Volume 1, number 3, November 1976

TIME-SYMMETRIC THERMODYNAMICS AND CAUSALITY VIOLATION

James A. Donald
Brian Martin[&]
Sydney University, Australia

INTRODUCTION

There is an impressive amount of evidence for the occurrence of certain phenomena, often classified under categories such as ESP, PK, or precognition, and generally referred to as psi. A characterisation of these phenomena is that the occurrence of certain specified events is found to be more often or less often than would be expected from an analysis of known and understood prior influences on the events. For example, certain quantum decays may be correlated with other events in the past or future in a way inexplicable by existing scientific theories. The idea of psi is usually taken to hypothesize the influence of humans or other living organisms on such events. The phenomena also may be referred to as instances of causality violation. This descriptive phrase emphasizes a breakdown in the way the past states of the universe are normally considered to influence the future states of the universe.

There have been a considerable number of theories offered to explain instances of causality violation, but none of these has yet achieved the status of a general working hypothesis (Chari, 1974). Indeed, this lack of a theoretical underpinning is probably one reason why many scientists have so readily ignored available experimental evidence. In this paper we present a formalism for time-symmetric thermodynamics which we feel may serve as a basis for explanation of occurrences of causality violation.

In physics, the universally observed increase in entropy with time may be considered to arise from boundary conditions in the past. The past is known to be a highly ordered or unusual state (thermodynamically), whereas normally there are considered to be no restrictions on the development of the universe which are based in the future. This asymmetrical situation is a favoured, (but not

[&] Presently at The Australian National University, Canberra.

the only) explanation of the second law of thermodynamics, and the associated unidirectionality of time (Terletskii, 1971). This explanation is related to intuitive ideas about past and future. From the point of view of a single observer, the past seems irrevocably fixed, while the future seems subject to partial control as a result of actions performed in the past or present.

There are reasons to re-examine these ideas, perhaps the best of which is the evidence for causality violation from experiments on psi. A completely different reason has been presented by Cocke (1967). It has been argued that in closed oscillating cosmological world models, the direction of time, as indicated by the observed change in entropy with time, must reverse itself. The problems associated with this reversal led Cocke to posit an hypothesis of complete time symmetry in oscillating cosmologies, and to develop a formalism for thermodynamics in which there are boundary conditions at two times, one in the past and one in the future.

In such a cosmology, if both past and future boundary conditions require the universe to be in a highly ordered or unusual state, the most probable general type of path between the two times is characterised at the beginning by a general increase in entropy, and later by a general decrease. However, during the entropy increase phase (for example) there are also anomalous occurrences of spontaneously decreasing entropy (so-called pre-effect), due to the influence of the future boundary conditions. Schmidt (1966) has also developed a model of an oscillating cosmos, but without an emphasis on anomalous instances of spontaneously decreasing entropy.

It would seem fruitful to relate this source of spontaneous decreases in entropy, or thermodynamic pre-effect, with observed instances of causality violation. Therefore we have been led to the development of a formalism for time-symmetric thermodynamics, a generalisation of Cocke's ideas, for the purpose of explaining instances of causality violation in psi. In this formalism there are two types of entropy. One type (future directed entropy, or f-entropy) may be identified with conventional entropy: it is associated with boundary conditions in the past, and increases towards the future. The second type (past directed entropy, or p-entropy) is associated with boundary conditions in the future, and increases towards the past. For the case in which p-entropy is maximal and constant, the time-symmetric thermodynamics reduces to normal thermodynamics with normal causality. Although our formalism contains boundary conditions on the future possible states of the universe, these do not have to be as restrictive or complete as the boundary conditions on the past (as is the case in Cocke's work). The first selection following is a description of our formalism for time-symmetric thermodynamics.

Although we have tried to make the description of this formalism as simple as possible, it still probably requires some background in statistical mechanics for full understanding. The essence of the section is that it is possible to develop a formalism which allows future events to influence the past as well as for past events to influence the future. In this formalism, p-negentropy is the means through which the future can influence the past.

To supplement this formalism, we tentatively assume that p-entropy is not maximal. (This means that p-negentropy is not quite zero.) We also assume that living organisms have developed the capacity to utilize p-negentropy. In the second section following we describe these assumptions, and suggest some reasons for their adoption. With the formalism and the two assumptions, we are then able to explain a number of features of causality violation experiments, and to make a few further predictions. These features and predictions are the concern of the final section.

TIME-SYMMETRIC THERMODYNAMICS

Our aim here is to illustrate a formalism for a thermodynamics that incorporates boundary conditions on both the past and future. This formalism contains conventional thermodynamics, which incorporates boundary conditions only on the past, as a special case. There are other ways to extend thermodynamics to include future boundary conditions in a time-symmetric way, but we hope that the method presented here is a minimal extension of conventional thermodynamics.

In our presentation, we will first describe the relation between ensembles and probability; then construct an ensemble whose members change with time according to specified transition probabilities; and finally introduce an ensemble constrained by boundary conditions on past and future. For this latter ensemble we define two types of entropy: future directed entropy, which may be identified with conventional entropy; and past directed entropy, changes in which may serve to explain occurrences of causality violation. After describing our formalism, we will point out some of the ways it agrees with and differs from conventional thermodynamics.

We begin by describing some aspects of ensembles. Let E denote an ensemble, or collection of systems. Each system or member of the ensemble may be considered to correspond to one unique microstate history, over a finite time period, of an (approximately) isolated section of space in which thermodynamic processes occur. For example, E might contain sets of space-time histories for a group of molecules in a box.

It is useful to imagine that there may be more than one system in the ensemble corresponding to any given unique microstate history. In other words, the ensemble may contain a number of copies of a specified microstate history. It is convenient to define certain operations on ensembles. If E and F are ensembles, the ensemble consisting of all systems in E and F may be formed, and denoted E+F. If c is a positive real number, the ensemble consisting of c copies of each system in E may be formed, and denoted cE. We assume that each ensemble is sufficiently large that it may be divided into parts without changing the ratios between the numbers of different systems in the ensemble. Therefore c does not have to be an integer.

We wish to relate probabilities to ensembles. At any given time t we may characterise each system in the ensemble E as being in a state k, k=1,2,.... For example, the systems might be classified into states according to the number of electrons in them, their total energy, etc.. Let $E_{k,t}$ be the ensemble of systems in E that are in a state k at time t (i.e. $E_{k,t}$ is obtained from E by discarding all systems not in state k at time t). Let n(E) be the number of systems in E. The probability that a system in E is in state k at time t is given by $n(E_{k,t})/n(E)$, according to the frequency definition of probability. In general both $n(E_{k,t})$ and n(E) will be infinite, but the ratios will still be meaningful in the sense of limits.

Consider now how systems in the ensemble change from one state to another with time. Let $P_{ij}(t_1,t_2)$ be the probability that a system in state i at time $t=t_1$ is in state j at time t_2. Thus far we have not specified how the ensemble E is constructed, so for the time being we can consider the P_{ij} to be an arbitrary set of probabilities, i.e. a set of real numbers satisfying, for all i and j, $P_{ij} \geq 0$ and $\sum_k P_{ik}(t_1,t_2)=1$.

We call an ensemble microreversible over the time interval (t_1,t_2) if there exists a set of numbers V_i, all non-zero, such that

$$V_i P_{ij}(t_1,t_2) = V_j P_{ji}(t_2,t_1). \qquad (1)$$

Cocke (1967) finds this condition sufficient for time symmetry in processes describable by a Markov chain formalism. He also demonstrates that the quantum measurement process, as well as classical and quantum mechanics, are completely time symmetric. Therefore all natural systems appear to be reversible in the sense of (1). (In some types of ensembles, the number V_i in (1) may be identified with the statistical weight or degeneracy of state i.)

We now consider a particular type of ensemble, an equilibrium ensemble. This is an ensemble for which $n(E_{k,t_1}) = n(E_{k,t_2})$ for all k, t_1 and t_2: in an equilibrium ensemble the number of systems in any state k is independent of time. Let $E_{i,t_1;j,t_2}$ be the sub-ensemble of systems in E that are both in E_{i,t_1} and E_{j,t_2}. Given the probabilities P_{ij}, we construct a particular equilibrium ensemble, G, such that

$$P_{ij}(t_1,t_2) = n(G_{i,t_1;j,t_2}) \;/\; n(G_{i,t_1}). \qquad (2)$$

In other words, out of possible equilibrium ensembles, the ensemble G is chosen so that the probability $P_{ij}(t_1,t_2)$ is identical with the transition probability calculated by counting the number of appropriate systems in G at times t_1 and t_2. Noting that by definition $G_{i,t_1;j,t_2}$ is equivalent to $G_{j,t_2;i,t_1}$, and substituting for P_{ij} and P_{ji} from (2) into (1), it follows directly that for the ensemble G,

$$n(G_{i,t}) \propto V_i \qquad (3)$$

In words, V_i is proportional to the probability at any time that a system in G is in state i.

For sections of spacetime sufficiently large that the gravitational energy is comparable with the rest mass, there is no thermodynamic equilibrium, since entropy may increase without limit (Tolman 1934, p. 420). In this case this formalism does not apply, but on any sufficiently small section of spacetime it remains valid.

We now proceed to construct a non-equilibrium ensemble K from different sub-ensembles of the equilibrium ensemble G. We expect that the ensemble K is able to represent any thermodynamic process. That is to say that K will contain all possible microhistories compatible with the observed macroscopic features of the thermodynamic process. K is defined only for times t satisfying $t_1 \leq t \leq t_2$. Using the operations of merging and making copies of ensembles, described earlier, K is constructed from a set of real non-negative numbers $u_{ij}(t_1,t_2)$:

$$K = \sum_i \sum_j u_{ij}(t_1,t_2)\ G_{i,t_1;j,t_2} \tag{4}$$

In words, K is an ensemble composed of a weighted sum of sub-ensembles of G, in which the value $u_{ij}(t_1,t_2)$ weights the sub-ensemble of systems in G that are in state i at time t_1 and in state j at time t_2.

We shall concentrate mainly on the important special case in which the initial and final conditions are independent, so that $u_{ij}(t_1,t_2)$ may be factorised:

$$u_{ij}(t_1,t_2) = w_{fi}(t_1)\ w_{pj}(t_2). \tag{5}$$

$w_{fi}(t_1)$ is called the future directed weighting of state i at time t_1; these weights represent the past influencing the future. $w_{pj}(t_2)$ is called the past directed weighting of state j at time t_2; these weights represent the future influencing the past.

We wish the weightings at different times to be related so that K is independent of the times t_1 and t_2. A sufficient condition for this to be true is that the weightings satisfy

$$V_i\ w_{fi}(t_2) = \sum_j V_j\ w_{fj}(t_1)\ P_{ji}(t_1,t_2), \tag{6}$$

$$V_i\ w_{pi}(t_1) = \sum_j V_j\ w_{pj}(t_2)\ P_{ji}(t_2,t_1). \tag{7}$$

We call (6) and (7) the simple time development equations. In the appendix we show how they may be derived using the implicit definition of the weightings by (4) and (5), as well as the relations (2) and (3).

The entropy associated with the past directed weightings, called p-entropy, may be defined statistically as

$$S_p(t) = -k \sum_i V_i\ w_{pi}(t)\ \ln w_{pi}(t), \tag{8}$$

where k is Boltzmann's constant and the w_{pi} are normalised so that $\sum_i V_i w_{pi}(t)=1$. When the V_i may be normalised to be integers (as is always the case in quantum systems), then one may define a new subscript i' and a new set of weightings $w'_{pi'}$ such that $w'_{pi'} = w_{pi}$ for all i' satisfying

$$\sum_{k=1}^{i} V_k \geq i' \geq \sum_{k=1}^{i-1} V_k.$$

In other words, the index i' has a different value for each individual system, whereas i labels a particular state comprising V_i systems. In terms of $w'_{pi'}$, the p-entropy appears in the more familiar form

$$S_p(t) = -k \sum_{i'} w'_{pi'}(t) \ln w'_{pi'}(t). \tag{9}$$

The entropy associated with the future directed weightings, called "f-entropy", may be defined analogously to (8) and (9). It is possible to show that f-entropy increases towards the future and that p-entropy increases towards the past, by using the simple time development equations (6) and (7), the microreversibility condition (1), and the standard assumptions about coarse-graining.

It is well known that negentropy, the difference between the maximum possible entropy and the actual entropy, can be considered to be a measure of the information available about a system (Brillouin, 1962). If we assume that p-negentropy is zero, then p-entropy is maximal and so the w_{pi} are equal. In this case the past directed weightings may be ignored and our formalism reduces to normal thermodynamics. Comparing our notation to that of Tolman (1938, p.460), our i, i', $w'_{pi'}$, w_{pi}, and V_i may be identified with his ν, n, P_n, P_ν/G_ν, and G_ν respectively, where P_n is the coarse-grained probability for the states n in a group of G_ν neighbouring microstates. Taking w_{fi} to correspond to

$$\sum_{j=1}^{V_i} \rho_{jj} \,/\, V_i \quad ,$$

where ρ is the quantum mechanical density matrix, S_f becomes equivalent to the Gibbs definition of entropy for non-equilibrium systems (see also Terletskii, 1971, p.163).

It may be useful to describe in a bit more detail the relation of our formalism to conventional thermodynamics. We again refer to the treatment by Tolman (1938). First, the normal way of setting up an ensemble is by including a range of microsystems such that the ensemble average agrees with available knowledge of thermodynamic variables (such as temperature) that have been measured. Thus, a representative ensemble might be given by

$$L = \sum_i w_i(t_1)\, G_{i,t_1} .$$

The microsystems are chosen assuming equal a priori probabilities and random a priori phases (Tolman, 1938, p.524). These assumptions mean that the microsystems in state i at time t_1 are not likely to be unusual in terms of what is known about the macrosystem (i.e. the ensemble average). These assumptions are reflected in our choice of sub-ensembles of G, rather than of some non-equilibrium ensemble, to construct L. Our procedure differs from this conventional one only in that the ensemble K is set up on the basis of knowledge of thermodynamic variables at two times, instead of one time as for L.

In conventional thermodynamics, time development equations similar to (6) and (7) are the consequence of physical laws, such as are represented by Schrödinger's equation, applied to the systems in a representative ensemble (Tolman, 1938, p.395-452). In our formalism, the simple time development equations are a consequence of requiring K to be independent of its defining times. However, the two procedures are in essential agreement, since our transistion probabilities are arbitrary and may be chosen so as to represent features of an observed thermodynamic process. A possible advantage of our approach is that it does not require full knowledge of the physical laws causing transitions between states; instead, transition probabilities may be inferred from observations.

Our formalism reduces to Cocke's two-time thermodynamics if the initial and final boundary conditions are similarly unusual thermodynamically. An example of this would be the case in which $w_{fi}(t_1) = w_{pi}(t_2) = \delta_{ij}$: the thermodynamic process is in state j at both the initial time t_1 and the final time t_2.

THE EXISTENCE AND USE OF P-NEGENTROPY: TWO ASSUMPTIONS

We have shown how our formalism for time-symmetric thermodynamics reduces to normal thermodynamics if there is no past directed negentropy. However, to be of interest in explaining experimental results involving causality violation, we must assume the existence of a sufficient quantity of p-negentropy at the surface of the earth. Furthermore, we must assume that biological organisms are capable of utilising this negentropy. We here discuss briefly these two assumptions and some plausible arguments for their tentative adoption.

It is possible to speculate on the existence of localised sources of past directed entropy and negentropy (or in other words, of boundary conditions in the future). Possibilities are black holes (in which closed timelike paths may occur when a sufficient concentration of angular momentum causes a sufficient rollover of light cones, generating p-negentropy by backscattering of f-negentropy) and singularities (in which p-negentropy may arise analogously to the way f-negentropy may be considered to arise from a past initial singularity). However, it is not necessary for there to be localised sources of p-negentropy. It is possible to assume that p-negentropy has its source in the distant future, in the same way that normal negentropy is assumed to arise from boundary conditions in the distant past. Finding a source of p-negentropy is not difficult in principle, and is mainly of interest in determining the precise details of how and in what manner p-negentropy might be incident on the earth and thereby available for utilisation by organisms.

From the overwhelming dominance of normal causality, it is evident that the amount of utilisable p-negentropy at the surface of the earth must be very small. Consider the amount of p-negentropy needed to ensure that an event which would have otherwise had a probability of ½ (assuming no change in f-entropy - e.g. due to equal future directed weightings as well), has instead a probability of 1. Using (8),

$$\Delta S_p = S_p(0,1) - S_p(\tfrac{1}{2},\tfrac{1}{2}) = k \log_e 2.$$

The negative of this is the amount of negentropy required: $-\Delta S_p = k \log_e 2$. This may be contrasted with $-\Delta S_f \sim 3 \times 10^{27}$ k which is roughly the amount of negentropy utilised by a human in one day's bodily metabolism (assuming a heat production of 3000 Kcal and an external temperature of 27 degrees Celcius). Thus the amount of p-negentropy required to produce significant effects would be negligible by everyday standards.

Now assume that p-negentropy exists naturally at the earth's surface. A life form that could collect and use p-negentropy in the same way it uses f-negentropy might be expected to have an evolutionary advantage, at least in certain cases. This would be true even if the quantity of available p-negentropy were extremely small, because in an otherwise random process even a small amount of p-negentropy could produce a marked change in the most probable result. Since in utilising p-negentropy an organism would be using the future organisation of the universe to influence the past, the organism would appear to act as if it knew the future. The evolutionary advantage of such an ability should be obvious.

At this stage it may be considered rather premature to ask about details of how organisms could be able to collect and utilise p-negentropy. Our assumption that they can is based only on the analogy to the known ability of organisms to collect and use f-negentropy. The question might be worth considering if other aspects of our model were found to be useful. However, to help provide a "feel" for what the use of p-negentropy might entail, it may be useful to provide a hypothetical example.

Before doing this, we wish to comment that there are a number of ways of thinking about p-negentropy and related phenomena, such as in terms of future boundary conditions. None of these ways of thinking is immediately easy to adopt; we ourselves required a considerable period of time before feeling natural in thinking of the formalism. This is because the idea of the future affecting the past is not part of our normal way of thinking about the world. Indeed, many of our tools for understanding the world, such as language, have built into them the assumptions of normal causality.

We find that the easiest way to think about p-negentropy is by analogy with f-negentropy: effects are the same in every respect (except the quantitative amount) with a reversal in the time direction. For example, since one stores f-negentropy in the past to use in the present or future, one would store p-negentropy in the future to use in the present or past.

Consider the analogy to f-negentropy from a slightly different perspective. One tries to affect the future by ordering the past in certain ways to make certain future events more probable. To order the past one uses f-negentropy and thus alters the future directed weightings w_{fi} at time t_1. Therefore certain systems in the ensemble K become more probable. By analogy, the utilisation of p-negentropy in the future changes the past directed weightings w_{pj} at time t_2. This also makes certain systems in the ensemble K more probable.

With this background, we now present a hypothetical example of how organisms might use p-negentropy. Consider a sugar molecule. An existing sugar molecule represents f-negentropy: it is a much more ordered form than its constituents CO_2 and H_2O. That is, the sugar molecule represents a narrow range of initial conditions each with a high future directed weighting, whereas the constituents CO_2 and H_2O of a potential sugar molecule represent a much larger range of initial conditions, each having a relatively lower future directed weighting. The sugar molecule was created in the past by utilisation of f-negentropy from the surrounding environment. By decomposing the molecule, an organism changes the future directed weightings w_{fi}, and thus influences the likely future state of the universe. Now imagine an organism which has control in the future over whether a sugar molecule will be synthesized out of less ordered constituents. This would be the result of utilisation of p-negentropy from the surrounding environment. Depending on whether this hypothetical synthesis were to take place, the most likely present state of the universe would be altered. For example, an organism might synthesize a sugar molecule in the future after a certain nuclear decay took place, and not synthesize the molecule in the future if the particular decay did not occur. By controlling the future synthesis, the occurrence of the nuclear decay thus could be made more likely. In other words, certain members of the ensemble K, which include the nuclear decay, would be given a preference by changing the past directed weightings. We again emphasize that the sugar molecule example is only for the purpose of illustrating how the use of p-negentropy might operate. It is not likely to be by this particular means, if only because of the large amount of negentropy held by a sugar molecule.

FEATURES OF CAUSALITY VIOLATION EXPERIMENTS

We now consider some predictions based on our formalism for time-symmetric thermodynamics and our assumptions about the use of p-negentropy by organisms. In each case we compare the predictions with selected available evidence on causality violation, in particular the admirable work of Schmidt, which is well adapted for our purposes.

If the p-negentropy available to influence a given event is less than $k \log_e 2$, then for the results to be noticeable the process must be random or near random with respect to future directed weightings. This requirement accords well with the fact that the most statistically significant results on causality violation have involved near-random processes, such as sequences of cards or of radioactive decays. On the other hand, our suggestions, at least at first sight, cannot explain events apparently requiring massive amounts of p-negentropy, such as spoon bending, table tapping, or levitation.

The requirement that events affected by application of p-negentropy be random or near random leads to a specific prediction. In a series of truly random events - such as nuclear decays - p-negentropy applied after the series could influence every single event. But in a series of pseudo-random events - such as computer generated random numbers - the influence of p-negentropy normally could not be so great. In a series of pseudo-random events, the sequence is fixed. The degree of randomness associated with the series is dependent on the number of possible (fixed) sequences that might have been generated. For a sufficiently long series, therefore, the degree of randomness associated with truly random events will be greater than for pseudo-random events. We predict that in such a direct comparison, higher significance levels will be achieved using truly random events than using pseudo-random events. Furthermore, by using a suitably limited generator of pseudo-random events, the expected difference in significance levels can be mathematically specified.

There is a somewhat subtle qualification to this prediction. It assumes a fixed sequence of choices by the subject. That is, successes above a chance level result from the use of p-negentropy to select out sub-ensembles of K which include sequences of random events which, for a given subject selected input sequence, result in a more than average number of hits. There is also the possibility that the subject might use p-negentropy to select out his or her own choices. But the amount of p-negentropy required to do this would almost certainly be much larger than that required to affect the sequence of truly random events. The difference between the two methods of applying p-negentropy becomes apparent in the case of a subject who continually makes the same choice (as is the case for one of Schmidt's (1969) subjects). Assuming the p-negentropy explanation, this technique can work well when a true random source is operative, since each event can be influenced after the trial. For a pseudo-random sequence of events, this method obviously would not be nearly so successful.

Next, consider <u>when</u> p-negentropy must be applied to change the probability of an event. Take the analogy to f-negentropy. If one uses f-negentropy at a time t_1 to change the weightings $w_{fi}(t_1)$, this will influence the weightings $w_{fi}(t)$ at all future times, $t > t_1$. Thus by changing the present, one influences the future. By analogy, if one were to use p-negentropy at a time t_2 to change the weightings $w_{pj}(t_2)$, this would influence the weightings $w_{pj}(t)$ at all previous times, $t < t_2$. In other words, by changing the present, one might influence the past. This means that it does not matter whether the event to be influenced by application of p-negentropy occurs in the present or in the past. In each case p-negentropy is applied in the future of the event. This prediction agrees with the observed independence of psi under time displacement (Schmidt 1975). In this vein, with p-negentropy it is no more difficult to explain precognition than ESP or PK. In each case the subject can be thought of as altering the probabilities of an event by applying p-negentropy in the future, or equivalently by changing the boundary conditions in the future.

In using p-negentropy in the future, and changing the most probable systems in K, it should not matter what happened to cause the event being influenced. One is changing the weightings of the possible histories of the universe on the basis of particular outcomes. In particular, it should not matter whether the system giving rise to the event is simple or complex, or whether the subject knows the operational details of the process whose result is being influenced. This prediction agrees with available experimental evidence (Kanthamani, 1974; Schmidt 1974; Schmidt & Pantas 1972) which shows that causality violation apparently occurs independently of the complexity of the source of the events (e.g. of a random number generator), and of knowledge by the subject as to the complexity of the source.

In using p-negentropy in the future, and changing the most probable systems in K, it should also make no essential difference where the event being influenced occurred. Again, one is changing the probabilities of the possible histories of the universe on the basis of particular outcomes. Aside from possible differences in psychological conditions and feedback, causality violation should occur independently of the distance of the agent from the event. This again is in agreement with the available evidence (Osis et.al., 1971). Indeed, the p-negentropy mechanism for causality violation avoids what has been considered a major problem in explaining psi phenomena (Beloff, 1970) - how the subject discriminates the target from an infinite number of other objects in the environment. With p-negentropy, the subject does not communicate with objects directly, but introduces correlations between different events by changing future boundary conditions, and thereby selecting out certain space-time histories of the universe as being more probable than they otherwise would be.

Suppose that an organism were to lose its ability to collect p-negentropy at some time in the future. Then after that time in the future it no longer would be able to exert further influence on events in the present. Our hypotheses suggest, therefore, that if an organism were prevented from collecting p-negentropy at all times after experimental tests for causality violation, then no significant results would be obtained, compared to the situation where the organism was able to collect p-negentropy. Therefore an experimental test of our ideas would be to compare test results on subjects that are and are not isolated from p-negentropy after the tests.

The obvious difficulty with this test is that we do not know how p-negentropy is utilised by organisms. One way around this problem would be to use plants (assuming that psi effects were not due to the experimenter) and to (say) incinerate selected groups immediately after the tests. This would certainly close all channels to p-negentropy. The idea here is that the longer the organism is able to collect p-negentropy after the tests, the greater the possible significance in the results. If an organism died immediately after testing, the chance of significant results having been recently achieved would be minimised; if the organism only died years later, p-negentropy could have been applied during the interval - the chance that death at this later stage would affect the results would usually be small.

This difficulty - that we do not know how p-negentropy is utilised by organisms - could be a source of further information. It might be possible to isolate subjects after completion of tests in different ways, and thereby to locate the channel through which p-negentropy is utilised. For example, if the skin were such a channel, one might find that clogged pores or deodorised skin reduced the effectiveness in using p-negentropy. Another important question involved in such tests concerns the length of time required by an organism to gather a quantity of p-negentropy. This might be roughly guessed by analogy to the time taken to gather f-negentropy, or inferred from psi experiments (e.g. Schmidt, 1973).

Often a certain experimental situation will lead to results showing significant causality violation, whereas a similarly prepared situation may unexplainably give results little different from chance. This could be explained in terms of our model if it were found that future histories of the experimental setups were significantly different. Thus it might be that in the experiment in which null results were obtained, the agent was in the future isolated from collecting and using p-negentropy. In other words, whereas the two experiments may have been identical with respect to past boundary conditions, they may have differed in terms of their future boundary conditions. We predict then that the outcome of tests for causality violation will be sensitive to changes in conditions, especially those depending on the results themselves, after the completion of formal testing.

Our formalism for time-symmetric thermodynamics gives mathematical predictions about how much a given amount of p-negentropy will change the probabilities for the occurrence of different events. For example, one may obtain a formula for the combined effect of different psi sources. The mathematics in this case is identical with that of Schmidt (1976). (Indeed, there are many similarities between this work of Schmidt's and our ideas.

P-negentropy may be considered to correspond to Schmidt's inductively postulated psi source.) Further assumptions are required before comparisons between theory and experiment can be made. For example, if one assumes that p-negentropy from a single source is supplied at roughly a constant rate to a series of otherwise random events, and is applied uniformly to the individual events, the increase in the scoring rate should vary inversely as the square root of the rate of generation of the random events (for small increases). This prediction is not incompatible with the results of Schmidt (1973). More generally, if a given amount of p-negentropy is applied with complete effectiveness to a series of events, the statistical significance of the outcome should not depend on the number of events being influenced.

There are a large number of other features of experiments on psi, such as chronological declines, psi-missing, temporary inhibition by change of task, position effects, the "sheep-goat" distinction, differential effects, etc.. Our hypotheses do not permit predictions concerning most of these features, especially about psychological aspects of psi. In some cases plausible subsidiary hypotheses enable an explanation to be made. For example, scoring especially well at the beginning of a test session could be explained by greater available time in the test situation for collecting and applying p-negentropy after the testing begins; later testing might be the time-reversed version of "warming up" or experience. The importance of these features for our purposes, though, is that none of them seems immediately incompatible with our hypotheses.

This is not to say that every bit of evidence unambiguously supports our model. At least some features of psi experiments are puzzling in terms of our hypotheses. For example, we would predict that PK experiments with dice would give results depending only on the outcomes, and therefore independent of the density of the dice, whereas this is not always observed in practice (Cox, 1971). Anomalies are expected with any model, and if ours is found to be useful, further elaborations certainly will be required.

Because of the inevitable presence of anomalies (Kuhn, 1970), it is not inconvenient for a model to have an all-encompassing explanation for most recalcitrant evidence. For our model, this involves reference to long term effects. Although p-negentropy used to change the probability of a current event usually will be collected and applied in the period immediately after the occurrence of the event, there is always the possibility that it may be applied long after the event. P-negentropy applied in the relatively distant future changes the past directed weightings at that future time. This change, propagated into the past through a long causal chain of events in the future, then can affect an event in the present. For example, the outcome of one experiment may affect the design of a later experiment. P-negentropy exerted in the later experiment will favour some designs more than others, and this could affect the outcome of the earlier experiment. (For example, an experiment where the dice are rigged so that one can not achieve a non-random score would probably be given a low past directed weighting.) If our model is to be useful, though, use of such a method of explanation must be kept to a minimum.

Our model predicts that feedback is essential. For application of p-negentropy to change the probability of an event, it is absolutely essential that the agent, at some time in the future, gain some knowledge of the outcome. This knowledge does not need to be complete; for example, it might be only that an interesting result was or was not achieved. Because of ambiguities concerning the most effective amount, timing, and type of feedback, we make no detailed predictions on this issue. Suffice is to note that the need for feedback for the effective application of p-negentropy accords well with the generally observed importance of feedback in experiments on causality violation.

We have discussed a number of areas where our hypotheses lead to testable predictions. In several cases they are in agreement with known features of causality violations in experiments on psi: that it is normally manifested in otherwise random sequences of events; that it is manifested independently of the event-generating apparatus; and that space or time displacement of the events has little effect on the significance of the results. Further plausible assumptions lead to other predictions in agreement with known results, such as that the statistical significance of the outcome should not depend on the number of events being influenced in a given time. Other features of psi - such as psychological aspects and the significance of feedback - are quite compatible with our hypotheses, although we do not make detailed predictions concerning them. Finally, we make some predictions that have not yet received an experimental test: that the significance of psi tests using truly random events will be greater than those using pseudo-random events; and that experimental conditions after the completion of formal tests, such as the isolation or disturbance of agents, will influence results.

SUMMARY

A formalism for time-symmetric thermodynamics is presented, and used as a basis for explaining the observed occurrences of causality violation in experiments on psi. In this formalism there

are two types of entropy: f-entropy (identifiable with normal entropy), arising from boundary conditions in the past, and p-entropy, arising from boundary conditions in the future. We suggest that p-negentropy may exist in small amounts and that it can be used by living organisms. With the thermodynamical formalism and with these latter two assumptions, a number of features of documented instances of causality violation are explained: that it is noticeable mainly in otherwise random sequences of events; that it is manifested independently of the complexity of the event-generating apparatus; and that it is manifested independently of time displacement of the events. Further, yet untested predictions also are made: that the results of psi tests using truly random events will be more significant than those using pseudo-random events; and that results will be sensitive to experimental conditions after the completion of formal testing.

ACKNOWLEDGMENT

We thank Drs. Graham Derrick, Helmut Schmidt, and George Vorlicek for valuable comments and advice.

REFERENCES

Beloff, J. J. Parapsychology, 34, 129-142, 1970.

Brillouin, L. Science and information theory. Academic Press, New York, (2nd ed.), 1962.

Chari, C.T.K. J. Parapsychology, 38, 1-15, 1974.

Cocke, W.J. Physical Review, 160, 1165-1170, 1967.

Cox, W.E. J. Parapsychology, 35, 108-119, 1971.

Kanthamani, H. J. Parapsychology, 38, 154-162, 1974.

Kuhn, T.S. The structure of scientific revolutions. University of Chicago Press, Chicago, (2nd ed.), 1970.

Osis, K. et al. J. A.S.P.R., 65, 245-288, 1971.

Schmidt, H. J. Mathematical Physics, 7, 494-509, 1966.

Schmidt, H. J. Parapsychology, 33, 99-108, 1969.

Schmidt, H.	J. Parapsychology, 37, 105-118, 1973.
Schmidt, H.	J. Parapsychology, 38, 47-55, 1974.
Schmidt, H.	PK effect on pre-recorded targets. preprint, 1975.
Schmidt, H.	J. A.S.P.R., 1976.
Schmidt, H. Pantas, L.	J. Parapsychology, 36, 222-232, 1972.
Terletskii, Ya. P.	Statistical physics. North-Holland, Amsterdam, 1971.
Tolman, R.C.	Relativity, thermodynamics, and cosmology. Clarendon Press, Oxford, 1934.
Tolman, R.C.	The principles of statistical mechanics. Oxford University Press, Oxford, 1938.

James A. Donald
Theoretical Physics Department
Sydney University
Sydney, N.S.W., Australia 2006

Brian Martin
Centre for Resource and Environmental Studies
The Australian National University
Box 4, P.O.
Canberra, A.C.T., Australia 2600

APPENDIX

We wish to show that the simple time development equations (6) and (7) are sufficient to make the ensemble K independent of the defining times t_1 and t_2. In specific terms this means that $n(K_{i,t})$ is to be unchanged when K is defined in terms of $w_{fi}(t_3)$ and $w_{pj}(t_4)$, where $t_1 \leq t_3 \leq t_4 \leq t_2$.

For convenience we define an ensemble

$$K^f = \sum_i w_{fi}(t_1)\; G_{i,t_1} \qquad \text{(A-1)}$$

The ensemble K is then

$$K = \sum_j w_{pj}(t_2)\; K^f_{j,t_2} \qquad \text{(A-2)}$$

We will show that the simple time development equation for the w_{fi} follows from requiring that $n(K^f_{k,t})$ be independent of t_1.

Define an alternative ensemble to K^f,

$$K^{fa} = \sum_i w_{fi}(t)\; G_{i,t} \qquad \text{(A-3)}$$

From (A-1) and (A-3) we have

$$n(K^f_{k,t}) = \sum_i w_{fi}(t_1)\; n(G_{i,t_1;k,t}) \qquad \text{(A-4)}$$

$$n(K^{fa}_{k,t}) = w_{fk}(t)\; n(G_{k,t}) \qquad \text{(A-5)}$$

Setting $n(K^f_{k,t}) = n(K^{fa}_{k,t})$, and using (2) and (3) gives the simple time development equation (6) for w_{fi}.

If this demonstration is to hold for the full ensemble K, then using (A-2) it must be true that:

$$\frac{n(G_{i,t_1;k,t;j,t_2})}{n(G_{k,t;j,t_2})} = \frac{n(G_{i,t_1;k,t})}{n(G_{k,t})} \qquad \text{(A-6)}$$

The truth of (A-6) can be seen by interchanging $n(G_{k,t;j,t_2})$ and $n(G_{i,t_1;k,t})$ and noting that in a system described by a Markov chain formalism (i.e. the transitions between states in the equilibrium ensemble G), the future development of the system depends only on the present state.

The derivation of the simple time development equation (7) for w_{pj} is entirely analogous to the above.