A configuration of graviton [1]

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Abstract

Some commonly agreed upon behaviors of graviton are that it is massless, propagates at the speed of light, is emitted, and is absorbed between matter particles, acts like a gravitational force carrier. In this essay we propose a novel configuration for gravitons. It is a massless object with zero net mass. When a quantum of energy is transferred to it, it can store the energy internally and travel at the speed of light. When the quantum of energy that it carries is transferred out of it, it becomes massless, and its momentum is zero. By exchanging this massless object, energy can be transferred between matter particles. The net effect of this exchange is the apparent gravitational interaction between matter particles. Therefore, we consider this massless object to behave like graviton.

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1. Introduction

Graviton is a hypothetical quantum of gravity, an elementary particle that mediates the force of gravitational interaction. If it exists, the graviton is expected to be massless and propagate at the speed of light. Many studies have investigated it [1-16], but no complete theory exists. In this essay, we wish to propose a novel configuration of a graviton as a gravitational force carrier.

In our study, we consider a massless object as an object with zero net mass. It consists of mass and negative mass—the concept of negative mass is relatively new [17-29] and it is of an opposite sign to that of a normal mass. At rest, this object is massless. After a quantum of energy is transferred to it, it carries the energy and travels at the speed of light. After the quantum of energy that it carries is transferred out of it, it becomes massless and has no momentum. During the process in which a quantum of energy is transferred between matter particles, this massless object acts like a force carrier to mediate the gravitational interaction between matter particles.

2. Methods

In the following paragraphs, we use the composition method to construct a massless object in a thought experiment. Here, by massless, we mean zero net mass. We then study the change in its state after a quantum of energy is transferred into and out of it.

2.1. Equilibrium State of Massless Object

First, we construct a massless object S_0, which consists of two negative masses and a mass, as depicted in Figure 1.

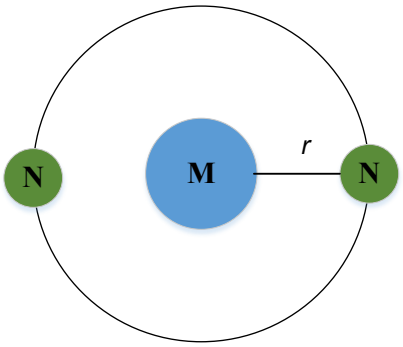

Figure 1. An object consists of two negative masses (N) and a mass (M). The two negative masses rotate around the mass at the center, and they are always on opposite sides of the orbit. With a particular distance r between a negative mass and the mass, the object is massless in its entirety.

Figure 1 shows a configuration in which a mass (M) is at the center, two negative masses (N) move around it in a circular orbit, r is the distance between a negative mass and the mass. The two negative masses are always on opposite sides of the orbit. The center of the negative masses is aligned with the center of the mass. The repulsion exerted on one negative mass by the other is $F_{NN} = G\frac{-N(-\mathrm{N})}{4r^2}$, and the attraction exerted on each negative mass by the mass is $F_{MN} = G\frac{M(-N)}{r^2}$. If $M > \frac{N}{4}$, then $|F_{MN}| > |F_{NN}|$, and the centripetal acceleration of each negative mass toward the mass keeps it in circular motion.

Next, let us determine whether there exists a distance r with which S_0 becomes massless in its entirety. In addition to the mass and negative masses, there is binding energy BE inside S_0. From the mass-energy equivalence principle, BE can be converted to mass. The massless condition of S_0 requires its net mass to be zero

$$M - 2N - \frac{BE}{c^2} = 0. \quad (1)$$

Furthermore, BE is the negative of the total gravitational potential energies among mass and negative masses, and the kinetic energies of negative masses. The potential energies are

$$-2G\frac{M(-N)}{r} - G\frac{-N(-N)}{2r} = G\frac{4MN-NN}{2r}, \tag{2}$$

whereas the kinetic energies can be derived as half of the potential energies but with opposite sign. Therefore, the binding energy is

$$BE = -\left(G\frac{4MN-NN}{2r} - \frac{1}{2}G\frac{4MN-NN}{2r}\right) = -G\frac{4MN-NN}{4r}, \tag{3}$$

plugging Eq. (3) into Eq. (1) we have

$$M - 2N + G\frac{4MN-NN}{4rc^2} = 0, \tag{4}$$

solving Eq. (4) we have

$$r = \frac{G}{4c^2}.\frac{4MN-N^2}{2N-M}, \tag{5}$$

if $2N > M > \frac{N}{4}$, then $r > 0$. We conclude that with some fixed values of M and N, there exists a distance r between each negative mass and the mass to make S_0 massless in its entirety. We say r is the equilibrium distance of S_0, or S_0 is massless, or S_0 is in an equilibrium state.

2.2. Non-equilibrium State of Massless Object

In Figure 1, if the distance between a negative mass and the mass is not equal to its equilibrium distance, then S_0 is not in an equilibrium state. If the distance is smaller, S_0 has positive energy; otherwise, S_0 has negative energy. This is the mechanism by which S_0 carries energy.

If S_0 does not carry energy, then its momentum is zero. We can prove this using the energy-momentum relation

$$E^2 = P^2c^2 + m^2c^4, \tag{6}$$

if both E and m are zero, then P must be zero.

What happens if a quantum of energy ΔE is transferred to it? The new energy ΔE becomes a part of S_0. That is, its binding energy BE increases or decreases accordingly. Hence, S_0 carries the energy ΔE.

A massless object carrying energy travels at the speed of light. This conclusion can be briefly derived from the energy-mass relation

$$E = \frac{mc^2}{\sqrt{1-\frac{v^2}{c^2}}}, \tag{7}$$

if m is zero and E is not zero, v must be equal to c.

On the other hand, what happens if S_0 loses the quantum of energy ΔE it carries? The loss of energy ΔE makes S_0 to be in an equilibrium state. Its momentum returns to zero.

3. Results

Here are the results. A massless object consists of mass and negative mass. It also has binding energy. If a quantum of energy is transferred into it, it carries that energy by changing its binding energy accordingly and moves at the speed of light. If the same quantum of energy that it carries is transferred out of it, it is in an equilibrium state, and its momentum is zero. We consider this massless object to be a force carrier that transfers energy between matter particles.

4. Discussion

Now, we have a candidate force carrier. We have noticed that the quantum of energy it carries is stored inside it as part of the binding energy. The binding energy is a gravitational potential energy. Hence, this force carrier is more suitable as a gravitational force carrier than other known massless force carriers. Let us further explore how it can be used for gravitational interaction mediation. That is, how this force carrier can fulfill the graviton's behaviors.

4.1. Mediating between Two Masses

We conduct another thought experiment to qualitatively demonstrate the gravitational interaction between two masses mediated by this force carrier. Assume that there are two normal matter particles, M_1 and M_2, separated by space, as depicted in Figure 2.

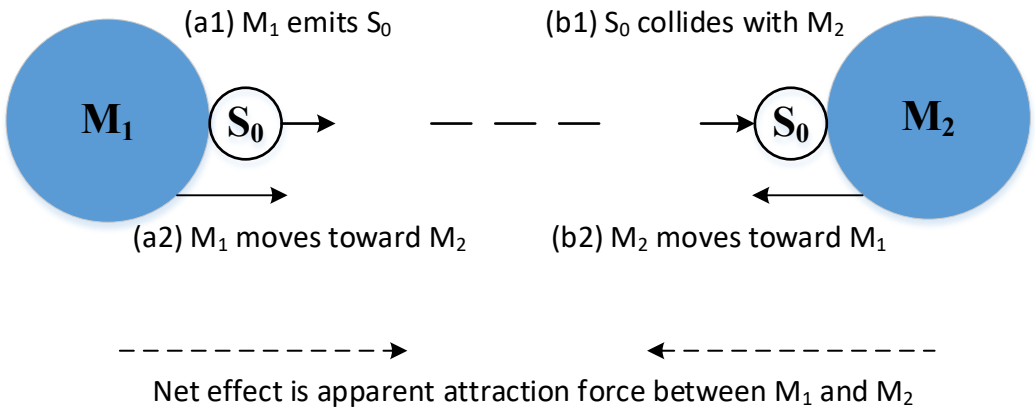

Figure 2. Two matter particles, M_1 and M_2, exchange massless object S_0 to make an attractive gravitational effect between them. (a) M_1 emits S_0, a gravitational force carrier, by transferring a quantum of negative energy to it. S_0 moves toward M_2. Since S_0 carries energy (negative), it travels at the speed of light. To conserve momentum, M_1 must move toward M_2. (b) Upon colliding with M_2, the quantum of negative energy which S_0 carries is transferred to M_2. S_0 becomes massless and its momentum is zero. To conserve momentum, M_2 must move toward M_1.

Figure 2 demonstrates the process of transferring energy between two matter particles by exchanging a massless object, resulting in an apparent attraction force between them. M_1 emits S_0, a gravitational force carrier, by transferring a quantum of energy (negative) to it. Upon carrying the energy, S_0 travels at the speed of light toward M_2. Let us choose the direction from M_1 to M_2 as positive. To conserve the total momentum of M_1 and S_0, before and after the emission, the following equation holds

$$0 + 0 = M_s V_s + M_1 V_1, \tag{8}$$

where V_1 is the velocity of M_1 after emitting S_0, and V_s is the velocity of S_0 after receiving energy. Before the emission, the momenta for S_0 and M_1 are zero. $M_s V_s$ is negative because S_0 carries negative energy. To satisfy Eq. (8), V_1 must be positive since M_1 is positive. Therefore, M_1 moves toward M_2.

After S_0 collides with M_2, it transfers the quantum of energy that it carries to M_2. It becomes massless and its momentum is zero. To conserve the total momentum of M_2 and S_0, before and after the collision, the following equation holds

$$M_s V_s + 0 = 0 + M_2 V_2, \tag{9}$$

where V_2 is the velocity of M_2 after absorbing S_0, and V_s is the velocity of S_0 before collision. $M_s V_s$ is negative because S_0 carries negative energy. To satisfy Eq. (9), V_2 must be negative since M_2 is positive. Therefore, M_2 moves toward M_1. Equations (8) and (9) indicate that the net effect of the process is that M_1 and M_2 move toward each other, which can be interpreted as a gravitational attraction.

4.2. Mediating between Two Negative Masses

Not only does the process described above work between masses, but it also works between negative masses by transferring a quantum of negative energy. The net effect is that both negative masses move away from each other, which can be interpreted as a gravitational repulsion.

4.3. Mediating between Mass and Negative Mass

Furthermore, this process works well between mass and negative mass by transferring a quantum of positive energy. The net effect is that the negative mass moves toward the mass, whereas the mass moves away from the negative mass, which can be interpreted as the so-called runaway motion.

5. Conclusions

In this essay, we consider massless as zero net mass. We study a type of massless object which consists of mass and negative mass. We then analyze its equilibrium state and the mechanism by which it can carry energy. Using this massless object as a gravitational force carrier, we demonstrate how graviton-like behaviors can be achieved by transferring energy between matter particles. We have noticed symmetry during the exchange of this force carrier between matter particles. It is always a quantum of negative energy transferred between like masses. For instance, in Figure 2, M_1 emits a quantum of negative energy and absorbs a quantum of negative energy at the same time. Therefore, statistically the mass of M_1 does not change during this process. It is also true that a quantum of positive energy is always transferred between unlike masses. In the future, we would like to further quantitively investigate the properties of this massless object as a gravitational force carrier.

References

1. Steven, W. 1993 Dreams of a Final Theory. Hutchinson Radius.

2. Feynman, R. P., Morinigo, F. B., Wagner, W. G., Hatfield, B. 1995 Feynman lectures on gravitation. Addison-Wesley.

3. Polchinski, J. 1998 String theory, Vols. 1 and 2, Cambridge University Press.

4. Will, C. M. 1998 Bounding the mass of the graviton using gravitational-wave observations of inspiralling compact binaries. Phys. Rev. D. **57** (4), 2061.

5. Randall, L. 2005 Warped Passages: Unraveling the Universe's Hidden Dimensions. Ecco Press.

6. Colosi, D. *et al.* 2005 Background independence in a nutshell: The dynamics of a tetrahedron. Classical and Quantum Gravity. **22** (14), 2971.

7. Rothman, T., Stephen B. 2006 Can Gravitons be Detected? Foundations of Physics **36** (12), 1801.

8. Harris, R. 2008 Modern Physics. Pearson Addison Wesley.

9. Zee, A. 2010 Quantum Field Theory in a Nutshell. Princeton University Press.

10. Dyson, F. 2013 Is a Graviton Detectable? Int. J. Mod. Phys. A. **28** (25), 1330041.

11. Ali, A. F., Das, S. 2015 Cosmology from quantum potential. Phys. Lett. B. **741**, 276.

12. Misner, C. W., Thorne, K. S., Wheeler, J. A. 2017 Gravitation. Princeton University Press.

13. Abbott, B. P. *et al.* (LIGO Scientific Collaboration and Virgo Collaboration) 2017 GW170104: Observation of a 50-Solar-Mass Binary Black Hole Coalescence at Redshift 0.2. Phys. Rev. Lett. **118** (22), 221101.

14. Carroll, S. M. 2019 Spacetime and Geometry: An Introduction to General Relativity. Cambridge University Press.

15. Parikh, M., Wilczek, F., Zahariade, G. 2020 The noise of gravitons. Int. J. Mod. Phys. D. **29** (14), 2042001.

16. Jaeger, G. 2021 Exchange Forces in Particle Physics. Foundations of Physics. **51** (1), 1–31.

17. Dirac, P. A. M. 1928 The quantum theory of the electron. Proc. R. Soc. A: Math. Phys. Eng. Sci. **117** (778), 610.

18. Ferrell, R. 1950 The possibility of New Gravitational Effects. Gravity Research Foundation.

19. Luttinger, J. M. 1951 On "Negative" mass in the theory of gravitation. Gravity Research Foundation.

20. Bondi, H. 1957 Negative Mass in General Relativity. Rev. Mod. Phys. **29** (3), 423.

21. Morris, M. S., Thorne, K. S., Yurtsever, U. 1988 Wormholes, Time Machines, and the Weak Energy Condition. Phys. Rev. Lett. **61** (13), 1446.

22. Bonnor, W. B. 1989 Negative mass in general relativity. Gen. Rel. Grav. **21** (11), 1143.

23. Forward, R. L. 1990 Negative Matter Propulsion. J. Propulsion. **6** (1), 28.

24. Price, R. H. 1993 Negative Mass Can Be Positively Amusing. Am. J. Phys. **61** (3), 216.

25. Milton, G. W., Willis, J. R. 2007 On modifications of Newton's second law and linear continuum elastodynamics. Proc. R. Soc. A: Math. Phys. Eng. Sci. **463** (2079), 855.

26. Hossenfelder, S. 2008 A Bi-Metric Theory with Exchange Symmetry. Phys. Rev. D. **78** (4), 044015.

27. Belletˆete, J., Paranjape, M. B. 2013 On Negative Mass. Int. J. Mod. Phys. D. **22** (12), 1341017.

28. Mbarek, S., Paranjape, M. 2014 Negative Mass Bubbles in De Sitter Spacetime. Phys. Rev. D. **90** (10), 101502.

29. Khamehchi, M. A., Hossain, K., Mossman, M. E., Zhang, Y., Busch, T., Forbes, M. M., Engels, P. 2017 Negative-Mass Hydrodynamics in a Spin-Orbit–coupled Bose–Einstein Condensate. Phys. Rev. Lett. **118** (15), 155301.