TAP 413-2: Measuring the charge to mass ratio for an electron

Using circular motion

Using a magnetic field to drive an electron round in a circle can give information about the acceleration.

The magnetic force acting is

$F = qvB$

and the force required to drive it round in a circle is given by

$F = \dfrac{mv^2}{r}.$

You can put these two equal to get

$\dfrac{q}{m} = \dfrac{v}{rB}.$

So three measurements can give the charge / mass ratio of the electron. Both the radius of the circular motion and the magnetic field strength can be measured in a fairly straightforward way. The measurement of the velocity, however, is harder.

Electrons are accelerated by an electron gun. So

$Vq = \frac{1}{2}mv^2$

so at first sight it looks as if you need q and m to get started. However, maths comes to our aid, allowing you to combine the two sets of relationships to get

$\dfrac{q}{m} = \dfrac{2V}{r^2 B^2}$

(arrange both relationships to give v^2 then put them equal).

Now we can measure three things in the laboratory in order to find the charge to mass ratio for the electron.

By extension you measure the charge / mass ratio for any charged particle, allowing you to characterise many particles.
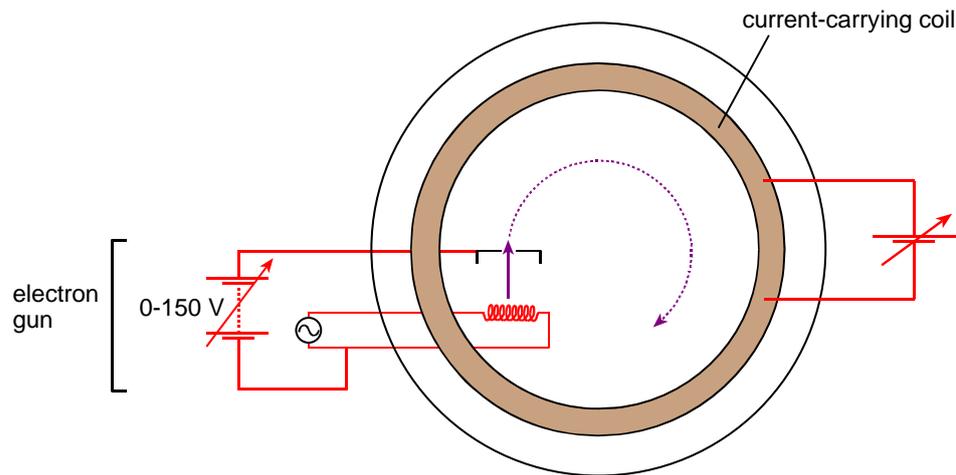
You will need:

- ✓ fine beam tube
- ✓ stand
- ✓ HT, 0–150 V
- ✓ power supply, 5 V dc
- ✓ rheostat
- ✓ Helmholtz pair of coils
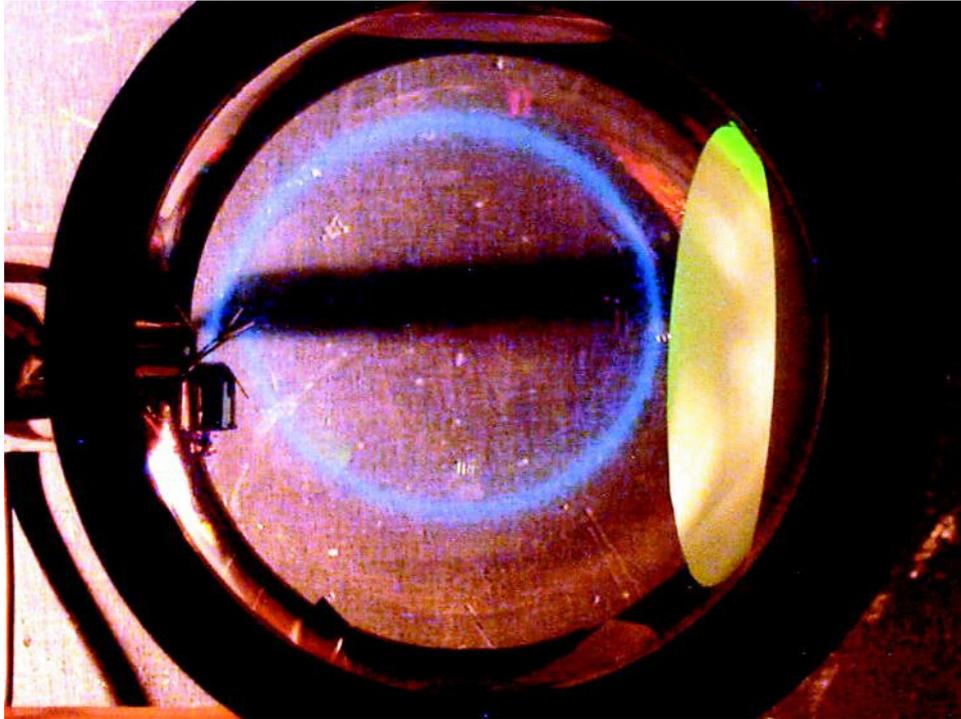- ✓ 4 mm leads with sprung shrouds for connections to HT circuits (some may need a female termination)

current-carrying coil

electron gun

0-150 V

Making the measurements

You will need to arrange the magnetic field and accelerating pd so that you can see a complete circular electron path.

Record the pd and radius of the beam (in metres). Switch off the HT.

Now remove the electron tube to allow the use of a calibrated magnetic field sensor, or a current balance, to measure the magnetic field where the electron beam was.

Now use the relationship

$$\frac{q}{m} = \frac{2V}{r^2 B^2}$$ to find q/m.

You have

1. a   Seen an arrangement of electric and magnetic fields that will drive electrons round in a circle.

2. in   Analysed the motion to give a relationship between q/m and things you can measure in the school laboratory.

3.   Made a measurement of q/m.

Practical advice

You will need to set this demonstration up in a well darkened room for maximum effect, more so than that needed for a deflection tube. You will also want to think carefully about how to display both the tube, in order to explain its action, and the resulting circle, to the size of group that you will be showing it to. Try covering the back of the tube with a black cloth

If new to wiring up electron deflection tubes you may well also wish to practice beforehand, and have a small bench top lamp to hand, well shaded so as not to destroy the dark adaptation of the group's eyes.

You will need to explain and show the actions of the electron gun and the coils, probably using a gimballed bar magnet to show the direction of the field. Make some play of the need to measure the magnetic field separately, using a technique familiar to the students. This is likely to involve the use of a current balance, or a calibrated magnetic field probe. A suitable design of current balance is the following:
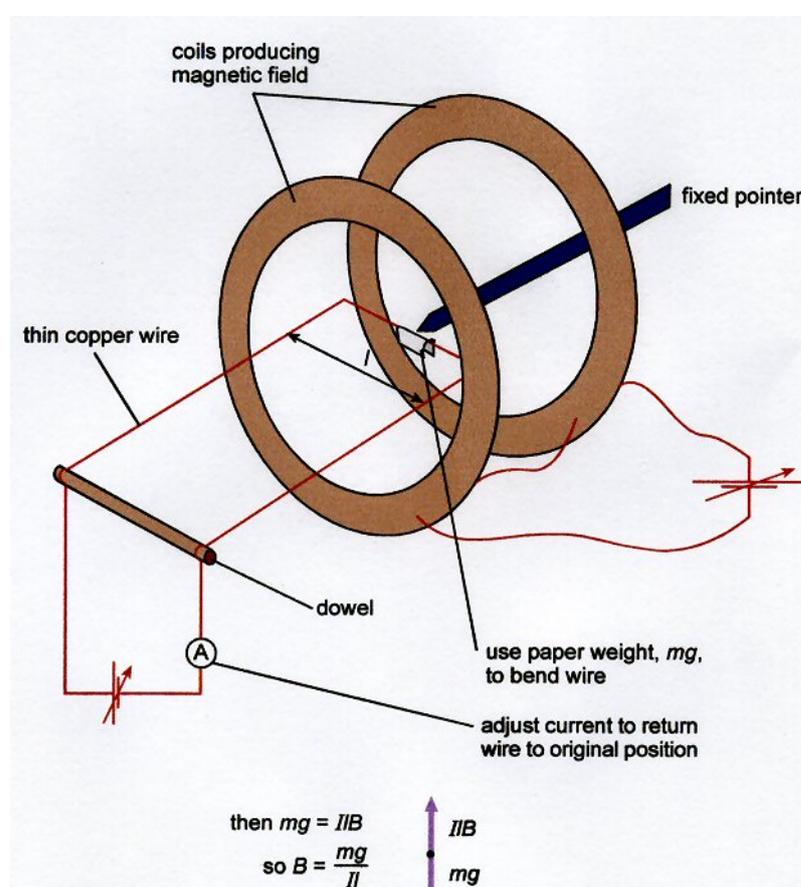
Student ingenuity can be harnessed to estimate the radius of the circle of the electron beam. With prior practice you will, in any case, have a good idea of the values you need to obtain in order to get an approximately correct value of q/m – about 1.8×10^{11} C kg^{-1}.

You will probably get a spread of circles, perhaps due to the field being non-uniform (a Helmholtz pair only produce an approximately uniform field in the central third of the volume they enclose), due to the electrons provided by the electron gun having a range of velocities, and due to random thermal motion superimposed on the velocity acquired from the action of the accelerating pd.

Alternative approach

Wire the circuits before the demonstration so the tube is ready to switch on.

The use of the current balance can be tricky. Use a calibrated Hall probe or you could

calculate the magnetic field using the formula for Helmholtz coils $B \approx 0.72\mu_0 \dfrac{NI}{R}$ where R is

the radius of the coil, N the number of turns and I the current in amps. You would have to include an ammeter in series with the coils to measure the current during the experiment. Students do not need to know the formula for Helmholtz coils.

	Safety
⚠	Wire carefully, no bare conductor above 40 V.
	HT supplies are always dangerous, especially so in the dark. Shrouded plug leads MUST be used. No connections should be changed with the power switched on.

External reference

This activity is taken from Advancing Physics chapter 16, 160D