley.

Morrison, P. (1958). Approximate Nature of Physical Symmetries. *Am. J. Phys.*, 26:358–368.

Morrison, P. and Gold, T. (1958). On the gravitational interaction of matter and antimatter. Essay written for the Gravity Research Foundation 1957 Awards for Essays on Gravitation. In *Essays on Gravity: Nine winning essays of the annual award (1949-1958) of the Gravity Research Foundation*, pages 45–50. Gravity Research Foundation, New Boston, N.H.

Muller, F. A. (2001). Sets, Classes and Categories. *Brit. J. Phil. Sci.*, 52:539–573.

Muller, F. A. (2011). Reflections on the Revolution at Stanford. *Synthese*, 183:87–114.

Muller, F. A. (2014). Circumveiloped by Obscuritads. The nature of interpretation in quantum mechanics, hermeneutic circles and physical reality, with cameos of James Joyce and Jacques Derrida. Preprint. arXiv:1406.6284 [physics.hist-ph].

Muller, F. A. and Saunders, S. W. (2008). Discerning Fermions. *Brit. J. Phil. Sci.*, 58:499–548.

Muller, T. (2015). twitter.com. January 30.

Nagel, T. (1986). *The View from Nowhere*. Oxford University Press, Oxford (UK).

Nauenberg, M. (2018). Newton's graphical method for central force orbits. *Am. J. Phys.*, 86:765–771.

Neyman, J. and Pearson, E. S. (1933). On the problem of the most efficient tests of statistical hypotheses. *Philos. Trans. Royal Soc. A*, 231(694–706):289–337.

Nienhuys, J. W. (2014). Een lezersbrief. Over Marcoen Cabbolets uitgebreide ZF-theorie (*A letter from a reader. On Marcoen Cabbolet's extended ZF theory*). *Wonder En Is Gheen Wonder*, 14(1):34. (In Dutch).

Nienhuys, J. W. (2015). Een bizarre dissertatie (*A bizar dissertation*). *Skepter*, 27(1):10–11. (In Dutch).

Norman, D. A. (2004). Beyond Reductionism and Dualism: Towards a Christian Solution to the Mind Body Problem. *Sci. Christ. Belief*, 16(1):3–12.

Norton, J. D. (2003). Causation as Folk Science. *Philos. Imprint.*, 3(4):1–22.

Olsthoorn, P. (2008). Geen nieuwe Einstein maar een prutser (*No new Einstein but a fuck up*). leugens.nl. (In Dutch).

Pascal, B. (1670). *Les Pensées de M. Pascal sur la religion et sur quelques autres sujets, qui ont esté trouvées après sa mort parmy ses papiers.* Guillaume Desprez, Paris (F), 2 edition.

Pauli, W. (1952). Der Einfluss archetypischer Vorstellungen auf die Bildung naturwissenschaftlicher Theorien bei Kepler. In *Naturerklarung und Psyche*, pages 109–194. Rascher Verlag, Zurich (CH).

Pauli, W. E. (1930). Address to Group on Radioactivity, Tübingen, Germany. (Unpublished).

Peebles, P. J. E. and Ratra, B. (2003). *Rev. Mod. Phys.*, 75:559–606.

Penzias, A. A. and Wilson, R. W. (1965). A Measurement of Excess Antenna Temperature at 4080 Mc/s. *Astrophys. J.*, 142(1):419–421.

Polkinghorne, J. (1994). *Science & Christian Belief: Theological Reflections of a Bottom-up Thinker.* SPCK Publishing, London (UK).

Popper, K. (1982). *Quantum theory and the schism in physics.* Hutchinson, London (UK).

Post, R. (2008). Addition to the lemma “Marcoen Cabbolet” in Wikipedia, January 23. (In Dutch).

Pound, R. and Rebka, G. (1960). Apparent Weight of Photons. *Phys. Rev. Lett.*, 4(7):337–341.

Powell, K. (2015). The future of the postdoc. *Nature*, 520:144–147.

Primas, H. (2003). Time-Entanglement Between Mind and Matter. *Mind and Matter*, 1(1):81–119.

Prugovecki, E. (1993). Historical and epistemological perspectives on developments in relativity and quantum theory. In Prugovecki, E., editor, *Quantum Geometry*, pages 433–485. Kluwer, Dordrecht (NL).

Prugovecki, E. (2002). *Dawn of the New Man: A Futuristic Novel of Social Change*. Xlibris Corporation, Bloomington, Indiana (US).

Puett, M. and Gross-Loh, C. (2016). *The Path: A New Way to Think About Everything*. Viking, London (UK).

Pusey, M. F., Barret, J., and Rudolph, T. (2012). On the reality of the quantum state. *Nature Phys.*, 8(6):475–478.

Putnam, H. (1962). What Theories Are Not. In Nagel, E., Suppes, P., and Tarski, A., editors, *Logic, Methodology, and Philosophy of Science: Proceedings of the 1960 International Congress*, pages 240–251. Stanford University Press, Stanford (CA).

Reijers, H. (2013). twitter.com. October 23.

Robinson, A. (1966). *Non-standard Analysis*. Princeton University Press, Princeton (US).

Rodin, A. V. (2016). Categorical Model Theory and Knowledge-How. Lecture held at the Free University of Brussels, Belgium, on November 8.

Rosaler, J. (2015). "Formal" vs. "Empirical" Approaches to Quantum-Classical Reduction. *Topoi*, 34:325–338.

Rossi, B. and Hall, D. B. (1941). Variation of the Rate of Decay of Mesotrons with Momentum. *Phys. Rev.*, 59(3):223–228.

Rudin, W. (1966). *Real and Complex Analysis*. McGraw-Hill, New York (US).

Ryle, G. (1949). *The Concept of Mind*. Chicago University Press, Chicago.

Sachs, M. (1988). *Einstein versus Bohr: the Continuing Controversies in Physics*. Open Court, New York (US).

Santilli, R. M. (1999). A classical isodual theory of antimatter and its prediction of antigravity. *Int. J. Mod. Phys. A*, 14(14):2205–2238.

Sarewitz, D. (2016). The pressure to publish pushes down quality. *Nature*, 533:147.

Scheers, R. (2016). Interview Gerard 't Hooft. *Eos*, 33(10):32–35. (In Dutch).

Schiff, L. I. (1959). Gravitational properties of antimatter. *Proc. Nat. Ac. Sc.*, 45:69–80.

Scholtens, B. (2008a). Nobelprijswinnaar haalt proefschrift onderuit (*Nobel laureate refutes dissertation*). *Volkskrant*, Edition January 18:3. (In Dutch).

Scholtens, B. (2008b). Tilburg wees dissertatie al af (*Tilburg already rejected dissertation*). *Volkskrant*, Edition February 9:K3. (In Dutch).

Schopenhauer, A. (1844). *Die Welt als Wille und Vorstellung*, volume 2. Brockhaus, Leipzig (D), 2 edition.

Schroedinger, E. (1926). An Undulatory Theory of the Mechanics of Atoms and Molecules. *Phys. Rev.*, 28(6):1049–1070.

Schutz, B. F. (1990). *A First Course in General Relativity.* Cambridge University Press, Cambridge (UK).

Schuyt, C. J. M., Dykstra, P. A., Hartog, J., Vliegenthart, J. F. G., Sixma, J. J., and Hondius, E. H. (2009). LOWI advies 2009 nr. 1. (Confidential).

Schwartz, L. (1950). *Theorie des Distributions. Tom I.* Hermann, Berlin (D).

Searle, J. (2007). *Freedom & Neurobiology: Reflections on Free Will, Language, and Political Power.* Columbia University Press, New York (US).

Sexl, R. U. and Urbantke, H. K. (2000). *Relativity, Groups Particles. Special Relativity and Relativistic Symmetry in Field and Particle Physics.* Springer, Vienna (A).

Shoenfield, J. R. (2001). *Mathematical Logic.* AK Peters Ltd, Natick (US).

Sider, T. (1997). Four Dimensionalism. *Phil. Rev.*, 106:197–231.

Skolem, T. (1922). Einige Bemerkungen zur axiomatischen Begrundung der Mengenlehre. *Proc.* 5th *Scand. Math. Congr. Helsinki*, pages 217–232.

Smart, J. J. C. (1959). Sensations and Brain Processes. *Phil. Rev.*, 68:141–156.

Spekkens, R. W. (2007). Evidence for the epistemic view of quantum states: a toy theory. *Phys. Rev. A*, 75:032110.

Stapp, H. P. (2009). *Mind, Matter and Quantum Mechanics.* Springer, Heidelberg (D), 3 edition.

Steward, H. C. (2015). What is a Continuant? *Aristotelian Society Supplementary Volume*, 89(1):109–123.

Styrman, A. and A., H. (2018). Finitist set theory in ontological modeling. *Appl. Ontol.*, 13(2):107–133.

Suppes, P. (1960). A Comparison of the Meaning and Uses of Models in Mathematics and the Empirical Sciences. *Synthese*, 12:287–301.

Suppes, P. (1967). What is a Scientific Theory? In Morgenbesser, S., editor, *Philosophy of Science Today*, pages 55–67. Basic Books, New York (US).

Susskind, L. (2011). Classical Mechanics: Lecture 3. Lecture for the theoretical minimum series at Stanford University.

Susskind, L. (2012). General Relativity: Lecture 1. Lecture for the theoretical minimum series at Stanford University.

‘t Hooft, G. (2002). Determinism beneath Quantum Mechanics. Preprint. arXiv:quant-ph/0212095.

‘t Hooft, G. (2008a). Unpublished pamphlet. (In Dutch).

‘t Hooft, G. (2008b). Elementaire-procestheorie allang achterhaald (*Elementary Process Theory already obsolete*). *Natuurwetenschap en Techniek*, 76(9):65. (In Dutch).

‘t Hooft, G. (2008c). Promotie Cabbolet (*PhD graduation Cabbolet*). Unpublished pamphlet. (In Dutch).

‘t Hooft, G. (2009). Unpublished letter to the LOWI. (In Dutch).

‘t Hooft, G. (2015a). Respons op een reactie van M. Cabbolet (*Reply to a comment by M. Cabbolet*). Published at uu.nl on March 1, 2015. (In Dutch; copy available at the repositorium of Foundation Liberalitas).

‘t Hooft, G. (2015b). Spookrijders in de wetenschap (*Ghost drivers in science*). *Skepter*, 27(1):5–10. (In Dutch).

Todorov, T. (1990). A nonstandard delta function. *Proc. Am. Math. Soc.*, 110(4):1143–1144.

Uffink, J. B. M. (2008). Unpublished letter.

Van Berkel, K. (2013). *Isaac Beeckman on Matter and Motion: Mechanical Philosophy in the Making*. John Hopkins U.P., Maryland.

Van Dalen, D. and Ebbinghaus, H. D. (2000). Zermelo and the Skolem paradox. With an appendix in German by E. Zermelo. *Bull. Symb. Logic*, 6(2):145–161.

Van Dantzig, D. (1937). Some possibilities of the future development of the notions of space and time. *Erkenntnis*, 7(1):142–146.

Van Der Duyn Schouten, F. A. (2008a). De kwestie Cabbolet *The case Cabbolet*. *Cursor*, 50(19):9. (In Dutch).

Van Der Duyn Schouten, F. A. (2008b). Weergave De Swart over promotie is misleidend *Description PhD graduation by De Swart is deceptive*. *Univers*, 54(19):4. (In Dutch).

Van Erp, P. (2015). twitter.com. November 27.

Van Fraassen, B. (1980). *The Scientific Image*. Clarendon Press, Oxford (US).

Van Gestel, A. F. H. (2008). What’s up? *Cursor*, 50(19):15. (In Dutch).

Van Hee, K. M. (2008a). Circular. (In Dutch).

Van Hee, K. M. (2008b). Zorgpunten bij proefschrift Cabbolet (*Concerns with dissertation Cabbolet*). Circular. (In Dutch).

Van Inwagen, P. (1975). The incompatibility of free will and determinism. *Phil. Stud.*, 27:185–199.

Van Inwagen, P. (1983). *An Essay on Free Will.* Oxford University Press, Oxford (US).

Van Joolingen, W. (2011a). twitter.com. October 14.

Van Joolingen, W. (2011b). twitter.com. October 16.

Van Joolingen, W. (2011c). Voor doctor Cabbolet valt het doek (*The curtain falls for doctor Cabbolet*). *Volkskrant*, Edition October 28:30. (In Dutch).

Van Nuffel, P. and Luyckx, F. (2013). Verbeelding in een dwangbuis (*Imagination in a straightjacket*). *Wonder En Is Gheen Wonder*, 13(3):28–31. (In Dutch).

Van Wayenburg, B. (2011). twitter.com. (In Dutch).

Verhaar, B. J. (2008). Unpublished pamphlet.

Verlinde, E. P. (2011). On the Origin of Gravity and the Laws of Newton. *J. High Energ. Phys.*, 4:29.

Vervoort, L. (2019). Probability Theory as a Physical Theory Points to Superdeterminism. *Entropy*, 21(9):848.

Vervoort, L. and Gingras, Y. (2015). Macroscopic Oil Droplets Mimicking Quantum Behaviour: How Far Can We Push an Analogy? *Internat. Stud. Philos. Sci.*, 29(3):271–294.

Villata, M. (2011). CPT symmetry and antimatter gravity in general relativity. *EPL*, 94:20001.

Villata, M. (2012). Reply to "Comment to a paper of M. Villata on antigravity". *Astrophys. Space Sci.*, 337(1):15–17.

Vlerick, E. (2013). Beperking en begrenzing in de voorkritische en kritische filosofie van Immanuel Kant. Master's thesis, Ghent University. (in Dutch).

Vlooswijk, E. (2007). 'Je moet je als een pitbull vastbijten en niet meer loslaten' (*'You have to hold on like a pit bull and never let go'*). *Cursor*, 50(14):2. (In Dutch).

Von Neumann, J. (1955). *Mathematical Foundations of Quantum Mechanics*. Princeton University Press, Princeton (US). (English translation of the original 1932 work 'Mathematische Grundlagen der Quantenmechanik' in German).

Wagner, T. A., Schlamminger, S., Gundlach, J. H., and Adelberger, E. G. (2012). *Class. Quantum Grav.*, 29:184002.

Watson, J. D. and Crick, F. H. (1953). A structure for deoxyribose nucleic acids. *Nature*, 171(4356):737–738.

Wendel, G., Martinez, L., and Bojowald, M. (2020). Physical Implications of a Fundamental Period of Time. *Phys. Rev. Lett.*, 124(24):241301.

Whitehead, A. N. (1978). Process and Reality: an Essay in Cosmology. page 3. The Free Press, New York (US). Corrected edition.

Witten, E. (1988). In Davies, P.C.W., B. J., editor, *Superstrings: A Theory of Everything*, page 98. Cambridge University Press, Cambridge (UK).

Witten, E. (1995). String theory dynamics in various dimensions. *Nucl. Phys. B*, 443(1):85–126.

Wittgenstein, L. (1922). *Tractatus Logico-Philosophicus*. Kegan Paul, Trench, Trubner & Co, London (UK).

Zermelo, E. (1908). Untersuchungen über die Grundlagen der Mengenlehre. I. *Math. Ann.*, 65:261–281.

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