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A Study of the Behavior of Mass of a Particle (Matter) under Gravitational Interaction with Another Particle in Relativistic Motion and the Mathematical Model

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Abstract

Gravitational interaction among objects of all sizes from subatomic particles (matters) having nonzero mass to clusters of galaxies in the universe whether at rest or in non-relativistic or relativistic motion tends to interact with each other. To understand the nature at deeper level, the study of gravitational interaction, theory of relativity and quantum mechanics is of great importance and is an active field of research these days. In the present work, an attempt is made to understand the gravity, quantum theory and theory of relativity together, and study the mass of an object under gravitational interaction with another object in relativistic motion. We compute the change in the mass of the two objects, total change in mass of the system of the two objects, and the energy released in the process. We find that in a closed system, the mass of an object (matter) decreases due to increase in mass of another object in relativistic motion and under gravitational interaction with the first object. This model thus in a way reveals theoretically and mathematically a relationship between gravity, quantum theory, and theory of relativity.

Subject Areas

Particle Physics

Keywords

Gravity, Relativity, Quantum, Field Theory, High Energy Physics, Mass, Speed

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1. Introduction

To study the variation of mass of a particle (matter) and a system of particles has been and is a very active and exciting field of research in science. According to the theory of relativity [1], mass of an object increases when it speeds up relativistically, and acquires infinite energy and thus infinite mass when its speed approaches the speed of light in free space (c). The object thus attains the maximum attainable speed by a particle which is the speed of light in free space. It is pertinent to mention here that in the literature all moving objects are categorized into three groups, namely tachyons, luxons and tardyons and they respectively have speed greater than, equal to and less than the speed of light in free space. First in 1962, E.C.G. Sudarshan along with Bilaniuk and Deshpandey have suggested [2] the possibility of particles (matters) moving faster than the speed of light in free space, and the questions arising from the assumption that a particle may move faster than the speed of light in free space in the framework of classical (nonquantum) theory of special relativity have been studied [3] [4] [5]. Feinberg in 1967 coined the word "tachyon" meaning swift, quick, rapid, fast, and the possibility of the tachyonic particles have been discussed [6]. It has been proposed that tachyonic particles have quanta of quantum field with negative squared mass and several researchers have studied [7]-[26] these moving objects in cosmic rays and in laboratories. In 1980, Edward A. Puscher [18] has discussed an interesting potential relationship between tachyons and anti-gravity, and has presented a review about some of the characteristics that must be possessed by tachyons if they have to exist without violating the special theory of relativity. In 2000, D. Mugnai, A. Ranfagni and R. Ruggeri have experimentally demonstrated [20] the possibility of observing superluminal behavior in the propagation of localized micro waves over distances of tens of wavelengths. Ashoke Sen [21] has discussed the construction of classical time dependent solutions in open string theory as well as in an effective field theory, and has described the motion of the tachyon on unstable D-branes. M. Skalsey *et al.* [22] have discussed a viable superluminal hypothesis about the tachyon emission from orthopositronium (o-Ps), and have described the possibility of finding the existence and nonexistence of tachyons in the measurement of the orthopositronium decay. In 2019, Roman Szostek has discussed [23] the derivation method of numerous dynamics in the special theory of relativity. On the other hand, Frank R. Tangherlini [24] has briefly discussed the possible unification of quantum theory and gravitation, and has described the Galilean-like transformation allowed by general covariance and consistent with the special theory of relativity. Reza Ahangar [25] [26] has discussed a unifying approach for the foundation of complex matter space and special theory of relativity, and has described the complex matter, complex energy and complex momentum. Necati Demiroglu has considered first [27] [28] the quantum right angled triangles and has discussed moving objects having speed greater (tachyons) than, equal (luxons) to and less (tardyons) than the speed of light in free space. The mass (real/imaginary), momentum, energy, and quantum probability state for tachyons and tardyons have been computed [27] [28] [29] [30] and they have found some interesting new equations in this context. It is to mention here that in these works mass is considered as a function of speed. However, in the present work, we have made an attempt to study the variation of mass of a particle (matter) under gravitational interaction with another object in relativistic motion. It is pertinent to mention here that recently quantum experiments at space scale (QESS) [31] have managed to perform a meaningful quantum optical experiment to test the fundamental physics between quantum theory, gravity and theory of relativity. Such experiments are expected to shed light on the supposed relationship between quantum theory, gravity and theory of relativity. On the other hand, the present model in a way theoretically and mathematically reveals a relationship between gravity, quantum theory, and theory of relativity. In the next section, we compute the variation of mass of an object due to interaction with another object using the law of gravitation and the theory of relativity. In Section 3, we present the discussion and summary of the result.

2. Present Model

Consider gravitational interaction between two particles (matters) with mass M and m placed at a distance X from their centers of gravity and mass M is greater than m (*i.e.*, $M > m$). Consider the two objects form a closed system and F is the gravitational force between them, G the gravitational constant, E the energy, 'v' the velocity, 't' the time and 'a' the acceleration. Initially, the velocity (v_0) and time (t_0) are zero. According to the law of gravitation, we have

$$F = GMm/X^2 = mv^2/X \Rightarrow X = GM/v^2 \tag{1}$$

We know that

$$X = v_0 t + (1/2)at^2 \tag{2}$$

Initially, $t_0 = 0$ and $v_0 = 0$. Therefore from Equation (2), we have

$$X = (1/2)at^2 \tag{3}$$

We know that

$$F = ma \Rightarrow a = F/m \tag{4}$$

Substituting the value of 'a' from Equation (4) in Equation (3), we get

$$X = (1/2)(F/m)t^2$$

$$\Rightarrow m = (1/2)(F/X)t^2 \tag{5}$$

Equation (4) implies that $F = ma = m\frac{\mathrm{d}v}{\mathrm{d}t}$. Therefore, we have

$$F\mathrm{d}t = m\mathrm{d}v \tag{6}$$

Substituting the value of 'm' from Equation (5) in Equation (6), we have

$$F\mathrm{d}t = (1/2)(F/X)t^2\mathrm{d}v \Rightarrow \mathrm{d}t/t^2 = (1/2)(1/X)\mathrm{d}v \tag{7}$$

Substituting the value of X from Equation (1) in this equation, we get

$$\mathrm{d}t/t^2 = (1/2)(v^2/GM)\mathrm{d}v \Rightarrow (2GM)(\mathrm{d}t/t^2) = v^2\mathrm{d}v \tag{8}$$

Integrating both sides, we get

$$\int (2GM)\cdot \mathrm{d}t/t^2 = \int v^2 \mathrm{d}v$$

$$\Rightarrow (2GM)(-1/t) = v^3/3 \Rightarrow M = -(1/6G)tv^3 \tag{9}$$

Initially $t_0 = 0$ and $v_0 = 0$, therefore $a = (v - v_0)/(t - t_0) = v/t$, and

$$X = (1/2)at^2 = (1/2)(v/t)t^2 = (1/2)tv \Rightarrow tv = 2X \tag{10}$$

Therefore, substituting the value of tv from Equation (10) and Equation (9), we have

$$M = (-1/6G)tv^3 = (-1/6G)(tv)v^2$$

$$\Rightarrow M = (-1/6G)(2X)v^2 = (-1/3G)Xv^2 \tag{11}$$

We know the energy, $E = FX \Rightarrow X = E/F$ and $F = ma = m(v/t)$, therefore, Equation (11) becomes

$$M = (-1/3G)(E/F)v^2 = (-1/3G)(E/(mv/t))v^2 \tag{12}$$

According to special theory of relativity, the energy E, the momentum p, and the mass m of a relativistic particle is respectively given by

$$E = pc, p = mc, m = \gamma m_0 c; \gamma = (1 - v^2/c^2)^{-1/2} \tag{13}$$

Therefore, we have

$$M = (-1/3G)(pc/(mv/t))v^2 = (-1/3G)(pct/mv)v^2$$

$$\Rightarrow M = (-1/3G)(ctpv/m) \tag{14}$$

Negative sign in Equations (9) to (12) and (14) and henceforth shows that the two objects with mass M and m form a closed system. Considering quantum right angled triangle, N. Demiroglu [27] [28] has computed

$$p = m_0 c \arcsin(v/c); m = \gamma m_0 = (1 - v^2/c^2)^{-1/2} m_0 \tag{15}$$

Substituting the value of 'p' from Equation (15) in Equation (14), we get

$$M = (-1/3G)(ctvm_0 c \arcsin(v/c)/\gamma m_0)$$

$$\Rightarrow M = (-1/3G)(c^2 tv/\gamma)\arcsin(v/c) \tag{16}$$

We consider that the two objects with mass M and m form a closed system and the event is measured from reference systems which are outside the closed system. Consider the event is measured with respect to two such reference systems Σ and Σ' where the reference system Σ is at rest and the other reference system Σ' is moving uniformly w.r.t. the reference system Σ. We know that in the reference system Σ,

$$t = \gamma(t' + X'v/c^2) \tag{17}$$

Substituting the value of 't' from Equation (17) in Equation (14), we have

$$M = (-1/3G)\left(c\gamma\left(t' + X'v/c^2\right)pv/m\right) \tag{18}$$

Substituting the value of 't' from Equation (17) in Equation (16), we get

$$M = (-1/3G)\left(c^2 v\gamma\left(t' + X'v/c^2\right)/\gamma\right)\arcsin(v/c)$$

$$\Rightarrow M = (-1/3G)\left(c^2 v\left(t' + X'v/c^2\right)\right)\arcsin(v/c) \tag{19}$$

Moreover, when $v = c$; $\arcsin(v/c) = \arcsin(1) = \pi/2$, and therefore, Equation (19) becomes

$$M = (-\pi/6G)(X' + t'c)c^2 \tag{20}$$

Now, it is to mention here that the right hand side (RHS) of Equation (14) denotes the mass of the first object due to relativity and the gravitational interaction with the second object having mass m. We denote M by M_1 and the mass expressed by RHS of Equation (14) by M_2. Similarly we denote mass of the second object m by m_1 and its mass due to relativity and gravitational interaction becomes m_2. Due to the relativistic effect and gravitational interactions, the speed of the second object v is denoted by v_2 and speed of the first object by v_1. The momentum of the second object p is denoted by p_2 and momentum of the first object by p_1. With these notations, from Equation (14), we have

$$M_2 = (-1/3G)(ctp_2 v_2/m_2) \tag{21}$$

Using Equation (15), the momentum of the second object is written by $p_2 = m_1 c \arcsin(v_2/c)$ and mass of the first object is given by

$$M_2 = (-1/3G)\left(c^2 t v_2 (m_1/m_2)\arcsin(v_2/c)\right) \tag{22}$$

The difference of mass of the first object,

$$\Delta M = M - M_2 = (-1/3G)\left(ctcv_2 (m_1/m_2)\arcsin(v_2/c)\right) \tag{23}$$

Similarly, the mass of the second object is given by

$$m_2 = (-1/3G)(ctp_1 v_1/M_2) \tag{24}$$

As $p_1 = M_1 c \arcsin(v_1/c)$, the mass of the second object becomes

$$m_2 = (-1/3G)\left(ctcv_1 (M_1/M_2)\arcsin(v_1/c)\right) \tag{25}$$

The difference of mass of the second object,

$$\Delta m = m - m_2 = m_1 - (-1/3G)\left(ctcv_1 (M_1/M_2)\arcsin(v_1/c)\right) \tag{26}$$

Thus, the total change in mass is given by

$$\begin{aligned}\Delta M + \Delta m = (M_1 + m_1) - \{&(-1/3G)c^2 t\{v_2 (m_1/m_2)\arcsin(v_2/c) \\ &+ v_1 (M_1/M_2)\arcsin(v_1/c)\}\}\end{aligned} \tag{27}$$

This is the expression describing the variation of mass due to the relativistic effect and the gravitational interactions between the two objects.

Moreover, the energy released in the process is given by

$$E = (\Delta M + \Delta m)c^2 = \Big[(M_1 + m_1) - \big\{(-1/3G)c^2 t\{v_2(m_1/m_2)\arcsin(v_2/c) + v_1(M_1/M_2)\arcsin(v_1/c)\}\big\}\Big]c^2 \quad (28)$$

In Equation (28), $\Delta M = M_1 - M_2$, $M_1(=M)$ is the mass of the first object, M_2 is the mass of the first object due to relativistic effect and gravitational interaction with the second object, $\Delta m = m_1 - m_2$, $m_1(=m)$ is the mass of the second object, m_2 is the mass of the second object due to relativistic effect and gravitational interaction with the first object, c is the speed of light in free space, G is the Gravitational constant, v_1 is the speed of the first object, v_2 $(=v)$ is the speed of the second object. This equation gives the amount of energy released between the two objects due to the relativistic effect and the gravitational interactions. It is pertinent to mention here that according to the law of gravitation, c.f. Equation (1), $F = GMm/X^2$. This equation implies that the two masses M and m are inversely proportional to each other *i.e.*, $M \propto (1/m)$ and vice versa. According to special theory of relativity, c.f. Equation (13), the mass $m = \gamma m_0 c$; $\gamma = (1 - v^2/c^2)^{-1/2}$. This equation implies that the mass m increases with the relativistic speed v. When the mass m increases, according to the law of gravitation the two masses M and m are inversely proportional to each other *i.e.*, $M \propto (1/m)$ and the mass M decreases. Therefore, we find that the mass of an object (matter) decreases due to increase in mass of another object in relativistic motion and under gravitational interaction with the first object. The energy released from a closed system due to gravitational interaction of the first object (matter) with another object in relativistic motion is given by Equation (28).

3. Discussion and Summary

In recent years the study of gravity, quantum physics and relativity together is an exciting area of research giving a new progress to understand at deeper level a number of connected open problems in physics these days and is expected to remain vibrant in coming decades. It is to mention here that the variation of mass of a particle (matter) with relativistic speed is well studied and verified. In the present work, we have made an attempt to study the variation of mass of an object under gravitational interaction with another object in relativistic motion and the energy released in the process. For this we consider two objects which form a closed system due to gravity. The mass of the first object under gravitational interaction with another object in relativistic motion is studied by using the gravitational law, quantum mechanics and the theory of relativity. We have computed the change in the mass of the two objects, total change in mass of the system of the two objects, and the energy released in the process. We find that in the closed system, the mass of an object (matter) decreases due to increase in mass of another object in relativistic motion and under gravitational interaction with the first object. This model thus in a way theoretically and mathematically reveals a relationship between gravity, quantum theory, and theory of relativity.

However, a more rigorous theoretical and experimental works are required to study in depth the relationship between gravity, quantum theory, and theory of relativity. The work is in progress and we hope to address it in our next work.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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