FEEBLE FORCES AND GRAVITY[*][†]

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Abstract

We develop a scenario in which feeble intermediate range forces emerge as an effect resulting from the compactification (a la Kaluza-Klein) of multidimensional theories. These feeble forces compete with gravity and in general permit different bodies to fall to Earth with different accelerations. We show that these feeble forces are mediated by vectors (V) and/or scalars (S), whose dimensionless coupling constants are typically of order

$$g_V \approx g_S \approx 10^{-20}.$$

Under certain plausible assumptions the ranges of these feeble forces are expected to be of order 1 metre to 1 kilometre. It is conjectured that the general strategy will prove applicable to realistic multidimensional theories such as the ten dimensional superstring theories. We speculate that deviations from the standard gravitational force - similar to the ones reported recently as a "fifth force" - may be interpreted as evidence for higher dimensions.

Recently Stacey [1] and Fischbach et al [2] reported evidence for a "fifth force". It is by now clear that the analysis advanced by Fischbach et al is at least partially defective [3]. Nevertheless, we have become convinced that there are good theoretical reasons to expect forces similiar to the "fifth force" as remnants of higher dimensions [4].

In our theory the origin of these forces is higher dimensional gravity. Nonetheless, after compactification to four dimensions they would appear to modify the gravitational force that the Earth exerts and provide deviations from Newtonian gravity. Thus Galileo's experiment, if repeated with sufficient accuracy, would show differences in the "gravitational" accelerations of different bodies containing differing kinds of atoms. Despite this there would exist only one type of gravity when viewed from the "unified" higher dimensional viewpoint.

The most puzzling aspect of the interpretation suggested in ref. [2] is the range and the tiny coupling constant of the "fifth force". The interparticle potential may be parameterized by

$$V = \frac{Gmm'}{r} \pm \frac{g^2 hc}{4\pi} \cdot \frac{BB'}{r} \cdot \exp(-r/R).$$

For a range of R $\approx$ 200 metres, the apparently inconsistent geophysical [1] and Eötvös [2] data suggest g $\approx$ 2•3x10^{-20} (−) and g $\approx$ 9•4x10^{-20} (+) respectively.

At first sight there is no natural theoretical explanation for such feeble forces. Although it is straightforward to extend the standard SU(3)xSU(2)xU(1) model by adding an extra U(1) that couples to matter in the desired manner, the smallness of the coupling g cannot naturally

be understood within the framework of grand unification. We propose a scheme whereby intermediate range forces akin to, but not quite the same as, the "fifth force" emerge as compelling theoretical concepts within the most interesting modern theories of fundamental physics, the Kaluza-Klein theories.

In early stages of our work Scherk's paper [5] provided us with some guidance. However, his mechanism for generating a coupling between the Kaluza-Klein vector boson and light fermions (masses via dimensional reduction) is inconsistent with modern compactification ideas, and in any case suggests an unrealistic compactification scale (100 fermi) for fitting to a small g.

We consider a toy model in five dimensions that contains five dimensional gravity, Yang-Mills fields, and spinorial matter. The fünfbein, when compactified on a circle, decomposes into a single scalar S (the dilaton), a single vector V, four dimensional gravity, and a tower of massive spin 2 particles ($m_n = nM$). The five dimensional Yang-Mills vector decomposes into a four dimensional Yang-Mills field, a tower of massive adjoint representation vector fields ($m_n = nM$), and a single scalar field in the adjoint representation. The five dimensional spinorial matter decomposes into a tower of four dimensional spinors ($m_n = nM$). Details of the model may be obtained from ref. [4]. Expansion of the five dimensional spinor kinetic energy [i det(E) $\overline{\chi} \not{D} \chi$] yields, in four dimensions:

$$i \det(e) \cdot \overline{\psi} \left[\not{D} - \sqrt{16\pi G} \not{V} D_5 \right] \psi \cdot \exp(\sqrt{4\pi G/3} \, S)$$

$$- \det(e) \cdot \overline{\psi} \left[i \, D_5 \right] \psi \cdot \exp(\sqrt{64\pi G/3} \, S).$$

By giving a vacuum expectation value to the fifth component of the Yang-Mills field ($\langle A_5 \rangle \neq 0$), the spinors acquire mass, vector couplings to V, and scalar couplings to S, with:

$$m = \text{"i } D_5 \text{"} := nM + g\langle A_5 \rangle$$

$$g_V = \sqrt{16\pi G}(\text{"i}D_5\text{"}) = \sqrt{16\pi G}\, m$$

$$g_S = \sqrt{12\pi G}(\text{"i}D_5\text{"}) = \sqrt{12\pi G}\, m$$

Estimating g_V by using an average current quark mass of 8 MeV yields $g_V \approx 1/2 \times 10^{-20}$. The tiny size of this coupling is the most important point of this essay. It is important to emphasize that vector bosons distinguish between particle and antiparticle whereas scalar bosons do not:

$$g_V(\text{antiparticle}) = -g_V(\text{particle}),$$
$$g_S(\text{antiparticle}) = +g_S(\text{particle}).$$

This has the important consequence that we do not expect a net vector coupling to the quark-antiquark ocean that surrounds a current quark, and dresses it to form a constituent quark. Scalars, on the other hand, generically will couple to the ocean. So a first guess is that to estimate g_V we should use current quark masses, whereas to estimate g_S we should use constituent quark masses. This analysis has the further important consequence that the vector coupling to atoms is tightly constrained. Vector bosons will posses no net coupling to the neutral virtual pion cloud that binds the nucleus, nor will vector bosons couple to the virtual photons binding the electrons to the

nucleus. Consequently

$$g_v(atom) = (B-Z)g_v{}^n + Z g_v{}^p + Z g_v{}^e$$

$$= g_v{}^n(B - \epsilon_v Z).$$

Here $\epsilon_v = (g_v{}^n - g_v{}^p - g_v{}^e)/g_v{}^n$; n,p,e stand for neutron, proton, electron respectively. We cannot reliably estimate ϵ_v, but as a first guess current quark masses give $\epsilon_v \approx 1/5$ whereas constituent quark masses give $\epsilon_v \approx 1/1000$.

A minor variation of this reasoning may now be applied to mesons;

$$g_v(meson) = \sqrt{16\pi G}\left(m_{quark} - m_{antiquark}\right).$$

In particular, for the Kaon, $K^0 = (d\bar{s})$, we estimate using $m_d \approx 10$ MeV, $m_s \approx 150$ MeV, that $g_v(K^0) \approx -8 \times 10^{-20}$. The fact that $g_v(K^0)$ is nonzero is enough to guarantee that K^0 and $\bar{K^0}$ couple differently to the classical feeble vector field generated by the Earth. This effect may then lead to anomalous effects in the K_S-K_L system as alluded to in ref. [2].

Turning our attention now to realistic models, we note that the ingredients we required (gravity, Yang-Mills, and spinors) are all present in the ten dimensional superstring theories. We this expect that some variant of the preceeding mechanism would work even for the superstring. Indeed in superstring theory the Weinberg-Salaam "Higgs" is expected to arise as part of the six dimensional "internal" portion of the Yang-Mills field [6]. It is this "Higgs" (with a vacuum

expectation value of order 100 GeV) which is responsible for generating masses for the light fermions. These masses are analagous to our $m = g\langle A_5 \rangle$ while the "Higgs" is analagous to our A_5. The details of such an extension to the superstring theory have not yet been worked out, but we expect some alteration of our estimates for g_v, g_s. For a generic compactification we would expect there to be many feeble vector forces [associated with Killing vectors on the internal manifold]; and many feeble scalar forces [associated with zero modes of the Lichnerowicz operator on the internal manifold].

Finally, we address the question of the range of these feeble forces. Observe that once we have a natural mechanism for obtaining feeble couplings ($g_v \approx g_s \approx 10^{-20}$), we can appeal to electroweak symmetry breaking ($\Lambda \approx 100$ GeV) to generate masses:

$$m_{v,s} \, c^2 \approx g_{v,s} \, \Lambda \approx 10^{-20} \cdot 100 \text{ GeV} \approx 10^{-9} \text{ eV} \approx hc/(200 \text{ metres}).$$

For instance this may be accomplished by a five dimensional Higgs mechanism in the toy model previously considered. Equally well we could appeal to technicolor or to any other electroweak breaking mechanism. There may be competing sources for the masses of the feebly coupled vectors and scalars, but $m \sim 10^{-9}$ eV/c² is a "natural" tree-level estimate.

In conclusion, we have presented what we feel are compelling reasons to expect intermediate range (R $\approx$ 200 metres) feebly coupling ($g \approx 10^{-20}$) vector and scalar forces in nature arising as remnants of higher dimensional gravity. For bulk matter we expect a modified "gravitational" potential:

$$V = \frac{Gmm'}{r} - \sum_V \frac{g_V^2 \; hc}{4\pi} \; \frac{(B-\epsilon_V Z)(B'-\epsilon_V Z')}{r} \cdot \exp(-m_V cr/h)$$

$$+ \sum_S \frac{g_S \; g_S' \; hc}{4\pi r} \cdot \exp(-m_S cr/h)$$

It should also be noted that, once we have accepted the desirability of a number of different feebly coupling scalar and vector fields, the apparent inconsistencies of refs. [1,2,3] can potentially be explained. More experiments are desparately required. Effects such as these feeble forces may be the only hope we shall ever have of experimentally probing the internal manifold of Kaluza-Klein theories. In this connection we mention that the sign of the effect reported by Stacey et al [1] is sufficient to imply the existence of a vector force, thereby rule out the currently popular Calabi-Yau compactification for super-string theories, and require instead a compactification that posesses at least one continuous isometry.

References

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