

Note-A-Rific: Cathode Rays

A lot of the original investigations into electrons and protons started with cathode ray tubes.

- Basically, a modern day television picture tube is a cathode ray tube with a few added gimmicks.
- The tube is nearly a vacuum, with two electrodes inside.
- If there is a high enough voltage between the two, it appeared as if something was being thrown off the electrode called the cathode.
- They called these cathode rays, but today we know that they were really just a bunch of electrons.

J.J. Thompson set up his cathode ray tube so that he was able to change the direction of electrons flying through it.

- Take a look at the diagram at the bottom of page 706.
- First he used a set of parallel plates to create a uniform electric field that the electrons flew through.
 - This caused a force on the charges that can be calculated using...

$$\mathbf{E} = \mathbf{F}_e/q \rightarrow \mathbf{F}_e = \mathbf{Eq}$$

- The tube was set up so that the electrons were pushed up by this force.
- He also set up two coils with a current flowing through them to induce a magnetic field.

$$\mathbf{F}_m = q\mathbf{vB}$$

- This magnetic field was arranged to push the electrons down.

Thompson now adjusted the magnetic and electric fields until the electrons hit the end of the cathode tube at the centre (as if no forces had affected it!).

- Since the two forces are exactly cancelling each other, they must be equal in magnitude, so...

$$\mathbf{F}_e = \mathbf{F}_m$$

$$\mathbf{Eq} = q\mathbf{vB}$$

You can solve this equation to find the velocity of the electron...

$$v = \frac{Eq}{Bq} \rightarrow v = \frac{E}{B} \quad \text{Equation 1}$$

So, for electrons that are moving at this specific velocity, the forces balance out!

- Electrons going at any other velocity wouldn't make it to the other side and hit dead centre.

Thompson next turned off the electric field (this is after he had set it all up to have balanced forces and taken his readings).

- With the electric field off, only the magnetic field remains to push the electrons around.
- The magnetic field's force downward on the electrons will actually cause them to start to accelerate down in an arc (centripetal acceleration, so centripetal force!)
- Since the centripetal force is caused (and equal to) the magnetic force...

$$F_c = \frac{mv^2}{r} \quad \text{and} \quad F_m = qvB$$

$$F_c = F_m$$

$$\frac{mv^2}{r} = qvB$$

$$\frac{q}{m} = \frac{v}{Br} \quad \text{Equation 2}$$

The value given by q/m is called the *charge-to-mass ratio*.

- It is important because even though we can't actually put an electron on a scale to find its mass, Milikan figured out the charge on an electron.
- Thompson used equation 1 to figure out the velocity of his electrons.
- Then he measured how far the electron was deflected to figure out the radius of the "circle" it was traveling.
- Using equation 2 he was able to find the mass of an electron as $9.11 \times 10^{-31} \text{kg}$
- He did a similar test (using hydrogen gas as a source of protons) to find the mass of a proton.

Example: You decide to try to recreate Thompson's experiment to find the mass of an electron. You set up your cathode ray tube with an electric field of $1.86 \times 10^4 \text{ N/C}$ between the plates and a magnetic field of $5.8 \times 10^{-4} \text{ T}$. After shutting down the electric field, you measure the path of the electron. It has a radius of 0.315m. What is the charge you calculate for the electron, and how close is it to the accepted value?

We will need to solve this problem in a couple of steps.

Step One: How fast is the electron going?

We can calculate this since the balanced electric and magnetic fields will only let a specific velocity electron all the way through.

$$F_c = F_m$$

$$Eq = qvB$$

$$v = \frac{Eq}{Bq}$$

$$v = \frac{E}{B} = \frac{1.86 \times 10^4 \text{ N/C}}{5.8 \times 10^{-4} \text{ T}} = 3.2 \times 10^7 \text{ m/s}$$

Step Two: What's the mass?

This is when the centripetal and magnetic forces are equal. We will assume that Millikan has already performed his experiment and use the accepted value for the charge of an electron.

$$F_c = \frac{mv^2}{r} \quad \text{and} \quad F_m = qvB$$

$$F_c = F_m$$

$$\frac{mv^2}{r} = qvB$$

$$\frac{q}{m} = \frac{v}{Br}$$

$$m = \frac{qBr}{v} = \frac{(1.6 \times 10^{-19} \text{ C})(5.8 \times 10^{-4} \text{ T})(0.315 \text{ m})}{(3.2 \times 10^7 \text{ m/s})} = 9.1 \times 10^{-31} \text{ kg}$$

Wow, exactly the same as the accepted value (with a little rounding off).