matters arising

Variation of G

DEARBORN and Schramm have considered limits on the variation of G imposed by the existence of clusters of galaxies and globular clusters of stars[1]. Their argument is that if G has been varying too rapidly the clusters would have dispersed and we would not see them now. They conclude that my theory of the variation of G, based on the Large Numbers Hypothesis, is untenable.

These authors (and several other workers in the field) have misunderstood the main feature of my theory. They work with a Newtonian theory in which gravitational mass can vary independently of inertial mass, so they are adopting a pre-Einstein view of gravitation. On such a basis there would be no explanation for the motion of the perihelion of Mercury.

The coefficient G has dimensions and its value depends on what units one uses. One might refer it to standard units of physics, g, s and cm. Then the question whether G varies depends on how these units are defined and is not a fundamental question of physics. One should avoid man-made units and use only those provided by nature. One may take units of time and distance provided by atomic clocks and the velocity of light, and a unit of mass provided by an atomic particle, say the proton. Referred to such units the variation of G has an absolute meaning.

If this G varies, the question arises of how to fit it into physical theory without destroying the successes of the Einstein theory. A natural way of doing that is to suppose that all the laws of classical mechanics, including the Einstein theory, are applicable only when referred to suitable units that differ from the atomic units. This is a development of an idea originally proposed by Milne[2], that there are two scales of time that are important in physics.

Let us call the units that must be used for the laws of classical mechanics to apply 'mechanical units'. For any problem involving dynamical motions and not referring to atomic processes one may work with mechanical units, and the calculations will then not be affected by the variation of G referred to atomic units. This variation may be ascribed to the variation of the atomic units referred to the mechanical units. Thus calculations of the stability of clusters can throw no light on the variation of G.

One can obtain evidence about the variation of G referred to atomic units by making astronomical observations with atomic apparatus. One method is to observe accurately the times of lunar occultations with atomic clocks. This method has been used by Van Flandern[3] who has obtained evidence that G does vary. Another method is to work with I. I. Shapiro's observations of radar reflected by the planets. These are not yet sufficiently accurate to give a definite result, but one can hope that they will be in the near future.

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Future impact of fossil CO_2 on the sea

WHITFIELD[1] has challenged, on chemical grounds, the conclusion[2-4] that uptake of fossil CO_2 by the sea will eventually lead to unsaturation of calcium carbonate. The optimistic conclusion that "serious environmental effects are not likely in the foreseeable future" is unwarranted for the following reasons. (1) Whitfield's theoretical analysis obviously fails to maintain equivalence between anions and cations as CO_2 is taken up by seawater. This impossible situation means only that the increase in total CO_2 predicted by mixing models is incompatible with the chemistry; changes in the degree of calcium carbonate supersaturation with increasing CO_2 partial pressure (P_{CO_2}) requires further analysis. (2) Whitfield assumed too high an initial concentration of total inorganic carbon (ΣCO_2) in seawater, equivalent to 2.66×10^{-3} M. We have measured ΣCO_2 in hundreds of samples of surface seawater (ref. 5 and A.W.F., and J.L.E., unpublished observations) as have Li et al.[6], which generally falls in the range $2.05 \pm 0.05 \times 10^{-3}$ M. For an initial seawater ΣCO_2 of 2.05 (pH 8.00) and using MacIntyre's[7] values of the stoichiometric solubility product constants (K_{sp}') of calcite ($10^{-6.17}$) and aragonite ($10^{-5.97}$), the carbonate concentrations for aragonite and calcite saturation are, respectively, 1.07×10^{-4} M and 0.68×10^{-4} M ($Ca^{2+} = 10^{-2}$ M); the corresponding reductions in carbonate are 0.99×10^{-4} M and 1.38×10^{-4} M, respectively. The latter is only 60% of the value estimated by Whitfield for his higher ΣCO_2 for seawater. (3) The degree of present-day supersaturation of seawater with respect to aragonite and calcite, and how this will change with increasing P_{CO_2}, depend on the choice of the various equilibrium constants of the ionic equilibria involved, about which there is some lack of concensus. The degree of supersaturation is expressed by the ratio $\alpha Ca_{2+} \cdot \alpha_{CO_3^{2-}}/K_{sp}$, where K_{sp} is the thermodynamic solubility product constant of $CaCO_3$, the αs are ionic activities γM, (where γ is the ion activity coefficient). Berner[8] measured γCa^{2+} to be around 0.21 ± 0.01, and $\gamma_{CO_3^{2-}}$ to be around 0.022 ± 0.004, depending on the chlorinity, in reasonably good agreement with Garrels and Thompson[9]. The very low activity coefficient of CO_3^{2-} ion reflects the fact that most of the carbonate ion in seawater is complexed with various cations. Using K_{sp} values from Latimer[10] and Jamieson[11] (K_{sp} at $25°$ C = $10^{-8.24}$ for calcite, $10^{-8.15}$ for aragonite), Berner calculated the degree of supersaturation for a typical warm ($25°$ C) surface seawater to be 2.8 for calcite and 1.8 for aragonite. On the other hand Li et al.[6] conclude on the basis of their measurements and MacIntyre's values of K_{sp}' that the degree of supersaturation of calcite and aragonite in seawater is about 5.5 for calcite and 3.5 for aragonite. There is no question that surface seawater is supersaturated with respect to both minerals at the present time, but there is some uncertainty as to the degree. (4) The solubility of CO_2 and $CaCO_3$ (both aragonite and calcite) in seawater increase with decrease of temperature. Therefore one needs to be concerned not only with what may happen in warm, tropical seas (at about $25°$ C) but also the subtropical ocean which Whitfield did not consider. At mid to high latitudes the average sea temperatures are much lower and these areas would be the first to achieve undersaturation of aragonite with increase of P_{CO_2}. Fortunately, the majority of calcareous organisms which flourish in the cold, subtropical seas are calcitic, and therefore less soluble; but aragonitic forms do occur[12]. We have