Discussion on Mass in a Gravitational Field

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Abstract: Various gravitation theories predict that a star with a large enough mass will shrink down to a final point, a gravitational singularity. The problem of the singularity is always a difficult one. We attempt to discussion gravitation from another angle in this work. Based on experimental analysis and theoretical verification, a hypothesis regarding mass in gravitational fields is presented. This can avoid the problem of singularity, and the meaning of gravitation is simple to determine.

Keywords: Mass, Gravitational field, Energy, Covariance

1. Introduction

Of the forces in nature, no force can prevent matter from collapsing into a point in a black hole. Scientists have long puzzled over why the singularity has zero volume and infinite density, and have been trying to uncover the secrets of black holes. Today, a black hole is not necessarily darkened [1,2], and many breakthroughs have been made in astrophysics. Even so, there are still many secrets about the universe to unlock [3,4]. The evidence of dark energy and dark matter remain to be answered [5,6]. The truth of black holes has yet to be confirmed [7]. In this work, we are trying to summarize our study to refer to gravitation to provide reference for others. For simplicity, the nouns and terms that we use conform to the definitions of fundamental physics. The “clock” is a timepiece in the physical sense; some examples include an atomic clock, a mechanical clock, a quartz clock or another chronometric instrument, excluding a gravity pendulum, which cannot work in outer space. The “ruler” is a length-measuring tool in the physical sense; some examples include a meter stick or another instrument that measures dimensions. “Mass” is inertial mass, a measure of an object's resistance to a change in its state of motion when a force is applied.

2. Methods

2.1 Annihilation test

Experiment 1: On the ground, antimatter (mass of $0.5\ m$) and matter (mass of $0.5\ m$) could be used to annihilate one another. They could be brought into contact gradually and translated into photons. All of the photons would be measured by an energy meter "c" in outer space. Finally, a certain amount of energy, E_1, would be obtained. This scenario is labeled with an "a" in Fig. 1.

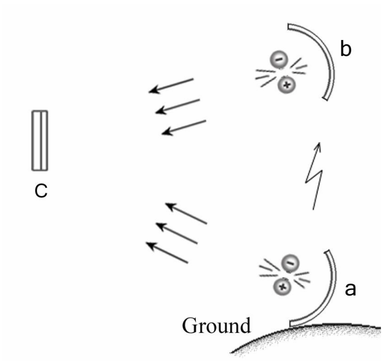

Fig. 1. (a): Annihilation were to occur on the ground, the photons reached the energy meter (c) in outer space and lost a part of energy. The gravitational field would disappear if this happen repeatedly.
(b): Annihilation were to occur in outer space.

Experiment 2: Equal amounts of antimatter and matter could be weighed. They could be kept separate and lifted out of the gravitational field by an elevator. Then, the matter and antimatter could be brought together, and a given energy, E_2, would be obtained. Annihilation in outer space is labeled with a "b" in Fig. 1.

It is thought that photons would need to overcome gravity to do work when they exit the gravitational field. In other words, the photons transfer part of their energy to the gravitational field. Theoretically, experiment 1 can be repeated continuously. (This is, of course, only a thought experiment, and given antimatter and matter attracts each other [8].) Ultimately, all of the mass available on the earth would be depleted, and the gravitational field should receive a significant amount of energy. However, the gravitational field would disappear with the earth. Where would the energy go?

Similarly, experiment 2 would be also repeated indefinitely. Lifting the objects out of the gravitational field requires a third party to provide external work. Finally, all the matter and the gravitational field would disappear. Where would the energy of the external work go?

2.2 Acceleration test

Compared with a clock period in outer space, the clock period within a radius R of a gravitational field is defined by the following relation [9]:

$$T = \frac{T_0}{\sqrt{1 - 2GM/c^2R}} \tag{2.1}$$

where T_0 is the clock period in outer space, G is the gravitational constant, c is the speed of light, and M is the mass of the body.

The standard ruler is defined by the speed of light. Because the speed of light is a constant anywhere:

$$\frac{L_0}{T_0} = \frac{L}{T} \tag{2.2}$$

Where L_0 is length of the standard ruler in outer space and L is its length at the radius R of the gravitational field. Thus:

$$L = \frac{L_0}{\sqrt{1 - 2GM/c^2R}} \tag{2.3}$$

Experiment 3: In outer space, a force F could be exerted on a mass m for a duration T_0 (labeled with a “b” in Fig. 2). The displacement is represented by

$$L_0 = \frac{1}{2} \cdot \frac{F}{m} \cdot T_0^{\;2} \tag{2.4}$$

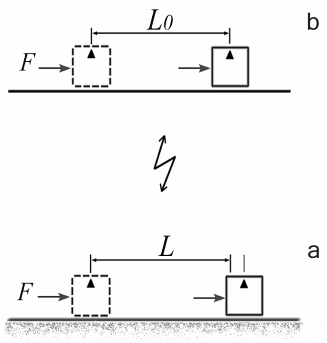

Fig. 2. An acceleration test could be staged on the ground (a) and in outer space (b), the clock and the ruler would be variable and the mass would be constant, and different results would be observed.

Experiment 4: On the ground, the object is accelerated in a smooth horizontal plane (no resistance), labeled “a” in Fig. 2. The displacement would be given by

$$\frac{1}{2}\cdot\frac{F}{m}T^2=\frac{F}{2m}\left(\frac{T_0}{\sqrt{1\text{-}2GM/c^2R}}\right)^2 \tag{2.5}$$

Given the above equations:

$$=\frac{L_0}{(\sqrt{1\text{-}2GM/c^2R})^2}=\frac{L}{\sqrt{1\text{-}2GM/c^2R}}>L \tag{2.6}$$

Different results would be observed in the experiments. However, there is no evidence to indicate that Newton's second law takes a different form at different altitudes, even if the relativistic effect was taken into account.

2.3 Energy in a gravitational field

In order to solve the antinomies in Fig .1, the following hypotheses have to be introduced:

ⅰ). Energy cannot be transferred between a photon and a gravitational field.

ⅱ). Mass is variable in a gravitational field.

If the mass in outer space is expressed as m_0 and the external work is expressed as W, the following equations can be obtained:

$$E_1=mc^2 \tag{3.1}$$

$$E_2=mc^2+W=m_0c^2 \tag{3.2}$$

$$E_2 - E_1 = W \tag{3.3}$$

In the case of the reverse process, a meteoroid is captured by the gravitational field, it accelerates toward the ground, and finally, the meteoroid hits the ground, and gives off light and heat. By this time, the gravitational potential energy of all matter in the gravitational field has been increased by the addition of the meteoroid. Considering the increased energy, light and heat, when a star collapses and becomes a black hole (a naked singularity with zero radius), its mass should increase infinitely, which would be disastrous.

From the theory of photon potential energy, given the energy expenditure, the following relationships can be obtained:

$$E_1 = mc^2 - W \tag{3.4}$$

$$E_2 = mc^2 \tag{3.5}$$

$$E_2 - E_1 = W \tag{3.6}$$

An object is pulled by a gravitational field must have gravitational mass, and it must have inertial mass in compliance with the equivalence principle [10]. However, a photon has inertial mass like an object would be unrealistic [11]. Although a photon can be changed in direction, it cannot be accelerated or decelerated. The bending of the light rays beside the Sun should not be interpreted as that the light rays is pulled by the Sun, if so, delay of the radar echo cannot be explained [12]. On the other hand, the trace and form of the energy that the gravitational field receives from photons cannot be explained reasonably, as was the case for the Sun for quite a long time. In fact, the photon potential energy theory cannot illustrate the energy relationships in Fig. 1, because both E_1 and E_2 have lost energy W.

In R. Pound's experiment of gravitational red shift by the Mossbauer Effect [13], the radiation source is placed at the top of a tower, and the absorber is placed on the ground. Photons can thus be absorbed. Now, an operator takes the absorber and ascends to the top of the tower. However, photons cannot be absorbed. Why? If photons accelerate in the process of free fall, this is inconsistent with the principle of the constant speed of light. On the other hand, energy of the removed photons decreases to zero in a black hole, the reverse process must be allowed. In other words, a zero-energy photon can increase in energy in a black hole. Quantum field theory states that photons and particles exist in the vacuum [14]. Furthermore, cosmic microwave background radiation (2.7 K) fills the cosmic space. Thus, the black hole should grow stronger continuously without any matter, which is hard to explain.

Now, the external work belongs to the lifted object in Fig. 1. In reference to special relativity, after external work W is done to an object of mass m, the final mass:

$$m_0 = \frac{m}{\sqrt{1 - 2W/mc^2}}$$

$$W = \frac{GMm}{R}$$

$$m = m_0\sqrt{1 - 2GM/c^2 R} \tag{3.7}$$

This relationship describes the difference in the mass of an object when in a gravitational field versus in outer space. Similarly, versus relationships of a ruler and a clock can be solved in the same way.

2.4 Covariance in a gravitational field

Lorentz covariance is a key property of space-time that follows from the special theory of relativity; the covariance requirement states that physical laws take the same form in any inertial coordinate system. For example, in a high-speed spacecraft, rulers become shorter and clocks tick more slowly, objects increase in mass. If the mass were to remain constant, an object were accelerated to the same speed would take less time in the spacecraft. Thus, we can determine the absolute velocity of the spacecraft by this. However, all of the attempts to explore absolute velocity have failed, but and time slows down in a high-speed system is proved by experiments [15].

From some perspective, mass refers to the rest mass, and everything else is kinetic energy. It should be noted that the kinetic energy just represents the relationships of relative motion when another reference frame is specified, and a single system do not involve kinetic energy. For example, the earth contains how much kinetic energy cannot be confirmed. There is one more question: Whether the time dilation would be a chance to identify an absolute motion? Actually cannot. In the high-speed spacecraft, clocks tick more slowly, but rulers become shorter. In other words, spectrum of hydrogen atom in the spacecraft has a lower frequency and a shorter wavelength. We still receive a usual spectrum of hydrogen atom on the earth which only includes information of velocity-redshift. An observer in the spacecraft also observes the same results that we do. The relativity principle is reliable. About the "twin paradox", because one of the twins has been applied external work which will change his space characteristic like that in a gravitational field, they should become different. Many literatures about The Special Relativity refer to the details.

Einstein theorized that physical laws have the same form in all reference frames and that they have the same covariance in any coordinate transformation [16]. Today, many laser interferometers are located around the world for detecting gravitational waves. They have improved the precision of the Michelson-Morley experiments to an unprecedented degree. The earth travels in the universe and with a 24-hour cycle of rotation, and the length of any body along the direction of motion is shortened, which includes the frame of the laser interferometers. However, no report has stated that the result has to do with the attitude of the earth. In view of various accurate experiments in modern times, there is no evidence that different forms of physical law are needed at different altitudes, even in outer space [17].

Consider the centripetal force of a circular motion in outer space:

$$F_0 = \frac{4p^2 m_0 r_0}{T_0^2} \tag{4.1}$$

where r_0 is the radius of the circular motion, T_0 is the period, and m_0 is the mass of the particle.

In a horizontal plane in a gravitational field,

$$F = \frac{4p^2 mr}{T^2} \tag{4.2}$$

Given the relationship of mass, length and time given above

$$F = F_0 (\sqrt{1 - 2GM/c^2 R})^2 \tag{4.3}$$

Based on the above discussion, in the gravitational field,

$$\frac{1}{2} \cdot \frac{F}{m} T^2 = \frac{L_0}{\sqrt{1\text{-}2GM/c^2 R}} = L \tag{4.4}$$

Thus, Newton's second law takes the same form.

As Albert Einstein suggested, experiments that are conducted in a free-falling elevator or in outer space are indistinguishable. Nevertheless, people have found that a clock slows down in a gravitational field. Why? The reason is that two identical clocks are used, and they are placed in different spaces to accomplish this. To be more precise, physical parameters from two spaces are compared in this research method. Two flat coordinate systems are combined by external work, and the concept of space warp is much simpler. If an equation is established in a single coordinate system on a large scale, given a local test get the same result regardless of any location, and time and length and mass change with radius, it will inevitably result in that the reality is a little more complicated.

When an electron enters a gravitational field, its mass decreases, the charge-mass ratio remains unchanged according to general covariance. Thus, the quantity of the elementary charge decreases. A proton does likewise. In other words, the bonding force between a proton and an electron are weakened in a gravitational field, which can explain the origin of the gravitational red shift very well, and the size of an object increases in a gravitational field. Put another way, a spring dynamometer has a smaller force in a gravitational field. It is easy to understand that a light source has wavelengths with unlimited length in the Schwarzschild radius.

2.5 Mercury's perihelion advance

Of all the planets in the solar system, Mercury is the closest to the sun, and changes in length and mass cannot be ignored. Namely, the weaker the gravitational field, the more precise Newton's theory will be. Let

$$x = \frac{R_0}{R} \tag{5.1}$$

where R is the true orbit radius of a particle and R_0 is the expectation.Then,

$$R = \int_0^{Rs} \frac{dr}{\sqrt{1 - 2GM/c^2 Rs - GMr^2/c^2 Rs^3}} + \int_{Rs}^{R} \frac{dr}{\sqrt{1 - 2GM/c^2 r}} \tag{5.2}$$

where R_S is the radius of the body of the gravitational field.

This equation can be solved numerically with a computer. We will give the approximate solution here. The length of a ruler in the gravitational field is shown in Fig. 3.

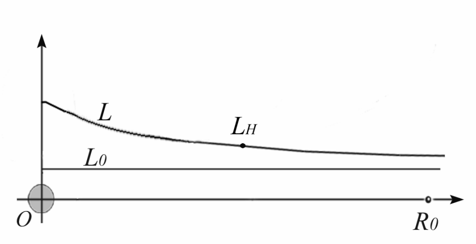

Fig. 3. L: the actual length curve of a ruler in a gravitational field, L_0: expected value. Integration of L can provide the real orbit radius.

It can be proven according to Gauss's theorem that

$$\frac{R_0}{R} = \frac{L_0}{L_H} \tag{5.3}$$

where L_H is the length of the ruler at one-half of the orbit radius. So,

$$x = \frac{1}{\sqrt{1 - 2GM/c^2(R/2)}} = \frac{1}{\sqrt{1 - 4GM/c^2 R}} \tag{5.4}$$

The description of mass can also be deduced by the same method. The modified parameters can applied to the equation of complete square:

$$F_G = \frac{GM(m/x)}{(R \cdot x)^2} \tag{5.5}$$

The equation can be expanded, and negligibly small terms are ignored:

$$F_G = \frac{GMm}{R^2} + \frac{6G^2M^2m}{c^2R^3} \tag{5.6}$$

The parameter F_G is substituted into the Binet equation:

$$\frac{d^2u}{dq^2}+u=\frac{GM}{h^2}+\frac{6G^2M^2}{h^2c^2}u \qquad (5.7)$$

where u=1/R and h are the moment of momentum of unit mass.

The differential equations is easy to solve, and the precession of the perihelion after one revolution is given by

$$\Delta q=\frac{6pGM}{a(1-e^2)c^2} \qquad (5.8)$$

where a is the semimajor axis of orbit, and e is the orbital eccentricity.

$$\Delta q=5.022\times10^{-7}\,rad$$

In a century, Mercury revolves around the sun 4.1521 times. Thus, the additional advance value is

$$\Delta q_C=43.001''$$

2.6 Delay of radar waves

In 1964, Shapiro, an American scholar, made radar waves pass the edge of the Sun. They reached Venus on the other side of the Sun and were reflected back to Earth. The actual time of travel was more than 200 microseconds longer than expected.

An observer outside the gravitational field uses his or her own clock and ruler to measure the speed of light at a radius R of the gravitational field. In view of the difference of the clocks and rulers, the result is

$$c_R=c(1-2GM/rc^2) \qquad (6.1)$$

The course of the radar waves is divided into two parts, and the actual time is

$$T_A=\int_{R_E}^{R_\Theta}\frac{dr}{c(1-2GM_\Theta/rc^2)}+\int_{R_D}^{R_\Theta}\frac{dr}{c(1-2GM_\Theta/rc^2)} \qquad (6.2)$$

where R_E is the radius of Earth's orbit and R_D is the radius of Venus’s orbit.

The expected time is thus

$$T_E=\frac{R_E-R_\Theta}{c}+\frac{R_D-R_\Theta}{c} \qquad (6.3)$$

$$\Delta T=T_A-T_E=\frac{2GM_\Theta}{c^3}(\ln R_E+\ln R_D-2\ln R_\Theta) \qquad (6.4)$$

$2\Delta T = 205.11ms$

In fact, this kind of phenomenon can be seen often. When a ray of light enters a piece of glass, it is slowed down. That is because that the evaluated clock and ruler in a vacuum instead of electric field of the atoms in the glass. It can be believed that an instrument big enough is good for detecting the gravitational waves.

3. Conclusions

Based on the above study, equal amounts of matter and antimatter experience complete annihilation, the gravitation field disappears, and energy that the photons lost cannot be explained. If a photon is decelerated by a gravitation field, the principle of the constant speed of light would be broke, and a black hole would grow stronger in the cosmic microwave background. Thus, hypothesis (i) that energy cannot be transferred between a photon and a gravitational field is tenable.

On the other hand, an object that is taken away from a gravitational field requires a third party to provide energy. Time and length are variable, and Newton's second law takes the same form on the ground and in outer space. A gravitational singularity does not have infinite mass. Therefore, hypothesis (ii) that mass is variable in a gravitational field is tenable. The tow hypotheses can mutually confirm each other, and can resolve issues regarding a gravitational field satisfactorily and consistent with the fundamental principle of general relativity.

4. Discussion

Reviewing some basic facts is suggestive. The uncertainty principle has been proclaimed that a particle with greater mass occupy smaller space, which is the theoretical basis of electron microscopes. De Broglie successfully extended the wave-particle duality of photons to the microcosmic field, and a particle with greater energy has a shorter wavelength. High-energy photons have a shorter wavelength. Particle physicists usually use mass to extrapolate the size of particles [18]. Overall, a heavier particle has a smaller size in the microscopic world.

Usually, a larger stone is heavier, but in the microscopic world, the opposite is true. However, there is also evidence of the same phenomenon in the macroscopic world, for example, when an object has a high speed, its size decreases, and its mass increases; when an object enters a gravitational field, its size increases, and its mass decreases. This change is a reflection of the microcosmic scale. In this sense, mass should be variable in a gravitational field.

It is not difficult to understand gravitation, given that an object entering a gravitational field can release energy. The space in a gravitational field has a lower energy state, and any particle will always jump toward the lower energy state and release energy, that is, gravitation.

From a reference point, when an object changes in rest mass *m* and gravitational potential energy *U* in a gravitational field, it can be proven that

$$\Delta U = \Delta mc^2$$

It could be called mass-field relationship. The typical proof of the relationship is the gravitational red shift. Theoretically, any point in the universe can be regarded as the reference point, as long as the relative external work of other points can be calculated. Of course, it is more representative that the reference point is set outside of the galaxy, which needs more energy if a satellite leaves it.

A way to verify the mass-field relationship is shown in Fig. 4. Two copper balls are fixed on both sides of an axis. The balls in the device, labeled “a,” rotate in the horizontal plane; balls in another device, labeled “b,” rotate in the vertical plane. They have the same structure, and are driven and receive the same initial velocity. *S* is a double-decked superconducting magnetic bearing used to monitor the energy loss. The direction of the axis of device *b* is perpendicular to the earth's axis (east-west direction) such that the directions of the axes have the same change in a day.

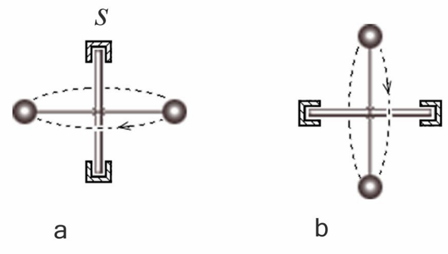

Fig. 4. Balls rotate around an axis in the horizontal plane (*a*) and in the vertical plane (*b*). The height of the balls in device *b* changes continuously, their gravitational potential energy also changes.

Based on this fact, any transformation of different forms of energy must take time, which is the theoretical basis of the clock. From the standpoint of the mass-field relationship, the height of the balls in device *b* changes continuously, which causes transformations between the mass and the gravitational potential energy. A delayed change of mass is equivalent to attaching a resistance to device *b*. lastly, the rotation of device *b* would lag behind that of device *a*.

We always think about whether the mass-field relationship is a universal relationship, and explore to apply to the electromagnetic force, the weak force and the nuclear force which might explain the origin of the mass defect and even provide a way to construct a universal theory. For example, a strong electric field or magnetic field is applied to the receptor of a Mossbauer spectroscope to study the change of the atomic energy level. Confirming the mass-field relationship might generate additional ideas about the current questions in the field [19-22].

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