Interaction weaker than gravitational in an induced quantum gravity

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An explanation based on an induced quantum gravity is proposed for an interaction weaker than gravitational.

Data from recent gravimetric measurements (see the review by Fischbach *et al.*[1]) show that at short range a Newtonian potential must be modified:

$$V(r) = \frac{G_N m_1 m_2}{r}(1 - \alpha \exp(-r/\lambda)), \qquad (1)$$

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where $\lambda \approx 200$ m and $\alpha \approx 0.0075$. The Yukawa term of potential (1) is associated with vector fields whose origin has been unclear.[2] In this letter we offer an explanation for potential (1) on the basis of the concept of an induced gravity. An approach to the Einstein action as the effective action of nongravitational fields was proposed in Ref. 3 and developed in Ref. 4. The idea of treating an induced quantum gravity as a theory of bound states of fundamental prefermions was formulated in Ref. 5, where a study was made of an effective action for the longest-range scalar component of the gravity, which is associated with a violation of gauge invariance. We show below that the following component—the vector component—which arises in a natural way in an induced quantum gravity makes it possible to drive potential (1).

In the formalism of an induced quantum gravity, the gravitational constant of the Einstein action is expressed in terms of the parameters of the low-energy region, Λ and M (the cutoff parameters for fundamental prefermion fields), and is given by[5] $G_N^{-1} = (\Lambda^2 - M^2)/6\pi$. The Dirac operator in a curved space is

$$\not{D} = -i\gamma^\alpha e^\mu_\alpha (\partial_\mu + {}^1\!/_4\,\omega_{\mu\beta\delta}\gamma^\beta\gamma^\delta) + \mu .$$

As we will see below, the relation $\mu/M \ll 1$ holds. The dynamic mass μ can be related to a condensate of gauge fields:

$$\mathrm{tr}\,\langle V_{\mu\nu} V^{\mu\nu}\rangle = -12\mu(3M\Lambda^2 - M^3) + O(\mu^2) . \tag{2}$$

We are interested in the interactions at distances on the order 10^2–10^5 m. Accordingly, we can ignore the curvature of space-time in the calculations below. The condition that the vacuum energy vanishes then relates the parameters of the low-energy region: $\langle T^\mu_\mu\rangle_0 = [\Lambda^4 - 6\Lambda^2 M^2 + M^4]/8\pi^2 = 0$, where $M = M - \mu$.

To distinguish composite vector degrees of freedom, we perform a transformation of the fundamental prefermion fields:

$$\psi \to e^{\not{\rho}}\psi , \quad \not{D} \to \not{D}_\rho = e^{\not{\rho}}\not{D} e^{\not{\rho}} , \quad \not{\rho} = \gamma^\mu \rho_\mu . \tag{3}$$

We construct a functional which is invariant under transformation (3):

$$Z^{-1}_{inv} = \int D\rho_\mu Z^{-1}_\Lambda (\not{D}_\rho),$$

where Z_Λ is a regularized generating functional of Green's functions of the fields ψ. We then have

$$Z_\psi = Z_\Lambda Z_h = Z_{eff} Z_{inv} Z_h ,$$

where Z_h describes high-energy prefermions, and Z_{inv} is independent of the variables in which we are interested here.

In order to distinguish the low-energy region and describe the low-energy dynamics in terms of the local limits of composite fields, we need to assume the existence of an asymptotically free interaction, which locks the prefermions in these fields. We will not write out this interaction explicitly.

The effective action for a vector field in a Euclidean space is given by

$$W_{eff} = -\log Z_{eff} = -\log\left(Z_{\Lambda}(\not{D})Z_{\Lambda}^{-1}(\not{D}_{\rho})\right). \tag{4}$$

The quadratic terms in (4) can be evaluated. Using (2) and the relationship between the parameters of the low-energy region, and carrying out a continuation into Minkowski space, we find the following results from these quadratic terms:

$$L = -\frac{1}{2\pi G_N}\rho_{\mu\nu} - \frac{1}{12\pi^2}\operatorname{tr}\langle V_{\mu\nu}V^{\mu\nu}\rangle\rho^2\,, \qquad \rho_{\mu\nu} \equiv \partial_\mu\rho_\nu - \partial_\nu\rho_\mu\,.$$

The kinetic and mass terms have the correct sign ($\operatorname{tr}\langle V_{\mu\nu}V^{\mu\nu}\rangle$ is negative definite). For the mass of the vector field we have

$$m_\rho^2 = -\frac{G_N}{6\pi}\operatorname{tr}\langle V_{\mu\nu}V^{\mu\nu}\rangle\,. \tag{5}$$

A lower limit on m_ρ can be found by considering only a gluon condensate in (5): $\langle G^a_{\mu\nu}G^{a\mu\nu}\rangle \approx (380\text{ MeV})^4$. We then have $m_\rho \geqslant 1.5\times10^{21}$ GeV and an interaction radius $\lambda \leqslant 1.6\times10^5$ m. This interaction is mediated by vector particles and is of the nature of a repulsion. To obtain $\lambda \sim 200$ m, we should take $\langle V_{\mu\nu}V^{\mu\nu}\rangle$ $(10\text{ GeV})^4$; this figure is close to the scale value of the electroweak theory.

Let us consider the interaction of a vector field with matter. The effective low-energy Lagrangian contains a mass term $m\bar{\varphi}\varphi$ of the fields of the matter which consist of prefermion fields. Taking transformation (3), we find the interaction $2mq\bar{\varphi}\not{\rho}\varphi$, where q is the effective ρ_μ charge of the field φ. Making use of the normalization of the kinetic term of the field ρ_μ, we find the coupling constant $2G_N^{1/2}m\pi^{1/2}q$. To find potential (1) we should take $q\sim0.1$. The interaction is proportional to the mass, and not to the hypercharge. The fact that potential (1) is proportional to the mass is evidence of a gravitational origin of the "fifth force."[6]

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