MAD 02/24/97
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Experiment 20
Electron Charge-to-Mass Ratio

Objective

In this experiment, we are going to measure the charge-to-mass ratio e/m for the electron, using concepts developed during the lecture part of this course.

Equipment

- e/m apparatus.
- Cenco low voltage power supply 79549 (filament current).
- Harrison 6200B DC power supply (accelerating potential).
- Epsco Model H filtered DC power supply (coil current).
- 3 Fluke 77 series II multimeters.

The e/m apparatus consists of a large vacuum tube containing some electrodes, a tiny bit of mercury, and some mercury vapor which will glow a pale blue when struck by moving electrons. The physical connections within the tube form an *electron gun.* There is a small filament, through which you'll pass a current; this heats the filament (and also causes it to glow), releasing electrons via the thermoelectric effect. In addition to the filament, there is a pair of accelerating plates (essentially a pair of capacitor plates). Outside the tube, there are two coils of wire (the Helmholtz coils) which will produce a nearly uniform magnetic field inside the tube. The 3 DC power supplies are for the filament current, accelerating voltage, and Helmholtz coil current. The ammeters are to keep track of the current in the Helmholtz coil and the filament current. The voltmeter is to measure the accelerating potential V.

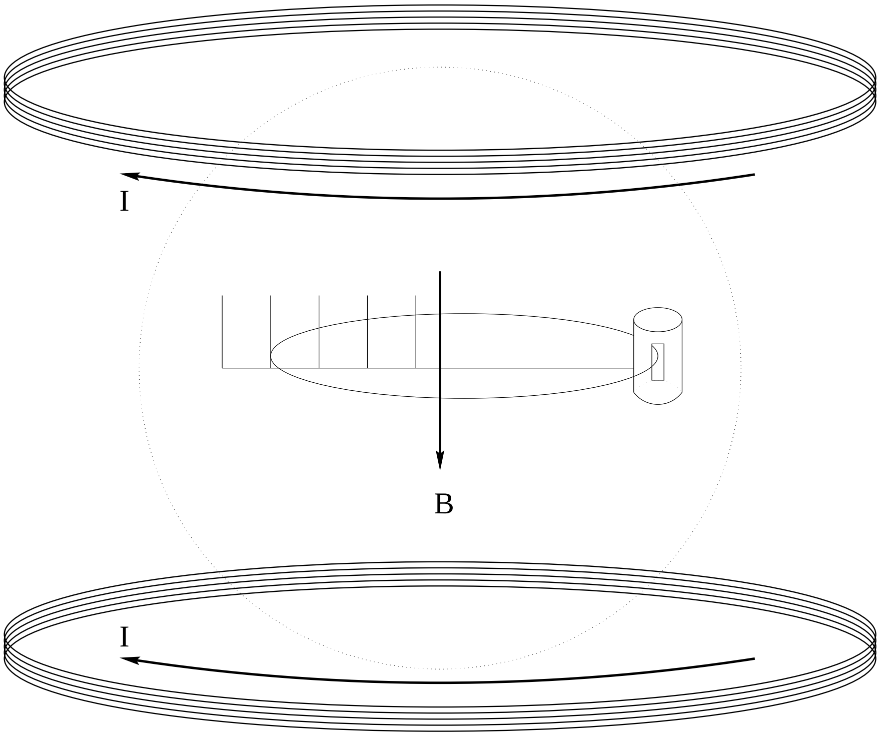
When measuring the radius of the electron beam, remember to use the part of the beam nearest the vertical wire in the middle of the tube. The magnetic field from the coils is most uniform near the center of the coils (where the center of the tube is placed), and those electrons are the ones with the most nearly horizontal velocity (if any part of the velocity of the electrons is vertical, $v_\perp$ will be smaller than v, and the radius of the circle will be smaller).

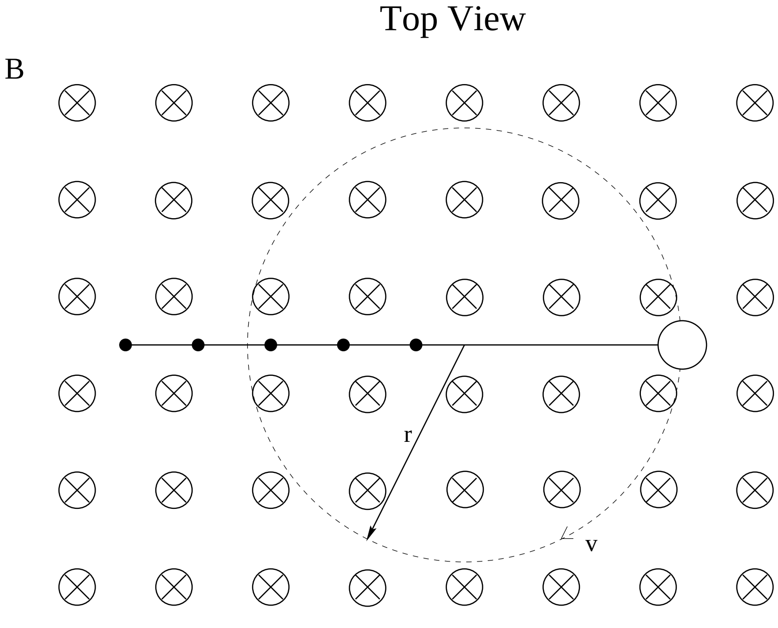
Theory

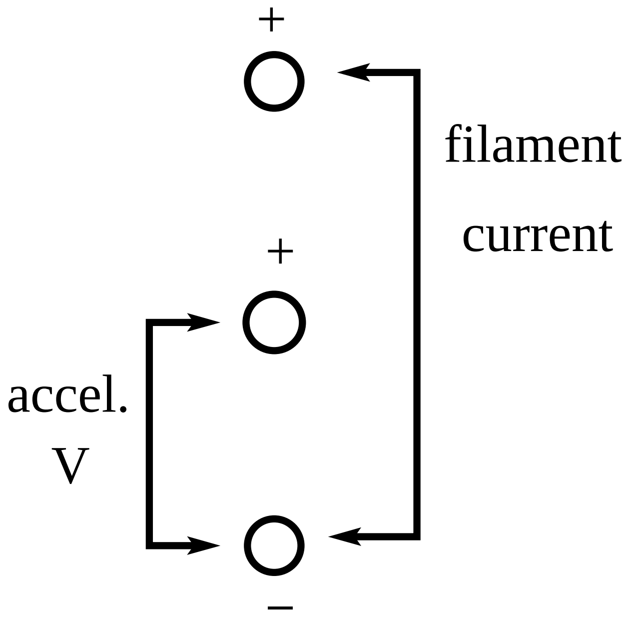
Capacitor plates, charged to some potential difference, will accelerate charged particles. In lecture, we discussed how a potential difference V will do work $W = qV$ on a charged particle. The work done changes the kinetic energy of the particle: $\Delta K = W = qV$. For a particle starting from rest, the final velocity can be found in terms of the accelerating potential by applying conservation of energy:

$$\tfrac{1}{2}mv^2 = qV \qquad \Longrightarrow \qquad v = \sqrt{2V\frac{q}{m}}. \tag{1}$$

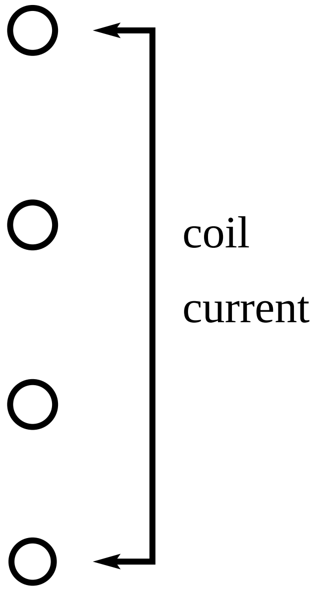
Once the electrons have left the accelerating region (the small, metal cylinder inside the glass tube), they move at this velocity.







Connection diagram for accelerating potential and filament current.



Connection diagram for the Helmholtz coil current.

A pair of coils whose separation is equal to their radius provides a nearly uniform magnetic field near their center. This combination of coils is known as a pair of *Helmholtz coils*. The magnetic field between a pair of Helmholtz coils is given by the expression

$$B = \frac{8\mu_0 NI}{R\sqrt{125}} \tag{2}$$

Finally, recall that a charged particle which is moving at constant speed perpendicular to a constant magnetic field will follow a circular path of radius

$$r = \frac{m}{q}\frac{v_\perp}{B}. \tag{3}$$

Since we know what v is in terms of the accelerating voltage V, we may insert Eq. (1) into this expression (to get rid of v), add Eq. (2) (to get rid of B), and do a little algebra:

$$\begin{aligned} \frac{q}{m} &= \frac{2V}{r^2B^2} \\ &= \frac{250R^2}{64\mu_0^2N^2}\,\frac{V}{I^2r^2} \end{aligned} \tag{4}$$

Thus, by measuring V, I, and r we can determine q/m (e/m) for the electron.

Procedure

0. The pins are located 6.5 cm, 7.8 cm, 9.0 cm, 10.3 cm, and 11.5 cm from the electron beam source. In addition, there are 72 turns of wire in each of the two Helmholtz coils, so $N = 72$ in Eqns. (2) and (4).

1. In order to calculate the magnetic field, you'll need to measure the radius R of the coils (measure the diameter and divide by 2) and the separation L of the coils. Since the coils themselves have a non-zero size, measure the *average* radius and separation. Verify that these are equal, and record R.

Radius of coils	$R =$
Separation of coils	$L =$

The circuit will be connected already. Make certain you understand the purpose of each power supply, and the limitations on the currents supplied. **The filament current must remain below 4.5 A**. Set this current to some safe value and leave it there. If this current is too large, it can damage the tube (or burn out the fuse). If this current is too small, you will not produce enough electrons. Record the filament current.

Filament current	

2. Apply the accelerating potential. The tube is designed to operate safely at a higher potential than the power supply can provide, so there is no maximum you need to worry about here. You should see a fain bluish glow, pointing perpendicular to the tube's main axis. This glow is caused by electrons colliding with the mercury vapor atoms in the tube. You may need to turn out the lights to see this clearly.

3. Apply the coil current. If the electron beam bends backwards (towards the "near" side of the tube instead of about the center) you need to reverse the leads from the power supply (which reversed the direction of current flow, which in turn reverses the direction of the magnetic field). Any upper limit on the current in the coils is much higher than the capability of the power supply.

4. Along the axis of the tube are several vertical wires extending upwards from a horizontal wire. These allow you to measure the *diameter* of the circular path of the electron beam. Choose one of these wires, and adjust the accelerating voltage and coil current so that the beam hits this wire. Make certain that you can adjust the accelerating voltage V and coil current I over a reasonable range, keeping the orbit diameter d fixed. Record d, V, and I. Find several (4 total) **other** combinations of V and I that give the **same** diameter orbit. Record the values of d, V, and I.

Data with fixed diameter $d =$ _________

Accelerating potential V	Helmholtz current I

5. Choose an accelerating voltage such that you can bend the beam with the magnetic field sufficiently to make 4 different diameter measurements. Keeping V fixed, adjust I so that the beam hits a vertical wire: record d, V, and I. Repeat for a total of 4 diameter measurements, recording d, V, and I for each.

Data with fixed accelerating potential $V =$ _________

Wire number	Diameter d	Helmholtz current I

6. Choose a coil current such that you can change the diameter of the beam with the accelerating voltage sufficiently to make 4 different diameter measurements. Keeping I fixed, adjust V so that the beam hits a vertical wire: record d, V, and I. Repeat for a total of 4 diameter measurements, recording d, V, and I for each.

Data with fixed coil current $I =$ _________

Wire number	Diameter d	Accelerating potential V

Analysis

A. With the help of Eq. (4), calculate q/m for each of the 12 data points collected during the lab. Calculate your average value of q/m and compare that with the accepted value of 1.76×10^{11} C/kg.
Note: This is a difficult experiment. There will very likely be a large difference between the accepted and actual values, perhaps 30%–40%. Considering the experimental difficulties involved, this is not a bad result. In addition, prepare 3 graphs of the data (either by hand or with the help of Excel):

B. with the 4 data points taken in step **4**, prepare a plot of V versus I^2.

C. with the 4 data points taken in step **5**, prepare a plot of I versus $1/r$.

D. with the 4 data points taken in step **6**, prepare a plot of V versus r^2.

In each case, the variable plotted have been chosen to give a straight line if the theory is correct. By rearranging Eq. (4), you can relate q/m (the thing we would like to measure) to the slope of your graphs (there is a different relation for each graph). For each graph which looks reasonably linear, determine a value of q/m from the slope of that graph. [Excel can be used to do a least-squares fit to the data, producing the slope values for you. All you have to do is drop this into your rearranged version of Eq. (4)].