Particles with Negative Mass: Production, Properties and Applications for Nuclear Fusion and Self-Acceleration

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Abstract

Some experiments have indicated the possible existence of particles with a negative inertial mass. It is shown under which conditions Weber's electrodynamics gives rise to this effect. Some specific experiments related to this aspect of Weber's law are described. Two particles equally electrified with charges of the same sign would then move toward one another if they had negative effective inertial masses. A new concept for nuclear fusion is presented based on the possibility of creating a negative effective inertial mass for ions. It is then considered some properties of the inertial dipole, that is, a system composed by a pair of particles in which one particle has a positive effective inertial mass while the other particle has a negative effective inertial mass. The possible utilization of the inertial dipole as a propulsion system is briefly discussed.

Key Words: Negative mass. Inertial dipole. Weber's electrodynamics. Nuclear fusion.

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1 Introduction

Two charges of the same sign repel one another. As they have positive inertial masses, their acceleration relative to an inertial frame of reference will be along the direction of the force, so that they will move away from each other. For the same reason, two charges of the same sign would move towards each other if they had negative inertial masses.[1]

Some recent experiments have indicated that test particles under appropriate conditions can behave as having negative effective inertial masses. Zeilinger and his team obtained neutrons with a positive or a negative effective mass.[2, 3, 4] Transient negative effective masses were also recently reported for electrons in n-doped GaAs under very high electric fields and short time-scales on the order of a few hundred femto-seconds.[5] Negative inertia was even simulated by a mechanical spring system that can be exploited for advanced damping solutions.[6] The motion synchronization of ions between two electrostatic traps has also been explained by the negative mass behavior.[7] If ions are injected into such a trap, the size of the ion cloud usually stretches out due to Coulomb repulsion. However, it was noted that a certain geometry and electrostatic potential leads to a stabilization (or self-bunching) of the ion cloud that was interpreted as being due to the ion's mass turning negative.

In this work we explore some consequences of this type of mass and how it might be produced in the laboratory under appropriate controlled conditions.

2 Negative Mass in Weber's Electrodynamics

Consider two charges q_1 and q_2 located at position vectors $\vec{r}_1$ and $\vec{r}_2$ relative to the origin of an inertial frame of reference S, moving relative to this frame with velocities $\vec{v}_1$ and $\vec{v}_2$, and accelerations $\vec{a}_1$ and $\vec{a}_2$, respectively. According to Weber's electrodynamics[8] the force $\vec{F}_{21}$ exerted by charge q_2 on charge q_1 is given by:

$$\vec{F}_{21} = \frac{q_1 q_2}{4\pi\varepsilon_o} \frac{\hat{r}}{r^2} \left(1 - \frac{\dot{r}^2}{2c^2} + \frac{r\ddot{r}}{c^2} \right) = -\vec{F}_{12} \ , \tag{1}$$

where $\varepsilon_o = 8.85 \times 10^{-12} \ A^2 s^4/kgm^3$ is the vacuum permittivity, $c = 2.998 \times 10^8 \ m/s$, $r = |\vec{r}_1 - \vec{r}_2|$ is the distance between the charges, $\hat{r}$ is the unit vector pointing from 2 to 1, $\dot{r} = dr/dt$ is the relative radial velocity between the charges, $\ddot{r} = d^2r/dt^2$ is the relative radial acceleration between them and $\vec{F}_{12}$ is the reaction force exerted by 1 on 2. The last component of $\vec{F}_{21}$, in particular, depends on the acceleration $\vec{a}_1$ of the test charge on which the force is being exerted. In what follows this aspect will be of crucial importance.

Consider now an ideal dielectric spherical shell of mass M and radius R which is uniformly charged with a total charge Q. The charges over the surface of the shell will be supposed to remain fixed in the shell, no matter the position nor the motion of other nearby charges. We will suppose that the shell is free to move as a whole with a constant linear acceleration $\vec{A}$ relative to the inertial

frame of reference S. By integrating equation (1), the force $\vec{F}_{sq}$ exerted by this shell and acting on a test particle of charge q and inertial mass m located anywhere inside the shell and which is moving with acceleration $\vec{a}$ relative to the inertial frame S is given by:[8, 9, 10]

$$\vec{F}_{sq} = \frac{qQ}{12\pi\varepsilon_o Rc^2}\left(\vec{a} - \vec{A}\right) = \frac{q\phi}{3c^2}\left(\vec{a} - \vec{A}\right) = m_W\left(\vec{a} - \vec{A}\right) = -\vec{F}_{qs} \ , \quad (2)$$

where $\phi = Q/4\pi\varepsilon_o R$ is the electrostatic potential of the shell, supposing the potential to be zero at infinity, $m_W = qQ/12\pi\varepsilon_o Rc^2 = q\phi/3c^2$ is what we call Weber's inertial mass for this geometry, and $\vec{F}_{qs}$ is the reaction force exerted by q and acting on the electrified spherical shell.

Consider now two particles of charges q_1 and q_2 and normal inertial masses m_1 and m_2, respectively, located inside the shell. According to Newton's second law of motion, the net force $\vec{F}_1$ acting on particle 1 should be equal to its mass times its acceleration, $\vec{F}_1 = m_1\vec{a}_1$. There are two forces acting on 1, namely, the force $\vec{F}_{21}$ exerted by q_2 and the force $\vec{F}_{s1}$ exerted by the surrounding spherical shell. For low relative velocity and for low relative acceleration the force exerted by particle 2 will be essentially the same as Coulomb's force, $\vec{F}_{21} = q_1 q_2 \hat{r}/4\pi\varepsilon_o r^2$. According to equation (2), the force exerted by the charged shell and acting on particle 1 is given by $\vec{F}_{s1} = m_{W1}(\vec{a}_1 - \vec{A})$. Utilizing $\vec{F}_{21} + \vec{F}_{s1} = m_1\vec{a}_1$ we are then led to:

$$\vec{F}_{21} - m_{W1}\vec{A} = (m_1 - m_{W1})\vec{a}_1 = m_{eff1}\vec{a}_1 \ . \quad (3)$$

In this last equation the magnitude m_{eff1} has been defined by:

$$m_{eff1} = m_1 - m_{W1} = m_1 - \frac{q_1\phi}{3c^2} = m_1 - \frac{q_1 Q}{12\pi\varepsilon_o Rc^2} \ . \quad (4)$$

This magnitude m_{eff1} is what we call the effective inertial mass of particle 1.

Equation (3) is similar to Newton's second law of motion, but now with the test particle behaving as if it had an effective inertial mass $m_{eff1} = m_1 - m_{W1}$ instead of its usual mass m_1.

Due to action and reaction, the force exerted by 1 on 2, $\vec{F}_{12}$, is given by $\vec{F}_{12} = -\vec{F}_{21} = -q_1 q_2 \hat{r}/4\pi\varepsilon_o r^2$. The analogous equation of motion for particle 2 is given by:

$$-\vec{F}_{21} - m_{W2}\vec{A} = (m_2 - m_{W2})\vec{a}_2 = m_{eff2}\vec{a}_2 \ , \quad (5)$$

where $m_{eff2} = m_2 - m_{W2} = m_2 - q_2\phi/3c^2 = m_2 - q_2 Q/12\pi\varepsilon_o Rc^2$ is the effective inertial mass of particle 2.

The equation of motion for the shell is given by $\vec{F}_{1s} + \vec{F}_{2s} = M\vec{A}$. Utilizing equation (2) we are then led to:

$$-m_{W1}\vec{a}_1 - m_{W2}\vec{a}_2 = M_{effs}\vec{A} \ , \quad (6)$$

where $M_{effs} = M - m_{W1} - m_{W2}$ is the effective inertial mass of the spherical shell.

The effective inertial mass of the test particle 1 can be positive or negative, depending on the sign of $q_1 Q$ and depending also on the magnitude of the electrostatic potential of the surrounding spherical shell. The critical condition in which the effective inertial mass goes to zero is characterized by $m_1 = m_{W1} = q_1\phi/3c^2$. The test charge can behave as if it had a negative effective inertial mass, $m_{eff1} < 0$, provided its charge has the same sign as that of the shell and that the magnitude of the electrostatic potential ϕ of the shell satisfies the following condition:

$$\left. \begin{array}{ll} \phi > 3m_1 c^2/q_1 \ , & \text{if } q_1 > 0 \\ \phi < 3m_1 c^2/q_1 \ , & \text{if } q_1 < 0 \end{array} \right\} \ . \tag{7}$$

For instance, if the spherical shell is negatively electrified, a free electron placed inside the shell will behave as having a negative effective inertial mass provided the shell is electrified with a potential having a magnitude greater than $1.5 \ MV$. A proton, on the other hand, will behave as having a negative effective inertial mass only when the shell is positively charged with a potential greater than $2.8 \ GV$.

By solving equations (3), (5) and (6) we obtain:

$$\vec{a}_1 = \frac{(m_2 M_{effs} - M m_{W2}) \vec{F}_{21}}{m_1 m_2 M_{effs} + m_1 m_{W2}(m_{W1} - M) + m_2 m_{W1}(m_{W2} - M) + M m_{W1} m_{W2}} \tag{8}$$

$$\vec{a}_2 = \frac{(M m_{W1} - m_1 M_{effs}) \vec{F}_{21}}{m_1 m_2 M_{effs} + m_1 m_{W2}(m_{W1} - M) + m_2 m_{W1}(m_{W2} - M) + M m_{W1} m_{W2}} \tag{9}$$

and

$$\vec{A} = \frac{(m_1 m_{W2} - m_2 m_{W1}) \vec{F}_{21}}{m_1 m_2 M_{effs} + m_1 m_{W2}(m_{W1} - M) + m_2 m_{W1}(m_{W2} - M) + M m_{W1} m_{W2}} \tag{10}$$

From equations (8) to (10) we obtain in the simplest case in which $Q = 0$ and $\phi = 0$ the usual results that $\vec{a}_1 = \vec{F}_{21}/m_1$, $\vec{a}_2 = -\vec{F}_{21}/m_2$ and $\vec{A} = \vec{0}$.

As usual we can define in the general situation the location $\vec{r}_{CM}$ of the center of mass of this system composed by particle 1, particle 2 and the spherical shell by $\vec{r}_{CM} = (m_1 \vec{r}_1 + m_2 \vec{r}_2 + M \vec{r}_s)/(m_1 + m_2 + M)$, where $\vec{r}_s$ is the location of the center of the spherical shell relative to the origin of the inertial frame S. From equations (8) to (10) it follows in general, with arbitrary values of m_1, m_2 and M that:

$$\frac{d^2 \vec{r}_{CM}}{dt^2} = \frac{m_1 \vec{a}_1 + m_2 \vec{a}_2 + M \vec{A}}{m_1 + m_2 + M} = \vec{0} \ . \tag{11}$$

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This equation indicates as usual that the center of mass of the whole system does not accelerate relative to the inertial frame of reference due only to their internal forces.

In the particular case in which $M \gg (m_1 + m_2)$ we obtain from equations (8) to (10) that $M_{effs} \approx M$ and $m_1 m_2 M_{effs} + m_1 m_{W2}(m_{W1} - M) + m_2 m_{W1}(m_{W2} - M) + M m_{W1} m_{W2} \approx M m_{eff1} m_{eff2}$. Therefore:

$$\vec{a}_1 \approx \frac{\vec{F}_{21}}{m_{eff1}} \ , \tag{12}$$

$$\vec{a}_2 \approx -\frac{\vec{F}_{21}}{m_{eff2}} \ , \tag{13}$$

and

$$\vec{A} \approx \frac{m_1 m_{W2} - m_2 m_{W1}}{M m_{eff1} m_{eff2}} \vec{F}_{21} \ . \tag{14}$$

3 Experiments Related to an Effective Inertial Mass as a Function of the Surrounding Electrostatic Potential

Mikhailov published an experiment indicating that the effective inertial mass of a test particle depends linearly on the electrostatic potential of the surrounding spherical shell according to equation (4). He put a neon glow lamp inside a glass shell that was coated by a thin layer of InGa and an RC-oscillator inside a Faraday shield below.[11] The coated glass shell imitates the charged dielectric shell as originally proposed in 1993.[9] According to Mikhailov, the period of oscillation of the lamp should be directly proportional to the effective mass of the electron. As a matter of fact, he observed that the lamp's period of oscillation changed if he electrified the spherical shell as predicted by equation (2) within a factor 3/2. Junginger and Popovich repeated this neon glow lamp experiment with some modifications.[12] They utilized a charged enclosure completely covered in conductive foil, forming a Faraday cage, instead of utilizing a charged glass sphere having InGa plating as Mikhailov. Moreover, Jungiger and Popovic implemented an optical counter, instead of electrically measuring the frequency of the lamp as had been done by Mikhailov, observing a null result. Little and collaborators performed a similar replication of the neon lamp experiment and noticed that the electric measurement of the lamp's frequency may be influenced by the Faraday's shield potential depending on the coupling capacitor used,[13] then observed a null result by eliminating the coupling capacitor which was present in Mikhailov's original experiment and replacing it with a non-metallic fiber-optic link to a detector located outside the metal shell. The signature of the effect with the coupling capacitor was similar to a parabola, being indifferent to the polarity of the applied potential, instead of the linear relationship obtained by Mikhailov.

In a second independent experiment, Mikhailov replaced the neon lamp by a Barkhausen-Kurz generator leading to similar results indicating the effect predicted by Weber's electrodynamics with the correct sign and order of magnitude.[14]

Finally, the first neon-lamp experiment was repeated with two charged concentric shells showing that the frequency/mass effect from charging up the first shell can be counterbalanced by oppositely charging the outer shell.[15] Once more the outcome of this third experiment coincided with the predictions of Weber's electrodynamics.

4 Applications for Nuclear Fusion and Self-Acceleration

4.1 Nuclear Fusion Through the Interaction between Charges of the Same Sign

If this effect of a negative effective inertial mass really exists, then it might lead to a new concept in order to achieve nuclear fusion. We first consider how it might be possible to induce a collision between two particles electrified with charges of the same sign.

Consider two equal particles 1 and 2. We represent the usual inertial mass of each one of them by $m_1 = m_2 = m$ and the electric charge of each one of them by $q_1 = q_2 = q$. Therefore, $m_{W1} = m_{W2} = m_W = q\phi/3c^2$ and $m_{eff1} = m_{eff2} = m - m_W = m - q\phi/3c^2$. We will consider that they are initially at rest relative to one another and also initially at rest relative to the inertial frame of reference S. When equation (7) is satisfied for both particles we will have $qQ > 0$, $m_{W1} > m > 0$, $m_{W2} > m > 0$, $m_{eff1} < 0$ and $m_{eff2} < 0$. According to equations (8) to (10) with $M \gg (m_1 + m_2)$, we then have $den > 0$, $\vec{a}_1$ will point in the opposite direction of $\vec{F}_{21}$, $\vec{a}_2$ will point along the same direction of $\vec{F}_{21}$, while $\vec{A} = \vec{0}$. Therefore the two equal charges will move towards each other due to the combined effect of the repulsive electrostatic force between them and their negative mass behavior.

In principle, they could come so close as to collide with one another, leading to a release of energy. This situation is illustrated in Figure 1 in which particles 1 and 2 are electrons inside a negatively charged spherical shell electrified with a potential larger than 1.5 MV. Figure 1 (a) presents the repulsive forces exerted between these negatively charged electrons. With this high potential of the surrounding spherical shell, they behave as having negative effective inertial masses. Therefore, these repulsive forces will accelerate the electrons toward one another, as illustrated in Figure 1 (b).

The analogous situation for protons is illustrated in figure 2. Each proton will behave as having negative effective inertial mass if the surrounding shell is positively charged with a potential greater than 2.8 GV. The magnitude of this potential is much greater than the magnitude of the negative potential in which an electron behaves with negative mass. For this reason there are many more charges over the spherical surface of figure 2 than the amount of negative
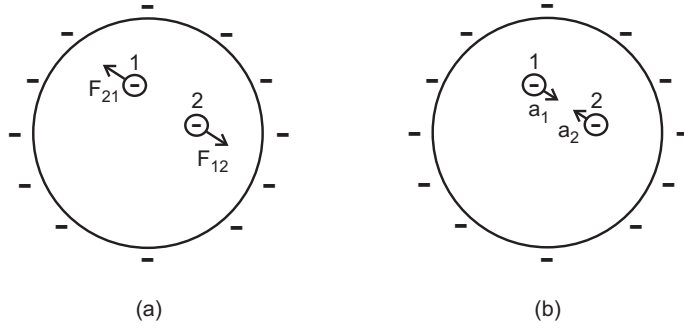
Figure 1: (a) Repulsive forces acting on both electrons. (b) They accelerate toward one another due to their negative mass behavior.

charges in the situation of figure 1. Two protons initially at rest inside the shell repel one another, figure 2 (a). When the potential of the shell satisfies equation (7), the protons behave with negative mass and move towards one another due to their repulsion, as indicated in figure 2 (b).
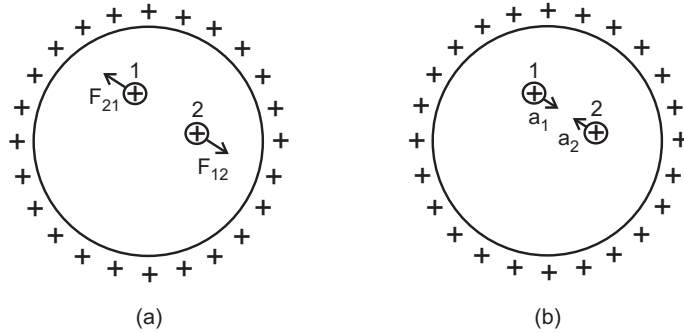

Figure 2: (a) Repulsive forces acting on both protons. (b) They accelerate toward one another due to their negative mass behavior.

Another interesting situation can happen when the two equal charges are not moving directly towards one another, so that each one of them has a velocity relative to an inertial frame of reference which is orthogonal the straight line connecting them. In normal newtonian theory we can have two stars orbiting around one another and describing circular orbits relative to the frame of fixed stars. This will happen when their gravitational attraction is exactly balanced by the mass of each star times the centripetal acceleration in a circular orbit. Likewise, two charges of the same sign moving inside a spherical shell electrified with a potential satisfying equation (7) can describe circular orbits around their common center of gravity. Consider for instance two electrons inside a spherical shell electrified to $-3\ MV$. Each electron of charge $q < 0$ would then behave as having a negative effective inertial mass $m_{eff} = -m_e$ of the same magnitude

of its normal positive mass m_e. In this case they will describe circular orbits of radius r around one another when the tangential velocity v of each particle satisfies the following condition:

$$\frac{q^2}{4\pi\varepsilon_o(2r)^2} = m_e\frac{v^2}{r} = m_e\omega^2 r \; , \tag{15}$$

where $\omega = v/r$ is the angular velocity of each electron describing a circular orbit relative to an inertial frame of reference.

That is, this configuration allows the creation of a bound system composed of two charges of the same sign orbiting around one another. This would be similar to a Cooper pair, but now with the condition for the formation of this system being controlled from the outside, that is, from the amount of charge in the shell.

This situation is illustrated in figure 3. In (a) we present the repulsive forces acting on each electron and also their tangential velocities. In (b) we present their centripetal accelerations due to their negative mass behavior and also their angular velocities with which they are orbiting around one another.
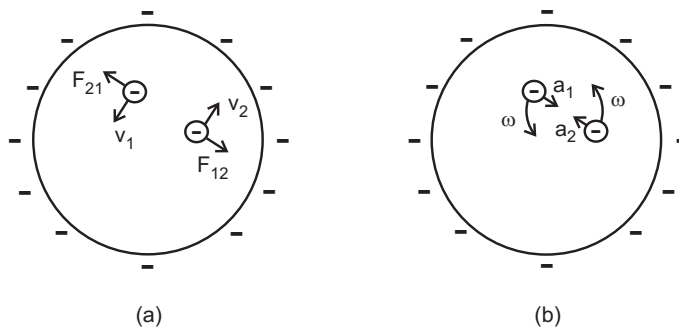

Figure 3: (a) Repulsive forces acting on both electrons which have initial velocities orthogonal to the line connecting them. (b) Their centripetal accelerations and their angular velocity $\omega = v/r$ relative to an inertial frame of reference.

If we have three or more equal particles inside the electrified shell, the negative mass behavior would be valid for all of them. That is, if a system of equal particles are initially at rest inside an electrified shell satisfying equation (7), after release they will move toward one another creating a great collision at the center. Suppose now that we have a gas of equally charged particles moving at random in all directions due to their thermal motion. By electrifying the shell such that equation (7) is satisfied, these particles could compose several bound systems made by charges of the same sign orbiting around one another.

In principle the electrification of the spherical shell is limited by the corona effect associated with the discharge in the surrounding air (breakdown electric field of the order of 3×10^6 V/m in the atmosphere). Although this might be appropriate to generate a collision between two electrons or between two positrons, for protons we would need to achieve voltages of the order of GV. In any event,

the negative mass behavior of protons might be tested with pulsed high voltage systems which could reach such extremely high electric potentials.[16]

4.2   Self-Acceleration Through the Inertial Dipole

In this Section we will be interested in what we have called the "inertial dipole."

The electric dipole is composed by a positive and a negative charge. The magnetic dipole is composed by a North or positive pole and a South or negative pole. Analogously we call an inertial dipole a system composed of two particles in which one of them has a normal positive inertial mass while the other particle has a negative effective inertial mass.

Robert Forward has already explored some unusual behavior of such a system as a possible propulsion system for rockets, although he did not consider how to produce a particle with a negative mass.[17] Friedwardt Winterberg has also considered the possibility of using negative matter for advanced space propulsion.[18] Weber's electrodynamics is a possible theoretical framework indicating how it might be possible to create particles which would behave as if they had a negative effective inertial mass. Later on we analyze the motion of an inertial dipole under these conditions, as first considered in 2013.[19]

In what follows we will neglect all other external forces acting on 1 and 2, except the force they exert on one another and the forces acting on them due to the electrified surrounding shell. The mass M of the shell will be always considered much greater than $m_1 + m_2$. Particles 1 and 2 will be considered in this Section as being electrified with charges of opposite sign, attracting one another. Moreover, they will be considered along the x axis passing through the center of the shell with $x_1 < x_2$. Therefore, $\hat{r} = -\hat{x}$, while $\vec{F}_{21}$ points along $\hat{x}$.

In order to build a perfect inertial dipole we must have $m_{eff2} = -m_{eff1}$ so that their effective inertial masses will have the same magnitude but opposite signs. According to equations (3) and (5), this condition will be satisfied whenever

$$m_1 + m_2 = \frac{(q_1 + q_2)\phi}{3c^2} \ . \tag{16}$$

As $m_1 + m_2 > 0$, this condition can only be satisfied if $q_1 + q_2 \neq 0$ and $Q \neq 0$. Moreover, $q_1 + q_2$ must have the same sign as Q.

As an example we can suppose particle 1 being a positron, $m_1 = m_e = 9.1 \times 10^{-31}$ kg and $q_1 = e = 1.6 \times 10^{-19}$ C, while particle 2 has twice the charge and twice the mass of the electron, being similar to a Cooper pair, such that $m_2 = 2m_e = 1.8 \times 10^{-30}$ kg and $q_2 = -2e = -3.2 \times 10^{-19}$ C. From equation (16) we obtain that this system will compose an inertial dipole when the surrounding spherical shell is electrified with a potential $\phi = 3(m_1 + m_2)c^2/(q_1 + q_2) = -9m_ec^2/e = -4.5 \times 10^6$ V. In this situation $m_{W1} = -3m_e$, $m_{W2} = 6m_e$, $m_{eff1} = 4m_e = 3.6 \times 10^{-30}$ kg, $m_{eff2} = -4m_e = -3.6 \times 10^{-30}$ $kg < 0$ and $M_{effs} = M + 3m_e \approx M$. Therefore we will have $\vec{a}_1 = \vec{a}_2 \approx \vec{F}_{21}/4m_e$, while $\vec{A} \approx -3\vec{F}_{21}/4M$. This means that both particles will be accelerated along $\hat{x}$ to the right, while the spherical shell will be accelerated along $-\hat{x}$ to the

left. Although the force $\vec{F}_{12}$ acting on particle 2 points to the left, it will be accelerated to the right due to its negative mass behavior. According to equation (2), the force exerted by particle 1 on the shell is given $\vec{F}_{1s} = 3\vec{F}_{21}/4$, while the force exerted by particle 2 on the shell is given by $\vec{F}_{2s} = -3\vec{F}_{21}/2$. Figure 4 (a) presents the attractive forces acting between particles 1 and 2, together with the forces exerted by each particle on the electrified spherical shell. Figure 4 (b) presents the accelerations of both particles relative to the inertial frame of reference S, together with the acceleration of the spherical shell, $\vec{A}$. Although $|\vec{A}| \ll |\vec{a}_1|$, the magnitude of $\vec{A}$ is represented out of scale in order to illustrate the fact that it is accelerated in the opposite sense of particles 1 and 2, such that the center of mass of the whole system does not move relative to an inertial frame of reference.
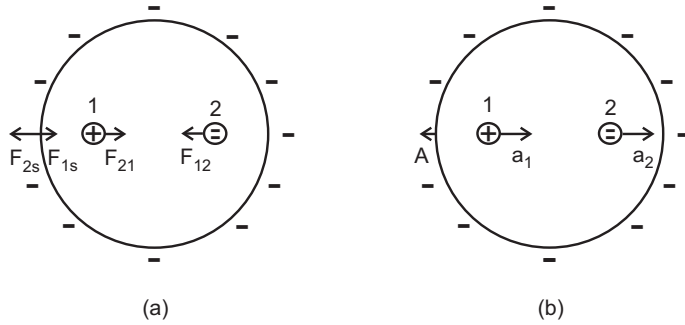
Figure 4: (a) Attractive forces acting the oppositely charged particles, $\vec{F}_{21}$ and $\vec{F}_{12}$, together with the forces exerted by each particle on the electrified spherical shell, $\vec{F}_{1s}$ and $\vec{F}_{2s}$. (b) Particles 1 and 2 are equally accelerated to the right, while the spherical shell is accelerated to the left. Particle 2 behaves as having a negative effective inertial mass.

Another example is when particle 1 is an alpha particle, $m_1 = m_\alpha = 6.6 \times 10^{-27}$ kg and $q_1 = 2e = 3.2 \times 10^{-19}$ C, while particle 2 is an electron. They will behave like an inertial dipole when the spherical shell is electrified with a potential $\phi = 4 \times 10^9$ V. In this case the effective inertial masses are given by $m_{eff1} = -m_\alpha/3 = -2.2 \times 10^{-27}$ $kg < 0$, $m_{eff2} = m_\alpha/3 = 2.2 \times 10^{-27}$ kg and $M_{effs} = M + m_\alpha/3 \approx M$. Therefore $a_1 = \vec{a}_2 \approx -3\vec{F}_{21}/m_\alpha$, while $\vec{A} \approx 3\vec{F}_{21}/M$. This means that both particles will be accelerated along $-\hat{x}$ to the left, while the spherical shell will be accelerated along $\hat{x}$ to the right. Although the force $\vec{F}_{21}$ acting on particle 1 points to the right, it will be accelerated to the left due to its negative mass behavior.

It is also possible to consider a more general situation in which one of the effective inertial masses is positive and the other negative, although not necessarily with the same magnitude. For instance, consider particle 1 as a proton, $m_1 = m_p = 1.7 \times 10^{-27}$ kg and $q_1 = e = 1.6 \times 10^{-19}$ C, while particle 2 is an electron. In this situation $m_{eff1} \approx m_p$ and $m_{eff2} = -m_e = -9.1 \times 10^{-31}$ $kg < 0$,

such that $m_{eff1} \gg |m_{eff2}|$. Therefore $\vec{a}_1 \approx \vec{F}_{21}/m_p$, $\vec{a}_2 \approx \vec{F}_{21}/m_e$ and $\vec{A} \approx -2\vec{F}_{21}/M$. This means that both particles will be accelerated to the right, with the acceleration of 2 being much greater than the acceleration of 1, while the spherical shell will be accelerated to the left.

When Robert Forward studied the situation of an inertial dipole, he did not consider how the negative inertial mass might be produced. He considered only two particles with inertial masses of opposite sign. By studying their motion he showed that they might be accelerated towards the same side due to their mutual attraction. The analysis presented in this paper, on the other hand, indicates that when this particle of negative effective inertial mass is produced due to its interaction with a surrounding electrified spherical shell, then the motion of the shell relative to an inertial frame of reference must also be considered in the analysis of the problem. It is then shown in the general situation that although both particles of the inertial dipole may be accelerated towards the same side (for instance, to the right), the spherical shell will be accelerated towards the other side (to the left in this example). Therefore, the center of mass of the whole system (composed by the inertial dipole and by the spherical shell) will not be accelerated relative to any inertial frame of reference, in compliance with the conservation of linear momentum.

Therefore, it is not possible to consider the whole system (two oppositely charged particles and the surrounding spherical shell) as an appropriate propulsion system for a rocket when this whole system remains inside the rocket. The only possibility of exploring this negative mass effect as a propulsion system would be to the consider the electrified spherical shell as being rigidly connected to the rocket, while the internal test particles could be ejected from the rocket as the normal fuel in present day rocket technology. Therefore, when these internal particles were ejected from the rocket in one direction, the rocket and the electrified spherical shell would be accelerated in the opposite direction.

To our knowledge the first experimental observation for optical pulses simulating an inertial dipole with both particles of opposite masses accelerating in the same direction, although working only with photons, has been recently made by Wimmer and collaborators.[20] This effect has been called "diametric drive acceleration." Weber's electrodynamics opens up a general method to study these effects for charged particles. The demonstration of Wimmer and collaborators opens new possibilities not only for frequency conversions and pulse-steering applications, as they mentioned, but also for the future development of a new propulsion system.[19, 21]

Acknowledgments:

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