A Note on the Mass Origin in the Relativistic Theories of Gravity

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Abstract

We investigate the most general Lagrangian in the Minkowski space for the symmetric tensor field of the second rank. Then, we apply the Higgs mechanism to provide the mass to the appropriate components.

The most general relativistic-invariant Lagrangian for the symmetric 2nd-rank tensor is

$$\begin{aligned} \mathcal{L} = &-\alpha_1(\partial^\alpha G_{\alpha\lambda})(\partial_\beta G^{\beta\lambda}) - \alpha_2(\partial_\alpha G^{\beta\lambda})(\partial^\alpha G_{\beta\lambda}) \\ &- \alpha_3(\partial^\alpha G^{\beta\lambda})(\partial_\beta G_{\alpha\lambda}) + m^2 G_{\alpha\beta}G^{\alpha\beta}\,. \end{aligned} \tag{1}$$

It leads to the equation

$$\left[\alpha_2\partial^2 + m^2\right] G^{\{\mu\nu\}} + (\alpha_1+\alpha_3)\partial^{\{\mu|}(\partial_\alpha G^{\alpha|\nu\}}) = 0\,. \tag{2}$$

In the case $\alpha_2 = 1 > 0$ and $\alpha_1 + \alpha_3 = -1$ it coincides with equations of Ref. [1]. There is no any problem to obtain the dynamical invariants for the fields of the spin 2 from the above Lagrangian. The mass dimension of $G^{\mu\nu}$ is $[energy]^1$.

We now present possible relativistic interactions of the symemtric 2nd-rank tensor. They should be the following ones:

$$\mathcal{L}^{int}_{(1)} \sim G_{\mu\nu}F^\mu F^\nu\,, \tag{3}$$
$$\mathcal{L}^{int}_{(2)} \sim (\partial^\mu G_{\mu\nu})F^\nu\,, \tag{4}$$
$$\mathcal{L}^{int}_{(3)} \sim G_{\mu\nu}(\partial^\mu F^\nu)\,. \tag{5}$$

The term $\sim (\partial_\mu G^\alpha{}_\alpha)F^\mu$ vanishes due to the constraint of tracelessness. Obviously, these interactions cannot be obtained from the free Lagrangian (1) just by the covariantization of the derivative $\partial_\mu \to \partial_\mu + gF_\mu$.

It is also interesting to note that thanks to the possible terms

$$V(F) = \beta_1(F_\mu F^\mu) + \beta_2(F_\mu F^\mu)(F_\nu F^\nu) \tag{6}$$

we can give the mass to the G_{00} component of the spin-2 field. This is due to the possibility of the Higgs spontaneous symmetry breaking [2]

$$F^\mu(x) = \begin{pmatrix} v + \partial_0\chi(x) \\ g^1 \\ g^2 \\ g^3 \end{pmatrix}\,, \tag{7}$$

with v being the vacuum expectation value, $v^2 = (F_\mu F^\mu) = -\beta_1/2\beta_2 > 0$. Other degrees of freedom of the 4-vector field are removed since they can be interpreted as the Goldstone bosons. It was stated that "for any continuous symmetry which does not preserve the ground state, there is a massless degree of freedom which decouples at low energies. This mode is called the Goldstone (or Nambu-Goldstone) particle for the symmetry". As usual, the Higgs mechanism and the Goldstone modes should be important in giving masses to the three vector bosons. It is interesting to note the following statement (given without references in wikipedia.org): "In general, the phonon is effectively the Nambu-Goldstone boson for spontaneously broken Galilean/Lorentz symmetry. However, in contrast to the case of internal symmetry breaking, when space-time symmetries are broken, the order parameter need not be a scalar field, but may be a tensor field, and the corresponding independent massless modes may now be fewer than the number of spontaneously broken generators, because the Goldstone modes may now be linearly dependent among themselves: e.g., the Goldstone modes for some generators might be expressed as gradients of Goldstone modes for other broken generators." As one can easily see, this expression does not permit an arbitrary phase for F^μ, which is possible only if the 4-vector would be the complex one.

Next, due to the Lagrangian interaction of fermions with notoph are of the order e^2 since the beginning (as opposed to the interaction with the 4-vector potential A_μ), it is more difficult to observe it. However, as far as I know the theoretical precision calculus in QED (the Landé factor, the anomalous magnetic moment, the hyperfine splittings in positronium and muonium, and the decay rate of o-Ps and p-Ps) are about the order corresponding to the 4th-5th loops, where the difference may appear with the experiments [3, 4]. Please see the theory of teh 4-vector field in REf. [5].

References

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