The Origin of Inertia, using an Action at a Distance Approach

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As Einstein has pointed out, general relativity does not account satisfactorily for the inertial properties of matter, so that an adequate theory of inertia is still lacking. [(2)]
- D.W. Sciama

Abstract

The advent of experimental evidence supporting Mach's principle, the gravitational origin of inertia, as stated by Sciama[(1,2,3)], opens the possibility of theoretical work that explores some of the implications of Sciama's work, one of the most obvious implications being that general relativity is an incomplete theory since it does not fully take into account Mach's principle. [(1,2)] Sciama in 1964 said that inertial forces must be derived from a field theory or an action at a distance approach in the sense of "absorber theory" of Wheeler and Feynman. In this work, we will use an action at a distance approach to look at the Origin of Inertia. In particular, we will look at the gravito-electric radiation interaction between an accelerating test mass, m_o, and the universe, M. The accelerating test mass will radiate gravito-electric waves that will travel to the future universe. This in turn will cause the future universe to accelerate and radiate gravito-electric waves from the future universe to the present test mass, with the net result being that the test mass experiences an inertial force on it.

Theory

In 1953, Sciama published a paper [(2)] in which he looked into the origin of inertia, using Mach's principle. According to Sciama,

Mach maintained that inertial frames are those which are unacclerated relative to the fixed stars. [(2)]

Sciama went on to say that,

The statement that the Earth is rotating and the universe is at rest should lead to the same dynamical consequences as the statement that the universe is rotating and the Earth is at rest, whereas this is not true based on absolute space alone. [(2)]

Using the analogy of the scalar and vector potentials in the electro-magnetism case, Sciama looked at the gravito scalar and vector potentials for the gravitational case. Why didn't Sciama use general relativity to look at the origin of inertia? According to Sciama,

General relativity was devised to incorporate this idea, but, as emphasized by Einstein, it failed to do so. Einstein showed that his field equations imply that a test particle in an otherwise empty universe has inertial properties. In view of this it seems to *be worth while searching for theories of gravitation which imply that that matter has inertia only in the presence of other matter.* (2)

The gravito-scalar potential of the universe is given by,

$$\phi=-\int_V \frac{p}{r}\,dV \qquad (1)$$

and the gravito-vector potential of the universe is given by,

$$\vec{A}=-\int_V \frac{\vec{v}\,p}{cr}\,dV \qquad (2)$$

Here p is the mass density of the universe, c is the speed of light, r is the distance between the universe and the test mass, and v is the velocity of the universe with respect to the test mass. A clarification is in order here. The velocity of the universe with respect to the test mass has nothing to do with the expansion of the universe. Instead, it is the apparent velocity of a rigidly moving universe in a given direction, with respect to the test mass as viewed at the test mass.

Since v is independent of r in this view, we can take it outside the integral. We then obtain

$$\vec{A}=\frac{\phi}{c}\vec{v}\quad . \qquad (3)$$

(2)

$$\phi=\frac{GM}{R}$$

R is the radius of the universe.

The change in p is very small so we can say that the gravito-electric field, E, and the force on a test mass, $|F|$, is given by equation 4. Assuming that ϕ is relatively uniform then,

$$\vec{E}=-\vec{\nabla}\phi-\frac{1}{c}\frac{d\vec{A}}{dt}=\frac{-\phi}{c^2}\frac{d\vec{v}}{dt}=\frac{-\phi}{c^2}\vec{a}\rightarrow\overset{\phi=c^2}{\rightarrow}\rightarrow-\vec{a} \qquad (4)$$

$$|F|=m_o a$$

$$\phi=\frac{GM}{R}$$

Here we see that the gravito-electric field has units of acceleration. Also $|F| = m_o a$, which is analogous to the electro-magnetic case of $F=q_oE$. This lends credibility to the supposition that an accelerating test mass, m_o, will gain inertia from the gravitational interaction of the test mass, m_o, and the universe, M. In 1964 Sciama said that,

Inertial forces have a dynamical rather than a kinematical origin, and so must be derived from a field theory [or possibly an action at a distance theory in the sense of J.A. Wheeler and R.P. Feynman]. (1)

For the most part, Mach's and Sciama's work on the origin of inertia have been swept aside. After all, does it really matter what the origin of inertia is, if general relativity works just fine? Until the 1990's Mach's and Sciama's theory on the origin of inertia was just that, a theory. No useful technological developments came out of this theory. However, Woodward [(3)] has shown in his 2004 paper, "Flux Capacitors and the Origin of Inertia" as well as prior work, that by using Mach's principle and Sciama's work a unique phenomena he calls "Mach effects" (called by others the Woodward Effect), which are not predicted by general relativity, can be experimentally tested. Recent experimental tests have indicated that these effects are real. [(3)]

In light of the experimental evidence[(3)] that Mach's and Sciama's take on the origin of inertia is indeed valid, my work will attempt to show what Sciama in 1964 intuitively guessed, that inertia arises from an action at a distance type of theory. I will look at the gravito-electric waves that are emitted from an accelerating test mass, m_o, and are subsequently absorbed by the future universe of total mass *M*. This in turn will cause the future universe, *M*, to accelerate and subsequently radiate gravitational waves as well. However, in this case the gravitational waves will travel from the future universe, *M*, to the present test mass, m_o. The present test mass, *mo*, will absorb these gravitational waves thereby giving the test mass, m_o, inertia.

The electric field radiated by an accelerating point charge is given by

$$\vec{E}=k\frac{q}{2}\frac{|R|}{(\vec{R}.\vec{u})^3}[\vec{u}(c^2+\vec{R}.\vec{a})-\vec{a}(\vec{R}.\vec{u})] \tag{5}$$

where,

$$u=c\hat{R}-\vec{v}$$
$$k=\frac{1}{4\pi\epsilon_o}.$$

Here R is the distance from the point charge to the absorber and v, a are the velocity and the acceleration of the point charge, with respect to a stationary third party observer. (See Griffiths for more detail) *c* is the speed of light.

Analogously, treating the gravitational interaction as a vector field interaction, the gravito-electric field for an accelerating test mass is given by

$$\vec{E}_g=G\frac{m_0}{2}\frac{|R|}{(\vec{R}.\vec{u})^3}[\vec{u}(c^2+\vec{R}.\vec{a})-\vec{a}(\vec{R}.\vec{u})] \tag{6}$$

G is Newton's constant of universal gravitation, that is $6.673\,10^{-11}\frac{N\,m^2}{kg^2}$, and m_o is the mass of the test particle.

Lets assume that a test mass, m_o, is traveling in the *x* direction with an initial velocity of 0, v(t=0) = 0, and a non-zero acceleration a(t). (Figure 1) Analogous to Griffith's treatment of an electron as a dumb-bell instead of a sphere, for math simplification purposes, I will treat the universe as a dumb-bell as well. Looking at Figure 1 we see that m_o is the mass of the test particle and *M/2* is half the mass of everything else in the universe, not including m_o. Where Griffiths is interested in computing the action of each bell on the other as they are accelerated to get the radiation reaction force they both feel, we are interested instead in computing the gravitational action of the bells on a test mass. We will assume that the test mass is equal distance between each bell of the dumb-bell. R is the radius of the universe, and L is the horizontal distance between the test mass and one of the bells. Equation 6 can therefore be simplified to equation 7, below. Here E_g is negative because the horizontal gravito-electric field exerted on each bell, is to the left. (Figure 2) By symmetry we can see that the vertical components cancel.

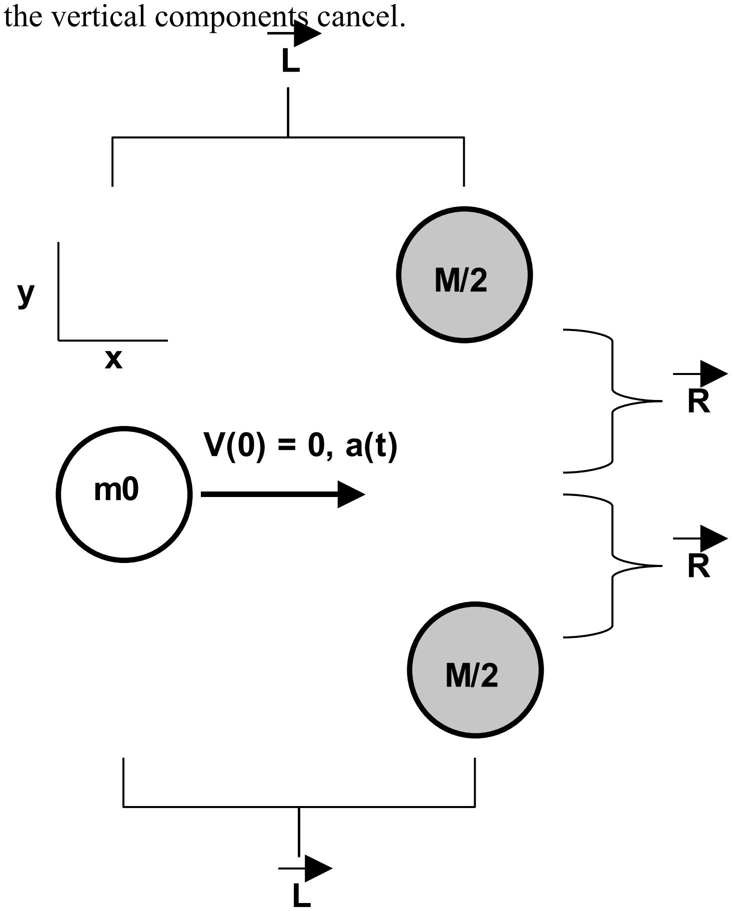

Figure 1: A test mass is traveling along the x-axis with an initial velocity of zero and a non zero acceleration to the right. *M/2* is half the mass of the universe, not including the test mass. L is the horizontal distance between the test mass and one of the bells. R is the radius of the universe.

$$\vec{E}_g = -G\frac{m_0}{2}\left[\frac{\vec{L}-\vec{a}\frac{R^2}{c^2}}{(L^2+R^2)^{\frac{3}{2}}}\right] \qquad (7)$$

One important assumption that I will make is that the radiation from the present test mass does not interact with the test mass' future self. Also, the radiation from the future universe does not interact with the present universe. In other words, the only gravito-electric interactions that occur are between the test mass and the universe, in the present and future respectively.

The distance between the test mass and a bell of the dumb-bell is $\sqrt{c^2T^2}$. Here c is the speed of light and T is the time it takes the gravito-electric radiation to travel from the present test mass to the future absorber, which in this case is the universe. L and R are 90 deg to each other, so

$$c^2T^2 = L^2 + R^2 \ .$$

Therefore we can say that T is given by equation 8.

$$T = \pm\frac{\sqrt{L^2+R^2}}{c} \tag{8}$$

If we make the approximation that $L << R$, then we can approximate equation 8 as equation 9.

$$T \approx \pm\frac{R}{c} \tag{9}$$

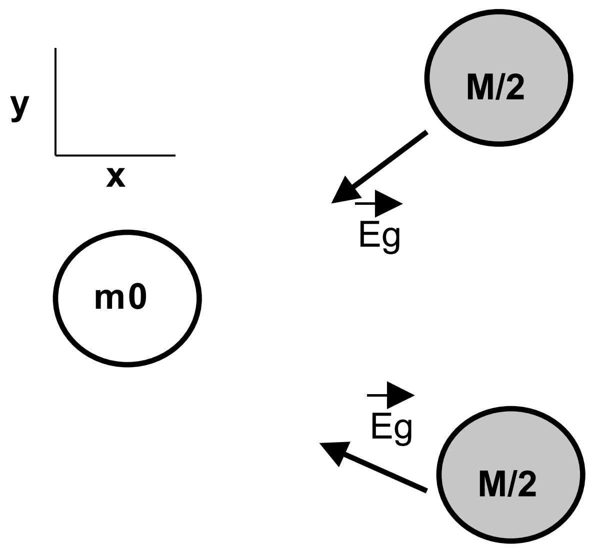

Figure 2: The horizontal gravito-electric field exerted on each bell is to the left. By symmetry, we can see that the vertical components cancel.

Therefore, the $\left[\frac{1}{\left(L^2+R^2\right)^{\frac{3}{2}}}\right]$ factor in equation 7 can be approximated, using equation 8 and taking the minus sign of equation 9, since the gravito-electric wave is traveling from the present to the future, we get $\left[\frac{-1}{R^3}\right]$. Also, the $L - a\frac{R^2}{c^2}$ term is equal to

$\frac{R^2}{c^2}\left(\frac{c^2}{R^2}L-a\right)$. Here we are just taking the x component of the vectors $L\, and\, a$, since the *y* components cancel. Combining the terms we find that the gravito-electric field, E_g, is given by equation 10.

$$E_g = G\frac{m_o}{2Rc^2}\left[H-a\right]; H = \frac{c^2 L}{R^2} \tag{10}$$

If we take into account that there are two horizontal E_g electro-gravitational fields acting on the universe, then the total field E_{tg} is equal to $2\ E_g$. (Equation 11)

$$E_{tg} = G\frac{m_o}{Rc^2}\left[H-a\right]; H = \frac{c^2 L}{R^2} \tag{11}$$

The total force acting on the universe, from the gravtio-electric radiation given off by the accelerating test mass is given by equation 12.

$$F = M\,E_{tg} = M\,G\frac{m_o}{Rc^2}\left[H-a\right]; H = \frac{c^2 L}{R^2} \tag{12}$$

Assuming that $\phi = \frac{GM}{R} = c^2$, as done by Woodward, then equation (12) simplifies to equation (13). Therefore, the force exerted on the future universe, by the present test mass' radiation, is given by equation 13.

$$F = m_o\left[H-a\right]; H = \frac{c^2 L}{R^2} \tag{13}$$

Now we will look at the gravito-electric radiation that is given off by this future universe when it is accelerated with an acceleration of a_u, with respect to the present test mass. Here $a_u = H - a$. (Figures 3 and 4) The future universe, at the time t_f, has an initial velocity of zero and a non-zero acceleration of a_u. The universe is being accelerated to the left, towards the present test mass. The math now is very similar to what we did before. The only difference is that for equation 7, E_g, is positive, and equation 9 is positive as well. E_g is positive because the gravtio-electric field points to the right of the test mass. *T* is positive because the universe is sending a gravito-electric wave from the future to the present.

After some algebra, and the substitution that $\phi = \frac{GM}{R} = c^2$, we end up with equation 14 for E_{tg} and equation 15 for F. Plugging in a_u into equation 15 we get equation 16.

$$E_{tg} = G\frac{M}{Rc^2}\left[H-a_u\right]; H = \frac{c^2 L}{R^2}, a_u = H-a \tag{14}$$

$$F = m_o\left[H-a_u\right]; H = \frac{c^2 L}{R^2}, a_u = H-a \tag{15}$$

$$F = m_o a \tag{16}$$

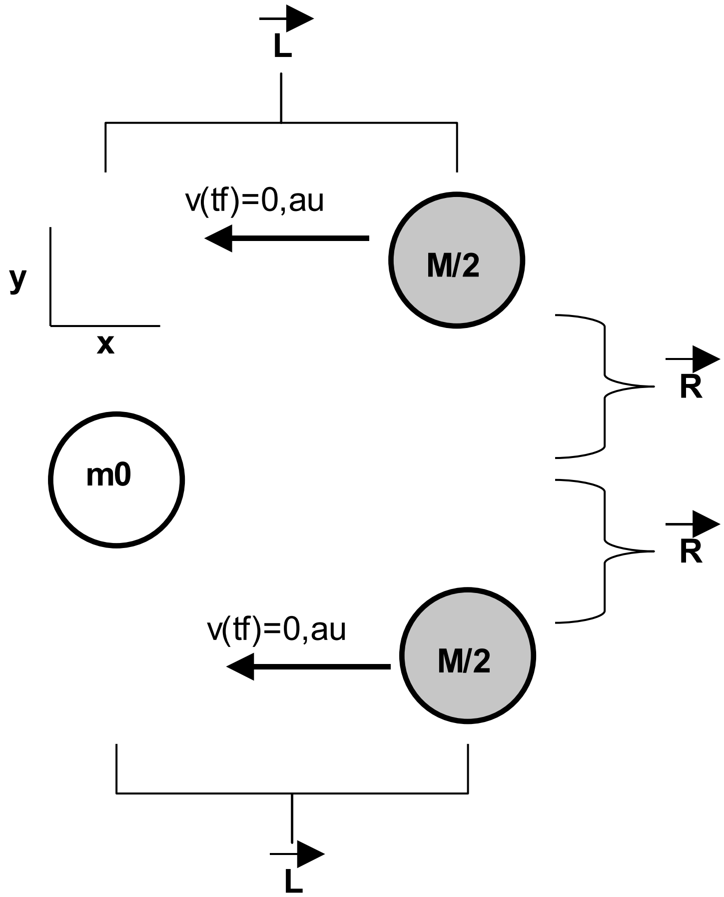

Figure 3: The future universe has an initial velocity of zero, and an initial acceleration of au. The universe is being accelerated toward the left.

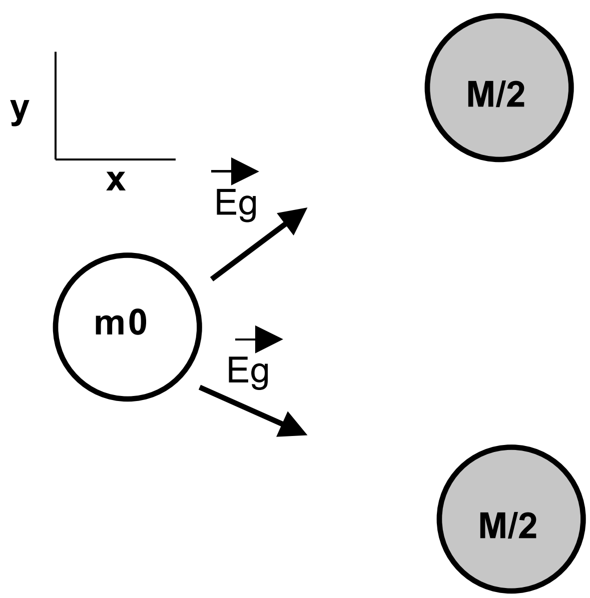

Figure 4: The test mass experiences a gravito-electric field to the right. Therefore, E_g is positive in this case. Also, the vertical components of E_g cancel each other, leaving us

with only the horizontal components. We will take $T=+R/c$ since in this case we have a gravito-electric wave traveling from the future to the past. In conclusion, the inertial reaction force of an accelerating test mass is $F = m_o a$.

Conclusion

These results validate Sciama's idea that inertia is the direct result of an action at a distance type of effect between the accelerating mass and the rest of the matter in the universe.

Acknowledgement

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