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Comments on the Proposal that the Speed of Light has varied with Time

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ABSTRACT

The theory of time variation of the speed of light and other fundamental constants, proposed by T. Norman and B. Setterfield, is examined. It is shown that even if changes have occurred, the theory of Norman and Setterfield is unacceptable, as the magnitude of the changes postulated would have interfered with biological and related processes. In addition the mechanism proposed for the change of fundamental constants is incorrect. Consequently their conclusions regarding cosmological and geological dating are invalid.

INTRODUCTION

In a report by Norman and Setterfield,[1] it is argued that the speed of light (denoted c) and several other fundamental constants have varied as a function of time. A theory is then developed in an attempt to characterize this variation and it is implied that certain indicators of the age of the universe and of the earth must be drastically revised. This claim is developed further in a supplement to the report,[2] and a recent paper by Setterfield[3] in response to comments provides clarification on certain details.

Norman and Setterfield are not alone in considering the possibility of a secular variation of fundamental constants. However, their proposal differs from others in that they claim that large changes have occurred dining the last few millennia, whereas other proposals involve a rate of change too small to have had major effects during recorded human history. In support of his hypothesis Setterfield[3] cites work by Troitskii,[4] who proposes a decrease in c and variation in other constants,[4,5] but Troitskii postulates only slow changes (for example, he assumes[4] that alpha decay rates have varied by at most 10 percent in 10^9 years). In this paper we will examine the arguments of Norman and Setterfield, in particular the theory proposed to characterize the variation and the possibility of large changes in fundamental constants over a period during which it is known that there have not been major changes in biological organisms.

COMMENTS ON THE EXPERIMENTAL EVIDENCE FOR CHANGES IN FUNDAMENTAL CONSTANTS

Norman and Setterfield present measurements of c over the last three centuries and of other physical quantities over shorter periods. The measurements appear to show that c has been decreasing and that several other fundamental constants have also changed systematically.

The decrease with time of the observed value of the speed of light c appears inconsistent with the type of variation which would result from random errors. However, it is possible that the trend may result from systematic errors which diminished as the techniques were improved. Although 16 different methods were used, there would probably have been certain aspects of the experimental procedures or of the equipment used in a given method which would have been related to procedures or equipment used in some other methods, so that a particular type of systematic error need not have affected only one method of determination of c.

Concerning the other quantities which appear to have varied with time, it is necessary to consider whether the measurements of one quantity are independent of those of another quantity. In determining some of these quantities, other fundamental constants would need to be known. Therefore, assuming that each worker used the values of such constants accepted at the time of his work, any variation with time in the accepted values of these constants would be reflected in a corresponding variation in the value calculated for the quantity being measured, irrespective of whether the variation of the constants used in the calculation was real or simply due to experimental error. For example, if the determination of the gyromagnetic ratio γ makes use of the value of c, or of some other constant which itself cannot be determined independently of c, then the change with time of the accepted value of c would automatically be followed by γ regardless of whether the change in the value of c was real. That is, an error in one fundamental constant would be propagated in the determination of all other quantities whose measurement depends on that constant. Norman and Setterfield appear to have allowed for this possibility in their discussion of the electronic rest mass m, by tabulating e/mc rather than m, where e is the elementary charge, but the problem is probably not limited to this particular quantity.

Norman and Setterfield state that measurements of c after 1967 would not be expected to show any variation because atomic time rather than dynamical time has been used as a standard since that date. It is pointed out that relative to an atomic clock, quantities such as c, Planck's constant h, and radioactive decay rates would not vary. Yet elsewhere in their report, in Tables 22 and 24 (intended to show that c and other quantities have varied with time), Norman and Setterfield include the very small rate of change of c calculated from measurements in the period 1966 to 1983. Norman and Setterfield also present measurements of 2e/h (using the ac Josephson effect), h/e^2 (using the quantized Hall effect) and the proton gyromagnetic ratio, obtained after 1967, and the apparent slight variation with time is interpreted by Norman and Setterfield as supporting their hypothesis. Some data collected after 1967 are also included in their tabulated values of e/mc and of radioactive half-lives.

Norman and Setterfield quote two determinations of the rate of change of atomic clocks relative to dynamical clocks using astronomical measurements: one involving Viking lander ranging data[6] which gave a null result, and one involving lunar occultations[7] which gave a small non-zero value. Norman and Setterfield accept the latter result but claim that the Viking result may be spurious as orbit radii are independent of clock rates. The result based on Viking data has also been rejected for a different reason by Ritter and Gillies.[8] Unfortunately these authors appear not to have published details of their argument, but Gillies,[9] treating the measurements as attempts to determine the rate of change of the gravitational constant G, states that all astronomical determinations of this quantity, including the lunar occultation method, may possibly be invalid on the same grounds. Gillies[9] gives an extensive bibliography of measurements of G and tests for changes in G. Incidentally, Norman and Setterfield, in Table 24 of their report, give the mean date of the Viking measurements as 1983, whereas in fact they cover the period 1976 to 1982, with some other, earlier astrometric data also being used.

Notwithstanding the above remarks, in the rest of this paper it will be supposed that the postulated changes in fundamental constants have in fact occurred and the theory proposed by Norman and Setterfield to account for this will be examined.

COMMENTS ON THE PROPOSED PHENOMENOLOGICAL THEORY OF CHANGES IN FUNDAMENTAL CONSTANTS

Norman and Setterfield present a phenomenological theory in which c is assumed to decrease and the change with time of various other fundamental constants is deduced, assuming that physical laws such as conservation of energy continue to hold. It is concluded that atomic and dynamical clocks ran at different rates, with atomic electron velocities and radiation frequencies being proportional to c.

Motions and Masses

The behaviour of atomic quantities is derived by assuming that energy is conserved as c varies so that the rest mass of any particle is inversely proportional to c^2. The question arises, why would the motion of the earth and other large objects not follow the same principle as that governing atomic particle motion, with the velocity changing in proportion to c so that energy is conserved as the mass varies as c^{-2}. This would result in atomic and dynamical clock rates being synchronized. Setterfield[3] answers this by claiming that the masses of macroscopic objects remains constant while atomic masses vary. This implies that macroscopic velocities do not change with c whereas atomic quantities such as electron and nucleon velocities, molecular vibrational and rotational frequencies, chemical and nuclear reaction rates, molecular speeds and diffusion rates, sound and thermal vibration frequencies, and thermal and electrical conductivities are all proportional to c.

To support his contention Setterfield states that atomic particle masses are electromagnetic in character. Note that, while some have suggested that the masses of electrons and possibly other leptons may be purely electromagnetic, it is generally accepted that only a small fraction of the masses of nucleons could be electromagnetic. Setterfield then asserts that the inertial mass of a macroscopic object is of a different nature to the particle masses which govern atomic motion with that object.

This claim appears irreconcilable with the following considerations. In the behaviour of atomic systems subject to both atomic and externally applied electric fields (for example, the Stark effect and ionization of an atom due to an external field), the same electron mass must determine motion in response to the two fields which combine to form a resultant field. In considering both atomic and macroscopic motion of an object in an externally applied electric field, the mean acceleration vector of each atomic particle must equal the macroscopic or bulk acceleration of the object at (hat point and the total force acting on the object is the sum of the forces acting on each particle. Hence the inertial mass governing macroscopic motion must equal the sum of the particle masses governing atomic motion. Finally, in the motion of an object subject to external electric and gravitational fields, the same mass governs the components of the motion due to each field.

Thus the same particle masses determine subatomic motion in atomic and external electric fields and macroscopic motion in electric and gravitational fields. Examples where atomic or molecular fields, external electric fields and gravitational fields all combine to determine macroscopic motion are the behaviour of dipolar fluids or of plasmas in electric and gravitational fields.

In the vibrations of a solid object, as the frequency increases the motion gradually changes from essentially rigid body motion to lattice vibrations (phonons) with atomic dimensions; at sufficiently high frequencies the vibrations can couple with electronic motion. If Setterfield's claim were accepted, the low frequency motion would be governed by the macroscopic inertial mass, whereas the high frequency motion would be governed by the atomic masses, yet there is no sudden change in behaviour in progressing along the frequency spectrum. A situation where microscopic and macroscopic motion must be considered together is a small nuclear explosion, where particles and debris ranging from nuclear particles up to macroscopic fragments can be simultaneously scattered, and subsequently undergo collisions with other matter covering a similar size range. It is hard to see how different types of mass could govern the interactions of differently sized objects, especially as the conservation laws of momentum and energy must apply to the collective motion.

Setterfield seeks to support his case by citing early measurements in which discrepancies were found between atomic masses determined in a mass spectrometer and Q value masses.[10] However, more accurate work not long after this[11,12] gave no significant discrepancies after allowance for experimental errors, and the earlier results were attributed to inconsistencies in calibration standards. Note that the Q values were obtained by measuring magnetic deflections of particles, so that caution should be exercised in treating them as non-inertial measurements.

In view of the above arguments the claim that atomic and macroscopic masses are fundamentally different appears unsustainable.

'Clocks' and Life

We now discuss models in which atomic and dynamical clocks differ in general. The following points apply both to the theory of Norman and Setterfield and to other proposals such as theories in which G varies, or theories in which c changes, but some of the assumptions of Norman and Setterfield, such as the premise that energy is conserved as c varies or the constancy of charge, permittivity or atomic radii, are modified. (A number of such theories imply a difference between atomic and dynamical clocks without requiring a difference in nature between atomic and macroscopic masses.) It is unlikely that any secular trend in fundamental constants (whether c, G or any other quantity or combination of constants) could lead to a large enough deviation between the rates of different types of clocks to affect significantly cosmological or geological dating during the period of human habitation of the earth, for the following reasons.

Many time-dependent physical quantities influence biological processes, including human, animal and plant metabolism, or influence the environment in a way that affects living organisms. For example, chemical reaction rates, molecular diffusion rates, electrical conductivities (in nerves), thermal conductivities and mechanical motion (in muscles and blood circulation) all play essential parts in metabolism. These physical quantities, which are related to atomic clocks, also affect the environment. Furthermore, the intensity of solar radiation influences biological processes through photosynthesis, the rate of which must depend on the photon flux (this is analogous to Setterfield's argument[3] that the rate of ^{14}C production in the atmosphere would have been greater in the past). This leads to a link between biology and the rate of nuclear reactions in the sun, unless changes in reaction rates are compensated by other changes in the sun or in the radius of the earth's orbit. Presumably any change in the rate of radioactive decay processes connected with geological dating would involve a change in nuclear properties which would also affect solar nuclear reactions. Therefore any large change in fundamental constants would need to have affected the rates of each of these processes by the same factor, during human history, for life to have existed in its present form throughout the entire period.

It is especially important to recognize that the frequency of rotation of the earth on its axis and also of its orbital revolution would have to change by the same factor as the rates of biological processes, and hence the rates of all of the above physical processes. This is due to the dependence of many plants and animals on seasons which are related to the length of a year, and also to the connection between the rate of human and animal metabolism and the length of day and night. For example, if the earth's rotational frequency changed at a rate significantly different to the rate of change of metabolic processes, we would need either more or less than one period of sleep per day and the amount of food required per day would change. Note that a higher rate of metabolism due to faster physical and chemical processes without a corresponding reduction in the length of the day and year would have the same biological effect as would longer days and years with no change in metabolic rate.

If life had existed in the last few millennia with a substantially different metabolic rate from the present but no change in the length of days and years, it would be evident from historical records that the situation differed substantially from conditions pertaining now. For example, the number of days for crops to grow would have been different, and the effects on human metabolism referred to above would obviously have resulted in a substantially different lifestyle from that of the present. Since the biological processes discussed above include the same physical processes as are involved in dating techniques, it follows that the clocks used for dating must run at close to (or exactly) the same rate as the dynamical clock established by the motion of the earth. Gradual variations in relative clock rates such as proposed by Dirac would be possible, but would be too slow to have a significant effect on dating during recorded human history.

Red-Shifts

In discussing astronomical red-shifts Norman and Setterfield modify the Doppler formula to allow for the proposed change in c. The resulting equations are ambiguous due to a discrepancy in the use of a term called the effective velocity of the source, denoted V_e. Initially this quantity is given by $V_e = V_o/C^*$, where V_o is the actual source velocity and C* the present value of c. Subsequently it is stated that the effective velocity becomes $V_e = NV_o$ if a term involving C_o is dropped, where C_o is the value of c at the time of emission from the source and $N = C_o/C^*$. These two equations for the effective velocity give different dimensions for V_e.

COMMENTS ON THE PROPOSED MECHANISM FOR CHANGES IN FUNDAMENTAL CONSTANTS

Norman and Setterfield propose a link between c and the cosmological constant, and based on this they obtain the following equation for the form of the dependence of c on time t:

$$c = \sqrt{[a + e^{kt}(b + dt)]} \qquad (1)$$

where a, b, d and k are constants. They refer to a model discussed by Landsberg and Evans[13] which describes the effect of a negative cosmological constant λ (A in the notation of Norman and Setterfield) on the cosmic evolution of a universe of negligible mass density.

In this model the parameter λ is assumed to be constant and the cosmological force $\underset{\sim}{F}_c$ of particle i, or mass m_i and position vector $\underset{\sim}{r}_i$ given by

$$\underset{\sim}{F}_c = (\lambda/3)\, m_i\, \underset{\sim}{r}_i \qquad (2)$$

is proportional to the radius of the universe as it expands or contracts. Norman and Setterfield have stated that it is the parameter λ which varies in proportion to the radius of the universe, whereas it is not λ but F_c which varies in the model discussed by Landsberg and Evans. Therefore this model does not imply a change in either λ or c as a function of the radius of the universe or of time. Of course, if c were to change for any reason, then it is possible that λ would change as well, but no change can be deduced from the model under discussion; in fact, the model assumes both λ and c to be constant.

Furthermore, Norman and Setterfield conclude from an equation given by Landsberg and Evans for the radius R of the universe, namely

$$\dot{R}^2 = (\lambda/3)\, R^2 - kc^2 \qquad (3)$$

with k = -1 to give an oscillating universe, that R exhibits damped simple harmonic motion. However, if λ and/or c are functions of time, then this equation does not give rise to simple harmonic motion, whether damped or otherwise.

Thus the arguments of Norman and Setterfield leading to their equation (8) are invalid. Without such an equation for the time dependence of c, it is impossible to extrapolate the value of c back in time beyond the last three centuries during which it has been measured.

CONCLUSION

It is apparent that the evidence for a secular trend in fundamental constants is not conclusive. However, whether or not such a change has occurred, the theory proposed by Norman and Setterfield to characterize it is untenable. Therefore their conclusions regarding cosmological and geological dating must be rejected.

One might ask whether an alternative theory of time variation of fundamental constants could be developed that does substantially affect cosmological and geological dating during recorded human history. Such a theory would need to be consistent with the recent trends in measured values (supposing these to be real changes and not experimental errors) and also consistent with the known constancy of certain combinations of fundamental constants, such as the fine structure constant, over cosmological and geological time (references to evidence for such invariant combinations are given by Norman and Setterfield). Furthermore, the variation would have to be such that biologically significant processes, and other phenomena that would be noted historically, would be unaffected, whereas age indicators, such as the time taken for light to arrive from distant galaxies and nuclear decay rates pertinent to radiometric dating, would have to be affected drastically. The difficulties involved in satisfying these two conditions simultaneously have been discussed above. Finally, there would have to be a sound basis for supposing that the variations in fundamental constants have been large, since merely finding a combination of hypothetical changes satisfying the above criteria would not constitute evidence that large changes of this type had actually occurred.

These constraints are very restrictive and it is therefore reasonable to suppose that no large changes of fundamental constants affecting cosmological and geological ages have occurred during recorded human history.

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