potential used is the average of the fits to the elastic data at 11.0 and 12.0 MeV. The deuteron spin-orbit coupling was neglected. The neutron potential included a spin-orbit coupling. A Gaussian finite-range function was used. Further parameters are given in the above reference. The nickel and silicon calculations are similar to those for calcium. For nickel a Perey deuteron potential, type B [C. M. Perey and F. G. Perey, Phys. Rev. 132, 755 (1963), and a Perey proton potential [F. G. Perey, Phys. Rev. 131, 745 (1963)] were used. For silicon a deuteron potential which gives an average fit to the elastic data in the energy range 8-12 MeV (real part of central potential is 120 MeV) and a Perey proton potential were used.

ELECTRICITY, GRAVITY, AND COSMOLOGY

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Thirty years ago, Dirac[1] expressed the opinion that very large dimensionless universal constants, such as the ratio of electrostatic and gravitational forces between two protons $e^2/\gamma m_p{}^2 = 1.24\times 10^{36}$, cannot possibly be pure mathematical numbers which will be derived sometime by somebody from some as yet nonexisting theory. He suggested that such very large pure numbers which sometimes occur in science must rather be considered as variable parameters characterizing the present state of the universe. Dirac noticed that the above-given large number, representing the ratio of electrostatic and gravitational forces, is very close to another large pure number which expresses the present age of the universe in terms of the elementary units of time, often called les tempons by French physicists. The tempon is defined as the duration which is necessary for light to cover a distance equal to the "classical" radius of an electron. Thus, one tempon (τ) is equal to $(e^2/mc^2)(1/c) \cong 10^{-23}$ sec. Assuming that the present age of the universe is about 10 eons (one eon is 10^9 y) or 3×10^{17} sec, we find that it is about 3×10^{37} tempons old. This number is fairly close (within a factor of $2\pi^2$) to the previously mentioned large ratio. Thus Dirac proposed to consider γ not as a constant at all but as a variable decreasing in inverse proportion to the age of the universe.

Ten years later, Teller published a short article[2] in which he argued that the decrease of γ with time would contradict the existing paleontological evidence. On the basis of the thermonuclear theory of the sun's energy production, he proved that, if γ decreases in inverse proportion to the age t of the universe, the luminosity of the sun must have been decreasing as t^7 and should have been considerably higher in the past geological eras. Also, if γ used to be larger, the diameter of the earth's orbit must have been smaller in the past, as can easily be proved on the basis of the law of the conservation of angular momentum. Combining these two factors, and taking for the age of the universe the value of about 2 eons (accepted by astronomers at that time), Teller showed that during the Cambrian era (some 500 million years ago) the surface of the earth must have been at the temperature up to and above 100°C and the oceans would have been boiling, making life uncomfortable for trilobites. In the pre-Cambrian era there would have been no oceans at all and all water would have existed only as superheated vapor in the atmosphere.

Since Teller's original article was published, the astronomically estimated age of the universe has been brought up to about 10 eons (9.25 eons to be exact),[3] so that the time period separating us from the Cambrian era became a smaller fraction of the total age of the universe. Correspondingly, the "age of boiling oceans" moved back in time, making the Cambrian and pre-Cambrain eras safe for marine life. On the other hand, still more recently, paleontologists have found the remainder of bacteria and algae in the deposits the age of which is estimated to be 3.1 eons by radioactivity-dating method.[4] And, even though Teller's argument makes life safe for the inhabitants of the Cambrian ocean, it certainly threatens the life of organisms living a few eons ago.

Also, a new approach has been developed to check the possibility of the brighter sun without any reference to the life on the surface of the earth. Pochoda and Schwarzschild[5] have shown, by using an electronic computer, that the original nuclear resources of the sun simply could not last long enough at such high energy expenditures, and that if the sun was burning two eons ago it would have by now burned up all its central hydrogen supply, turning into a red giant star. Being unaware of that publication, I came to the same conclusion[6] by using a simpler but mathematically less exact method of homology transformations. Summing up, one can say that the possibility of the change of gravity forces in inverse proportion to the age of the universe has been completely ruled out.

But it would be too bad to abandon an idea so elegant and so attractive as Dirac's proposal. And one unwillingly asks oneself: Is it not possible that, while γ remains constant, e^2 increases in direct proportion to the age of the universe? Let us see first what will result from such an assumption in the problem of the surface temperature of the earth in its past history. First of all, of course, the change of e^2 will have no effect on the radius of the earth's orbit. The problem of the sun's luminosity is somewhat more difficult. Contrary to the common notion, the luminosity of a star is determined not so much by the amount of energy which can be produced by the nuclear sources near its center as by the amount of energy which can be transported through its body to its surface. In fact, due to the very high temperature sensitivity of thermonuclear reactions, a small change of the temperature and other parameters characterizing the body of a star would result in very large changes of the energy production rate, and thus adjust it to the amount which can be carried out from the center. For example, in the case of the changing gravitational constant, one can assume (and so Teller did) that the thermonuclear source is infinitely sensitive to the temperature, and "blame" the luminosity changes on the changing transport facilities affected by gravitational forces.

In our case the change in the rate of energy transport can be blamed directly on the change of the opacity coefficient κ_0 caused by the change of the electric charge of the electrons. According to Kramers's well-known formula, this coefficient is proportional to $e^6 = (e^2)^3$, and thus must increase as the cube of time counted from the beginning of expansion. According to the homology transformations[7] the brightness of the sun increases as

$$L \sim \kappa_0^{-(2n+6)/(2n+5)} \sim (e^2)^{-3(2n+6)/(2n+5)} \sim t^{-3(2n+6)/(2n+5)}, \quad (1)$$

where n is the exponent in the temperature dependence T^n of the thermonuclear reaction. (For example, $n = 17$ for the C-N cycle). Putting $n = \infty$, we find that

$$L \sim t^{-3} \quad (2)$$

as compared with

$$L \sim t^{-7} \quad (3)$$

in the case of changing γ.

If we assume just that, the surface temperature of the earth will be changing as

$$T_{\oplus} \sim L^{1/4} \sim t^{-3/4} \quad (4)$$

instead of

$$T_{\oplus} \sim \left(\frac{L}{R^2}\right)^{1/4} \sim \left(\frac{t^{-7}}{t^2}\right)^{1/4} \sim t^{-2.25} \quad (5)$$

in the case of the changing γ.

Thus if e^2 and not γ changes with time, even for t equal to one third of the present age of the universe, the surface temperature of the earth would be just about the boiling point of water.

Similarly, the total amount of energy radiated by the sun from a certain time t_1 in the past to the present time t_2 (obtained by the homology method) becomes in the case of variable e^2

$$\tfrac{1}{2}L(t_2)t_2\left[\left(\frac{t_2}{t_1}\right)^2 - 1\right] < \frac{0.06M_{\odot}\epsilon}{m_p} \quad (6)$$

leading to the condition:

$$\frac{t_2}{t_1} < \left(\frac{0.12M_{\odot}\epsilon}{m_p L(t_2)t_2} + 1\right)^{1/2} = 1.5. \quad (7)$$

Thus,

$$t_2 - t_1 < t_2(1 - 0.5) = 5 \times 10^9 \text{ y}$$

which does not contradict the fact that the sun was shining at least as long as the planetary system was in existence.

It goes without saying that one cannot neglect the thermonuclear source altogether while speaking about the changes of the sun's luminosity caused by the increase of the elementary electric charge with the age of the universe. Of course, the smaller value of e^2 in the past would lower the potential barriers surrounding the atomic nuclei, thus increasing the chances of penetration of protons inside the nuclei. On the other hand, the smaller value of e^2 would also decrease the probability of γ-ray emission, thus decreasing the probability of radiative capture after the penetration. Whereas these two effects can easily be calculated, there are more serious difficulties concerning the change of nuclear forces which determine nuclear radii. The first question to answer is: how will it affect the rate of Critchfield's H-H reaction which depends on the process of β emission? How does Fermi's constant g depend on e^2? Since we do not have the complete theory of elementary particles, we can rely here only on qualified guesses. Thus, for example, dimensionally as well as numerically there is a relation

$$g=\alpha\mu_n^{\,2}, \tag{8}$$

where α is the fine structure constant and μ_n the nuclear magnetic moment.[8] Substituting the values of α and μ_n, we get

$$g=\frac{e^2}{\hbar c}\left(\frac{\hbar e}{m_p c}\right)^2=\frac{e^4\hbar}{m_p^{\,2}c^3}. \tag{9}$$

If there is any physical sense in the above relation, the probability of the reaction $H+H\rightarrow D+\beta$ must vary as t^4. Since this rate of change is probably different and even opposite from that for α decay, it could, at least in principle, be noticed by observing the radioactive halos in ancient quartz rocks. And, of course, a revision will be due in the dating of old rocks by the U-Pb method.

Leaving all these details aside for further discussion, let us turn now to the cosmological problems. Can the change of spectral lines caused by the change of the Rydberg constant be detected by observing very distant galaxies? It surely can! All lines of the spectra will be shifted to the red with $\Delta\lambda/\lambda$ being the same in any particular case. Thus it will be possible to distinguish between the red shift due to the change of e^2, and that due to the Doppler effect. It may be that the large red shifts now observed in quasars (or rather, qualaxies) are partially due to the change e^2. Another, more difficult, task would be to detect the change of the fine-structure constant by observing the lines of the hydrogen spectrum in the distant galaxies. Or maybe one can notice the change of elementary charge by observing the Lamb effect in hydrogen lines emitted by gaseous nebulae in the Andromeda spiral only 2 million years ago. Certainly, if it is e^2 and not γ that is changing, there will be many questions to be asked and answered!

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