One Good Reason Why Not The Higgs

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Abstract

This is a sceptical appreciation of the Higgs solution for providing mass to the fundamental particles within the gauge theory description in the standard model. My reasoned scepticism about the success of the Higgs search at LHC and elsewhere is based on my conviction that the standard model that does not include gravity will not reveal the origin of the charge of gravity. The essential point is that interaction-induced inertia is not the same as the charge of gravity and to qualify as mass it has to play the dual role of inertia and the gravitational charge. The final picture should respect the equivalence principle, at least approximately. Some imperfect analogy with another context of effective mass of the dressed electron in condensed matter is pointed out to support the scepticism.

There are very good reasons for particle physicists to search for the Higgs particle. Observed fundamental particles are not massless and the gauge theory description has been very successful so far. A simple mechanism that provides mass from an interaction with a new field is very attractive and desperately needed to progress further with such a theory. Standard model jigsaw puzzle is almost solved except for the position of that crucial piece, which in most physicists' minds is a matter of time and luminosity.

Perhaps the outcome is not that obvious. There is a real good reason why the actual physical situation could be far from what the standard model describes. This can be raised in a straightforward way by noting that the

Higgs mechanism should be attempting to explain the origin of the charge of gravity and not just the origin of inertia. As we will see later, even though it is obvious that an interaction can generate and modify inertia, and slow down dynamics, it is not possible to logically link the resulting inertia to the source of gravity. Since the standard model does not include gravity as one of the fundamental interactions it describes, there is good likelihood that it is not yet capable of addressing the issue of the origin of the charge of gravity and hence the origin of mass. Let us examine this scepticism in some detail now.

In field theories that preserve gauge invariance, the fundamental particle fields have to start off as massless fields. Clearly, a mass term in the Lagrangian for the vector field itself, of the form $m^2 A_\mu A^\mu$ is not gauge invariant. Without repeating much of the technicalities that most people are aware of, let us look at the essential idea [1]. When there is a coupling between a massless field ϕ another massless vector field A_μ with coupling constant e, the derivative momentum operator is modified to $\partial_\mu \rightarrow D_\mu = \partial_\mu + ieA_\mu$. This structure preserves the gauge invariance under local phase transformation on the field, $\phi'(x) = \exp(-i\alpha(x))\phi(x)$, when the vector field transforms as $A'_\mu(x) = A_\mu(x) + (1/e)\partial_\mu \alpha$. However, the Lagrangian density for the two fields now contains the quadratic term $(D_\mu \phi)^2$. Since the derivatives are modified by the vector field into

$$\partial_\mu \phi \rightarrow \partial_\mu \phi + ieA_\mu \phi \tag{1}$$

the Lagrangian density will contain terms of the form,

$$(D_\mu \phi)^2 = \partial_\mu \phi \partial^\mu \phi + e^2 A_\mu^2 \phi^2 \tag{2}$$

The second term defines a mass for the vector field $m^2 = e^2 \langle \phi^2 \rangle$ if the vacuum expectation value of the scalar field $\langle \phi^2 \rangle \neq 0$. This is one part of the Higgs mechanism that gives mass to the vector field. The other part of the mechanism is how to provide a relatively stable non-zero $\langle \phi^2 \rangle$ to the scalar field ground state. This is done by a potential for the scalar field, $V(\phi) \sim \mu \left(\phi^2 - \phi_0^2\right)^2$ which is double-well shaped after a spontaneous symmetry breaking at sufficiently low 'temperature', and the ground state of the scalar field will be in the minimum, ϕ_0 which also provides a mass to the scalar field $m_\phi = 2\sqrt{2\mu \langle \phi^2 \rangle}$. Indeed, there is the example of superconductivity, the context in which the idea originated [2], where the electromagnetic field acquires 'mass' $\left(e^2 \left|\psi\right|^2 /2m\right)^{1/2}$ by interacting with the condensate 'scalar field' with density $\left|\psi\right|^2$, leading to screening.

For fermionic Dirac fields with handedness, the difficulty with the mass term in the Lagrangian for the field is different in detail, though associated with gauge invariance. However, a Yukawa coupling g of the Dirac field with the scalar field with its non-zero vacumm expectation value $\langle\phi^2\rangle \neq 0$ gives the mass $g\sqrt{\langle\phi^2\rangle}$ to the Dirac particle as well [3].

Higgs mechanism is a simple and very attractive way of generating inertia to motion from interaction. In fact, most people who explain the Higgs mechanism to audience outside formal particle physics do use the analogy of multiple interactions with a 'field' of particles (or people) slowing down the natural free motion of a test particle (a 'famous' person), even though the same 'forces' are acting. Essentially, the inertia of the Higgs field, by virtue of its self interaction potential being a minimum at a non-zero value of the field, is manifest in any other massless field that couples to the Higgs field, in proportion to the coupling strength between the two fields.

Now we ask the crucial question. Is this the 'mass' we really need to build the world with massive elementary particles, as we observe today? Or is it that we are confusing interaction-induced inertia to dynamics as 'mass' because both terms are identified in the context of free particle dynamics? It turns out that we have a good criterion to decide this because mass plays the dual role in physics as inertia to motion and as the charge of gravity. The weak equivalence principle is based on the observed universal ratio of the (approximately) *localized* inertial and gravitational masses in free particle dynamics in a gravitational field. However, interaction-induced inertia need not generate equivalent gravity as we now argue from a familiar example. Then, such inertial mass does not have a true gravitational mass counterpart and hence cannot be the true physical mass. The criterion of the source of gravity being localizable within a compact spatial region is also important to qualify as the gravitational mass, when nonlinear source terms associated with the gravitational field itself can be ignored. The mass of the nucleon arising out of interactions between the quarks seem to satisfy this criterion and provides an example of the mass arising from an interaction, but both inertia and the gravitational mass localized within a compact spatial region. In contrast, localizability is not a strict criterion when we consider inertia. However, I do not discuss this important point further because it requires a more rigorous quantitative discussion.

We do have a familiar physical situation, though imperfect as analogy, of interaction-induced inertia in condensed matter systems that dresses the electron with interaction from the lattice to provide an effective mass that could be very different in magnitude and even sign from the bare mass of the electron. However, the tricky and crucial point now is whether the mechanism can generate a property that has to play the dual role of inertia (inertial mass) and the charge of gravity (gravitational mass) with *complete* equivalence and universality, as demanded by the weak equivalence principle. It is this stringent requirement that supports valid scepticism about the Higgs mechanism as the real solution to the mass problem.

In condensed matter, the modification to bare mass of the electron is due to interactions with the crystal lattice and other electrons, impurities etc. Denoting the external force as F_e and the internal forces F_i, the dynamics is determined by

$$\vec{a} = \left(\vec{F}_e + \vec{F}_i\right)/m \tag{3}$$

As the inertial response to the external field, the effective mass m^* is then defined by

$$\vec{a} = \vec{F}_e/m^* \tag{4}$$

Thus, the effective mass depends on the details of the internal forces. More correctly, the inertial mass is obtained from the equation of dynamics, which is the Schrodinger equation, or from the de Broglie relations, and we have

$$a = \frac{1}{\hbar^2}\left(\frac{\partial^2 E}{\partial k^2}\right)\hbar\left(\frac{dk}{dt}\right) = \left(\frac{dp}{dt}\right)\frac{1}{\hbar^2}\left(\frac{\partial^2 E}{\partial k^2}\right) \tag{5}$$

$$m^* = \hbar^2\left(\frac{\partial^2 E}{\partial k^2}\right)^{-1} \tag{6}$$

Examining condensed matter systems, especially the heavy fermion systems [4], the effective mass of the electron (or hole) could even be a 1000 times larger than its bare mass, making its inertia formally comparable to that of a free nucleon. It can even be strongly temperature dependent. However, the gravitational field generated by such an electron is not enhanced by this mechanism in proportion. In fact, the *effective mass of an electron in a solid can be negative or even diverge in magnitude*, without any gravitational signature, signifying that the inertia generated by interaction in that case is only a pseudo-mass without a gravitational implication. It is true that there is no high precision experiment that checked whether the weight of a sample of heavy fermion material would change by some small amount, exceeding the sum of the partial weights of the ingredients. Even if only a small fraction of all electrons are behaving as heavy fermions, with an effective mass of $1000m_e$, it is not difficult to check whether it corresponds to a gravitationally weighty effective mass. However, the dressing mechanism suggests that we do not expect a correspondingly large contribution to the gravitational mass, either active or passive. This fact immediately instructs us to be cautious about any scheme that merely provides inertia in the sense of enhanced reluctance to free motion, without generating enhanced gravitational field. Since the standard model without incorporating gravity does not contain a formalism to check whether the inertia gained in the Higgs mechanism generates gravity, we have to be content with reasonable and strong scepticism, based on such analogies, and conclude that it is unlikely that the Higgs mechanism is the real reason why particles have a gravitational mass. Any mechanism that cannot endow particles with charge of gravity does not qualify as a mechanism that gives 'mass'. Inertia that does not contribute its full gravitational equivalence is not true mass. Gravitational mass is more fundamental than inertial mass and the hard task of the theory is to explain the origin of the gravitational mass.

Over the past few years during which I have been expressing this scepticism, the experimental scenario has progressed a lot, and the results from LHC so far has perhaps strengthened the scepticism, even to the point of speculating that the Higgs particle as the mass-giver will not be found. (This does not rule out finding some other unexpected new scalar particles in the future runs of such machines, of course). On the other hand, if the Higgs particle with the right properties and ability to induce gravitational mass is found, that would not only rank among the greatest of ideas about real nature, but also indicate a most valuable clue about incorporating gravity in the standard model of particle physics.

References

[1] Most standard text books on particle physics or field theory contain a detailed description of the elementary aspects of the Higgs mechanism. See for example, 'Particle Physics: A comprehensive introduction', A, Seiden (Pearson Education/ Addison-Wesley 2005).

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