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Centrifugal Electrical Force

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Abstract

We calculate the force on a point charge moving within a charged spherical shell spinning with $\vec{\omega}(t)$ according to Weber's law. We compare this result with the one given by Lorentz's law and show that Weber's law predicts an extra centrifugal electrical force and an extra inertial electrical force. We give orders of magnitude for these forces and propose some experiments to test the existence of these terms.

Since 1982 physicists have been performing experiments trying to distinguish the laws of force between current elements of Ampère and of Grassmann (sometimes known as Biot-Savart's law)[1−4]. Although most of these experiments seem to favour Ampère's law, this is still a controversial subject. As is well known[5−8], with Weber's force law we can derive Ampère's force, but not Grassmann's force, while with Lorentz's force law we can derive Grassmann's force but not Ampère's force. Due to this fact we propose in this work a clear experiment to distinguish and test directly Weber's law versus Lorentz's law.

Weber's expression for the force of q_2 on q_1 is

$$\vec{F} = \frac{q_1 q_2}{4\pi\epsilon_0}\frac{\hat{r}_{12}}{r_{12}^2}\left(1 - \frac{\dot{r}_{12}^2}{2c^2} + \frac{r_{12}\ddot{r}_{12}}{c^2}\right) = \frac{q_1 q_2}{4\pi\epsilon_0}\frac{\hat{r}_{12}}{r_{12}^2}\left[1 + \frac{1}{c^2}\left(\vec{v}_{12}\cdot\vec{v}_{12} - \frac{3}{2}(\hat{r}_{12}\cdot\vec{v}_{12})^2 + \vec{r}_{12}\cdot\vec{a}_{12}\right)\right] , \quad (1)$$

where $\vec{r}_{12} \equiv \vec{r}_1 - \vec{r}_2$, $r_{12} \equiv |\vec{r}_{12}|$, $\hat{r}_{12} \equiv \vec{r}_{12}/r_{12}$, $\vec{v}_{12} \equiv d\vec{r}_{12}/dt$, $\vec{a}_{12} \equiv d\vec{v}_{12}/dt$, $\dot{r}_{12} \equiv dr_{12}/dt = \hat{r}_{12}\cdot\vec{v}_{12}$, $\ddot{r}_{12} \equiv d\dot{r}_{12}/dt$ and $c \equiv$ ratio between electromagnetic and electrostatic units of charge. This constant c has the same value as the light velocity in vacuum.

On the other hand the force on q_1 in a region with electric and magnetic field is, according to Lorentz force,

$$\vec{F} = q_1\vec{E} + q_1\vec{v}_1 \times \vec{B} \ . \quad (2)$$

In this expression $\vec{v}_1$ is the velocity of q_1 relative to an inertial frame[9].

Comparing Eq. (1) with Eq. (2) we note that the main difference is that according to Weber there are two force components proportional to the square of the velocities of q_1 and q_2 and also a component proportional to the acceleration of q_1 and these three components don't appear in Eq. (2). In other components they are essentially equivalent. Because it has long been known that besides being compatible with Coulomb's law, with Weber's law we can derive Ampère's circuital law and also Faraday's law of induction[5].

In an earlier work we applied Weber's law to gravitation and obtained in this model an explanation for inertia following Mach's principle[6].

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In order to test these ideas we return now to Weber's original law as applied to charges because the electrical forces are many orders of magnitude greater than the gravitational ones. This means that they are easier to be tested in the laboratory than small corrections in Newton's law of universal gravitation.

Integrating Eq. (1) for the force on q_1 inside a uniformly charged spherical shell made of an insulator material spinning with angular velocity $\vec{\omega}(t)$ yields

$$\vec{F} = m_{w1}\left[\vec{a}_1 + \vec{\omega} \times (\vec{\omega} \times \vec{r}_1) + 2\vec{v}_1 \times \vec{\omega} + \vec{r}_1 \times \frac{d\vec{\omega}}{dt}\right] . \tag{3}$$

In this expression m_{w1} is what we call Weber's inertial mass and is given by $m_{w1} = q_1 V/(3c^2)$, V is the potential inside the shell ($V = Q/(4\pi\epsilon_0 R)$, Q being the net charge on the shell and R its radius) and $\vec{r}_1$, $\vec{v}_1$ and $\vec{a}_1$ are, respectively, the radius vector, velocity and acceleration of q_1 relative to the center of the spherical shell. The first aspect to take notice according to Eq. (3) is that a free charge cannot be at rest inside a spinning charged sphere unless it is on the axis of rotation otherwise it will suffer a net force of the shell. To balance this force and keep q_1 at rest we need other bodies and kinds of force.

In this work we study two charges q_1 and q_2 with the same polarity ($q_1 q_2 > 0$) held at rest inside a spinning charged shell by a spring of elastic constant k. In a first situation there is no charged sphere (or it is uncharged) so that (supposing $z_1 = z_2 = 0$)

$$\frac{q_1 q_2}{4\pi\epsilon_0}\frac{1}{(\rho_1+\rho_2)^2} = k(\rho_1 + \rho_2 - l_0) , \tag{4}$$

where l_0 is the relaxed length of the spring. Suppose that now we charge the external shell made of an insulator material to the voltage V and spin it with a constant $\omega\hat{z}$. The new equilibrium situation in which q_1 and q_2 remain at rest needs to satisfy ($\vec{r}_1' = -\rho_1'\hat{x}$, $\vec{r}_2' = \rho_2'\hat{x}$, $\rho_1' > 0$ and $\rho_2' > 0$) the following equations, supposing that k remained unaltered:

$$-\frac{q_1 q_2}{4\pi\epsilon_0}\frac{1}{(\rho_1'+\rho_2')^2} + k(\rho_1' + \rho_2' - l_0) + m_{w1}\omega^2\rho_1' = 0 , \tag{5}$$

$$+\frac{q_1 q_2}{4\pi\epsilon_0}\frac{1}{(\rho_1'+\rho_2')^2} - k(\rho_1' + \rho_2' - l_0) - m_{w2}\omega^2\rho_2' = 0 . \tag{6}$$

This means that

$$q_1\rho_1' = q_2\rho_2' . \tag{7}$$

This is a very remarkable result, which only happens with Weber's law.

Combining Eqs. (5) to (7) we obtain the following results: If $q_1 Q > 0$ then q_1 and q_2 will be "attracted" to the center of the shell ($\rho_1' < \rho_1$ and $\rho_2' < \rho_2$), otherwise they will be "repelled" ($\rho_1' > \rho_1$ and $\rho_2' > \rho_2$). From Eqs. (5) to (7) we also obtain another equilibrium equation to replace Eq. (4), namely

$$\frac{q_1 q_2}{4\pi\epsilon_0}\frac{1}{(\rho_1'+\rho_2')^2} = k(\rho_1' + \rho_2' - l_0) + m_{w1}\omega^2\frac{q_2(\rho_1'+\rho_2')}{(q_1+q_2)} . \tag{8}$$

Before proceeding we must discuss the same problem from the point of view of Lorentz's force law. As is well known, a charged spherical shell made of an insulator material at rest or spinning with constant $\vec{\omega}$ generates no electric field inside itself. But it will generate a constant uniform magnetic field inside the shell supposing a constant $\vec{\omega}$, given by

$$\vec{B} = \frac{2\mu_0 R\sigma\vec{\omega}}{3} = \frac{2V\vec{\omega}}{3c^2},$$

see Ref. [10]. According to Eq. (2) this means that the only force on q_1 will be given by

$$\vec{F} = q_1\vec{v}_1 \times \vec{B} = 2m_{w1}\vec{v}_1 \times \vec{\omega}\,. \tag{9}$$

Comparing this with Eq. (3) with constant $\vec{\omega}$ shows that there are two new components of force acting on q_1 besides Eq. (9), according to Weber: The inertial electrical force $q_1\alpha\vec{a}_1$ and the centrifugal electrical force $q_1\alpha\vec{\omega} \times (\vec{\omega} \times \vec{r}_1)$, where

$$\alpha \equiv \frac{V}{3c^2}.$$

We call $q_1\alpha\vec{\omega} \times (\vec{\omega} \times \vec{r}_1)$ a centrifugal electrical force due to its resemblance with the usual "fictitious" centrifugal force, although the electrical one can be centripetal or centrifugal depending on the sign of $q_1 Q$. We also observe that the Coriolis electrical force $2q_1\alpha\vec{v}_1 \times \vec{\omega}$ is the usual magnetic force given by Lorentz's law.

Usually the centrifugal electrical force is extremely small. For instance, for $q_1 = q_2 = 10^{-10}$ C, $V = 1.5 \times 10^6$ V ($m_{w1} = m_{w2} \simeq 5 \times 10^{-22}$ kg), $r_1 = r_2 = 1$ m and $\omega = 10^3$ s^{-1} we obtain $F_c \cong 10^{-15}$ N. But this can be increased by a convenient choice of q_1, r_1, V and ω.

It is of interest to know the value of the parameters to counterbalance Coulomb's law. That is, two charges of the same sign repelling each other can be maintained at relative rest even without the spring or other forces, but only through the centrifugal electrical force ($q_1 Q > 0$). To this end we need to have satisfied Eqs. (5) to (7) with $k = 0$. Supposing $q_1 = q_2$ then $\rho_1' = \rho_2'$ and

$$V\omega^2 = \frac{3c^2 q_1}{16\pi\epsilon_0\rho_1'^3}\,. \tag{10}$$

Usually we want to minimize V and ω^2 (it is difficult to generate a voltage much bigger than some mega-volts and even more difficult to rotate this high-voltage system) which means that q_1 should be small and ρ_1' large. To estimate the order of magnitude we suppose $q_1 \simeq Q$ and $R \simeq \rho_1'$, R just a little bigger, and from Eq. (10) we get

$$\rho_1'\omega \simeq c\,,$$

which means that this could only be realized microscopically ($q_1 \simeq$ electron charge, $\omega \simeq 10^{21}$ s^{-1} and $\rho_1' \simeq \hbar_c = 3.7 \times 10^{-13}$ m).

Returning now to Eqs. (5) to (7) we observe that equation (7) should be valid for equilibrium situations independent of the order of magnitude of the centrifugal electrical force. This means that even if this force is much smaller than the force of the spring or of Coulomb's force, which means that

$$\rho_1' + \rho_2' \simeq \rho_1 + \rho_2\,,$$

the system will rearrange itself so as to satisfy Eq. (7) in a new equilibrium situation. And this could be tested in a laboratory, provided that this centrifugal force is large enough to overcome random fluctuations due to air impurities and that the system can arrive at the new equilibrium situation in a reasonable time.

In conclusion we should emphasize that Weber's law predicts a clear result for the force inside a charged spherical shell (3), and this is quite different from Lorentz's prediction (9). Some experiments should be performed to test the existence of these new terms. This could help to settle the controversy surrounding Ampère's law and Grassmann's law.

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