LETTERS TO NATURE

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Lepton Creation and the Dirac Relationship between Fundamental Constants

CAVALLO[1] has proposed an interpretation of the large number ratios between some of the fundamental constants occurring in physics and cosmology, in terms of rotating cosmological models. The purpose of this communication is to suggest another interpretation of these large dimensionless numbers in terms of lepton creation.

The starting point of this theory is the usual action principle for gravitation and electromagnetism but with the difference that charged leptons can be created or annihilated in the cosmological space-time. That is, the worldlines of these particles can have a beginning or an end, or both. The action can be written either in the field form or in the form of action at a distance[2]. The variation of the worldline of a lepton of mass m and charge e gives the following condition at the beginning or end of a worldline:

$$m\mathbf{u}_i = -eA_i \tag{1}$$

where A_i is the four-potential from the rest of the particles in the Universe and $\mathbf{u}_i$ is the four-velocity of the lepton.

I now apply this to a Robertson–Walker space-time used by most cosmologists, and used by Dirac in his discussion[3]. This represents an expanding homogeneous and isotropic Universe. In any given cosmological model of this type, it is possible in principle to calculate the A_i from charges of one species, although in practice the relevant integral may not be expressible in terms of elementary functions[4]. But if the Universe as a whole is electrically neutral the total A_i appearing on the right hand side of equation (1) will be zero.

I now propose a departure from strict neutrality in the following way. Suppose we consider particles of electric charge e. Although cosmological models differ in detail (such as deceleration parameter, the value of the λ constant, big bang or steady state, and so on), only the time-like component of A_i from all these particles is non-zero and it has the magnitude of the order of

$$Ne/R \ (R=c/H) \tag{2}$$

where N is the number of such charges in a spherical region of radius R. The parameters c and H in equation (2) are the velocity of light and the present value of the Hubble constant respectively. In the case of strict charge neutrality particles of opposite charge $-e$ will make an equal contribution $-Ne/R$ and thus cancel equation (2) exactly. But if the charge balance is a statistical effect, small fluctuations from it are likely to be present. This would mean that there is an overall electrostatic potential of the order

$$A_4 \sim \pm N^{1/2}e/R \tag{3}$$

The fluctuation effect assumed in equation (3) is of the order $N^{-1/2}(\sim 10^{-40})$.

Using equation (3) in equation (1), for a lepton created at rest in the cosmological substratum,

$$mc^2 = \mp N^{1/2}e^2/R \tag{4}$$

Since the left hand side is positive, the creation condition specifies that only the + sign on the right hand side is applicable. That is, only charge of one species can be created in a given region. We will return to this point again at a later stage, accepting for the time being the + sign in equation (4).

The relation (4) can be rewritten in a more familiar form:

$$R/(e^2/mc^2) \cong N^{1/2} \tag{5}$$

stating that the 'radius' of the universe bears to the radius of the electron the ratio $N^{1/2} \sim 10^{40}$. This is one of the dimensionless numbers relating the fundamental constants.

The second relation follows when we take account of the relation between the Hubble's constant, the constant of gravitation G and the mean density ρ of matter in the universe. For the Friedmann model[5] with the deceleration parameter $q_0 = 1$, or for the steady state model with the C field[6],

$$\rho = 3H^2/4\pi G \tag{6}$$

Other models usually yield different coefficients of H^2/G on the right hand side, but they are of the same order as $3/4\pi$. Taking equation (6) to fix ideas, the mass of the matter in a sphere of radius R is around

$$4\pi R^3\rho/3 \cong c^3/HG \tag{7}$$

Observations of the Universe show that matter is largely made of equal numbers of electrons and protons at least in our neighbourhood. Taking M for the mass of a proton, the above relation gives an estimate of N:

$$NM \sim c^3/HG = c^2R/G \tag{8}$$

If we now eliminate R between equations (5) and (8) we get

$$e^2/GMm \sim N^{1/2} \sim 10^{40} \tag{9}$$

The relations (5) and (9) are the core of the so-called Dirac relationships between fundamental constants. I now interpret these and discuss their astrophysical significance in the present picture by making the following points.

(1) Both relations express the overall dynamics of the Universe. The relation (5) arises from creation of charged leptons, the electrons and positrons in the cosmological framework. Although particles are created there is no overall loss of energy and momentum. Relation (8) may be looked upon either as an equipartition between the gravitational energy and the energy of expansion according to Einstein's equations or as a Machian relation determining the gravitational constant in terms of the matter content of the Universe[7,8].

(2) Although charge conservation is apparently violated when an electron is created, the violation is local, not global. The statistical fluctuation which requires the + sign in equation (4) for a given region is balanced by an opposite fluctuation which favours the creation of the opposite charge in another region. Thus we will tend to have electrons created in one region, positrons in another. Also the process is stable in the sense that the creation of too many electrons in a given region will produce a local contribution to A_4 which will soon cancel the cosmological contribution and thus control the process.

(3) Relation (6) owes its origin to a statistical fluctuation and hence is not exact. That is, it is not possible to fix the coefficient of $N^{1/2}$ on the right hand side which will make it exact although the coefficient will be of the order unity. The relation (8) is exact in any given cosmological model. (The

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$\sim$ sign appears because I have not specified the model in my discussion.) If I use the present determinations of c, H and G, I find that $N^{1/2} \sim 7 \times 10^{40}$ from equation (5) and $N^{1/2} \sim 1.3 \times 10^{40}$ from equation (8)—a reasonably good agreement.

(4) It may be possible to turn equation (4) round and argue that it implies creation of leptons of different masses as H varies or as we take into account the variation in fluctuation. This raises the interesting possibility that the electron mass is not fixed all over the Universe. This avenue is worth exploring in view of the puzzles about the QSO redshifts unearthed by recent observations[9,10].

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Production of Organic Molecules by Proton Irradiation

IN recent years there has been considerable interest in the production of complex organic molecules in primitive atmospheres. The emphasis of most of this work has been on mechanisms for prebiological synthesis of amino acids and related molecules, but the feasibility of producing organic chromophores which may account for the colours observed on planets and satellites in the outer Solar System by these same processes has become a topic of research effort in the past few years.

The early experiments[1-5] employed mixtures of methane and ammonia[4,5], sometimes with hydrogen[1] or water[2,3]; and indeed amino acids (in the experiments with H_2O) and related organic molecules have been produced. More recently[6-8], in attempts to simulate atmospheres likely to contain sulphur (those of Jupiter and primitive Earth), mixtures including hydrogen sulphide have been used. The results of these experiments were qualitatively similar to the non-sulphur ones, except for the production of free sulphur, alkyl sulphides and thio-amino acids. In one case involving a sulphur-free mixture a red polymeric material was reported[4], and this is considered a tentative candidate for the red colouring agent on Jupiter.

With the exception of the work of Palm and Calvin[2], in which energetic electrons were used, one of two types of energy sources was employed: electrical discharges[1,3-5] and ultraviolet light from a mercury lamp[6-8]. Electrical discharges may be initiated by strong atmospheric turbulence (similar to the familiar electrical storms) in the primitive atmospheres, and there is a significant amount of ultraviolet flux in the solar radiation. There is another source of energy, however, that is becoming increasingly worthy of consideration: energetic protons in the solar wind and in planetary radiation belts. Considerable attention has been given to the structure and composition of the radiation belts around Jupiter and the proton (and electron) flux is believed to be far from insignificant[9]. The satellites of the outer planets certainly are exposed to the solar wind, and two of these, Io and Titan, are unusually red[10]. Titan is especially interesting as it is known to possess an atmosphere of at least H_2 and CH_4 (ref. 11). Also, protons can bombard a planetary atmosphere directly from discharges in the radiation belts. It is possible, then, for proton bombardment to have a measurable effect on the organic chemistry of primitive planetary atmospheres.

The following preliminary experiments were carried out to investigate the effectiveness of proton irradiation for producing organic chromophores. The source of the 2 MeV protons used in the experiments was a model FN tandem Van de Graaff accelerator of the physics department at Stony Brook. The beams used ranged from 870 nA (5.44×10^{12} protons cm^{-2} s^{-1} over 1/3 cm diameter) to 220 nA (1.35×10^{12} protons cm^{-2} s^{-1}). Based on the nominal model[9] for the flux in Jupiter's radiation belt at six Jupiter radii from the planet (approximately the distance of Io), these beams correspond to 1.72 and 0.43 Earth years at Jupiter per second of exposure. Thus, for typical exposures of 3 and 6 h respectively, the total proton fluences are equivalent to those of 1.9×10^5 yr and 9.2×10^4 yr at Jupiter.

The gas cells used were hollow aluminium cylinders, each with a gas volume of approximately 125 cm^3. Attached to both ends of each cell were infrasil quartz windows, enabling visual inspection of any reaction products and gas phase spectroscopy from 0.2 to 4 μm. A very thin pure nickel foil window was attached over a hole in the centre of each cell, perpendicular to the cylinder axis, to allow entry of the proton beam into the cell without loss of gas. The cells were evacuated to less than 10^{-3} mm Hg, filled with the appropriate gas mixtures (see below) and stored in a helium atmosphere to prevent contamination by air. The exposures were accomplished by placing the cells in a large target chamber, evacuating the chamber to 5×10^{-5} mm Hg, and running the beam into the cell for the desired length of time. The beam was stopped at the rear wall of the cell with approximately 1/2 MeV of the energy lost in the nickel window and 1 MeV deposited in the gas.

Five gas mixtures were used in this first series of experiments, none of which contained water. The first cell contained 50 cm^3 CH_4 and 51 cm^3 NH_3 at a total pressure of 615 mm Hg, and was exposed for 3 h at 870 nA. High resolution mass spectrometry of the gas phase indicated the presence of C_2H_2, C_2H_4, C_2H_6 and their methyl homologues, as well as C_4H_2 (diacetylene), CH_3CN, and residual CH_4 and NH_3. The orange-brown oily liquid produced was analysed by computer assisted gas chromatography-mass spectrometry[12,13], which indicated the presence of the expected alkyl hydrocarbons and alkyl amines. Some unexpected and interesting products were the tricyclic alkyl amines, hexamethylene tetramine ($C_6H_{12}N_4$) and its methyl and dimethyl homologues.

The second experiment was essentially the same as the first, except that the beam intensity was cut by a factor of four and the exposure was twice as long, resulting in the reduction of the total dose by half. The results of this run were similar to those of the first, except that the lower molecular weight molecules were enriched relative to the higher molecular weight ones. This indicates an 'evolutionary' sequence from low molecular weight to higher molecular weight, but further work will be done to confirm this.

A 1 : 1 : 1 mixture of CH_4 : NH_3 : H_2S at a total pressure of 605 mm Hg was used in the third experiment. Before the irradiation, a thin white haze (NH_4SH ?) was observed inside the cells, but it was not seen after the exposure. This seems to be analogous to the white residue noticed by Sagan and Khare[8] in one of their experiments. The gas phase contained several simple hydrocarbons, saturated and unsaturated, along with CH_3CN and $(CH_3)_2S$. The gas chromatogram of the

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