

# Evaluation of the Influence of a Field-Less Electrostatic Potential on Electron Beam Deflection as Predicted by Weber Electrodynamics

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**Abstract**—Assis predicted that based on Weber’s electrodynamics, an alternative direct-action model formulated before Maxwell, a charge accelerating inside a sphere at constant electric potential, should have a measureable effective mass. Although initially some experiments appeared in the literature that indeed claimed such an effect, all recent studies found no evidence. All experiments so far used either discharges or electrons with non-constant accelerations that could mask the existence of Assis’s prediction. We performed an experiment using a Perrin tube, which produces a beam of electrons with a constant velocity that can be deflected by Helmholtz coils to hit a Faraday cup. The tube assembly was put inside a spherical shell, which could be charged up to 20 kV. Any effective mass of the electrons would have changed their position on the Faraday cup. We found no variation of the electron position within our experimental accuracy, which rules out Assis’s effect by two orders of magnitude. This confirms Maxwell’s theory and the fact that electrostatic potential energy cannot be localized to individual charges.

## 1. INTRODUCTION

It is well known that electrostatic interaction energy contributes to mass. Consider a pair of charges  $q_1$  and  $q_2$  separated by a length  $l$ . For the case of non-relativistic velocities, the effective mass for the pair with respect to its rest mass will change by

$$\Delta m = \frac{q_1 q_2}{4\pi\epsilon_0} \frac{1}{lc^2}, \quad (1)$$

where  $\epsilon_0$  is the electric constant and  $c$  the speed of light. This is a classic example of the famous  $E = m \cdot c^2$  equation. It can also be derived by calculating the electric forces exerted on each other using classical Maxwell electrodynamics in a form that properly takes acceleration and retardation into account [1, 2] like the Liénard-Wiechert potentials or approximations like those developed by Page and Adams [3] (see also recent work that resolved the factor 2 paradox for a longitudinal dipole configuration [4, 5]). For simplicity, let’s assume a transversal dipole with two charges at positions  $(x, l/2)$  and  $(x, -l/2)$  accelerating in the  $x$ -direction. Assuming slow velocities, if charge 1 is moving with acceleration  $a$ , an electric field  $E$  is produced which in turn leads to a force at the position of charge 2 like

$$E_{x1} = -\frac{q_1}{4\pi\epsilon_0} \frac{1}{2lc^2} \cdot a, \quad F_{x2} = q_2 E_{x1} = -\frac{q_1 q_2}{4\pi\epsilon_0} \frac{1}{2lc^2} \cdot a, \quad \Delta m_2 = \frac{F_{x2}}{a} = -\frac{q_1 q_2}{4\pi\epsilon_0} \frac{1}{2lc^2} \quad (2)$$

The same can be done for charge 2 that is also accelerating and therefore produces an electric field causing a similar force and effective mass on charge 1. Adding both up leads to our Eq. (1).

It is important to note that Eq. (1) is only valid for the pair as a whole. Accelerating one charge and leaving the other at rest will only cause the accelerating charge to radiate. The non-accelerating

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charge will not radiate and therefore does not contribute to the inertial mass of the accelerated charge, as first noted by Cavalleri [6].

This was challenged by Assis [7], who predicted that an accelerating individual charge inside a sphere with stationary charges on the outside will change its inertial mass similar to Eq. (1), although with a slightly different pre-factor. He derived his result using Weber electrodynamics [8], which is a field-free action-at-a-distance alternative formulation of electrodynamics that was popular in the 19<sup>th</sup> century and established before Maxwell. In this theory, Coulomb's interaction energy is velocity dependent, which leads to a force that only involves the relative distance  $r$ , velocity  $\dot{r}$ , and acceleration  $\ddot{r}$  between two charges,

$$F = \frac{q_1 q_2}{4\pi\epsilon_0} \frac{\hat{r}}{r^2} \left( 1 - \frac{\dot{r}^2}{2c^2} + \frac{r\ddot{r}}{c^2} \right). \quad (3)$$

Weber electrodynamics eliminates the position of the observer and only deals with relative quantities between charges. This leads to exactly the opposite behavior of what we expected classically: An accelerated pair of charges will see no change of its inertial mass as there is no relative acceleration between them, and an individual charge accelerating with respect to a stationary one will indeed see a significant change of its inertial mass. Assuming a hollow spherical shell charged up to a homogenous potential  $V$ , the predicted Weber mass change is equal to

$$\Delta m_W = \frac{qV}{3c^2}. \quad (4)$$

A similar result (although without Weber electrodynamics) with slightly different values for hollow spheres and cylinders was also proposed by Sapozhnikov [9]. Also Özer used this relationship claiming the validity of an electrical equivalence principle [10]. Considering a single electron inside a sphere with positive potentials in the Megavolt range could therefore lead to electrons with effective negative mass, which would certainly be of interest [11]. Assis was successful in using Weber mass to calculate self-inductance in electric circuits [12], and recent experiments with electron beam deflection near solenoids also showed that Weber electrodynamics can lead to accurate predictions [13–15].

As the consequences would be significant if indeed Eq. (4) is correct, it is important to look for experiments that can directly measure if this effect exists. The first investigation which claimed a positive result was from Mikhailov [16, 17], who used a Neon discharge lamp with an electric oscillator inside a Faraday cage. His claim was that when the Faraday cage was set on an electric potential, the oscillation frequency, which was linked to the electron's mass, was changing similar to what Assis predicted. Shortly afterwards, replication efforts revealed that this effect was due to the electric measurement circuit only and that if the oscillation frequency was observed optically, no change in frequency occurred [18–20]. However, as noted by Lörincz and Tajmar [20], a discharge lamp may not be the correct tool to test this effect as in addition to electrons, also ions will be generated in close vicinity which can mask this effect completely.

A second experiment from Mikhailov used a Barkhausen-Kurz generator [21], which causes the oscillations of electrons inside a vacuum tube in the absence of ions, where the frequency is linked to the electron's charge-to-mass ratio. Again, the claim was that the frequency changed similar to Assis's prediction if the oscillator was placed inside a metal cage that was charged up to high potentials. However, Mikhailov used a flawed indirect method to measure the frequency and subsequent testing with proper oscilloscopes did not show any frequency variation [22]. As mentioned by Weikert and Tajmar, also the shape of the electron cloud contributes to the frequency and a change in the electron's mass might have changed the oscillation length in such a way that it also counteracted against the sought after effect.

An experiment with a simple vacuum diode inside a Faraday cage was published by Yatsenko [23]. As the current of the tube also depends on the electron's charge-to-mass ration, he expected a variation of the diode current as a function of the potential on the Faraday cage. Here too, no variation was found ruling out Assis's prediction by two orders of magnitude. Still, there might be one critic left as the vacuum tube-diode constantly accelerates the electrons such that there is a distribution of electrons with different velocities inside the tube. According to Weber's Eq. (3), a velocity-dependent force component may also counteract Assis's prediction.

We decided to perform an experiment taking into account all the lessons learned to settle the question. The core consists of a commercial Perrin-tube, which generates an electron beam of constant

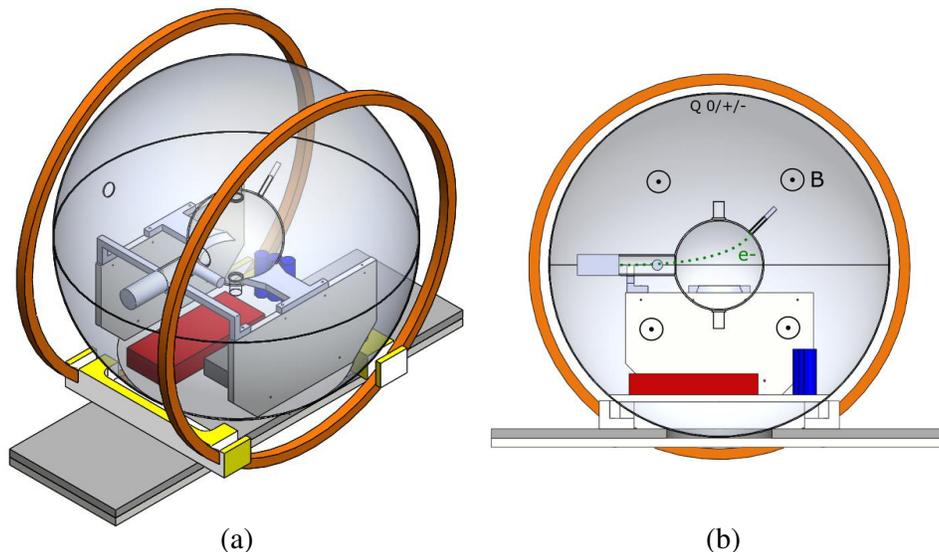
velocity, which is deflected by a magnetic field generated with Helmholtz coils allowing a phase of constant radial acceleration where any mass change would manifest in a different end position that can be monitored by a Faraday cup. The whole tube is located inside a large hollow sphere that can be charged up to high potentials. The constant velocity during the magnetic deflection phase ensures that the relative velocity or acceleration between the beam electrons is minimal such that they will mainly interact with the sphere's stationary charges (and the initial electrons from the gun until they leave the anode). Since previously similar electron gun experiments revealed a good comparison with the Weber force (although no Weber mass change was tested in such a configuration), we believe that this setup is very suitable to test for such an effect [13–15].

## 2. EXPERIMENTAL SETUP

The Perrin tube was purchased from 3B Scientific (Perrin Tube D 1000650) [24], which featured an electron gun that generated an electron beam with a fixed velocity depending on the acceleration potential  $V_A$  used. This beam was injected into a larger glass bulb with a diameter of 16 cm, which had a fluorescence screen at the end as well as a Faraday cup at a specific location, which the electron beam can only hit at a curvature radius of approximately  $r_c = 16$  cm. By applying a homogenous magnetic field  $B$  through Helmholtz coils, there is a direct relationship for the electron's charge-to-mass ratio as given by

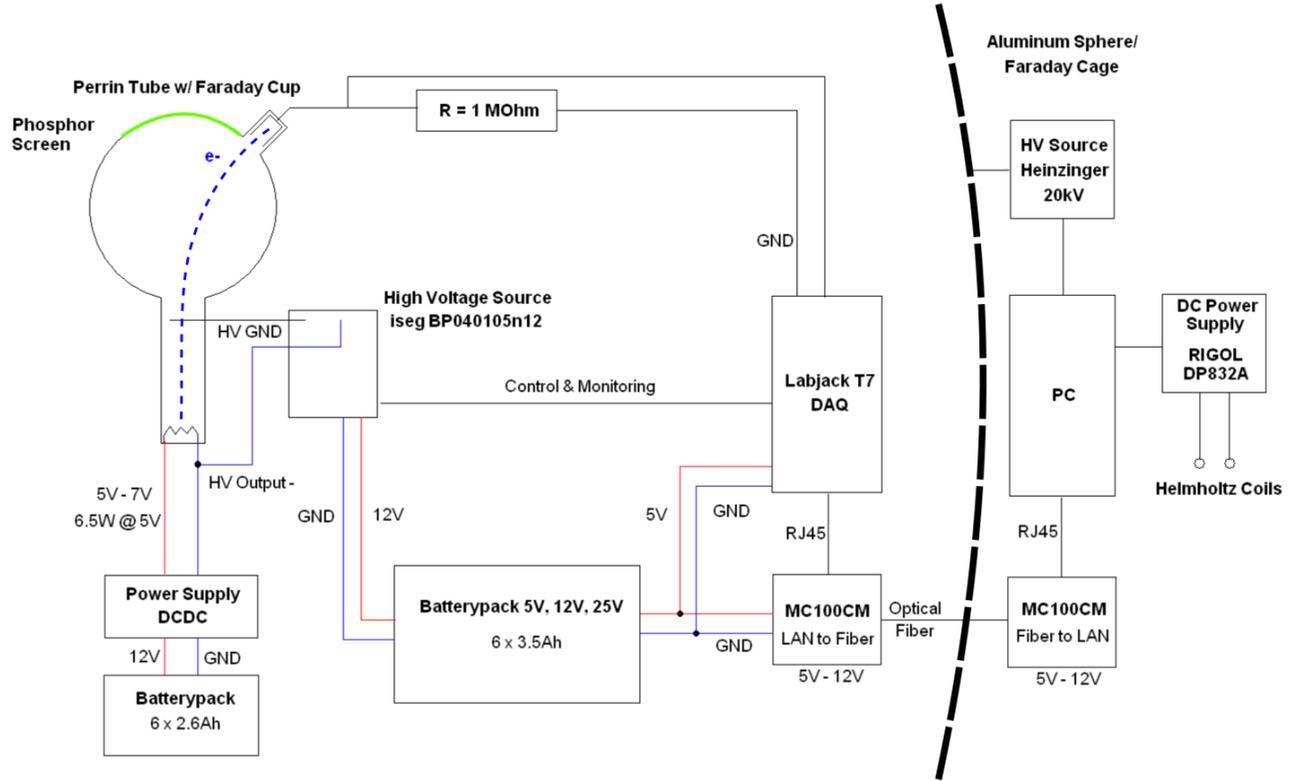
$$\frac{e}{m} = \frac{2V_A}{(Br_c)^2}. \quad (5)$$

The tube is operated on battery power with power supplies and data acquisition inside a 490 mm diameter hollow aluminum sphere with the main glass bulb at the geometric center. A glass fiber cable is used through a small hole in the sphere to connect to a computer to command the experiment in order to prevent all high-voltage related issues. Outside of the sphere, two Ferronato Helmholtz coils were placed with an effective diameter of 533.5 mm and 89 turns, which produce a magnetic field of 0.3 mT/A. This value was experimentally verified using a MLX90393 magnetic field sensor. The overall setup is illustrated in Fig. 1.



**Figure 1.** Schematic sketch of the experiment ((a) overall, (b) sectional view with indication of electron flight path).

The electric setup is summarized in Fig. 2. We used a DPS 5005 power supply with an individual battery to power the heater of the electron gun at 5 V and a power consumption of 6.5 W. An iseg modular high voltage converter and LabJack T7 data acquisition system was powered by another battery



**Figure 2.** Electrical setup.

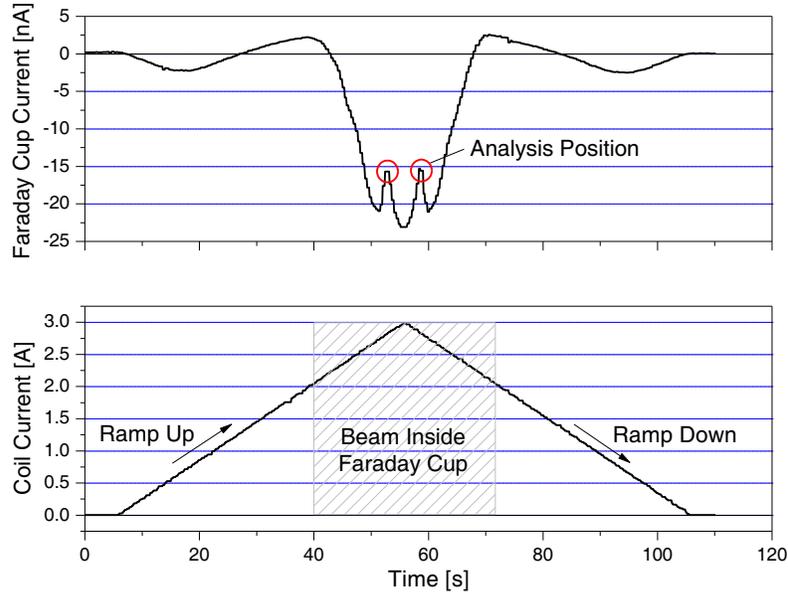
to command the electron gun acceleration potential and a 1 MOhm resistor was used to measure the current of the Faraday cup. A TP-Link MC-100CM LAN-Fiber converter was used to connect the Labjack to the computer outside the sphere. In addition, this computer also controlled a Heinzinger 20 kV power supply to charge up the sphere itself as well as a Rigol DP832A power supply to control the current and therefore magnetic field of the Helmholtz coils.

### 3. MEASUREMENTS

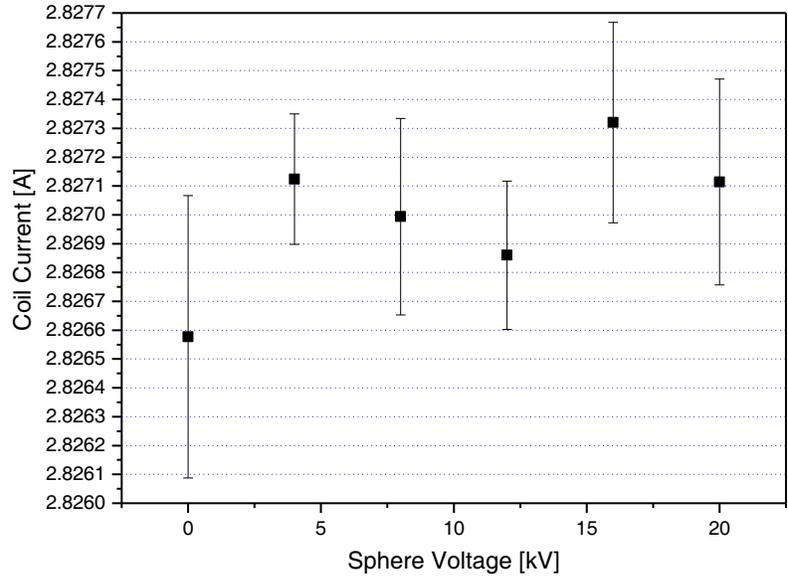
All measurements were performed with a fixed electron gun acceleration voltage of  $V_A = 2$  kV, which generated a beam current of approximately  $25 \mu\text{A}$ . As the anode consists of a plate with a small hole in the middle in order to generate a thin electron beam, only around  $1/1000^{\text{th}}$  of the beam actually enters the large bulb area, which is eventually captured by the phosphor screen or Faraday cup. Using Eq. (5) and the known curvature radius and Helmholtz current relation, we therefore expected a coil current of 3 A to obtain the maximum Faraday cup current. Fig. 3 shows a typical ramp up and down of the coil current and the corresponding Faraday cup measurement, which indeed peaks at 3 A. Using the known  $e/m$  ratio, we can estimate our experimental accuracy. Utilizing our operational values and Eq. (5), we obtain  $e/m = 1.9 \times 10^{11}$  C/kg, which is within 10% of the known value. This error includes our uncertainties in the geometrical radius  $r_c$  as well as velocity deviations due to energy spread from space charge effects.

Due to the geometrical constraints of the cup (see Fig. 2, the entrance of the Faraday cup is a cylinder that can shield part of the beam during sweeping), there are two sharp peaks in the current measurement that we termed “Analysis Position”, which represents a fixed reference for our beam position.

Our procedure was as follows: We performed measurements at six different sphere potentials from 0–20 kV. During each measurement, we performed five ramp up and downs similar to Fig. 3 and then



**Figure 3.** Faraday cup current as a function of the Helmholtz coil current.



**Figure 4.** Coil current necessary to maintain analysis position versus sphere voltage.

evaluated at which coil current the Faraday cup currents peaked at the characteristic Analysis Position as summarized in Fig. 4. We made sure that the ramps were made slow enough that we could see current variations within the resolution of our coil power supply, which was 0.1 mA.

The measurements showed no variation of the coil current over the sphere voltage range within their error bar of 0.3–0.4 mA. Using Eqs. (4) and (5), we would have expected a change of the necessary magnetic field to maintain the electron’s final position to be

$$\Delta B = \frac{1}{r_c} \cdot \left[ \sqrt{\frac{2V_A (m + \frac{eV}{3c^2})}{e}} - \sqrt{\frac{2V_A m}{e}} \right]. \tag{6}$$

Using  $V_A = 2\text{ kV}$ ,  $r_c = 16\text{ cm}$  and the electron’s charge  $e$  and mass  $m$ , this translates into a change

of the magnetic field of  $\Delta B = 6.1 \mu\text{T}$  and therefore a coil current of  $\Delta I = 20.4 \text{ mA}$  for the maximum  $V = 20 \text{ kV}$  sphere potential. Our error bar therefore rules this effect out by approximately two orders of magnitude.

Two potential limitations have been raised in the literature that could have influenced our experiment:

a. Metallic sphere versus dielectric sphere with fixed charges: Assis [7] originally proposed a dielectric sphere with fixed charges instead of a metallic enclosure to test the effect in order to avoid the interference of mirror-charges that could mask the effect. Although previous experiments tested both types of enclosure with no difference [20], we can estimate the mirror charges effect by comparing the number of charges on the sphere with the number of changes inside the Perrin tube, which could potentially mask the effect.

The total amount of charge on the aluminum sphere is given by its capacity and the applied voltage as

$$Q_{\text{sphere}} = 2\pi\epsilon_0 D \cdot V. \quad (7)$$

where  $D$  is the sphere's diameter. On the other hand, we can estimate the amount of charge inside the tube by using the beam current, which is accelerated from the cathode to the anode (neglecting the beam that actually goes through the hole and secondary-electron effects from the phosphorous screen and Faraday cup — as those are three orders of magnitude below) using

$$Q_{\text{beam}} = I \cdot \sqrt{\frac{2md^2}{eV_A}}. \quad (8)$$

where  $d$  is the cathode-anode distance of approximately 2 cm. By comparing both values, we see that  $Q_{\text{sphere}}$  is some 7 orders of magnitude larger compared to  $Q_{\text{beam}}$ , which should make mirror or residual charges in the tube irrelevant.

b. Modification of Weber's force law. Several proposal have appeared to modify Weber's potential energy such as Phipps to avoid negative effective masses [25, 26], or Newton's force law in order to make Weber electrodynamics compatible with relativity theory [27, 28]. However, all these modifications are only relevant at speeds comparable to the speed of light. Due to our rather low anode voltage of 2 kV, the speed of the electrons is just 9% compared to  $c$  and thus the Lorentz factor is only 1.0039. We therefore do not expect that those alternatives are relevant.

## 4. CONCLUSION

We performed an experiment to test a predicted mass change for an accelerating charge inside a charged sphere. The setup consists of a Perrin tube, which includes an electron gun inside a glass vacuum bulb with a Faraday cup at a specific location that was used as a geometric reference. The tube and all associated battery-powered electronics were mounted inside a large aluminum sphere that could be charged up to 20 kV. Helmholtz coils caused the electrons to be deflected and therefore constantly accelerated in the radial direction following a curved path. Any mass change would have caused a slightly different position at the Faraday cup.

Our measurements rule out the effect predicted by Assis [7] and Sapozhnikov [9] by two orders of magnitude. This is in line with the most recent experiments that were looking for a similar effect [18, 20, 22, 23], although they had some experimental shortcomings, which we believe to have taken into account in this work.

This confirms the classical theory of electrodynamics and demonstrates that electrostatic potential energy cannot be localized to individual charges but only exists for the system as a whole.

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