Massless objects and their physical implications

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Abstract: Normal massless objects have no mass but do have energy, and they always move at the speed of light. This article proposes another way to construct massless objects theoretically by combining normal mass and negative mass of equal magnitudes. Such objects have zero net mass, qualifying as massless, and can be used to investigate the behaviors of general massless objects. Particularly, two kinds of such proposed massless objects, neutral and electrically charged, are studied under the influences of gravity and electric fields. By excluding the factor of mass, it is discovered that the motion of electrically charged massless objects is counterintuitive. The physical implications of the motion of massless objects are analyzed in detail within the framework of classical physics. Some surprising results arise from these analyses, and possible explanations of these dilemmas lead to the possibility of a new relationship between electric charge and mass.

1. Introduction

Massless objects are known to exist in nature. One example is a photon that does not have mass but does have energy. Can other kinds of massless objects exist in theory? Can a massless object consist of mass and "negative mass" of equal magnitudes so that its net mass is zero?

The concept of negative mass is relatively new. It is abstract and of opposite sign to normal mass. There has not been any conclusive physical evidence that it ever existed. But in 2017, a team from Washington State University [1] claimed to have observed negative mass behavior in rubidium atoms. In 2018, University of Rochester [2] researchers reported success in creating particles with negative mass in an atomically thin semiconductor. Nonetheless, the lack of convincing physical evidence supporting the existence of negative mass has not hindered people's interest in studying it [3-10]. A conclusion from this research is that the existence of negative mass does not violate the laws of classical physics.

Another attempt to study the concept was to construct massless systems which consisted of mass and negative mass of equal magnitudes [11], so that a massless object could be studied in the contexts of Newtonian mechanics and electromagnetism.

In this article, the author briefly reviews the previous work of constructing massless objects; then extends the study of massless objects (neutral and electrically charged) under gravity and electric fields; presents the physical dilemmas that arise; and finally deduces the physical implications of massless objects within the framework of classical physics.

2. Assumption and Terminology

Based on previous research, we can make two assumptions.

Assumption 1: Existence of negative mass does not violate physical laws.

Assumption 2: Physical laws are the same for negative mass as for mass—negative mass can be substituted for mass in physical laws (with the same magnitude but opposite sign).

From *Assumption 2*, it can be deduced that negative mass generates a gravitational field with the same strength as that of mass, but with opposite sign; negative mass accelerates in the opposite direction as that of the force which acts on it; negative mass reacts to a gravitational field with opposite sign.

We can further deduce the following attributes.

Attribute 1: Negative mass repels negative mass.

Attribute 2: Negative mass repels mass.

Attribute 3: Mass attracts negative mass.

From *Attribute 1*, it follows that a plural quantity of negative masses is unstable if no other forces bind them together. The negative mass can be quantized, and the smallest unit of it is stable. That unit will be referred to as a ***Yinon*** in this article. There could be various kinds of yinons with different magnitudes.

Let's suppose that there exists a unit of normal mass with equal magnitude to that of a yinon. For convenience we simply call that unit of mass a ***Masson*** in the rest of this article.

3. **Internal Configuration of a Massless System**

Let's carry out some thought experiments to construct massless systems. To simplify the experiments, we restrict the configurations to be on a two-dimensional plane and treat them as systems of point particles or systems of point charges.

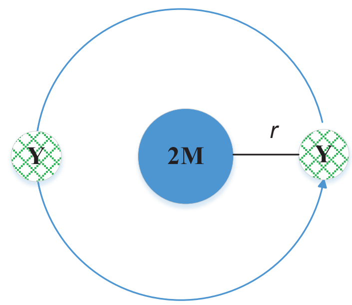

Fig.1 Two yinons rotate around two massons at the center

Figure 1 shows a configuration of two massons (M) at the center while two yinons (Y) move around them in a circular orbit. The two yinons are always on the opposite sides in the orbit. The repulsion exerted on one yinon by the other is $F_{yy} = G\frac{-m_y(-m_y)}{4r^2}$, and the attraction exerted on each yinon by the massons is $F_{my} = G\frac{2m_m(-m_y)}{r^2}$. Since $|F_{my}| > |F_{yy}|$ a centripetal acceleration of each yinon toward the massons keeps it in circular motion. The repulsions exerted on the center massons by each yinon cancel each other out. The center of mass of the yinons is aligned at the center of mass of the massons. Thus, this configuration is stable. We can treat it as a system of point particles. Considering the motion of the yinons in this configuration, $|m_m|$ should be larger than $|m_y|$ to make the entire system massless.

There are other configurations which consist of an equal number of yinons and massons, and these configurations can be stable too.

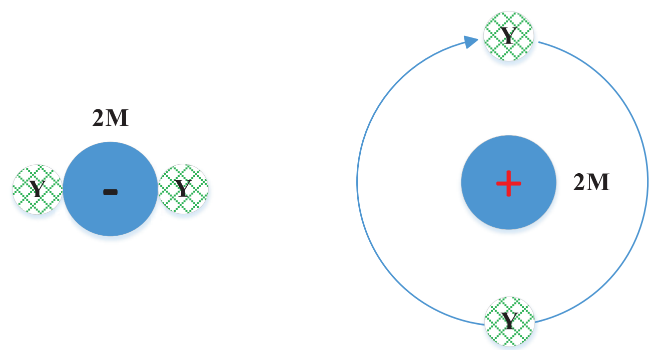

Fig.2 Two yinons combine with two massons carrying an electric charge

Figure 2 shows two possible configurations where the two massons at the center carry an electric charge. In addition to being a stationary massless system, each of them has an electric charge. Since there is only one electric charge, there is no electric interaction inside the configurations. Therefore, we can isolate an electric charge from its host matter. I.e., an object can have zero net mass yet still have an electric charge. We can treat it as a system of point charges.

4. **Motion of a Massless Object**

So far we have proposed massless systems consisting of an equal number of yinons and massons. Let's examine the motion of massless objects under gravity and electric fields within the framework of classical physics.

4.1. Massless object in a gravitational field

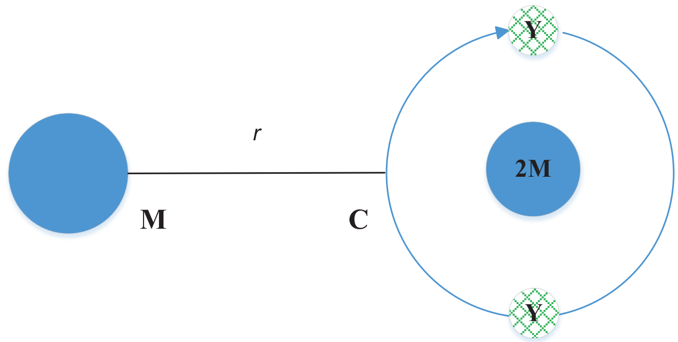

Fig.3 A massless object is influenced by gravity

Let there exist a massless object C and a mass M, separated by a distance r, as shown in Fig.3.

The gravitational force exerted by M on C is zero according to

$$F_{mc} = G\frac{m_m m_c}{r^2} = 0, \text{ where } m_c = 0. \tag{1}$$

Based on Newton's second law,

$$F_{mc} = m_c a_c = 0, \text{ where } m_c = 0. \tag{2}$$

So C's acceleration a_c can be positive, negative or zero.

However, inside object C, the yinons are attracted to M—according to *attribute 3*—with an acceleration of

$$a_{yinon} = G\frac{m_m}{r^2}, \text{ where } m_m > 0; \tag{3}$$

while the massons are attracted to M with an acceleration of

$$a_{masson} = G\frac{m_m}{r^2}\text{, where } m_m > 0. \tag{4}$$

Thus, both the yinons and massons move toward M with the same acceleration. So the center of mass of C can move toward M at the acceleration of

$$a_c = a_{yinon} = a_{masson} > 0. \tag{5}$$

This implies that a mass can attract a massless object. Even though it is counterintuitive, Newton's second law still holds for massless objects. The non-zero acceleration of C, Eq. (5), does not contradict the previous conclusion of a_c being positive, negative or zero, Eq. (2).

Newton's first law does not seem to hold for massless objects, if we consider how C can accelerate toward M without a net force acting on it. But considering this consequence in the context of General Relativity, we conclude that the gravity of M influences everything including massless objects.

4.2. Massless object with an electric charge in a gravitational field

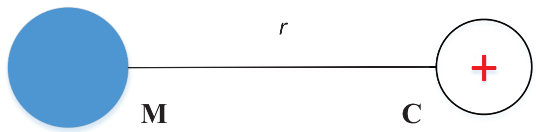

Fig.4 A massless object with electric charge is influenced by gravity

Let's assume there is a massless object C which carries an electric charge, and a mass M, separated by a distance r, as shown in Fig.4.

Since there is no electric interaction between them, this case is a variation of case 1. The massless object carrying an electric charge moves toward the mass.

Equation (5) indicates that C accelerates toward M. Since its mass is zero, C does not have kinetic energy, and neither does it have gravitational potential energy. However, an accelerating electric charge produces an electromagnetic field which has energy. Where does this new energy come from? In order to conserve energy for C, there should be some change in C's total energy to compensate the creation of electromagnetic energy.

Let's assume C has moved from position P_1 to position P_2 under the gravitational force of M.

At P_1, C has neither kinetic energy nor gravitational potential energy, due to its mass being zero; C has no electric potential energy due to a lack of electric field around it. Thus, at P_1, C's total energy is zero. However, C has an electric charge q_1.

Likewise, at P_2, C's total energy is zero. But C still has an electric charge q_2.

We know that electric charge is conserved. I.e., q_1 should equal q_2. But can a part of the electric charge be transformed into the new energy created in the form of an electromagnetic field?

If so, we denote the relationship between electric charge and energy

$$\Delta E = T(\Delta Q), \tag{6}$$

where Q is the quantity of electric charge and E is the quantity of energy. T is a transformation between electric charge and energy. It is also a transformation between electric charge and mass:

$$\Delta M c^2 = \Delta E = T(\Delta Q), \tag{7}$$

where M is the quantity of the equivalent mass, and c is the speed of light.

4.3. Interaction between an electric charge and a massless object

If we assume that the charge has no mass, such as in Fig. 2, then there is no motion for both the charge and the massless object, since there is neither gravitational nor electric interaction between them.

4.4. Massless object with an electric charge in an electric field

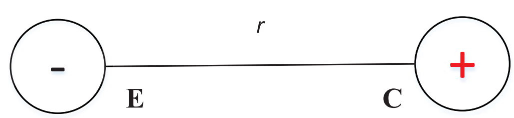

Fig.5 A massless object with electric charge is influenced by the electric field

Let's assume there is a massless object C which carries a positive electric charge (e^+), and a massless object E which carries a negative electric charge (e^-), separated by a distance r, as shown in Fig.5.

First, let's analyze C's motion using Coulomb's law and Newton's laws.

The electric attractive force exerted by E on C is

$$F_{ec} = K\frac{e^- e^+}{r^2} > 0 \text{, where } e > 0 . \tag{8}$$

The gravitational force exerted by E on C is zero since E is massless. Therefore the net force acting on C is $F_{ec} > 0$.

According to Newton's second law

$$F_{ec} = m_c a_c > 0, \text{ where } m_c = 0. \tag{9}$$

Thus, we can conclude that a_c cannot be a finite number.

Second, let's analyze C's motion using energy and momentum.

Let the *x*-axis be oriented in the direction from E to C, with the origin at E.

We assume that under E's electric field, C has an electric potential energy $V(x)$ at position x. Whereas at x, C has neither kinetic energy nor gravitational potential energy. So at x, C's total energy is $E = V(x)$. According to the principle of potential energy, the force on object C is

$$F_c = -\frac{dV(x)}{dx}. \tag{10}$$

According to the energy-momentum relationship,

$$E^2 = P^2c^2 + m^2c^4, \tag{11}$$

where c is the speed of light, m is the mass, E is energy, and P is momentum.

We have $E = |P|c$ when $m = 0$. So

$$|P| = \frac{E}{c} = \frac{V(x)}{c}. \tag{12}$$

Also from the force and momentum relationship, we have

$$F = \frac{dP}{dt}, \tag{13}$$

and when we plug Eq. (12) into Eq. (13), we obtain

$$F_c = -\frac{dV(x)}{cdt}, \tag{14}$$

where P takes a negative sign.

Combining Eq. (10) with Eq. (14), we have

$$\frac{dx}{dt} = c. \tag{15}$$

Equation (15) implies that a massless object with electric charge moves at the speed of light in an electric field regardless of the quantity of its charge.

If C does move under the influence of E's electric field, how does its total energy change?

Let's assume C has moved by Δx. C's electric potential energy has changed by $V(x + \Delta x) - V(x)$. Since C moves at a uniform velocity, it does not accelerate. There will be no electromagnetic energy created during the motion. Also, if the magnetic field energy created by the motion is constant, then for C's total energy to be conserved, some form of energy change is needed to compensate the change of its electric potential energy. In this case, one possibility is that the quantity of C's electric charge changes. Based on Eq. (15), C's uniform motion is not affected by the quantity of its electric charge. Therefore, a massless object with electric charge continues moving at the speed of light while the quantity of its electric charge keeps changing.

5. Discussion and Conclusion

In the 4.2 thought experiment (Fig. 4) the laws of Newtonian mechanics and electromagnetism hold. However, there is energy created but not accounted for.

In the 4.4 thought experiment (Fig. 5) the laws of electromagnetism hold. But Newton's second law does not hold. There is also an energy change that was not accounted for.

Both 4.2 and 4.4 give rise to a possibility of a transformation between electric charge and energy, and therefore between electric charge and mass. What kind of transformation is it?

From Eq. (7) if T is a real transformation for electric charge, then its equivalent mass should be reflected in its dynamics. However, the physical effects of a real transformation from electric charge to mass have not yet been observed. E.g., an electric charge does not interact with a mass directly. Therefore, we can assume that the transformation from electric charge to mass is not real, but imaginary, by which it means that they are not in the same dimension. We denote it as follows:

$$\Delta M = iT(\Delta Q). \tag{16}$$

How is T calculated? Here we deduce a possible solution.

Let's assume there are two electric charges of equal quantity *q*, separated by a distance *r*. From Eq. (16), their corresponding masses are equal, say *m*.

According to Newton's gravitational law, the force between the two corresponding masses is

$$F_{mm} = G\frac{mm}{r^2}. \tag{17}$$

Plugging Eq. (16) into Eq. (17), we have

$$F_{mm} = -G\frac{T(q)T(q)}{r^2}. \tag{18}$$

Also, according to Coulomb's law, the force between the two electric charges is

$$F_{qq} = K\frac{qq}{r^2}. \tag{19}$$

If electric charge can be manifested as mass, then the electric charges' effects on each other should be equivalent to the corresponding masses' effects on each other. The force between the objects is such an effect. Therefore we can reason that the magnitude of the force between the electric charges is equal to the magnitude of the force between the corresponding masses.

$$|F_{mm}| = |F_{qq}|. \tag{20}$$

We have

$$\left| -G\frac{T(q)T(q)}{r^2} \right| = \left| K\frac{qq}{r^2} \right|. \tag{21}$$

It reduces to

$$GT(q)T(q) = Kqq. \tag{22}$$

It further reduces to

$$T(q) = \sqrt{\frac{K}{G}}\, q. \tag{23}$$

Plugging Eq. (23) into Eq. (16), we have

$$\Delta m = i\sqrt{\frac{K}{G}}\, \Delta q. \tag{24}$$

So far we have discussed the possible motion in thought experiments 4.2 and 4.4. There is another possibility for them as well—if an object's net mass becomes zero, then the object's net electric charge becomes zero too. Hence we can reason that, in 4.2, when the massless object accelerates, there is no new energy created in the form of an electromagnetic field since its electric charge is zero. Likewise, in 4.4 there is no electric force exerted on the massless object, and so it does not have nonzero motion.

In this article, the author made two assumptions regarding negative mass, and then went further to construct massless systems. The proposed massless objects are put into thought experiments within the framework of classical physics.

Throughout these thought experiments, we have analyzed the motion of massless objects under the influences of gravitational and electric fields. The resulting implications are quite thought-provoking. A few dilemmas have emerged from these thought experiments and we have given possible reasonings for the dilemmas. In order to explain the intricacies involving massless objects we may need to go beyond classical physics or we may interpret the paradoxes as proof of the non-existence of negative mass, or as the non-existence of equal quantities of negative mass and mass in the universe.

References

1. Scientists observe liquid with “negative mass”, which turns physics completely upside down, The Independent, April 21, 2017.

2. Device creates negative mass -- and a novel way to generate lasers. NewsCenter. January 3, 2018.

3. Dirac, P. A. M.: Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences. **117** (778), 610 (1928).

4. Ferrell, R.: Awards for Essays on Gravitation. Gravity Research Foundation (1950).

5. Luttinger, J. M.: Awards for Essays on Gravitation. Gravity Research Foundation (1951).

6. Bondi, H.: Reviews of Modern Physics. **29** (3), 423 (1957).

7. Forward, R. L.: Journal of Propulsion and Power. **6** (1), 28 (1990).

8. Price, R. H.: American Journal of Physics. **61** (3), 216 (1993).

9. Bonnor, W. B.: General Relativity and Gravitation. **21** (11), 1143 (1989).

10. Belletˆete, J., Paranjape, M. B.: Awards for Essays on Gravitation. Gravity Research Foundation (2013).

11. Wang, T.: Physics Essays. **33** (1), 91 (2020).