Archimedes' Principle and Gravitational Levitation

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In recent years, several researchers have reported experimental devices that allegedly exhibit variable weight during operation. The notion that these devices may be interacting with vacuum electromagnetic zero-point radiation to generate negative energy near the devices is considered. Newtonian theory is used to explore the gravitational effects of generating negative energy within a spherical shell of ordinary matter. It is shown that negative energy alters the weight of ordinary matter in a manner analogous to Archimedes' Principle. As an alternative to using negative energy, a method for inducing gravitational fields by rotating gravitomagnetic fields is explored. It is found that in all cases the enormity of the energy requirement precludes the possibility that gravitational levitation is the source of any observable weight variation. It is concluded that an electromagnetic basis for the variable weight should be investigated.

I. INTRODUCTION

In recent years, several researchers have reported experimental devices that appear to exhibit varying degrees of gravitational levitation during operation. One notable case is the work of Podkletnov and Nieminen wherein a super conducting ring was reported to have reduced the weights of objects suspended above the ring by up to 2%.[1] Another interesting case is the work of Roschin and Godin in which a complex arrangement of magnetized rings and peripheral rollers was reported to lose up to 35% of its weight during operation.[2] Assuming these devices function as reported, what is missing is a reasonable explanation of how such a weight reduction is induced.

One possible explanation is that the devices are somehow interacting with the gravitational field of the earth. Another possible explanation is that the devices may be interacting with other hitherto unexplored aspects of gravitation. Still, the weight reduction might not be gravitational at all; rather electromagnetic phenomena might be providing lift forces.

One popular proposal is that the weight of ordinary matter is chiefly due to red-shifting of electromagnetic vacuum zero-point radiation near large gravitational sources, such as the earth. If this is indeed the case, then manipulation of zero-point radiation should affect the weight of matter. In Sec. 2, it is shown that reducing the energy-density of zero-point radiation within the cavity of a sphere of ordinary matter does alter the weight of the sphere. Rather than considering the electromagnetic nature of zero-point radiation, zero-point energy is treated analogously to a fluid capable of exerting forces on matter. The resulting expression for the weight of the sphere suggests an analog to Archimedes' Principle wherein a material body is buoyed by displacement of a zero-point radiation fluid.

Section 3 delves into another approach to zero-point phenomena which centers on exotic matter, having negative mass-energy content. While in the previous section, zero-point radiation is treated as real and observable, in this section zero-point phenomena are viewed as virtual; only differences in zero-point energy give rise to detectable phenomena. Thus, with the exotic matter approach, the sphere resides in seemingly empty space. Within the interior cavity of the sphere is a hypothetical engine which draws positive zero-point energy from inside to the out-side of the sphere, leaving a seemingly negative energy within the sphere.[3,4] Similar to the analysis of Sec. 2, the negative energy affects the weight of the sphere analogously to Archimedes' Principle. The form of the resulting expression for the sphere's weight suggests that the quantity of negative energy required to render the sphere weightless is at least equal to the rest mass-energy content of the sphere.

In Sec. 4, an alternative to negative energy and zero-point phenomena is explored. A recent proposal asserts that gravitomagnetic fields already present within ordinary matter can be utilized to induce gravitational fields. This concept is used to derive the gravitational field induced outside a rotating magnet. The resulting expression for the force on a nearby test body again suggests an analog to Archimedes' Principle. As in the previous sections, the energy required to create any noticeable alteration in the weight of the above-mentioned devices[1,2] appears to rule out gravitational levitation.

In Sec. 5, it is argued that due to the massive energy requirement, the devices[1,2] reported above cannot possibly be generating true gravitational levitation. It is pointed out that even if zero-point radiation turns out to be the origin of gravitational forces, such forces cannot be efficiently manipulated by altering the energy content of zero-point radiation. Section 5 closes with a proposal that an electromagnetic basis for the lifting forces observed in connection with the above devices[1,2] should be investigated.

II. DISPLACEMENT OF REAL ZERO-POINT RADIATION

A popular proposal is that the devices[1,2] mentioned in the Introduction are interacting with real zero-point radiation. If this is assumed to be the case, the question still remains as to how zero-point radiation can be effectively manipulated so as to alter the weight of the devices. One possible explanation is that the devices may be inducing vacuum electromagnetic zero-point radiation to perform positive work. Specifically, whenever vacuum electromagnetic zero-point radiation performs positive work in a localized region of space-time, a corresponding drop in zero-point field energy occurs, relative to the rest of space-time.[3] Such a drop in energy theoretically could be used to alter the weight of the above-mentioned devices. In order to demonstrate this, zero-point radiation is treated as a real radiation field capable of exerting forces on ordinary matter.

The devices mentioned in the previous section are complex, but the physical mechanism underlying the reported weight reduction ought to be straightforward. For the sake of simplicity, let us consider an idealized spherical shell of ordinary mass-density ρ, having an inner radius a and an outer radius b, and residing at a distance r from the center of a large gravitational source, such as the earth. The sphere and the gravitational source reside within a real zero-point radiation background field, characterized by an energy-density, u_{OUT}. As pointed out in the Introduction, the zero-point radiation is red-shifted due to the presence of the gravitational source, and thus contributes to the weight of the sphere.

Within the sphere, an ideal engine is envisioned which performs positive work to transfer energy from the cavity, $r < a$, to the region $r \geq b$ outside the sphere.[3,4] The ideal engine is analogous to a refrigerator which moves heat energy from a cold reservoir to a hot reservoir. Thus, while the ideal engine is operating, we have $u_{IN} < u_{OUT}$. Of course, energy transferred to the outside of the sphere contributes to u_{OUT}. Although this additional energy contribution is not considered here, the contribution to u_{OUT} is taken into account in the next section. The net force on the sphere due to its weight and the difference in zero-point energy-density inside and outside the sphere may be expressed as

$$\mathbf{F} + \mathbf{F}_B = \mathbf{F}_W \tag{1}$$

where $\mathbf{F}$ is the net force on the sphere, $\mathbf{F}_B$ is a buoyancy force on the sphere due to the difference in energy-density inside and outside the sphere,[4] and $\mathbf{F}_W$ is the weight due to the mass of the sphere. Using the familiar expression $\mathbf{F} = -\nabla U$, Eq. (1) may be put in the form

$$\mathbf{F} = -\nabla \left(U_{IN} - U_{OUT}\right) + m\mathbf{g} \tag{2}$$

where U_{IN} and U_{OUT} are the gravitational potential energy due to zero-point radiation inside and outside the sphere, respectively, m is the mass of the sphere, and $\mathbf{g}$ is the gravitational field vector of the earth. It should be noted that in absence of the energy difference in the first term of Eq. (2), zero-point radiation contributes to the mass, m, of the sphere.

Equation (2) can be simplified by expressing the gravitational potential energy of the zero-point energy-density within the sphere as[6]

$$U\left(\mathbf{x}\right) = \int \rho\left(\mathbf{x}'\right) \phi\left(\mathbf{x}'\right) d^3x' \tag{3}$$

where $\rho\left(\mathbf{x}'\right)$ is the mass-density of the zero-point radiation, $\mathbf{x}$ and $\mathbf{x}'$ are position vectors, $\phi\left(\mathbf{x}'\right)$ is the gravitational potential, and the integration is taken over the interior volume of the sphere, V_a. As the reader will recall, $\mathbf{x}$ points from the origin to a position from which observations are performed and $\mathbf{x}'$ points from the origin to a position occupied by an elementary portion of the gravitational source.[6] Using Eq. (3) in Eq. (2), and relating energy-density to mass-density by $u = \rho c^2$, leads to

$$\begin{aligned} \mathbf{F} = \frac{\nabla}{c^2} \int \phi\left(\mathbf{x}'\right) u_{OUT}\left(\mathbf{x}'\right) d^3x' + \ldots \\ - \frac{\nabla}{c^2} \int \phi\left(\mathbf{x}'\right) u_{IN}\left(\mathbf{x}'\right) d^3x' + m\mathbf{g}. \end{aligned} \tag{4}$$

Assuming the gravitational potential and the zero-point energy-density are sufficiently uniform across the volume of sphere allows Eq. (4) to be expressed simply as

$$\mathbf{F} = -\frac{V_a}{c^2}\left(u_{IN} - u_{OUT}\right)\nabla\phi + m\mathbf{g}. \tag{5}$$

Upon expressing the zero-point energy inside the sphere as $E_{IN} = u_{IN}V_a$ and the gravitational field as $\mathbf{g} = -\nabla\phi$, the gravitational force on the sphere simplifies to

$$\mathbf{F} = \mathbf{g}\left[m + \frac{E_{IN}}{c^2}\left(1 - \frac{u_{OUT}}{u_{IN}}\right)\right]. \tag{6}$$

Thus, the difference in zero-point energy inside and outside the sphere gives rise to an extra mass term. It is straightforward to see that when $u_{IN} < u_{OUT}$ the weight of the sphere is reduced, when $u_{IN} > u_{OUT}$ the weight is increased, and when $u_{IN} = u_{OUT}$, Eq. (6) reduces to the usual expression for the weight of the sphere, $\mathbf{F} = m\mathbf{g}$.

Equation (6) shows that manipulation of the zero-point energy-density within the sphere can affect the weight of the sphere. The next natural question is by how much must the zero-point energy within the sphere be reduced in order to render the sphere weightless? When $\mathbf{F} = \mathbf{0}$, solving Eq. (6) for the difference in zero-point energy inside and outside the sphere, and recalling that $E = uV$, leads to

$$E_{OUT} - E_{IN} = mc^2. \tag{7}$$

Thus the zero-point energy within the sphere must be reduced by a quantity equal to the rest mass-energy of the sphere. Equation (7) should be considered a minimum; were the contribution to u_{OUT} by the ideal engine taken into account, the energy requirement would be greater then mc^2.

III. GENERATING EXOTIC MATTER

Another approach to zero-point phenomena centers on the notion of using exotic matter, possessing negative mass-energy, to effectively cancel the gravitational attraction associated with ordinary matter. As in the previous section, let us consider an idealized spherical shell of ordinary mass-density ρ, having an inner radius a and an outer radius b. In the preceding section, zero-point radiation was treated as real and directly observable. In this section, zero-point radiation is viewed as virtual and undetectable with only differences in zero-point energy becoming manifest. Thus, rather than being immersed in a real, observable radiation field, as in the previous section, here the sphere resides in empty space near a gravitational source such as the earth.

Within the sphere is an ideal engine which performs positive work to harvest positive zero-point energy from the vacuum within the cavity of the sphere and deposits the energy outside the sphere. As pointed out in the preceding section, such an engine is analogous to a refrigerator which moves heat energy from a cold reservoir to a hot reservoir. Thus, initially, while the engine is not operating we have $u_{IN},\ u_{OUT} = 0$. While the engine is operating, an energy-density $u_{IN} = -u$ is apparent within the region $r < a$, and an energy-density $u_{OUT} > 0$ resides in the region $r \geq b$.[3,4] From the vantage of observers outside the sphere, the ideal engine appears to be generating exotic matter within the sphere and producing positive energy outside the sphere. For the sake of argument, let us assume that the exterior energy-density assumes the form $u_{OUT} = f/r^4$, where f is a coefficient of proportionality.

The gravitational potential ϕ outside the sphere can be determined by using the familiar expression[6]

$$\phi = -G \int \frac{\rho(\mathbf{x}')}{|\mathbf{x} - \mathbf{x}'|} d^3x' \tag{8}$$

where $\mathbf{x}$ and $\mathbf{x}'$ are position vectors, $\rho(\mathbf{x}')$ is the mass-density of the gravitational source, G is the gravitational constant, and the integration is taken over primed quantities. The vector $\mathbf{x}$ points from the origin to a position from which observations are performed, $\mathbf{x}'$ points from the origin to a position occupied by an elementary portion of the gravitational source, and $|\mathbf{x} - \mathbf{x}'|$ is the magnitude of the vector difference in the two positions.[6] Applying Eq. (8) to the region outside the sphere and performing the angular integrations leads to

$$\begin{aligned}\phi\left(\mathbf{x} > \mathbf{b}\right) = \frac{4\pi G}{rc^2}\left(u\int_0^a r'^2 dr' - \rho c^2 \int_a^b r'^2 dr'\right) + \dots \\ - \frac{4\pi G f}{c^2}\left(\frac{1}{r}\int_b^r \frac{dr'}{r'^2} + \int_r^\infty \frac{dr'}{r'^3}\right)\end{aligned} \tag{9}$$

where the relation $u = \rho c^2$ has been used in all but the second term. Carrying out the integrations and noting that we may put $V_a = 4\pi a^3/3$ and $V_b = 4\pi b^3/3$, leads to

$$\begin{aligned}\phi\left(\mathbf{x} > \mathbf{b}\right) = -\frac{G\rho}{r}\left(V_b - V_a\right)\left(1 - \frac{uV_a}{m_S c^2}\right) + \dots \\ - \frac{4\pi G}{c^2}\frac{f}{rb}\left(1 - \frac{b}{2r}\right)\end{aligned} \tag{10}$$

where the mass of the spherical shell is $m_S = \rho\left(V_b - V_a\right)$.

The gravitational field outside the sphere can be readily de-termined by using the familiar expression, $\mathbf{g} = -\mathbf{e}_r \partial\phi/\partial r$. Differentiating Eq. (10) and performing some minor simplifications leads to

$$\begin{aligned}\mathbf{g}\left(\mathbf{x} > \mathbf{b}\right) = -\frac{Gm_S}{r^2}\left(1 - \frac{uV_a}{m_S c^2}\right)\mathbf{e}_r + \dots \\ - \frac{4\pi G}{c^2}\frac{f}{r^2}\left(\frac{1}{b} - \frac{1}{r}\right)\mathbf{e}_r.\end{aligned} \tag{11}$$

This expression clearly contains a term that acts in opposition to the gravitational field due to the ordinary mass of the sphere. It should be noted that when u and f are allowed to drop to zero, Eq. (11) reduces to the usual expression for the gravitational field outside a sphere of mass-density, ρ.

Equation (11) can be used to determine the gravitational force on the sphere by simply using the expression $\mathbf{F} = M\mathbf{g}$, where M is the mass of the earth. Carrying this out gives

$$\begin{aligned}\mathbf{F} = -\frac{GMm_S}{r^2}\left(1 - \frac{uV_a}{m_S c^2}\right)\mathbf{e}_r + \dots \\ + \frac{4\pi GMf}{r^2c^2}\left(\frac{1}{b} - \frac{1}{r}\right)\mathbf{e}_r.\end{aligned} \tag{12}$$

It is straightforward to see that, while the ideal engine is operating, the effective mass of the sphere assumes the form:

$$m' = m_S\left(1 - \frac{E}{m_S c^2}\right) + \frac{4\pi f}{c^2}\left(\frac{1}{b} - \frac{1}{r}\right) \tag{13}$$

where E is the total energy within the cavity of the sphere. The first term on the right-hand side of Eq. (13) is a direct analog to the effective mass arising due to Archimedes' Principle, wherein a body submerged in a fluid is buoyed up by a force equal to the weight of the fluid displaced by the body. The notable difference, here, is that there is no fluid; rather, Eq. (13) arises merely due to the difference in energy inside the sphere and the rest mass-energy of the sphere.

As a final thought, it is interesting to consider the amount of internal energy required in order to completely mask the sphere from the exterior gravitational field, $\mathbf{g}$. At a particular separation distance, r, the sphere will appear weightless when $m' = 0$. Carrying this out in Eq. (13) and solving for the energy inside the sphere gives

$$E = m_S c^2 + 4\pi f\left(\frac{1}{b} - \frac{1}{r}\right). \tag{14}$$

Just as with the analysis in the previous section, Eq. (14) suggests that for the sphere to appear weightless, the energy within the sphere must be reduced by an amount at least equal to the mass-energy of the sphere. The rightmost term arises due to the energy transferred from inside to outside the sphere, and provides an additional barrier that must be overcome before any detectable weight reduction can occur.

IV. ROTATING GRAVITOMAGNETIC FIELDS

The previous sections dealt with manipulating vacuum electromagnetic zero-point energy in order to generate gravitational levitation. But is there any reasonable explanation of the physics underlying the devices[1,2] discussed in the Introduction which doesn't involve negative energy or zero-point phenomena? Indeed, there is such an explanation. Gravitomagnetic fields already present in ordinary matter theoretically can be rotated so as to induce gravitational fields in a manner entirely analogous to electromagnetic induction.[7,8]

Consider a simple current loop of area A. Charge carriers moving within the material of the loop give rise to a magnetic dipole moment of the form $\mu_q = i_q A$, where i_q is the current and the subscript denotes charge current. But the charge carriers also possess mass, and thus it stands to reason that there exists a mass-dipole moment of the form $\mu_m = i_m A$, in which $i_m = m/\Delta t$ is defined as a mass-current. It is straightforward to see that since magnetic fields in materials are ultimately due to the motion of electrons, we may put

$$\mu_e = \frac{e}{m_e}\mu_m \tag{15}$$

where e and m_e are respectively the charge and mass of the electron. Equation (15) suggests that since macroscopic magnetic fields arise due to the motion of electrons, there also exists a gravitomagnetic field having the same field topology, albeit at a much weaker field strength. Viewed in this way, a gravitomagnetic field $\mathbf{h}$ may be treated as a scaled magnetic field, $\mathbf{B}$. Using Ampere's law for both fields suggests that we may put

$$\oint_C (N\mathbf{B} - \mathbf{h}) \cdot d\mathbf{l} = N\mu_0 i_q - \mu_g i_m = 0 \tag{16}$$

where N is a scale factor and μ_g is a gravitomagnetic permeability given by[7,8]

$$\mu_g = \frac{4\pi G}{c^2}. \tag{17}$$

Solving Eq. (16) for the scale factor, N, using Eq. (15), and then solving for the gravitomagnetic field leads to

$$\mathbf{h} = \frac{4\pi G m_e}{\mu_0 e c^2}\mathbf{B}. \tag{18}$$

Thus, once the magnetic field is known, the corresponding gravitomagnetic field can be easily determined.

With Eq. (18) now in hand, let's consider the gravitomagnetic field outside a rotating disk-shaped magnet. Outside the magnet, the field is

$$\mathbf{B} = \frac{\mu_0 \mu_e}{4\pi r^3}\left(2\cos\theta\mathbf{e}_r + \sin\theta\mathbf{e}_\theta\right). \tag{19}$$

Substituting into Eq. (18) and, again, using Eq. (15) immediately leads to a gravitomagnetic field of the form

$$\mathbf{h} = \frac{G\mu_m}{c^2 r^3}\left(2\cos\theta\mathbf{e}_r + \sin\theta\mathbf{e}_\theta\right) \tag{20}$$

where it should be noted that μ_m is due to only those charge carriers that participate in producing the exterior field.

As is very well known, when a magnetic field, $\mathbf{B}$, rotates with a velocity, $\mathbf{v}$, an electric field, $\mathbf{E}$, is induced according to $\mathbf{E} = \mathbf{v} \times \mathbf{B}$. Similarly, when a gravitomagnetic field rotates with a velocity, $\mathbf{v}$, it can be shown that a gravitational field is induced according to[9]

$$\mathbf{g} = \mathbf{h} \times \mathbf{v}. \tag{21}$$

For the present case of the rotating disk-shaped magnet, the velocity is $\mathbf{v} = \omega r \mathbf{e}_\phi$, where ω is the angular velocity of the magnet. Using this expression for the velocity and the field given by Eq. (20) in Eq. (21) gives

$$\mathbf{g} = -\frac{G\mu_m\omega}{c^2 r^2}\left(2\cos\theta\mathbf{e}_\theta - \sin\theta\mathbf{e}_r\right). \tag{22}$$

This induced gravitational field arises in addition to the usual gravitational field due to the mass of the magnet. When a test body of mass, M, is positioned near the magnet at $\theta = \pi/2$, the total gravitational force on the body is

$$\mathbf{F} = -\frac{GmM}{r^2}\mathbf{e}_r + \frac{G\mu_m\omega}{c^2 r^2}M\mathbf{e}_r \tag{23}$$

where m is the mass of the rotating magnet. Simplifying things a bit puts the force in the form

$$\mathbf{F} = -\frac{GmM}{r^2}\left(1 - \frac{\mu_m\omega}{mc^2}\right)\mathbf{e}_r. \tag{24}$$

As in the previous sections, here again the force assumes a form analogous to Archimedes' Principle. The terms within parentheses suggest that $\mu_m\omega$ must approach the rest mass-energy content of the rotating magnet before any weight reduction will become detectable.

V. CLOSING REMARKS

The preceding sections have demonstrated logical approaches to inducing gravitational levitation forces on ordinary matter, were plenty of energy available. The resulting expressions for the weight of matter suggest an analog to Archimedes' Principle where ordinary matter is buoyed by an apparent displacement of the effective rest-mass energy of matter. All three approaches illustrated herein lead to the same eventual result: the quantity of energy required to affect the weight of ordinary matter is comparable to the rest mass-energy content of matter.

The analysis makes it straightforward to see that the devices discussed[1,2] in the Introduction cannot logically be producing their own gravitational fields. The energy required to render either of the devices weightless is at least equal to the rest mass-energy content of the device itself. It seems reasonable to state that neither device produces anywhere near enough energy to have any detectable effect on the device or nearby matter. Moreover, even if the devices were interacting with new, presently unknown gravitational phenomena, the energy requirements still must be considered. It seems far more logical to investigate an electromagnetic basis for the forces reported in connection with the devices.[1,2] No doubt, an electromagnetic body force which mimics gravitation, while requiring far less energy, would prove novel and quite useful in a wide variety of industrial applications.

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