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Some Facts for Relating Electromagnetic Field and Gravitational Field - A Review

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Abstract

Characteristics of some physical entities like gravity, mass, charge, energy etc. have been discussed. It has been clarified that these lead to the interrelation between electromagnetic field and gravitational field in some way or other. It is shown that on the basis of this interrelationship gravitoelectromagnetic equations could be proposed.

Introduction

In early days when the theory of quantum mechanics was not fully developed, there were two classical field theories – electromagnetic and gravitational. In electromagnetic theory Maxwell unified electricity, magnetism and light. Similarly in general theory of relativity Einstein unified space-time and gravitation. But, what about the unification of electromagnetism and gravitation?

For a long time several workers tried to unify electromagnetic field and gravitational field. So-many papers were published on "gravitoelectromagnetism". But, no satisfactory result , based on experiments, have come out. It is to be mentioned that this sort of trial for unification was stopped for about 60 years. This type of work, again, revived around 1980.

It should be pointed out that there is the grand unified theory which dealt with the fundamental fields (electromagnetic field, strong field and weak field). But gravity has not been included in it due to the fact that strength of gravitational field is too small.

Since 1980, several workers tried to unify electromagnetism and gravity considering different aspects of the two.

In this work trial would be made to discuss some fundamental physical entities. The line of discussion would be to make clear the facts – how these entities interrelate electromagnetism and gravity. These discussions have been presented lucidly in this dissertation. From these discussions one may find in which way the mentioned physical entities interrelates electromagnetism and gravitation.

It should be mentioned that this review may be thought of as a step towards interrelationship between electromagnetism and gravity.

Some fundamental physical entities

Let us discuss some preliminary physical entities related to the problem which shows the relation between electromagnetic field and gravitational field.

1. Concept of gravity

A long standing question is—what is gravity and where does it come from?

The answer is –Gravity is the 4-dimensional interaction.

According to Einstein's theory of general relativity gravity is the curvature of space-time that is produced due to a massive object. Basically, it is a stress energy tensor. Gravity is related to Big-Bang [1].

Einstein's opinion is that [2] all forces of nature are rooted to gravity. Gravitation exists everywhere where there is some space [3] and gets over any substance. It is impossible to imagine space and gravitation separately. The space surrounds us since the whole matter carries gravitational charge of only one sign. This leads to the relation between gravitational charge and gravity.

2. Concept of gravitational charge

We know that the sum potential of the electric field in our space is zero. So, all bodies and space-time as a whole are electrically neutral showing relation between space and electric charge. This is based on two unique properties—

i) Values of electric charge of different signs of elementary particles are exactly equal,

ii) The number of elementary particles which carries electrical charges of different signs are equal.

This shows relation between space and electric charge.

3. Concept of charge and mass

Let us discuss some characteristics of charge and mass as well as their interrelationship.

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What are charge and mass?

We know that charge is an electric phenomenon and mass is gravitational effect. General Theory of Relativity implies that gravity and electromagnetics affect each other. Again, charge itself is an effect of 3-D space and the basic mathematical rule of vectors [4]. It is created by the polarization of the neutral vacuum energy by the force of a vector cross product from the intersection of two waves. Similar to the creation of charge, the creation of mass is a clear example of E= m c^2. So, mass is nothing but energy. When energy is confined to a particle, we detect it as mass.

4. Similarity between charge and mass

We know that the charges are the sources and sinks of electrostatic fields, where the electric field lines emanate from positive charges and terminate at the negative charges. Similarly, in Newton's gravitation masses are the sources of fields so that field lines terminate at objects that have mass. Poisson's equation $\nabla^2\varphi = -\dfrac{\rho}{\varepsilon_0}$ is valid for electrostatic fields where the fields are produced by gradient of scalars. We have formalized Gauss's law for electrostatic fields to be $\iint \boldsymbol{E}.d\boldsymbol{S} = \dfrac{q_e}{\varepsilon_0}$ which gives $\nabla.\boldsymbol{E} = \dfrac{\rho_e}{\varepsilon_0}$ and for masses $\iint \boldsymbol{g}.d\boldsymbol{S} = -4\pi G_c m$ which leads to $\nabla.\boldsymbol{g} = -4\pi G_c \rho_m$ where ρ_e and ρ_m are the charge and mass densities respectively. This arises from the similarity of the form of Newton's law of gravitation and Coulomb's law. Since, the force fields are derived from gradient of potentials, hence

$$\boldsymbol{E} = -\nabla\varphi_e \text{ and } \boldsymbol{g} = -\nabla\varphi_g$$

(1)

So, Poisson's equation for the two cases become

$$\nabla^2\varphi_e = -\frac{\rho}{\varepsilon_0} \text{ and } \nabla^2\varphi_g = 4\pi G_c \rho_m$$

(2)

If there be no source term (i.e. for vacuum or paired charges) these potentials obey Laplace's equation $\nabla^2\varphi = 0$.

Above discussion shows that charge and mass behave similarly.

5. Quantum Mechanical Description

Attempts were made to compute electromagnetic mass in quantum theory of electrons [5] using the field reaction. Now, "the electron having a charge, produces an electromagnetic field around itself. The field, in turn, interacts with the electron." This is termed as " field reaction" [6]. Again, 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 the electromagnetic mass. The first general electromagnetic approach towards electromagnetic mass was due to Einstein [7].

He strongly believed that an electromagnetic mass was possible [8] and that field is in the form of energy-momentum tensor. Here, stability of electron was considered to be due to gravitational forces and the contribution to mass comes from it which speaks about the relation between mass and charge i.e. between electromagnetics and gravity.

6. Correction to mass

By considering vacuum fluctuations of the fields a correction [9] to the mechanical mass has been introduced in quantum electrodynamics or quantum field theory [10]. The observed mass has been expressed as $m = m_0 + \delta m,$ where m_0 is the non-electromagnetic and δm , the electromagnetic mass. Here the radiation reaction of a charged particle or the self-energy of the particle is normally known as the electromagnetic mass of the particle. Classical theory of stochastic electrodynamics believes that the fluctuations of zero-point energy are responsible for the existence of electromagnetic mass of the charged particle. So, the zero-point energy associated with the particle is assumed to give the correction to the mass of the particle. This reveals that charged particles have electromagnetic mass meaning the relation between mass and charge i.e. between gravity and electromagnetism.

7. Quantum Mechanical World View

Quarks and gluons are thought to be the building blocks of photons and neutrons like all the hadrons. These hadrons contribute more than 99% mass to the ordinary matter through their quasi-stable equilibrium states. Similarly, the mass of electron is due to the excitation of an electron field in an infinite ocean of zero-point energy of vacuum. Perhaps the huge dark energy which provides repulsive gravitation and has some underlying relationship with that of vacuum energy of space [10] is responsible for the present acceleration in the expanding universe. Since, excitation of an electron field produces mass, so mass and charge are interrelated which means the interrelationship between gravitation and electromagnetism.

8. Classical Theory of Electromagnetic Mass Model

Lorentz termed electron mass as electromagnetic mass which does not possess any “material mass” and , thus, thought about a relationship between gravitation and electromagnetism.

According to Lorentz theory of electromagnetic fields we come across mass depending on electric field (actually the rest mass) as

$$m_{em} = \frac{e^2}{6\pi a c^2} = \frac{4U}{3c^2} \quad (3)$$

where $U = \dfrac{e^2}{8\pi a}$ is the electrostatic energy. This relation unifies gravitation with electromagnetism. It means that if someone takes out electromagnetic field then no gravitational field counterpart will be left for an observer. It is to note that J.J.Thomson [11], Wilczek [12] believed in the idea of " electromagnetic inertia".

Again, Abraham [13] arrive at the same concept that mass of a charged particle is associated with its electromagnetic character. Richardson [14] defined electron as a particle consisting of a geometrical configuration of electricity and nothing else, whose mass is all electromagnetic. He examined the Abraham-Lorentz model to account for the factor $\frac{4}{3}$ in electromagnetic mass expression [15, 16, 17]. Fermi opined that all the works mentioned here are on the basis of electromagnetic theory of matter.

The result of this is that mass of charged particle is associated with its electromagnetic character i.e. gravity and electromagnetism are interrelated.

9. Properties of electron

Over and above the general properties of electron such as mass, charge etc. there are some other properties of it as mentioned below.

a) Vacuum fluid – Electron behave as a fluid in vacuum also and obeys an equation of state $p = -\rho$ and takes definite result for construction of a model [18, 19],

b) Negative mass – In the central region of the source it is needed to maintain stability against the repulsive force of Coulomb [10, 20, 21]. This requires negative mass.

c) Repulsive Gravitation – It is produced by the negative mass of the polarized vacuum and is connected to the Poincare stress [22].

Of course, there are some models which do not use these properties.

Lorentz's conjecture, now, takes different meanings having deep root where " electromagnetic mass" is emerging into a mass of global character. Lorentz also showed that mass must depend on velocity which may be controlled by magnetic field. It leads to the fact that there is interaction between gravity and electromagnetic field.

10. Unifications

Since, Newton sets the foundation of physics, progress has come mostly in the form of unification [23]. Maxwell unified electricity, magnetism and light into one theory of electromagnetism. Einstein unified space-time and gravity into one theory of general relativity. More recently, the nuclear forces have been (partially) unified with the electromagnetic force by Wienberg and others [24].

The unified field theory accepts a unification of four known fields [25 – 29] viz. gravitational field, electromagnetic field, strong field and weak field. Gravity has not been included in the grand unified theory while others have been. This is due to the fact that gravity has some peculiar properties unlike other interactions. The main fact is that the strength of gravitational interaction is very small. However, the weak and electromagnetic forces were unified by Glashow

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[30], Salam [31], Winberg [32] and others [33,34,35].

This discussion shows that there is weak interaction between electromagnetic and gravitational fields.

11. Equivalence of Magnetic and Kinetic Energy

It is known that an electric charge placed in a medium produces an electrostatic field that surrounds the charge. When an observer moves relative to a charge, the observed electrostatic field changes with time. So, there is production of current with respect to the observer. Again, the observer moving relative to the charge will also measure a magnetic field due to the current produced. The presence of magnetic field indicates magnetic energy. Similarly, for an observer moving relative to a mass, the relative speed of the mass produces kinetic energy.

Thus, kinetic and magnetic energies are comparable in the way that both forms of energy exist only when there is relative motion of an electric charge with respect to an observer.

12. Field Equation

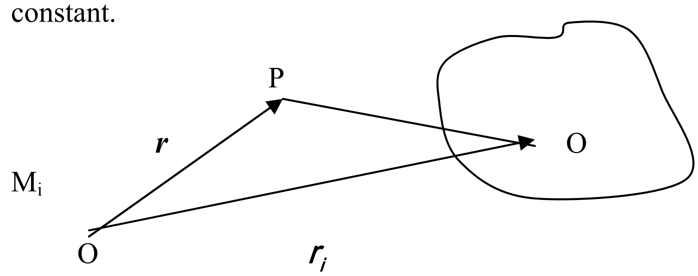
A field equation describes how any one of the fundamental forces (gravitation, electromagnetism, strong and weak fields) interacts with matter [36].

Before the theory of quantum mechanics was fully developed we know about two classical field theories, namely, gravitation and electromagnetism. The first field theory of gravity was Newton's theory of gravitation. According to this the gravitational field at the point **r** due to several masses M_i located at points $\mathbf{r_i}$ is given by

$$\boldsymbol{G} = -G_c \sum_i \frac{M_i(\boldsymbol{r}-\boldsymbol{r}_i)}{|\boldsymbol{r}-\boldsymbol{r}_i|^3}$$

(4)

where G_c is the Newton's gravitational constant.



It is to be noted that the direction of the field points from the position $\boldsymbol{r}$ to the position of the masses $\boldsymbol{r_i}$ which is ensured by the negative sign.

Equation (4) is similar to Coulomb's law in case of electric charge which may produce electromagnetic field.

13. Equations

Now, Maxwell's equations describe how electromagnetic fields are produced from charged particles which could be written in the frame work of special relativity as in [37]. Thus,

$$F^{ab}_{,a} = kJ^b$$
(5)

which arises from the Lagrangian

$$L = -\frac{1}{4\mu_0} F^{ab} + j^a A_a$$
(6)

Again, Einstein's field equation which describes how curvature is produced by the masses is

$$G_{ab} = kT^{ab}$$
(7)

In the above context, interactions in the cases of quarks and gluons may be considered. In the standard model of quarks [38] the coupling strength of forces depends upon distances. It has been shown that at distances below 10^{-32} m, the strong, weak and electromagnetic interactions are different facets of one universal interaction [10, 39, 40].

14. Einstein's Theory

After a long gap of sixty years investigations started again from around 1980 with the net result that total mass is of electromagnetic origin.

From Einstein's theory of relativity it was found that gravity is not a force but a kind of field for which a body rolls down along the space-time curvature according to the equation [33]

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -kT_{ij} = 8\pi G_c T_{\alpha\beta}$$
(8)

Here, the left hand side is space- time geometry and right hand side is energy momentum tensor. Einstein used the above equation in a modified way and concluded that $\frac{3}{4}$ th of the energy constituting matter is to be ascribed to electromagnetic field.

Again, we have Maxwell's equations which relate electromagnetic field to the sources(charge and current) while Einstein's equation relates space-time curvature to its source(the mass energy of matter). Also, above equation is due to Einstein while Newton's field equation as given in (2) is

$$\nabla^2 \varphi_g = 4\pi G_c \rho_m$$
(9)

where ρ_m = rest mass density, φ = gravitational potential and G_c = gravitational coupling constant.

Now, magnetic field due to an electric charge depends upon relativity. Since, the change of magnetic field is produced due to change of electric and gravitational field while change of magnetic field produces change of electric and gravitational fields the following gravitoelectromagnetic equations have been proposed [41] which shows the interaction between the changes in the three fields— electric, magnetic and gravitational.

$$i)\nabla.\boldsymbol{E}=0, ii)\nabla.\boldsymbol{G}=0, iii)\nabla.\boldsymbol{H}=0, iv)\nabla\times\boldsymbol{E}=-\mu_{G0}\frac{\partial \boldsymbol{H}}{\partial t}$$

$$v)\nabla\times\boldsymbol{G}=-\mu_{E0}\frac{\partial \boldsymbol{H}}{\partial t}, vi)\nabla\times\boldsymbol{H}=\varepsilon_{G0}\frac{\partial \boldsymbol{E}}{\partial t}-\varepsilon_{E0}\frac{\partial \boldsymbol{G}}{\partial t}$$

(10)

Conclusion

From the above discussions it is revealed that space-time is related to electric charge. Also, there is similarity between the actions of mass and electric charge and both gravity and electromagnetism affect each other. Again, the similarity between Newton's law of gravitation and Coulomb's law has been mentioned in this work. The behavior of mass and charge as a source and sink is, also, same ultimately leading to similar equations like Poisson's equation and Laplace's equation in the two cases.

Now, according to quantum mechanics the apparent mass of an electron changes and the observed mass is the sum of original mass and electromagnetic mass. This shows the effect of electromagnetic field on mass i.e. gravitational field.

Thus, relation (3) is said to unify gravitation with electromagnetism. Mass of a charged particle is associated with its electromagnetic character. Consideration of electromagnetic mass showing the relation between gravitation and electromagnetism takes place in global form. Again, both magnetic and kinetic energies are produced due to relative motion. So, they, may, assumed to have an implicit link between them where relative velocity is the linking entity.

Considering Maxwell and Einstein's field equations, Einstein proposed equation (8) where $T_{\alpha\beta}$ may be related to electromagnetic fields which, in turn, is related to gravity.

Thus, all the discussions lead to the fact that interrelation between electromagnetic and gravitational fields may be possible.

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