Lorentz's Electromagnetic Mass: A Clue for Unification?

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We briefly review in the present article the conjecture of electromagnetic mass by Lorentz. The philosophical perspectives and historical accounts of this idea are described, especially, in the light of Einstein's special relativistic formula $E = mc^2$. It is shown that the Lorentz's electromagnetic mass model has taken various shapes through its journey and the goal is not yet reached.

Keywords: Lorentz conjecture, Electromagnetic mass, World view of mass.

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Introduction

The Nobel Prize in Physics 2004 has been awarded to D. J. Gross, F. Wilczek and H. D. Politzer [1,2] "for the discovery of asymptotic freedom in the theory of the strong interaction" which was published three decades ago in 1973. This is commonly known as the Standard Model of microphysics (must not be confused with the other Standard Model of macrophysics - the Hot Big Bang!). In this Standard Model of quarks, the coupling strength of forces depends upon distances. Hence it is possible to show that, at distances below 10^{-32} m, the strong, weak and electromagnetic interactions are "different facets of one universal interaction"[3,4]. This instantly reminds us about another Nobel Prize award in 1979 when S. Glashow, A. Salam and S. Weinberg received it "for their contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including, inter alia, the prediction of the weak neutral current". In this connection we can also mention the theories of the unification of electricity and magnetism by Maxwell, and that of earth's gravity and universal gravitation by Newton.

Problems

Then, what is left of the unification scheme? Though there has been much progress towards a unification of all the other forces - strong, electromagnetic and weak - in grand unified theory, gravity has not yet been included in the scheme.

The hierarchy problem

There are, of course, problems with gravity in the sense that unlike other interactions it has some peculiar properties which do not match with some standards of unification, e.g., the strength of the gravitational interaction which is enormously

Table 1: Fundamental forces

Interaction	Relative magnitude	Behavior	Carrier particle
Strong nuclear force	10^{40}	$1/r^7$	gluon
Electromagnetic force	10^{38}	$1/r^2$	photon
Weak nuclear force	10^{15}	$1/r^5 - 1/r^7$	gauge boson
Gravitational force	10^0	$1/r^2$	graviton

weaker than any other force (Table 1). This is the hierarchy problem. Probable answer to this, according to the higher dimensional theories, involves leaking of gravity into the extra dimensions.

The field theoretical problem

The most prominent theory of gravitation, Einstein's general relativity, does not consider gravity as a force, rather as a kind of field for which a body rolls down along the space-time curvature according to the equations

$$R_{ij} - \frac{1}{2}g_{ij}R = -\kappa T_{ij}, \tag{1}$$

where the left hand part represents the space-time geometry while the right hand side is the energy-momentum tensor. The field theoretical effect as described by Wheeler is as follows: "Matter tells space-time how to bent and space-time returns the complement by telling matter how to move." This, gravitational field, due to its intrinsic property, is difficult to blend with other forces of nature.

The 'electromagnetic mass' model

The study of electromagnetic mass with a century-long distinguished history, can be divided into three broad categories - classical and/or semi-classical, quantum mechanical and general relativistic. The classical period was started by Thomson. It was followed by Abraham, Lorentz, Poincaré and ended by Richardson.

The classical theory

In this context we can look at the conjecture of Lorentz [5] where he termed the electron mass as 'electromagnetic mass' which does not possess any 'material mass' and thus thought about a phenomenological relationship between gravitation and electromagnetism as long as one hundred years ago!

It may be a mere coincidence that in the same centenary year of 'electromagnetic mass' model of Lorentz related to electron-like extended charged particle (i.e. one of the members of lepton) Nobel Prize has been awarded to the quark-based Standard Model. According to this Standard Model of particle physics leptons and quarks are the building blocks of all the matters. So, here one can see some glimpses of hope for new unification schemes though it should be kept in mind that while Standard Model calculation is a quantum mechanical one Lorentz's treatment is purely classical.

In the classical point of view Lorentz tried to tackle the problem of the electrodynamics of moving bodies. His apparent motivation was to solve the null result of Michelson-Morley experiment keeping the existence of ether as it is. Actually, his motivation was much deeper as he wanted to represent an *elec-*

tromagnetic world view in comparison to the Maxwellian electromagnetic theory. Based on this philosophy Lorentz [6] developed his Theory of Electron in 1892. For this he was awarded Nobel Prize in Physics in 1902 along with his student Zeeman who verified the theory in the presence of magnetic field. The main hypothesis of the theory, in the language of Lorentz [5], is as follows: "I cannot but regard the ether, which can be the seat of an electromagnetic field with its energy and its vibrations, as endowed with a certain degree of substantially, however different it may be from all ordinary matter". Thus, he considered the electric field vector $\vec{E}$ and magnetic flux density vector $\vec{B}$ in this absolute ether frame and obtained

$$\vec{F} = q[\vec{E} + (\vec{v} \times \vec{B})/c]. \tag{2}$$

This electromagnetic field and hence, in turn, force is generated by the charged particles, like electrons. According to Einstein [7], "It is a work of such consistency, lucidity, and beauty as has only rarely been attained in an empirical science". In this way Lorentz tried to provide a complete theory of all electromagnetic phenomena known at that time. Obviously, his new task was to investigate the electrodynamical character of moving bodies under this framework of his electron theory. As a further development of the theory Lorentz obtained the transverse mass (actually the relativistic mass) for electron in the form

$$m = \frac{e^2/6\pi a c^2}{\sqrt{1 - v^2/c^2}}, \tag{3}$$

where e is the electronic charge, a it's radius, v is the velocity with which electron is moving and c, the velocity of light.

According to this theory, the spherical electron would experience an ellipsoidal change in it's shape while it is in motion. In a straight forward way, the relation yields the electric field dependent mass (actually the rest mass) as

$$m_{em} = \frac{e^2}{6\pi ac^2} = \frac{4}{3}\frac{U}{c^2}, \tag{4}$$

where $U[= e^2/(8\pi ac^2)]$ is the electrostatic energy.

Certainly, this relation unifies gravitation with electromagnetism meaning that if someone just takes out electromagnetic field then no gravitational field counterpart will be left for that observer! For this unique result the reaction of Lorentz [5] was: "*... that there is no other, no "true" or "material" mass*" and thus through Lorentz the concept of 'electromagnetic mass' was born. However, historically we should mention that even before Lorentz there were other notable scientists too, who had expressed the idea of electromagnetic mass in their works. Firstly, J. J. Thomson [8] who, even in 1881, believed in the idea of "electromagnetic inertia". In this context Richardson [9] wrote, "For it opens up the possibility that the mass of all matter is nothing else than the electromagnetic mass of the electrons which certainly form part, and perhaps form the whole, of its structure." Secondly, Abraham [10] arrived, from a different point of view, at the same concept that the mass of a charged particle is associated with its electromagnetic character. But his theory ultimately suffered from some serious drawbacks, mainly due to the idea of rigid structure of electron, which does not follow the Fitzgerald-Lorentz contraction.

However, at this time Poincaré, with the aim of overcoming the instability and inconsistency of Abraham's model to the special relativistic Lorentz transformations, provided a mechanism to hold the charges together by assuming the existence of non-electromagnetic cohesive forces. On the other hand, Richardson published an advanced level textbook - The Electron Theory of Matter - in 1914 based on a course of lectures at Princeton. Richardson [9] had such a strong belief in the idea of "electromagnetic mass" that in his book he defined electron as a particle consisting "of a geometrical configuration of electricity and nothing else, whose mass, that is, is all electromagnetic." Here we would like to quote from an editorial note of Nature [11] reporting the 1928 Nobel prize to Richardson: "Richardson's "Electron Theory of Matter" is also well known to students of electricity and atomic physics, and although published between the advent of the Bohr and the Wilson-Sommerfeld theories of the atom and with a strong classical bias, is still much used." However, the classical bias and trail was always there and even now exists through the re-examination of, basically, the Abraham-Lorentz model to account for the factor of 4/3 in the electromagnetic mass expression [12,13]. This was initiated by 21-years-old Fermi [14] whose belief in "the concept of electromagnetic mass" was related to a far-reaching aspiration that, "It is the basis of the electromagnetic theory of matter". Therefore, he solved the 4/3 factor, being motivated by "the tremendous importance" of the problem, related to the discrepancy between the Lorentz's electromagnetic mass equation (3) and the Einstein's mass-energy equivalence $E = mc^2$. Surprisingly enough, this important work did not receive its due recognition till 1965 [15]!

The quantum mechanical description

The main drawback of electromagnetic mass idea was, therefore, lying in the fact that the approach was either purely classical or special relativistic semi-classical and hence lacked a quantum mechanical description. However, there were attempts to compute the electromagnetic mass in quantum theory of electron, particularly, by Weisskopf [16] who obtained it as a result of field reaction. The process as described by Tomonaga [17] is like this: "The electron, having a charge, produces an electromagnetic field around itself. In turn, this field, the so-called self-field of the electron, interacts with the electron." This interaction is called by Tomonaga [17] as the field reaction. He goes on to describe the process: "Because of the field reaction the apparent mass of the electron differs from the original mass. The excess mass due to this field reaction is called the electromagnetic mass of the electron and the experimentally observed mass is the sum of the original mass and this electromagnetic mass." But here also the problem was related to the infinite mass due to point-size electron. This is the well known self-energy problem and Lorentz solved it, apparently, assuming that the electron is of finite size. Many scientists have tried to incorporate this extended electron into the relativistic quantum theory but failed anyway. Actually, quantum mechanics treats electron as a point-like charged particle with spin and hence extended electron could not be accommodated within it. In that sense, it seems that instead of describing the electron structure in general relativity based Einstein-Maxwell space-time either Einstein-Cartan-Maxwell or Einstein-Maxwell-Dirac space-time will be much meaningful [18], as far as spin is concerned. However, we'll come again to the quantum aspect with a different viewpoint.

The general relativistic approach

The first remarkable general relativistic approach towards an electromagnetic mass was possible due to Einstein [19]. To overcome the drawbacks of Mie's theory Einstein proposed a formalism where gravitational forces would provide the necessary stability to the electron and also the contribution to the mass would come from it. Using his well known equation (1) in a modified way

$$R_{ij} - \frac{1}{4} g_{ij} R = -\kappa T_{ij}^{(em)}, \tag{5}$$

he obtained the result: "... of the energy constituting matter three-quarters is to be ascribed to the electromagnetic field". This obviously does not fully agree with the conjecture of Lorentz. One possibility of such discrepancy may be due to the consideration of non-electromagnetic origin of the self-stabilizing stresses [20].

Then, after a long silence of six decades investigations again started mainly in the 1980's (except some scattered work even in 1960's and 1970's) and a lot of papers have been published in a coherent way by several people highlighting different properties of the models. In a nutshell, the first and foremost character is that, unlike Einstein's result the total mass of the charged particle is of electromagnetic origin. The other general properties are: (1) "vacuum fluid" obeying an equation of state, $\rho = -p$, is taking definite role for the construction of the model [21,22]; (2) "negative mass" in the central region of the source is needed to maintain the stability against the repulsive force of Coulomb [23,24,25]; (3) "repulsive gravitation" produced by the negative mass of the polarized vacuum is connected to the Poincaré stress [26]. Of course, there are some exceptions of these general properties where even without employing "vacuum fluid" equation of state one can construct a stable model with electromagnetic mass [27]. On the other hand, there are also evidences in the literature that "negative mass" is not an essential ingredient of the models [28]. An interesting extension of these type of models is that they, under suitable mathematical manipulations, not only yield astrophysically important Weyl-Majumdar-Papapetrou class of static charged dust sources [29,30] but also Raissner-Nordström-Curzon field [31], Lane-Emden model [20,32] and even Tolman-Bayin solutions [33].

The world view of mass

The special relativistic world view

Let us now look at the electromagnetic mass model through the broad window of special relativistic mass-energy relation $E = mc^2$. The idea expressed, via $m = E/c^2$, is that mass which has been commonly referred to as "quantity of the permanent substance of matter" is a kind of "trapped" energy of any type, e.g., rest, kinetic or heat energy as it is transferable one. Thus, comparison of this mass expression of Einstein with that of equation (3) of Lorentz shows that regardless of its origin mass must depend on velocity. Then, in one way or another, Lorentz's conjecture now takes different meaning with a deep root where "electromagnetic mass" is emerging into a mass which has a *global* character.

The quantum mechanical world view

On the other hand, the singularity or self-energy problem in Lorentz's model according to the modern quantum mechanics can be better explained by quantum fluctuations and also contribution of electric field energy of an electron to its total mass can be shown to be a small part. "Thus Lorentz's dream, in its original form, is not realized" - Wilczek [34] put the things in this way. In view of this, let us now see the *quantum mechanical world view* of mass. The quantum electrodynamics (QED) of Standard Model of particle physics, where chiral gauge symmetry plays an important role, works without any mass parameter. On the other side, in the quantum chromodynamics (QCD) of Standard Model, quarks and gluons are thought to be the building blocks of protons and neutrons like all the hadrons. These hadrons contribute more than 99% mass to the ordinary matter. The truncated QCD (or QCD Lite), which deals with only the up-down quarks and colour gluons, do not attribute any mass to these entities. These energetic but massless quarks and gluons, therefore, give rise to masses of the protons and neutrons through their quasi-stable equilibrium states. In the similar way, the mass of electron can now be regarded as excitation of an electron field of an infinite ocean of zero point energy of vacuum. Thus, in quantum mechanics field or energy becomes the primary one whereas mass is the secondary quantity. There is somewhat favorable evidence of this in the macrocosm also. The contribution of ordinary matter, dark matter and dark energy to the whole volume density of the Universe, respectively, are about 3%, 30% and 67%. Perhaps, this huge dark energy, which provides repulsive gravitation and has some underlying relationship with that of vacuum energy of space [25], is responsible for the present acceleration in the expanding Universe.

Experimental status

So, we have travelled a very lengthy and jig jag path of classical, quantum and relativistic realm to get familiar with Lorentz's conjecture about 'electromagnetic mass" – its past and present. On the way we have seen so many ups and downs, flash and patch: we enjoyed it and were frustrated as well. All these, at least, theoretically seem to be very sound. But unless experimental evidences support it nobody would know the fate of this beautiful conjecture on the unification of gravitational and electromagnetic interactions. Of course, indirect evidence is there in favor of this conjecture with respect to the transverse mass (actually, relativistic mass in equation (3)) effect by Bucharer [35]. He verified the incorrect results (rather interpretation of the results) of Kaufmann [36] following the idea of Planck [37]. However, some direct experiments are to be performed regarding gravitational or inertial mass, which was thought to be of electromagnetic character, to obtain more conclusive results as "...these measurements can no longer be regarded as a confirmation of the assumption that all mass is of electromagnetic origin" [38].

Conclusions

Here, at the end of our journey, we would like to mention Einstein regarding the aspect of unification who initiated the program "...to find all-embracing laws which unify the whole of the physical world" [39]. Einstein strongly believed that all forces of nature are rooted in gravity. Therefore, he started with a non-Euclidean geometry of space-time following his general relativistic field theoretical approach. But it is now an unfortunate truth that he, along with scientists like Weyl, Eddington, Schrödinger, was not successful in this attempt. On the other hand, Heisenberg believed in the group theoretical approach and thought of unification in the realm of elementary particles. Most probably the infrastructural facilities available at that time and the procedures adopted by these giants were not adequate to solve this sublime problem.

What is then the best tool for searching *THE ONE*? Is it relativity – both the special and general at the same time or quantum mechanics with its variants or mixture of special relativity with quantum mechanics or general relativity with quantum mechanics or superstring theory as one of the candidates of the so-called *theory of everything*? So many paths and possibilities are ahead of the scientists – but nobody knows which one is the most acceptable wayout for solving the long lasting problem. In this respect the comment by Born [40] seems appropriate to quote: "Whether one or the other of these methods will lead to the anticipated "world law" must be left to future research." Or equally may also quote Feynman [41]: "...may be all the mass of an electron is purely electromagnetic, maybe the whole 0.511 Mev is due to electrodynamics. Is it or isn't it?" If the answer is yes, then classical and general relativistic version of *electromagnetic* mass will take important role for unification-goal and if it is negative then quantum and special relativistic version of *transcendent* mass will be established. So, one has to take the 'wait and watch' policy here as time only can test and tell the truth.

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