Glossary of some terms used by Johnston and by Goldsmith et al.

$2.4 \times 10^{-9} = .000\,000\,002\,4$
$6.8 \times 10^{-9} = .000\,000\,006\,8$
$6.8 \times 10^{-8} = .000\,000\,068$
$10^9 = 1\,000\,000\,000$
$10^8 = 100\,000\,000$

amount of ozone above any point of the earth's surface

See: ozone column.

atomic oxygen (or O)

Atomic oxygen or O is a single unattached atom of oxygen. See: ozone.

Chapman classical theory (or, pure O photochemical system)

Chapman in 1930 postulated that a series of chemical reactions involving oxygen could account for the presence of upper atmospheric ozone. His theory served as the basis for future developments of theories of ozone. Hence it is called a 'classical' theory. The Chapman reactions are reactions (a), (b), (c), and (e) in Johnston's list, page 517.

concentration

The concentration of a gas is the number of molecules of the gas in a given volume. Consider a volume of one cubic meter. If there are 10 molecules of ozone in the cubic meter, the ozone concentration is 10 molecules per cubic meter (also written 10 molecules m^{-3}, or 10 molecules/m^3). If there are a million million molecules in one cubic centimeter, the concentration is 1 000 000 000 000 molecules per cubic centimeter (also written 10^{12} molecules/cm^3 — see Johnston's Figure 1, page 521). The concentration of ozone in a given volume does not depend on what other molecules are in the volume. For example, in the cubic meter above, there might be millions of molecules of oxygen, nitrogen, and others besides the 10 molecules of ozone. The ozone concentration will still be 10 molecules per cubic meter.

dissociation

When a molecule is broken down into smaller molecules or atoms, this is referred to as dissociation. For example, if H_2O breaks up into HO and H, this is a dissociation reaction. The HO molecule then might combine with an oxygen atom in another reaction to form an HO_2 molecule. The various possible compounds resulting from H_2O breaking up and further reactions occurring, such as HO and HO_2, are called its dissociation products.

If dissociation is caused by light, this is called photodissociation. An example is the photodissociation of an oxygen molecule, by ultraviolet light, into two oxygen atoms: this is Johnston's reaction (a).

equilibrium constituent

Imagine a certain amount of gas that is kept at a constant temperature and reasonably isolated from outside influences. One example is air inside a glass flask. Another example is air within a nuclear blast. Various chemical reactions will occur in this gas, some slowly and some quickly. These reactions will change certain chemical constituents in the gas into others. After a sufficiently long period of time, the *amount* of any given chemical constituent will remain constant (although reactions will still occur). This constituent is then in equilibrium.

The time required before equilibrium is attained may vary widely, depending upon the circumstances. Most important in determining this time is the temperature. At 3000 K, NO in air may require less than a millionth of a second to reach equilibrium. At 293 K (room temperature), this same process may take centuries. In the earth's atmosphere outside influences are important, so NO never does reach equilibrium levels.

high latitudes

High latitudes are latitudes towards the north or south poles, say from roughly 60° to 90°. Low lattitudes are those towards the equator, say from 0° to roughly 30°.

$h\nu$

$h\nu$ stands for a photon or quantum of light energy. h is Planck's constant and ν is the frequency of the light. The wavelength (given by Johnston in nanometers) equals c/ν, where c is the speed of light in a vacuum.

In the reaction $O_2 + h\nu \rightarrow O + O$, an oxygen molecule O_2 absorbs the energy ($E = h\nu$) of a photon, which splits the O_2 molecule into its two component atoms O + O. To do this, the photon must have sufficient energy: its wavelength must be less than 242 nm.

K (or °K)

K represents temperature in degrees Kelvin (or absolute). Subtract 273 to get the temperature in degrees Centigrade. For example,

2300 K =	2027°C	(= 3681°F)	
293 K =	20°C	(= 68°F)	(room temperature)
220 K =	-53°C	(= -63°F)	

[M]

M indicates a molecule (or atom) of *any* kind: O_2 or N_2 or O_3 or NO, etc. As indicated at the top of Johnston's Table 1, page 519, the square brackets stand for concentration in molecules per cubic centimeter. [M] therefore is the total gas concentration, that is the total number of molecules of gas in a given volume. Thus

$[M] = [O_2] + [N_2] + [O_3] + [NO] + \ldots$

molecular oxygen (or O_2)

Molecular oxygen or O_2 is a molecule made up of two oxygen atoms. O_2 is the oxygen we breathe.

Light of sufficient energy can split an O_2 molecule into the two oxygen atoms which it is composed of. This occurs regularly in the upper atmosphere. The process of light splitting an oxygen molecule is represented by Johnston's reaction (a).

mole fraction

The mole fraction of NO_X at a place in the stratosphere is the average fraction of the molecules of all kinds that are molecules of NO_X. If the mole fraction of NO_X is 2.4×10^{-9}, this means that out of every 10^{10} air molecules, on average 24 will be molecules of NO or NO_2.

nanometer

1 nanometer (1 nm) = 10^{-9} metre = 0.000 000 001 metre. 300 nanometers in Johnston's abstract refers to a particular wavelength of light. Light that we can see has wavelengths ranging from about 700 nm (red light) to 400 nm (violet light). Light with slightly shorter wavelengths than violet light is called ultraviolet light. The shorter the wavelength of light, the greater its energy. Because of the potent biological effects of short wavelength light, Johnston calls it "harsh".

nitric oxide

See: nitrogen oxide.

nitrogen oxide (or, oxides of nitrogen; or, NO_X)

See Johnston's note (3), page 522. NO or nitric oxide is a molecule composed of one nitrogen atom and one oxygen atom; NO_2 or nitrogen dioxide is a molecule composed of one nitrogen atom and two oxygen atoms.

Goldsmith et al. in the second paragraph of their paper describe how NO is produced in any high temperature combustion process. At slightly lower temperatures NO is converted to NO_2 by oxidation (burning).

nm

See: nanometer.

NO_x

See: nitrogen oxide.

O

See: atomic oxygen.

O_2

See: molecular oxygen.

O_3

See: ozone.

oxides of nitrogen

See: nitrogen oxide.

ozone (or, O_3)

Ozone or O_3 is a molecule composed of 3 oxygen atoms. By contrast, the most common oxygen compound in the atmosphere, the one we need to breathe to live, is composed of 2 oxygen atoms. This is called molecular oxygen, O_2, or just oxygen. A single atom of oxygen, denoted O, is called atomic oxygen.

Ozone is created in the stratosphere through Johnston's reactions (a) and (b). The approximate distribution of ozone in the stratosphere is given in Johnston's Figure 1, page 521.

ozone column (or, total ozone content; or, amount of ozone above any point on the earth's surface)

The number of ozone molecules per unit area above a point on the earth's surface is the ozone column at that point. Take an area of one square centimeter on the surface of the earth, and count all the ozone molecules in the air above this square. The total obtained is the ozone column in units of molecules per square centimeter (molecules cm^{-2}). The ozone column is sometimes referred to as the "ozone shield", because ozone absorbs most of certain ultraviolet light that would otherwise cause great damage to living organisms.

ozone layer

Ozone in the atmosphere is present only in very small amounts. Its greatest concentration is five to ten millionths of the concentration of the air with which it is mixed. There is no separate 'layer' of ozone in the atmosphere. Nevertheless, the small amounts of ozone that are in the atmosphere lie mainly in the altitude range of 20 to 40 kilometers above the surface of the earth (see Johnston's Figure 1, page 521). This region of relatively high concentration is called the ozone layer.

ozone profile (or, distribution of ozone)

The ozone profile is the distribution of ozone with height in the atmosphere: a certain concentration of ozone at one height, another concentration at another height, and so forth. If the concentration is plotted on a graph as a function of height (see Johnston's Figure 1, page 521), this gives a curve — hence the term profile.

ozone shield

See: ozone column.

parts per

If the mole fraction of NO_2 is 1 part per 10^9, then out of every 10^9 air molecules, on average 1 will be a molecule of NO_2.

photochemical, and photochemistry

In the context of Goldsmith et al.'s and of Johnston's papers, the term "chemistry" refers to a set of chemical compounds and to the reactions between them. Some reactions involve light as well as chemical compounds. These reactions are called photochemical reactions. Examples are Johnston's reactions (a) and (c). Photochemistry then refers to a set of chemical compounds and to their reactions with each other (chemical reactions) and with light (photochemical reactions).

pure O photochemical system

See: Chapman classical theory.

rate coefficient

To obtain the number of times a chemical reaction occurs each second in one cubic centimetre of the stratosphere, one multiplies the concentrations of the reacting atoms and molecules times the rate coefficient. In Johnston's reaction (a), page 517, column 3, the only reacting species is O_2. So to find the number of times O_2 is dissociated into $O + O$ each second in a cubic centimetre, we multiply the concentration of O_2 (which is written $[O_2]$) times the rate coefficient j_a, giving the rate expression $j_a[O_2]$. Note that this rate expression is written after Johnston's reaction (a). At 15 kilometres altitude with no NO_x in the stratosphere ($\alpha = 0$), Johnston gives in his Table 1 the values $j_a = 10^{-17.02}$/molecule/second and $[O_2] = 10^{17.92}$ molecules/cm^3, so the rate expression is $j_a[O_2] = 10^{-17.02}$/molecule/second × $10^{17.92}$ molecules/cm^3 = $10^{.90}$/cm^3/second = 0.794/cm^3/second. This means that in each 1000 cubic centimetres at 15 kilometres in Johnston's model atmosphere, 794 reactions $O_2 + h\nu \rightarrow O + O$ will occur on average during each second. Similarly, the rate coefficient for Johnston's reaction (b) is k_b, and the rate expression is $k_b[O]\,[O_2]\,[M]$. Thus the rate expression is proportional to the concentrations of the various reacting atoms and molecules and also proportional to the rate coefficient, which takes into account factors such as temperature, size of the molecules and binding energies.

rate expression (or, reaction rate)

See: rate coefficient.

residence half-life

A molecule of gas at 20 kilometers altitude will be moved by winds and turbulence (mixing by air motions up and down and back and forth). It may move up, down, and to different latitudes and longitudes. The residence time (Johnston's "residence half-life" is a minor misnomer) is the average amount of time a molecule will spend in the stratosphere before leaving it. Typically the molecule leaves the stratosphere by moving down into the troposphere, and then being absorbed in rain or on the surface of the earth.

The value of the residence time is uncertain because wind motions are hard to determine, and because they vary greatly from time to time and from place to place. SCEP and Johnston adopt a value of 2 years, a compromise value

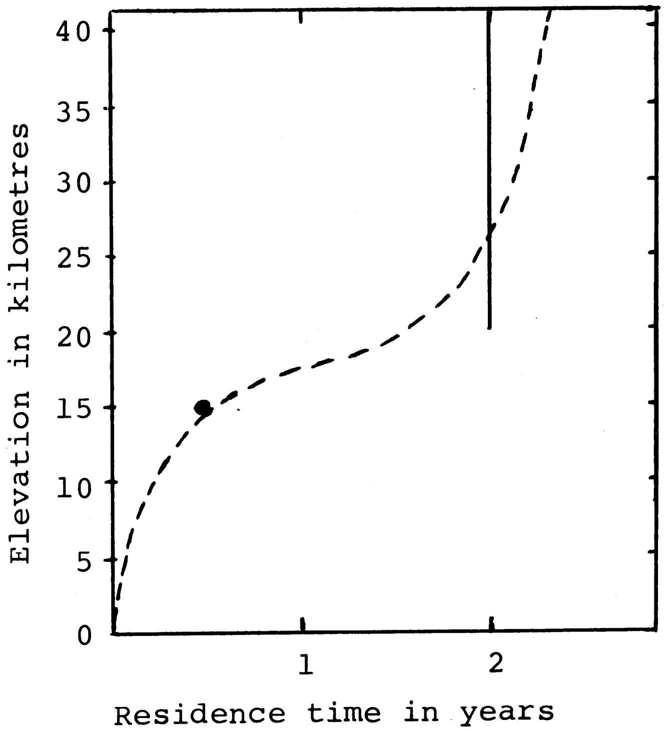

Fig. A Residence time of a molecule in the atmosphere as a function of the altitude. The values for the residence time given by the SCEP report are 6 months at 15 kilometres, given as the large dot in the figure, and 2 years at 20 kilometres and above, which is given by the vertical solid line. These values are listed in Johnston's Table 1, item 5. The dotted line represents a hypothetical residence time which always increases with height, as logically must be the case.

intermediate to other estimates. Since the 2-year residence time is an *average* time, some molecules starting at 20 km will spend longer than 2 years in the stratosphere, and others less.

On reaching 15 km, the residence time figure of 6 months indicates that a molecule will on average spend 6 months in the stratosphere before leaving. Some of this time may be spent above 15 km. Thus the average amount of time spent moving from 20 km to 15 km by a molecule by these figures would be 18 months.

Actually the SCEP values seem somewhat peculiar (see Figure A). It would seem that the residence time must increase with height (given that it does not vary significantly with latitude or longitude). If a particle at height 20 km takes 2 years on the average to exit from the stratosphere, then one at 25 km must take longer — it will still take 2 years after it reaches 20 km, and it must take some time to move from 25 km to 20 km.

stratosphere

The stratosphere is a region of the atmosphere extending from about 12 km to about 50 km above the surface of the earth. The region below about 12 km, from the surface of the earth to the stratosphere, is called the troposphere. In the troposphere, the air temperature usually drops as one ascends in altitude. Eventually as one ascends, the temperature stops decreasing, and at higher altitudes stays roughly constant or increases. The region of constant or slowly increasing temperature is called the stratosphere. (For the temperatures in the stratosphere, see Johnston's Table 1, page 519, item 2.) The main reason that the stratosphere does not get colder at higher altitudes like the troposphere is the absorption of light by ozone.

The place where the temperature stops decreasing is called the tropopause. This is an imaginary boundary between the troposphere and the stratosphere. The tropopause varies in altitude at different latitudes. For example, at the equator it is at about 15 km, and at the poles about 9 km. Also, the tropopause is at different heights at different times. A typical configuration of the troposphere, tropopause and stratosphere is presented in Figure B.

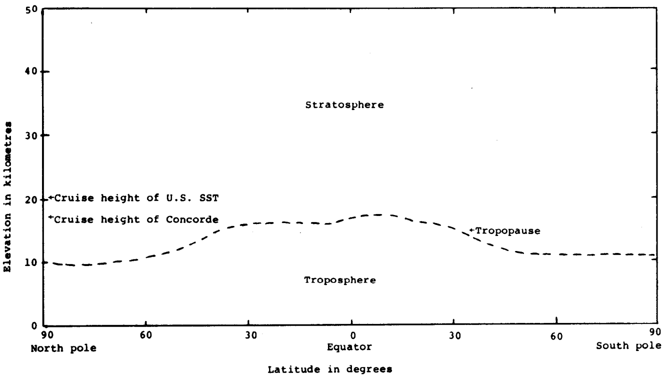

Fig. B A typical configuration of the troposphere, tropopause (represented by the dotted line) and stratosphere in July.

supersonic transport aircraft (or, SST)

A supersonic transport aircraft, or SST, is a passenger jet aircraft that can travel faster than the speed of sound. Examples are the French-British Concorde, the Russian Tupolev-144, and the proposed U.S. Boeing 2707 SST. The term SST alone is generally taken to refer to any or all of these aircraft.

temperature inversion

A temperature inversion occurs when the temperature of the atmosphere increases as one ascends in altitude.

In the lower atmosphere (the troposphere) it is normal for the temperature to decrease with height. The greater the rate at which the temperature decreases with height, the greater the instability in the atmosphere, and the more turbulence and mixing there is. When there is a temperature inversion, the atmosphere is very stable, and mixing is far less pronounced. This is the case for the stratosphere, in which the temperature generally increases with height. (See Johnston's Table 1, page 519, item 2.)

total ozone content

See: ozone column.

troposphere

The troposphere is the region of the atmosphere up to about 12 kilometers. It contains most of the normal features of the weather, such as clouds, rain, storms, winds and turbulence. See: stratosphere.

ultraviolet radiation

Ultraviolet radiation or u.v. is light that has more energy than the violet light we can see. See: nanometer.

worldwide steady-state distribution of nitrogen oxides in the stratosphere after several years of SST operation

Assume that a fleet of 500 SSTs had been flying and emitting NO_x in the stratosphere for a considerable number of years. The SSTs would add a certain amount of NO_x to the stratosphere each year, and approximately the same amount would be removed by natural causes (chemical reactions, movement to the troposphere and absorption in rain). NO_x would be in a steady-state, in that the average amount of it at any place in the stratosphere would not change significantly from year to year.

This steady-state distribution would require considerably more than 2 years to be achieved. Consider a fleet of 500 SSTs starting up operations all at once. After 2 years, 2 years' input of NO_x to the stratosphere will have been made, but also some of this NO_x will already have been removed. Only after many years of operations will 2 years' input of NO_x actually reside in the stratosphere (assuming a residence time of 2 years).