f-Gravity and the Proton-Electron Mass Ratio.

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In recent papers ([1,2]) two of the present authors (C.S. and K.P.S.) have demonstrated that, if we invoke the short-range massive strong gravity field (mediated by f-mesons) with a coupling constant G_f, which is considerably larger than the Newtonian constant G_N corresponding to the weak massless gravity field of EINSTEIN (mediated by massless gravitons), it appears that general relativity plays a crucial role in determining the masses of elementary particles. In fact reasonable values were obtained for the hadron masses by invoking strong gravity ([2]).

Also in another recent paper ([3]) the present authors have shown that the massive spin-2 f-meson is a (massive) Yang-Mills field for the general–co-ordinate transformations. It is by now well known that the electromagnetic interaction of hadrons is different from that of electrons ([4]). For instance application of the Dirac equation to the proton or neutron yields entirely wrong values for their magnetic moments. While leptons directly interact with the massless photons of the electromagnetic field, the hadrons interact with the gauge nonet of vector (spin-1) mesons (ρ, φ, ω, K^*) which includes the ρ^0-meson having the same quantum numbers as the photon and hence called the heavy photon. Thus a hadron like proton emits and reabsorbs ρ^0-mesons which have a finite transition amplitude for conversion into photons which in turn could be absorbed or emitted by leptons (*e.g.* electron). This two-stage picture of the electromagnetic interaction for hadrons is now generally accepted ([4]). Now the existence of massive spin-2 mesons, in particular the f^0-meson having identical quantum numbers as the graviton, strongly implies an analogous situation for the gravitational interactions of hadrons. That is, the f-meson plays the role of a massive graviton for hadronic gravitational interactions just as the ρ^0 is the massive photon for hadronic electromagnetic interactions. The quantum gravitational interaction of hadrons proceeds via the interconversion of the spin-2 mesons to Einstein's gravitons which in turn couple directly to leptons. Further it is interesting to note that the spin-2 mesons f (1270 MeV, 2^+, 0^+, $Y=0$), f′ (1514 MeV, 2^+, 0^+, $Y=0$), K^* (1420 MeV, 2^+, $\frac{1}{2}$, $Y=1$), A_2 (1310 MeV, 2^+, 1^-, $Y=0$) etc. form an SU_3 nonet, with f and f′ being analogous to ω and φ

(1) C. SIVARAM and K. P. SINHA: *Lett. Nuovo Cimento*, **8**, 324 (1973).
(2) C. SIVARAM and K. P. SINHA: *Lett. Nuovo Cimento*, **9**, 704 (1974).
(3) E. A. LORD, K. P. SINHA and C. SIVARAM: *Prog. Theor. Phys.*, to be published.
(4) A. SALAM: *Progress in renormalization theory since 1949*, ICTP preprint (1973).

of the spin-1 nonet. Hence they can arise from a « mixing » of an SU_3-singlet B and the isospin singlet of the SU_3-octet Y. From the octet mass formula of OKUBO and GELL-MANN we get $m_Y = 1545$ MeV, and the mixing angle is found to be around 35° (close to the φ-ω mixing angle) and in agreement with the SU_6 theoretical prediction $\operatorname{tg}\theta = 1/\sqrt{2}$. With this mixing angle we find that the mass of the unitary singlet spin-2 resonance (unobserved) is about 1360 MeV.

All this strengthens the belief that the gravitational interaction of hadrons at the quantum level is also a two-stage picture like their electromagnetic interactions. As shown earlier [2] the coupling constant for this strong (f) gravity is much larger than the Newtonian constant. A major puzzle of elementary-particle physics is the existence of two stable particles (*i.e.* those having infinite lifetime), the proton and the electron, with such a large mass ratio. In what follows we shall attempt to explain this mass anomaly as arising from the different mechanisms of the gravitational interactions for hadrons and leptons (*i.e.* the ability of the proton to take part in strong gravitational interactions also) just as the anomalous electromagnetic properties of the nucleons can be traced to the different nature of their electromagnetic interactions.

One can write Einstein's equations with a cosmological term for the f-meson field $f_{\mu\nu}$ and this will provide a de Sitter-type metric for the space within an elementary particle (see ref. [1]). It can be shown that the field equation for a massless linear spin-2 field $g_{\mu\nu}$ coupled to itself in the manner prescribed by the Yang-Mills hypothesis reduces to precisely the Einstein equations $R_{\mu\nu} = 0$, with $R_{\mu\nu}$ being the Ricci tensor [5]. In the linearized approximation $R_{\mu\nu} \sim \Box g_{\mu\nu}$, what suggests that the appropriate nonlinear Yang-Mills field equation (see ref. [3]) for an f-meson (with rest mass m_f) must be

$$R_{\mu\nu} = -\tfrac{1}{2} m_f^2 f_{\mu\nu} \,. \tag{1}$$

This is just the Enstein equuation ($R_{\mu\nu} = \Lambda f_{\mu\nu}$) with a cosmological constant defined as [1]

$$\Lambda = -\tfrac{1}{2} m_f^2 \,. \tag{2}$$

The simplest solution of these equations is the de Sitter solution having a space with constant curvature. A massless Dirac particle (such as a neutrino) in a curved space-time satisfies the equation

$$\gamma^\mu \psi_{;\mu} = 0 \,, \tag{3}$$

where $;\mu$ is the covariant derivative. This leads to the curved-space Klein-Gordon equation

$$\psi^{;\mu}_{;\mu} + \tfrac{1}{4} R \psi = 0 \,. \tag{4}$$

Thus the massless Dirac field acquires a rest mass given by $m^2 = \frac{1}{4} R$. For the de Sitter space implied by eqs. (1) and (2)

$$m = \sqrt{|\Lambda|} = \frac{m_f}{\sqrt{2}} \,. \tag{5}$$

Using the mass obtained earlier for the spin-2 singlet we have $m = 960$ MeV, very close to the nucleon (proton) mass.

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[5] E. A. LORD: *Proc. Camb. Phil. Soc.*, **69**, 423 (1971).

Or course, if one starts with the Dirac equation for a massive particle such as the electron, this would imply the acquisition of an additional mass given by $m^2 = \frac{1}{4}R$, owing to the curvature in the particle region caused by the strong gravity field.

The foregoing analysis shows that the difference in the proton and electron masses perhaps arises from the fact that the former interacts with the strong (f) gravity field and acquires an additional mass $\sqrt{\frac{1}{4}R} = m$. In our case this additional mass has the value of about 960 MeV. Since the electron does not take part in f-gravity, we have $\Lambda = R = 0$ and the equation becomes the usual Dirac equation in flat space-time. The origin of the mass anomaly between the electron and the proton thus seems to lie in the ability of the proton to undergo f-gravity interactions, in addition to ordinary infinite-range massless gravitational interactions. It is interesting to connect this with other recent works [6,7] by two of us (C.S. and K.P.S.). By using the Kerr metric (which is an exact particular solution of the Einstein field equations that represents the gravitational field of a rotating body) it can be shown, by assuming half-integral quantized values for the angular momentum J of the rotating body (*i.e.* $J = \frac{1}{2}n\hbar$), that the mass of the body cannot be less than

$$M = \left(\frac{\hbar c}{2G_f}\right)^{\frac{1}{2}} = 1.6 \cdot 10^{-24}\ \text{g}\,, \tag{6}$$

where G_f is the strong (f) gravity coupling. Thus given the coupling constant G_f one could understand why the lowest baryon mass is of the order of the proton mass. Further, noting [8] that the proton-electron mass ratio is roughly g^2/e^2, where $g^2/\hbar c \approx 14$ is the dimensionless coupling constant for the strong interactions and $e^2/\hbar c$ is the electromagnetic fine-structure constant, gives an interesting relation between the coupling constants for strong gravity and strong interactions, *i.e.*

$$g = \left(\frac{\hbar c}{2G_f}\right)^{\frac{1}{4}} \frac{e}{\sqrt{m_e}}\,, \tag{7}$$

m_e being the electron mass.

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(6) C. Sivaram and K. P. Sinha: *Lett. Nuovo Cimento*, **10**, 227 (1974).
(7) C. Sivaram and K. P. Sinha: *Pramana* (*Phys. Journ. Ind. Acad. Sci.*) (1974) (in press).
(8) C. Sivaram and K. P. Sinha: to be published.