

Inertial and gravitational masses

Masanori Sato^{1,a)} and Hiroki Sato²

¹*Honda Electronics Co., Ltd., 20 Oyamazuka, Oiwa-cho, Toyohashi, Aichi 441-3193, Japan*

²*Kokugakuin University, 4-10-28 Higashi, Shibuya-ku, Tokyo 150-8440, Japan*

(Received 1 September 2014; accepted 3 February 2015; published online 28 February 2015)

Abstract: The equivalence of inertial and gravitational masses is discussed. The resistance (i.e., the impedance) from accelerated motion in the ether is considered to be inertia. Mass is an eddy-making resistance generated by the accelerated motion of a massive particle in the ether, in which the eddy is de Broglie wave, that is, adhered photon. The resistance in the ether is isotropic; thus, the inertial mass is equivalent to the gravitational mass. © 2015 *Physics Essays Publication*. [<http://dx.doi.org/10.4006/0836-1398-28.1.95>]

Résumé: L'équivalence entre masse inertielle et masse gravitationnelle est évoquée. La résistance (c'est-à-dire l'impédance) due au mouvement accéléré dans l'éther est considérée comme de l'inertie. La masse est un tourbillon produisant de la résistance générée par le mouvement accéléré d'une particule massive dans l'éther, dans lequel le tourbillon est une onde de De Broglie, autrement dit un photon adhérent. La résistance dans l'éther est isotrope, par conséquent la masse inertielle est équivalente à la masse gravitationnelle.

Key words: Equivalence Principle of Inertial and Gravitational Masses; Ether; de Broglie Wave; Elimination of the Gravitational Singularity.

I. INTRODUCTION

This study was motivated by the simple question of whether the acceleration (i.e., inertial mass) is affected by the gravity. Figure 1(a) shows that the equivalence principle is satisfied on the moon when the gravitational mass m_g becomes 1/6 on the moon's surface; thus, the inertial mass m_i is also 1/6. This is interpreted that both gravity g and acceleration α become 1/6 without changing the mass m . Not only the gravitational mass but also the inertial mass varies depending on the gravity. At this stage, we define the mass m as the value measured on the earth. It is considered that both inertia and weight become 1/6 on the moon's surface. We elucidate this point in Fig. 1(b): weightlessness in an airplane does not cancel the inertial mass. On the moon's surface, both gravity g and acceleration α become 1/6.

Ether plays an important role in the definition of mass. In this paper, we tentatively define the ether as a vacuum that contains electromagnetic, electrostatic, and gravitational fields resulting from the mass. Let us discuss an experiment on ether drift that was performed recently. In 2010, Wang¹ reported a "first order ether drift experiment," in which he directly observed the ether drift velocity. Wang used a linear array photo sensor, not an interferometer, in the experiment (see Sec. II).

Einstein² stated in his book that "Mass is defined by the resistance that a body opposes to its acceleration (inert mass). It is also measured by the weight of the body (heavy mass)." In the standard model, the inertial mass m_i is produced by the Higgs mechanism.³ By analogy with the Higgs boson, we propose that an inertial mass m_i is the

resistance (i.e., the impedance) from an accelerated motion to the ether.

Maxwell⁴ stated that "Newton himself, however, endeavored to account for gravitation by differences of pressure in an aether, but he did not publish his theory." That is, the gradient in the ether density ρ_E is proportional to the gravitation: $f \propto (d\rho_E/dr)$. In this paper, we will follow Newton's proposal: gravitation is related to the ether; therefore, inertial mass is related to the ether.

Hatch⁵⁻⁷ proposed an elastic ether-based theory of gravitation. He described the gravitation F_G as

$$F_G = \frac{d}{dr} \left(e^{-\frac{GM}{rc^2}} \right) mc^2 = \frac{GMm}{r^2} \left(e^{-\frac{GM}{rc^2}} \right), \quad (1)$$

where G is the gravitational constant $= 6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$, M is the mass of the earth, m is the mass of an object, r is the distance from the center of the earth, and c is the speed of light. Hatch noted, "Thus, Newton's inverse square law is a very good approximation. This equation shows that the gravitational force arises from the spatial gradient of the rest mass energy."

Ives⁸ noted that "The equality of the mass equivalent of radiation to the mass lost by a radiating body is derivable from Poincaré's momentum of radiation (1900) and his principle of relativity (1904). The reasoning in Einstein's 1905 derivation, questioned by Planck, is defective. He did not derive the mass-energy relation." Hecht^{9,10} stated that "Leaving aside that it continues to be affirmed experimentally, a rigorous proof of the mass-energy equivalence is probably beyond the purview of the special theory." Baierlein¹¹ asked "Does nature convert mass into energy?" In deriving $E = mc^2$, Einstein assumed that a photon is energy. Baierlein¹¹ stated "First of all, a photon is not just 'energy.'"

^{a)}msato@honda-el.co.jp

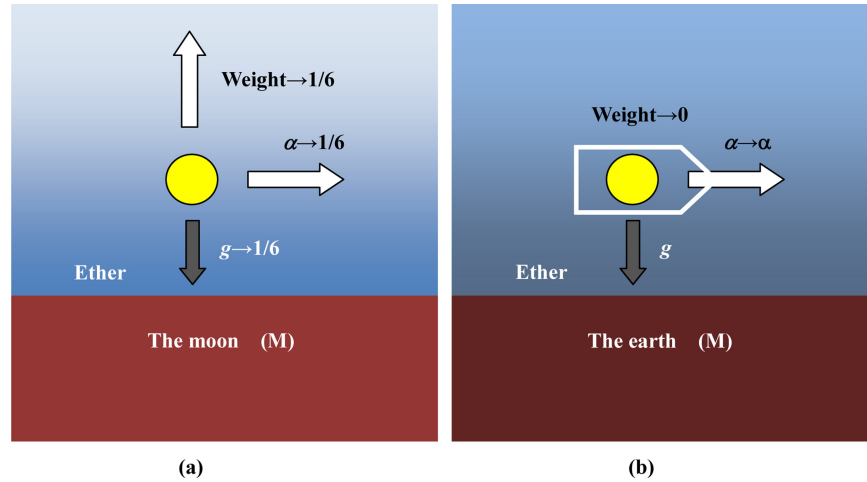


FIG. 1. (Color online) (a) Illustration showing an inertial mass m_i and its weight on the moon’s surface. (b) Weightlessness in an airplane: free fall around the surface of the earth.

Sato and Sato¹² reported that $E = mc^2$ represents the energy of photon and does not indicate the equivalence of the mass and energy. The Balmer series photon absorption of H α (656 nm) indicates an increase in the mass of the hydrogen atom. This increased mass is considered to be the rest mass of a 656-nm photon. Newtonian mechanics has also been discussed from the perspective of de Broglie wave theory¹³ (see Sec. III). Thereafter, a model of an adhered photon was developed to explain the relativistic mass. Figure 2 shows a model of an adhered photon that indicates the origin of the inertial mass: The eddy-making resistance of the Lord Kelvin’s vortex rings¹⁴ in the permittivity and permeability can be considered to generate inertia, which is proportional to the ether density.

In this paper, we report that the ether is associated with the mass. We discuss the inertial and gravitational masses in terms of a hypothesis: inertial mass is the impedance resulting from accelerated motion in the ether at the limit of v is 0.

II. WANG’S FIRST ORDER ETHER DRIFT EXPERIMENT

In these days, the technological development of Fabry–Pérot interferometer, linear array photo sensor, and the global positioning system (GPS) has refined the ether experiment. Wang’s first order ether drift experiment observed

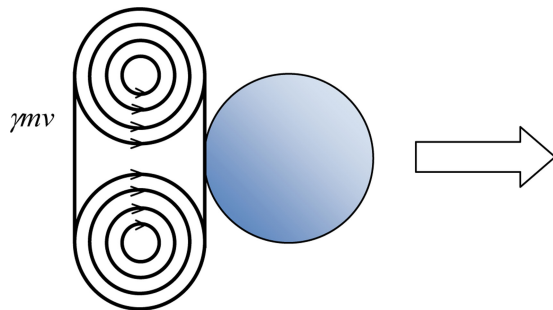


FIG. 2. (Color online) Origin of the inertial mass: Lord Kelvin’s vortex rings (Ref. 14) in the permittivity and permeability can be considered to generate inertia, which is proportional to the ether density. Adhered photon $\gamma m v$ is the driving force of massive particle.

ether drift. The GPS experiments are beginning to find the property of ether.

A. Fabry–Pérot interferometer

It was experimentally confirmed that Fabry–Pérot interferometer observes null results. Figure 3 illustrates a schematic diagram of a bouncing photon clock by Brilliet and Hall¹⁵ in 1979, which was considered as a precise Michelson–Morley type experiment. Eisele *et al.*¹⁶ reported that “a search for an anisotropy of the resonance frequencies of electromagnetic cavities. The apparatus comprises two orthogonal standing-wave optical cavities interrogated by a laser,” thereafter that “The measurements are interpreted as a search for an anisotropy of the speed of light,” and concluded the isotropy of light propagation at the 10^{-17} level.

Sato¹⁷ discussed single-photon Michelson–Morley experiment as shown in Fig. 4. There is only a single photon in the Michelson interferometer. In spite of the presence of only a single photon, interference is observed. This experiment does not show the simultaneous arrival of two photons. It only shows the interference condition. Not only the resonance experiments but also the interference experiments are not sensitive to the ether drift. Not the interference but the direct observation is required.

B. Wang’s first order ether drift experiment

In 2010, Wang¹ reported a “first order ether drift experiment,” in which he used a linear array photo sensor,

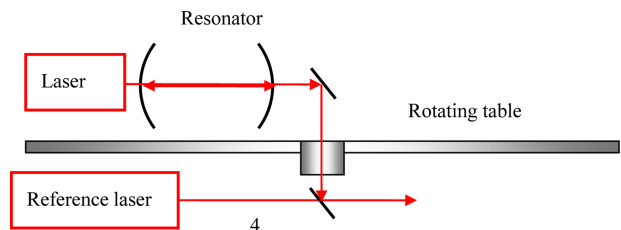


FIG. 3. (Color online) Schematic diagram of bouncing photon clock: (Fabry–Pérot interferometer).

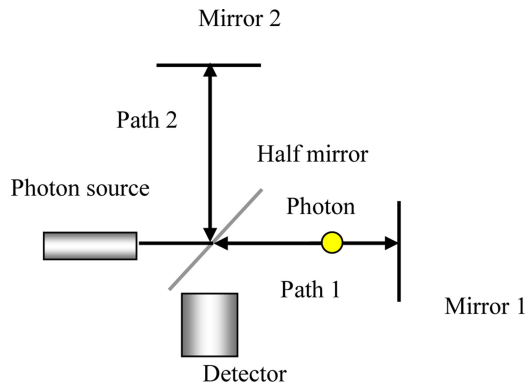


FIG. 4. (Color online) Single-photon Michelson–Morley experiment (Ref. 17). There is only a single photon in the Michelson interferometer: in spite of the single photon, interference is observed. This experiment does not show the simultaneous arrival of two photons.

not an interferometer, in the experiment as shown in Fig. 5. The experimentally measured spin velocity was reported to be 0.30 ± 0.94 km/s. Wang¹ described that to measure the earth’s spin velocity of 0.38 km/s, the statistical error of 0.94 km/s should be reduced. However, we consider that Wang’s first order ether drift experiment observed ether drift velocity. Figure 6 shows that the experimental results of laser beam position appear sinusoidal curve (permission of Wang and Physics Essays). Positive peak and negative peak of laser beam position appears when the device is oriented north-south. The statistical error looks rather small with regard to the angular orientation; that is, less than 0.30 km/s.

C. Noon-midnight red shift in the GPS

There were discussions of no noon-midnight red shift in the GPS by Ashby¹⁸ and Hatch.¹⁹ Ashby discussed “Why there is no noon-midnight red shift in the GPS?” He noted

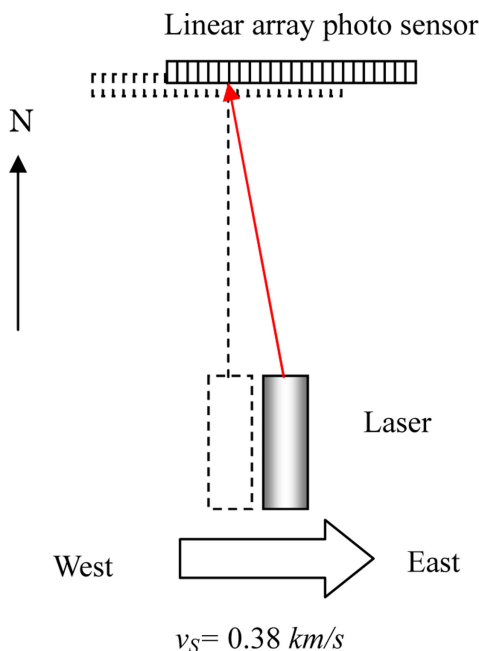


FIG. 5. (Color online) Wang’s first order ether drift experiment using linear array photo sensor. Earth’s spin velocity v_s is 0.38 km/s at Tennessee.

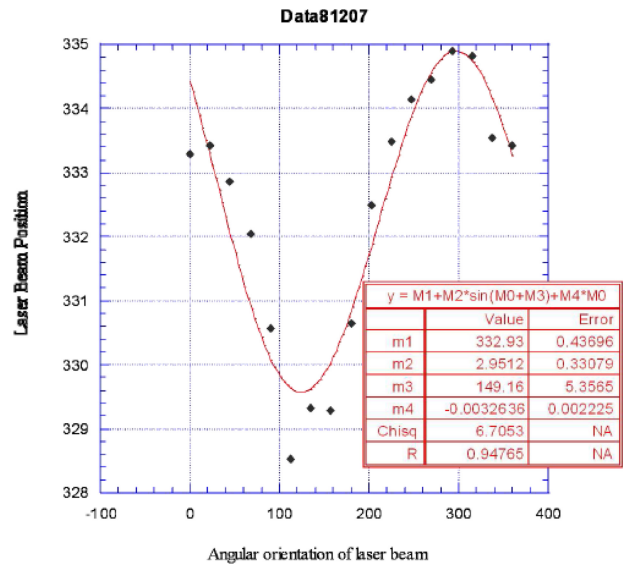


FIG. 6. (Color online) Wang’s first order ether drift experiment (From L. Wang, Phys. Essays 23, 473 (2010), Copyright © 2010 by Physics Essays Publication. Reprinted by permission of Physics Essays Publication).¹

that “This issue has been discussed in a misleading way in terms of cancellations arising from a second-order Doppler shift in the literature for almost 50 years.” Thereafter, he concluded “The induced kinematical acceleration that arises when the reference frame is in free fall in a gravitational field, superimposes on the true gravitational field due to the sun’s mass, in such a way as to precisely cancel.” Hatch counter argued that the second-order Doppler shift is valid.

Sato^{17,20} discussed experimental evidence of the ether-dragging hypothesis in GPS data; that is, the GPS is functional in the Stokes’ completely dragged ether by the gravitational field of the earth. The conclusion of Michelson–Morley experiment²¹ was “the ether is at rest with regard to the earth’s surface.” This is the solution of no noon-midnight red shift in the GPS.

D. Lagrangian description

Phipps²² thoroughly discussed Maxwell’s equations without ether hypothesis. Although, our idea is clearly depends on the ether hypothesis; however, we followed Phipps’ discussion on Lagrangian description.

Let us summarize the Lagrangian description of the wave equation.²⁰ The earth-centered locally inertial (ECI) coordinate system enclosed by a capsule moves in the solar system at the drift velocity of 30 km/s as shown in Fig. 7. The ether surrounding the earth is enclosed by an ether sphere (the radius is more than 380 000 km, which is the distance from the earth to the moon), and the ether in the solar system is also enclosed by a large ether sphere. In the ECI coordinate system (point A), as well as in the solar system (point B), the wave equations are satisfied. We are in a drifting ether sphere; thus it is assumed that we are in the stationary ether sphere (there is no ether drift). The Lorentz transformation can be calculated with respect to the stationary ether sphere. The gravity of the sun modifies the density distribution of the ether sphere. The modification is small

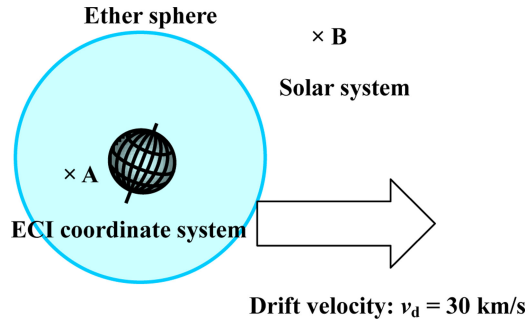


FIG. 7. (Color online) Lagrangian description: The ECI coordinate system enclosed by an ether sphere moves in the solar system at a drift velocity of 30 km/s. From solar system, we see the ECI coordinate system on the medium drift.

enough not to cause noon-midnight red shift in the GPS. Therefore, we can easily utilize the GPS.

E. Rotation of the ether sphere

Senior *et al.*²³ reported that “Characterization of periodic variations in the GPS satellite clocks,” in which they showed that “The equivalent fundamental period is 11.9826 ± 0.0030 h, which surprisingly differs from the reported mean GPS orbital period of 11.9659 ± 0.0007 h by 60 ± 11 s. We cannot account for this apparent discrepancy but note that a clear relationship between the periodic signals and the orbital dynamics is evidenced for some satellites by modulations of the spectral amplitudes with eclipse season.” The fluctuation of ether around the earth causes the periodic variations in the GPS satellite clocks; the periodic variations delay by 60 ± 11 s every 12 h. The experimental results can be considered to show that the ether rotates against earth’s spin by 60 ± 11 s every 12 h. The ether sphere takes 730 ± 132 days to one rotation. (It is similar to spin 1/2.)

Montenbruck *et al.*²⁴ reported GPS satellite clock variations of β -angle (between the sun and the GPS orbit plane) dependency as shown in Fig. 8. At low β -angle (the sun is in the GPS orbital plane), the deviations of the GPS clocks were observed. Figure 9 shows variation of the L1/

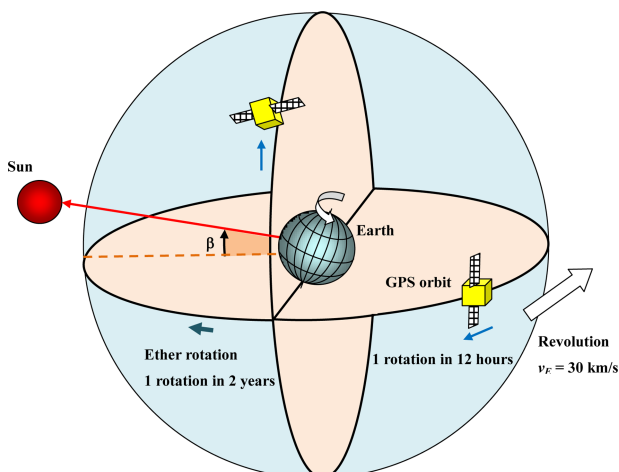


FIG. 8. (Color online) GPS satellite orientation and angles describing the alignment of the sun, earth, satellite, and orbital plane.

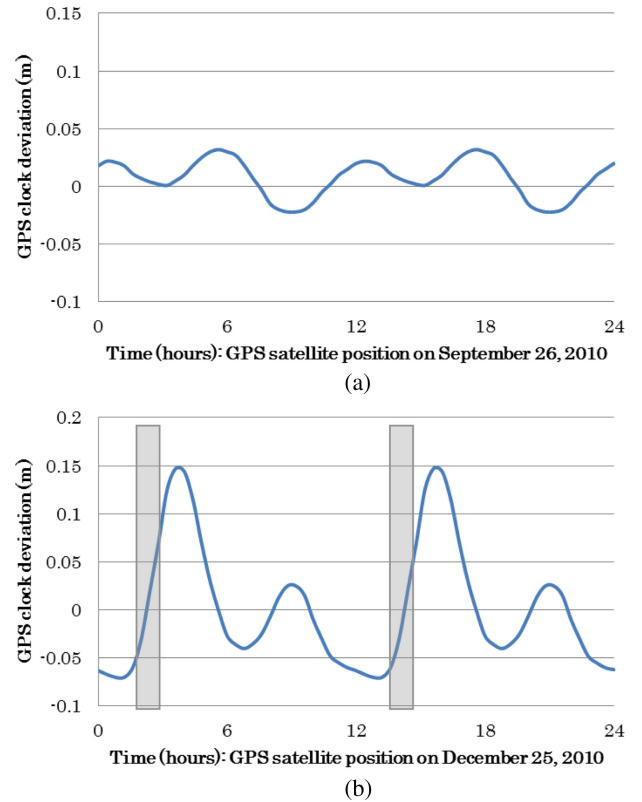


FIG. 9. (Color online) Variation of the L1/L5-minus-L1/L2 clock offset difference of SVN62 as derived from triple-frequency carrier phase observations by Montenbruck *et al.* (These figures were reproduced using picked up data from Fig. 2 in their paper.²⁴) Shaded part shows the eclipsed period by the earth. (a) High β -angle September 26, 2010 and (b) Low β -angle December 25, 2010.

L5-minus-L1/L2 clock offset difference of SVN62 as derived from triple-frequency carrier phase observations by Montenbruck *et al.* (This figure is picked up from Fig. 2 in their paper). Shaded part shows the eclipsed period by the earth. Although they explained that this deviation was caused by thermal artifacts; however, we consider this is an experimental evidence of the ether modification by the sun.

III. DE BROGLIE WAVE REPRESENTATION OF NEWTONIAN MECHANICS

In this section, we will summarize the de Broglie wave representation of Newtonian mechanics.¹⁷ As shown in Fig. 2, de Broglie wave can be considered to be adhered photon, which is the driving force of massive particle. To make discussion simple, we use nonrelativistic condition; the momentum of adhered photon is represented as mv instead of γmv .

The wavelength of de Broglie wave is represented as

$$\lambda = \frac{h}{mv}, \quad (2)$$

where v shows the velocity of massive particle as well as the group velocity of the de Broglie wave

$$\frac{\partial \omega}{\partial k} = v. \quad (3)$$

The wave number is represented as

$$k = \frac{2\pi}{\lambda} = \frac{2\pi \times mv}{h}. \quad (4)$$

Let us illustrate the relation between the frequency ω and the wave number k . From Eq. (3), we can assume the $\omega - k$ relation as

$$\omega = \frac{k^2}{2}. \quad (5)$$

The phase velocity is represented as

$$\frac{\omega}{k} = \frac{k}{2} = \frac{v}{2}. \quad (6)$$

We obtain the frequency of de Broglie wave as

$$f \equiv \frac{\omega}{2\pi} = \frac{kv}{4\pi} = \frac{v}{2\lambda} = \frac{mv^2}{2h}. \quad (7)$$

Thus the energy of de Broglie wave is

$$\varepsilon = hf = \hbar\omega = \frac{1}{2}mv^2. \quad (8)$$

Figure 10 shows frequency versus wave number ($\omega - k$) diagram of de Broglie wave. At point P, the group velocity $\partial\omega/\partial k$ is v , and the phase velocity ω/k is $v/2$.

On the moon's surface, the gravity constant g_M becomes $1/6$

$$g_M = \frac{1}{6} \times g. \quad (9)$$

Let us compare the de Broglie wave on the earth's surface and moon's surface as shown in Table I.

IV. EQUIVALENCE PRINCIPLE

The equivalence of the inertial and gravitational masses is a strong indicator of a mechanism involving the mass. At a distance r from the center of the earth, the impedance of a motion is isotropic; that is, the mass does not depend on the direction of the measurement.

In this section, we introduce the hypothesis that mass results from a mechanism in the density as well as distribution

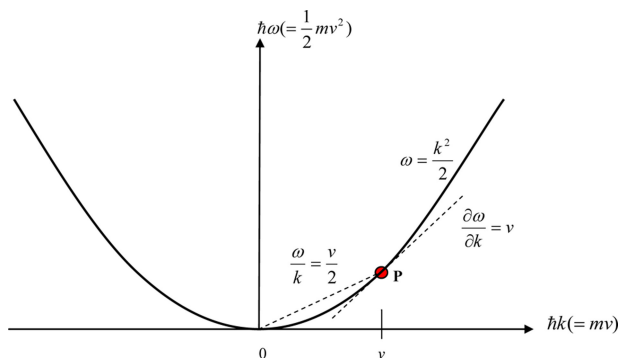


FIG. 10. (Color online) Frequency vs. wave number ($\omega - k$) diagram of the de Broglie wave of massive particle: At point P, the group velocity $\partial\omega/\partial k$ is v and the phase velocity ω/k is $v/2$.

TABLE I. De Broglie wave of moon's surface.

| | Earth's surface | Moon's surface |
|------------------|-----------------------------------------------------------------------------------------|-----------------------------------|
| Gravity constant | g | $g_M = \frac{1}{6} \times g$ |
| Mass | m | m |
| Weight | m | $\frac{m}{6}$ |
| Inertia | m | $\frac{m}{6}$ |
| Wavelength | $\lambda = \frac{h}{mv}$ | $\lambda = \frac{h}{mv} \times 6$ |
| Frequency | $f \equiv \frac{\omega}{2\pi} = \frac{kv}{4\pi} = \frac{v}{2\lambda} = \frac{mv^2}{2h}$ | $\frac{f}{6}$ |

of the ether. We define the gravitational mass following Newton's hypothesis; that is, the gravitation is the gradient in the ether density $\rho_E: f \propto (d\rho_E/dr)$. We consider that ether originates from mass. The gradient in the ether density results from the mass distribution.

At the same time, the equivalence of the inertial and gravitational masses leads us to represent the ether density distribution as an exponential function $y = e^{-1/r}$, as shown in Fig. 11. This form is chosen because $y = e^{-1/r}$ satisfies $(dy/dr) = (1/r^2)y$. In Fig. 12, the solid line corresponds to $(dy/dr) = (1/r^2)e^{-1/r}$, and the dotted line corresponds to $(dy/dr) = (1/r^2)$.

Figure 1 illustrates the inertial mass m_i and the gravitational mass m_g . Both the gravitational mass and the inertial mass increase in a region of high-density ether, that is, around the earth (or the moon). Inertia can be defined as follows: "mass is the impedance of motion in the ether"; that is, the motion of an object is impeded in high-density ether.

V. ETHER DENSITY AND ORIGIN OF INERTIA

Regarding the gravitational mass m_g , we follow Hatch's hypothesis⁵ that the density of ether can be expressed in an exponential form. The gravitational mass is related to the gradient in the ether density, and the inertial mass is related to the ether density. The gravitational mass is equivalent to the inertial mass, which indicates that the equations for the gravity and inertial force have an exponential form. We performed a dimensional analysis on these forces by assuming the following: (1) the forces have exponential forms, (2) the

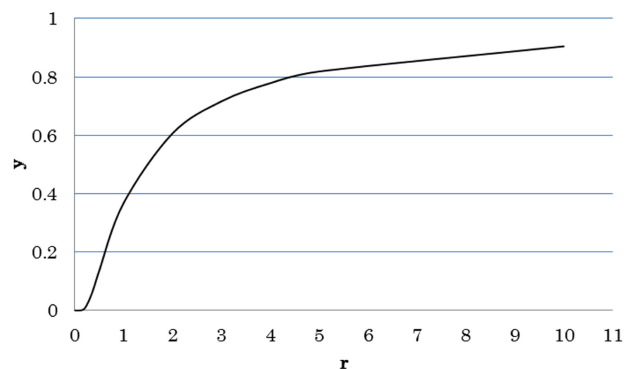


FIG. 11. (Color online) Illustration of the equation $y = e^{-1/r}$, which is used to model the distribution of the ether density from a point mass.

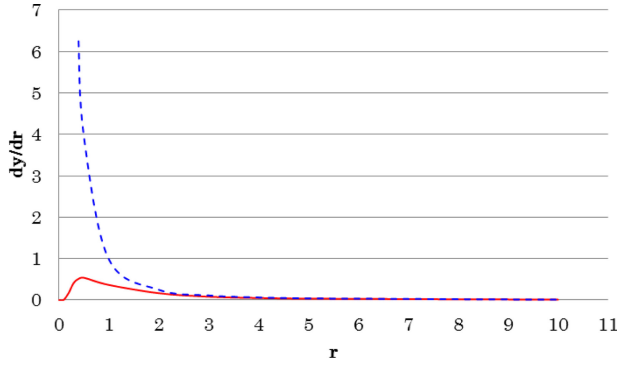


FIG. 12. (Color online) Plot of equations: the solid line corresponds to $(dy/dr) = (1/r^2)e^{-1/r}$, and the dotted line corresponds to $(dy/dr) = (1/r^2)$.

forces are proportional to the permittivity of free space ϵ_0 and the permeability of free space μ_0 , and (3) the equations for these forces are compatible with Newton's law.

In Eq. (1), we cancel c^2 and introduce a constant K_ρ , which is the elastic modulus of the ether. We make this substitution to ensure that $(1/c^2) = \epsilon_0\mu_0$ appears in the equation because the product $\epsilon_0\mu_0 \propto \rho_E$ determines the resistance on the moon; that is, the value of the inertial mass is $1/6$. At the same time, we require that the speed of light $c \equiv \sqrt{K_\rho/\epsilon_0\mu_0}$ is approximately equal on both the earth and the moon. Thus, we obtain

$$f_g = \frac{d}{dr} \left(e^{-\frac{K_\rho GM}{rc^2}} \right) \cdot m_g = \frac{GMm_g}{r^2} \cdot \frac{K_\rho}{c^2} e^{-\frac{K_\rho GM}{rc^2}}. \quad (10)$$

Equation (10) contains $(1/c^2) = \epsilon_0\mu_0$; that is, the gravitational force is proportional to the permittivity and the permeability of the ether.

In the limit of infinite r ($r \rightarrow \infty$), as noted by Hatch, Eq. (10) is compatible with Newton's inverse square law. Equation (10) also shows that f_g becomes 0 in the limit that $r \rightarrow 0$; that is, the gravitational singularity is eliminated.

The gravitational acceleration g is represented as

$$g = \frac{GM}{r^2} \cdot \frac{K_\rho}{c^2} \cdot e^{-\frac{K_\rho GM}{rc^2}}. \quad (11)$$

From the equivalence principle of inertial and gravitational masses,

$$\begin{aligned} \therefore f_g &= m_g \cdot \frac{d\rho_E}{dr} = m_g \cdot \frac{GM}{r^2} \cdot \frac{K_\rho}{c^2} \cdot e^{-\frac{K_\rho GM}{rc^2}} = m_g \cdot g \\ &= m_i \cdot \alpha = f_\alpha. \end{aligned} \quad (12)$$

If we set $m_i = m_g$,

$$g = \alpha = \frac{GM}{r^2} \cdot \frac{K_\rho}{c^2} \cdot e^{-\frac{K_\rho GM}{rc^2}}. \quad (13)$$

Equation (13) indicates that the impedance to an accelerated motion in ether is inertia.

VI. NUMERICAL ESTIMATE

We estimate the numerical value of K_ρ as follows: $(GM/rc^2) = (4.0 \times 10^{14} \text{ m}^3 \text{ s}^{-2}) / (6.37 \times 10^6 \text{ m} \times (3 \times 10^8 \text{ m/s}^2)) = 0.62 \times 10^{-8}$.

For compatibility with Newton's inverse square law, we require that $(K_\rho/c^2) \cdot e^{-(K_\rho GM)/rc^2} = 1$.

We assume the following on the earth's surface: $(K_\rho/c^2) = 1$,

Thus, we obtain $K_\rho = c^2 \approx 9 \times 10^{16} \text{ m}^2/\text{s}^2$.

VII. DISCUSSION

Equation (2) has two interesting properties. The first property is similar to that for Newton's law: gravity is not a propagation force but an entanglement. Newton's law corresponds to entanglement; however, Einstein's theory corresponds to force propagation. Therefore, we consider that these two theories describe different physical process. Eddington²⁵ discussed the problem of gravity propagation. He remarked that if gravity propagated with a finite velocity, the motion of the planets around the Sun would become unstable because of a torque acting on the planets. This problem was already known to Newton and was investigated by Laplace.²⁶

The origin of entanglement is that the ether field of point mass moves simultaneously to the point mass. Although the motion of point mass generates the gravitational wave that travels with finite velocity, entanglement is caused by the simultaneous motion of the ether field. This is similar to the Coulomb potential and electromagnetic waves.

The second property is the elimination of the gravitational singularity, as shown in Fig. 12. The solid line corresponds to $(dy/dr) = (1/r^2)e^{-1/r}$ in which the singularity is eliminated, and the dotted line corresponds to $(1/r^2)$, which is Newton's inverse square law.

The equivalence of mass and energy is one of the most important themes in physics. Figure 13 shows a conditional energy mass conversion: (1) Bremsstrahlung \rightarrow (2) pair production \rightarrow (3) pair annihilation. The Bremsstrahlung may generate a 1.02 MeV gamma photon, followed by the pair production of an electron-positron pair. The electron-positron pair decays into two 511 keV gamma photons. Figure 13 indicates that mass turns conditionally into energy. This result also indicates that energy conditionally turns into mass. However, as Baierlein¹¹ noted, "a photon is not just 'energy.'" He also noted that "There is no need to speak of 'converting' mass to energy or vice versa." The kinetic energy of a moving massive particle produces a particle of a photon through the Bremsstrahlung. This is considered that the relativistic mass turns into a photon. However, we cannot claim that mass-energy equivalence is unconditionally valid.

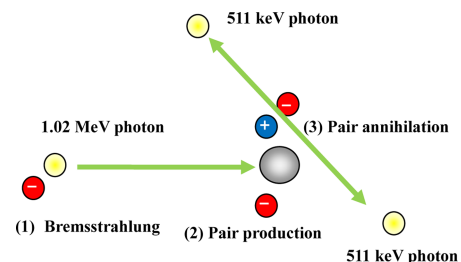


FIG. 13. (Color online) Conditional energy mass conversion: Baierlein (Ref. 11) noted that "a photon is not just 'energy'" and thus, "There is no need to speak of 'converting' mass to energy or vice versa."

VIII. CONCLUSION

The equivalence of the inertial and gravitational masses reveals that mass is the impedance of accelerated motion in ether. The accelerated motion of a massive particle in ether suffers resistance; that is inertial mass. The gradient of the ether density causes gravity. If the gradient of the ether density is proportional to the density, the inertial mass is proportional to the gravitational mass.

¹L. Wang, *Phys. Essays* 23, 473 (2010).

²A. Einstein, *Ideas and Opinions* (Three Rivers Press, New York, 1982).

³See http://en.wikipedia.org/wiki/Higgs_boson for Higgs boson (last accessed June 02, 2014).

⁴J. Maxwell, *Ether*, 9th ed. (Encyclopædia Britannica, Edinburgh, UK, 1878), Vol. 8, pp. 568–572. http://ether.wikiext.org/wiki/Maxwell_1877_en.

⁵R. Hatch, *Phys. Essays* 20, 83 (2007).

⁶R. Hatch, “Searching for a better way,” <http://www.insidegnss.com/node/451>, 2008.

⁷R. Hatch, *Phys. Essays* 20, 207 (2007).

⁸H. Ives, *J. Opt. Soc. Am.* 42, 540 (1952).

⁹E. Hecht, *Am. J. Phys.* 79, 591 (2011).

¹⁰E. Hecht, *Am. J. Phys.* 77, 799 (2009).

¹¹R. Baierlein, *Am. J. Phys.* 75, 320 (2007).

¹²M. Sato and H. Sato, *Phys. Essays* 24, 467 (2011).

¹³M. Sato and H. Sato, *Phys. Essays* 25, 150 (2012).

¹⁴Lord Kelvin, *Phil. Mag.* XXXIV, 15 (1867).

¹⁵A. Brilliet and J. L. Hall, *Phys. Rev. Lett.* 42, 549 (1979).

¹⁶Ch. Eisele, A. Y. Nevsky, and S. Schiller, *Phys. Rev. Lett.* 103, 090401 (2009).

¹⁷M. Sato, *Phys. Essays* 23, 405 (2010).

¹⁸N. Ashby and M. Weiss, e-print [arXiv:1307.6525](https://arxiv.org/abs/1307.6525).

¹⁹R. Hatch, *Phys. Essays* 27, 267 (2014).

²⁰M. Sato and H. Sato, *Phys. Essays* 27, 68 (2014).

²¹A. Michelson, and E. Morley, *Am. J. Sci.* 34, 333 (1887).

²²T. Phipps, Jr., *Old Physics for New* (Apeiron, Montreal, 2006).

²³K. Senior, J. Ray, and R. Beard, *GPS Solutions* 12, 211 (2008).

²⁴O. Montenbruck, U. Hugentobler, R. Dach, P. Steigenberger, and A. Hauschild, *GPS Solutions* 16, 303 (2012).

²⁵A. Eddington, *Space, Time and Gravitation* (Harper Torchbooks, New York, 1959), p. 94.

²⁶P. Laplace, *Mechanique Celeste* (Chelsea Publication, New York, 1966) (volumes published from 1799–1825, reprinted English translation).