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# DOES THERE EXIST A GRAVITATIONAL ANALOGUE OF THE ELECTRO-WEAK UNIFICATION?

by

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## Abstract

We examine the idea of the existence of a new short range force mediated by massive spin 2 particles. We propose a model by means of which this force allows an unified description with gravity within the electro-weak SU(2)×U(1) model.


Key-words: Fifth force; Gravity; Unification.

From the detection of light and neutrino of the supernova SN 1987-A one concludes (under some reasonable although model-dependent hypothesis) that if the coupling of the neutrino to gravity is lower than the coupling of photons with gravity by a factor $\xi = 1-B$ then B must be $\lesssim 10^{-3}$.

Even such small possible violation of the Equivalence Principle (EP) of the gravitational interaction of the neutrino has far reaching consequences on the standard description of gravity and correlated interactions. We will examine this problem here and suggest a model to describe it.

Let us, for simplicity, restrict ourselves in this letter to the behavior of leptons – and specifically only to the electron and to its associated neutrino. The case of other leptons goes along a similar argument.

Leptons interact with photons, with the intermediate bosons of the weak interaction and with gravity.

The success of the SU(2)×U(1) unified scheme to describe electro-weak processes induces us to treat electrons and neutrinos by means of an isotopic doublet

$$L = \frac{1+\gamma_5}{2} \begin{pmatrix} \nu \\ e \end{pmatrix}$$

and a singlet

$$R = \frac{1-\gamma_5}{2}\, e$$

The isotopic invariance of the Lagrangian of the standard electro-weak unified scheme imposes that both electron and neutrino must be treated as massless, leaving the mass term of the electron to have its origin later on by means of the spontaneously symmetry breaking process through an isotopic doublet of scalar fields

$$\phi = \begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix}$$

If the Equivalence Principle is not violated in the leptonic world then the interaction of electrons and neutrinos with gravity (represented by the symmetric tensor $\phi^{\mu\nu}$) is made through the energy-momentum tensor $T_{\mu\nu}$. The Lagrangian takes the form

(1)
$$L_{int} = \sqrt{k_E}\left[T_{\alpha\beta}(e) + T_{\alpha\beta}(\nu)\right]\phi^{\alpha\beta}$$
$$= \sqrt{k_E}\left[\bar{L}\gamma_{(\alpha}\nabla_{\beta)}L + \bar{R}\gamma_{(\alpha}\nabla_{\beta)}R\right]\phi^{\alpha\beta}$$

in which $k_E$ is Einstein's constant. We use natural units $\hbar = c = 1$.

Note that once SU(2) is a local symmetry we must deal with vector gauge fields under the form:

(2)
$$i\nabla_\mu L = (i\partial_\mu - \frac{1}{2} g\vec{\tau}.W_\mu + \frac{1}{2} g'B_\mu)\, L$$
$$i\nabla_\mu R = (i\partial_\mu + g'B_\mu)R$$

The gauge fields $\vec{W}_\mu$ and $B_\mu$ are the intermediate bosons of the electro-weak interaction.

The validity of the EP has the consequence that only the identity element of the SU(2) algebra appears in $L_{int}$. In this case only diagonal tensorial "currents" do matter.

However, if the EP is violated and the neutrino coupling to gravity is $\xi$ times the electron coupling to gravity, then an extra tensorial current, represented by $\bar{L}\gamma_{(\alpha}\nabla_{\beta)}\tau_3 L$, appears. Indeed, in this case the interacting Lagrangian becomes

$$(3) \qquad \tilde{\mathcal{L}}_{int} = \sqrt{k_E}\left[T_{\alpha\beta}(e) + \xi T_{\alpha\beta}(\nu)\right]\phi^{\alpha\beta}$$

$$= \sqrt{k_E}\left\{\left(\frac{\xi+1}{2}\right)\bar{L}\gamma_{(\alpha}\nabla_{\beta)}L + \bar{R}\gamma_{(\alpha}\nabla_{\beta)}R + \right.$$

$$\left. + \left(\frac{\xi-1}{2}\right)\bar{L}\gamma_{(\alpha}\nabla_{\beta)}\tau_3 L\right\}\phi^{\alpha\beta}$$

The appearance of the term $T_{\alpha\beta}{}^{(3)} = \bar{L}\gamma_{(\alpha}\nabla_{\beta)}\tau_3 L$ induces automatically the presence of the extra mixing terms $T^{(+)}_{\alpha\beta} = \bar{L}\gamma_{(\alpha}\nabla_{\beta)}\tau^+ L = \bar{e}\gamma_{(\alpha}\nabla_{\beta)}\frac{1+\gamma_5}{2}\nu$ and its hermitian conjugate $T^{(-)}_{\alpha\beta}$, in order to close the algebra of the electro-weak symmetry. These extra terms $T^{(\pm)}_{\alpha\beta}$ cannot couple directly with gravity $\phi^{\mu\nu}$ due to charge conservation. To what quantities do these $T^{(\pm)}_{\alpha\beta}$ couple ? In order to answer this question the most natural way seems to be the introduction of charged spin two fields $\phi^{(\pm)}_{\mu\nu}$. Thus, we are led to conjecture of the existence of a quantity $\phi^{(i)}_{\mu\nu}$ which is a tensor in the coordinate indices and an SU(2) vector in the index (i).

We would like to stress the fact that we do not modify the gauge structure of the theory, because $\phi^{(i)}_{\mu\nu}$ is a true vector of SU(2) and not a connection. In this sense, as we will see, in the present theory gravity is not treated as a gauge field. Although this seems to be an heresy, we will explore this idea here and see what would be the observational consequences of such hypothesis.

Besides $\phi^{(i)}_{\mu\nu}$ it is necessary, as it is transparent from the paradigm of electro-weak unification, to introduce a singlet $\psi_{\mu\nu}$. Now let us turn to the dynamical model of our theory.

The leptonic interacting part of the Lagrangian is given by

$$(4) \qquad L_{(2)} = -\frac{1}{2}\sqrt{k_a}\,\bar{L}\gamma_{(\alpha}\nabla_{\beta)}\vec{\tau}L.\vec{\phi}^{\mu\nu} + \frac{1}{2}\sqrt{k_b}\,\bar{L}\gamma_{(\alpha}\nabla_{\beta)}L\psi^{\alpha\beta} + \frac{1}{1+4\xi}\sqrt{k_b}\,\bar{R}\,\gamma_{(\alpha}\nabla_{\beta)}R\,\psi^{\alpha\beta}$$

in which $k_a$ and $k_b$ are constants with the same dimension as $k_E$.

We redefine the fields $\phi^{(3)}_{\mu\nu}$ and $\psi^{\mu\nu}$ by the rotation

$$(5) \qquad \begin{pmatrix} \phi^{\mu\nu(3)} \\ \psi^{\mu\nu} \end{pmatrix} = \begin{pmatrix} \cos\eta & -\sin\eta \\ \sin\eta & \cos\eta \end{pmatrix} \begin{pmatrix} Z^{\mu\nu} \\ \phi^{\mu\nu} \end{pmatrix}$$

We will identify the gravitational field with the tensor $\phi^{\mu\nu}$.

Then, using this rotation (5) into the Lagrangian (4) and taking into account that the gravitational field $\phi^{\mu\nu}$ couples with the electron by the constant $k_E$ and to the neutrino by $\xi k_E$ one obtains

$$(6) \qquad \cos\eta = \sqrt{\frac{k_a}{k_a+k_b(1-2\gamma)^2}}$$

$$\sin\eta = \sqrt{\frac{k_b}{k_a+k_b(1-2\gamma)^2}}\,(1-2\gamma)$$

with $\gamma \equiv \frac{1}{1+4\xi}$ and

$$k_E = \frac{16\gamma^2\ k_a k_b}{k_a + k_b(1-2\gamma)^2}$$

The kinetic term for the tensors consists on two parts

$$L_{(3)} = L(\vec{\phi}^{\mu\nu}) + L(\psi^{\mu\nu})$$

For our purposes here it is not necessary to explicit neither $L(\vec{\phi}^{\mu\nu})$ nor $L(\psi^{\mu\nu})$. The attentive reader can use either the linearized Lagrangian of spin two field or the complete exact Einstein's non-linear dynamics (see Grischuk et al.) to characterize $L_{(3)}$.

The isotopic doublet $\Phi$ is used to give mass to three of the tensorial fields, leaving gravity $(\phi^{\mu\nu})$ massless. The most economic hypothesis is to consider that the same field that gives mass to the vector bosons of the weak interaction yields mass terms for the new fields.

We thus set

$$L_{(4)} = \left| (\vec{\tau}.\vec{\phi}^{\mu\nu} + \psi^{\mu\nu})\Phi \right|^2 + L(\Phi)$$

Using rotation (5) and the standard spontaneous breaking of symmetry mechanism to yield

$$\Phi = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \lambda + \phi(x) \end{pmatrix}$$

in which $\lambda$ is a constant,
one obtains that the mass of $\phi^{\mu\nu}$ will be null if

$$(\cos\eta + \sin\eta)^2 = 0$$

This will give for the masses of the tensors $\phi^{\pm}_{\mu\nu}$ and $Z_{\mu\nu}$ the values

$$m^2(\phi^{\pm}_{\mu\nu}) = \lambda^2$$

$$M^2(Z_{\mu\nu}) = \lambda^2 \ (\cos\eta - \sin\eta)^2$$

The above model presents a new kind of interaction, of short range (aprox. $5.10^{-4}$ fermi) mediated by massive spin two particles.

In the low energy limit, this force appears as a point-like interaction involving four fermions, with a constant of coupling $k_F$ of the order of

$$k_F = \frac{k_E}{m^2}$$

in which $m = m(\phi^{\pm}_{\mu\nu}) = \lambda \approx 172{,}2$ GeV.

The new force can be characterized thus by the dimensionless number

$$k_F m^4 \approx 3.10^{-32}$$

How could done detect such interaction ?

The simplest way is to put into evidence the existence of the intermediate tensorial bosons. The best way to produce the $Z_{\mu\nu}$ bosons is by colliding $e^+e^-$ beams and look for a resonance effect at energies of the order of the mass M of $Z_{\mu\nu}$.

The cross section for transition to an arbitrary state if the resonance is achieved is given by

$$\sigma = \frac{4\pi.(2s+1)}{4M^2}\,\frac{\Gamma(Z \to e^+e^-)}{\Gamma(Z \to \text{everything})}$$

in which s = 2 and M = 354 GeV.

We find

$$\sigma = 3.10^{-33}\ cm^2 \quad .$$

Although this cross section is only one order of magnitude lower than the corresponding cross section for the production of the vector boson $Z_\mu$, the small value of $k_F$ makes it difficult to perform actual observations in the existing laboratories. Perhaps a more viable way should be the exam of the angular distribution of the reaction products which, due to the tensorial character of the new particles should give

$$\frac{d\sigma}{d\Omega} = (3\cos^2\theta - 1)\ F(\omega)$$

where ω is the total energy in the center of mass system.

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