

Electrons

1 Discharge tube

- As p.d. increased from 0V, initially no glow
- p.d. increased further - suddenly glows can be seen and p.d. drops as the gas now conducts
- Increasing p.d. further causes gas to glow brighter

When several kV is applied a narrow band "glow" causes gas to glow brighter

1.1 Explanation of how it works

- The high p.d. is sufficient to ionise the gas
- The positive ions accelerate towards the cathode
- The ions will hit the metal cathode with sufficient energy to release free electrons from the surface
- The free electrons from the metal (low energy) can recombine with the gas ions-emitting photons and will be a continuous spectrum
- The free electrons accelerate towards the anode. These free electrons will **inelastically** collide with gas atoms (and ions) causing bound electrons to be excited, then de-excited. This will produce a discrete spectrum which is seen in the positive column.

2 Thermionic emission

When a metal is heated the free electrons can gain enough energy to be released from the surface. This is called thermionic emission (similar to the photoelectric effect).

In the presence of an electric field the thermionic electrons can be accelerated to form a narrow beam.

When accelerated through a p.d. of V volts the electron gains eV in energy in the form of kinetic energy.

3 Determining the specific charge of an electron

3.1 Method 1

1. Thermionic electrons are accelerated through a p.d. V_a and gain kinetic energy:

$$eV_a = \frac{1}{2}mv^2 \quad \frac{e}{m} = \frac{\frac{1}{2}v^2}{V_a}$$

2. Electrons pass through an electric field (Field strength, E) and are deflected.

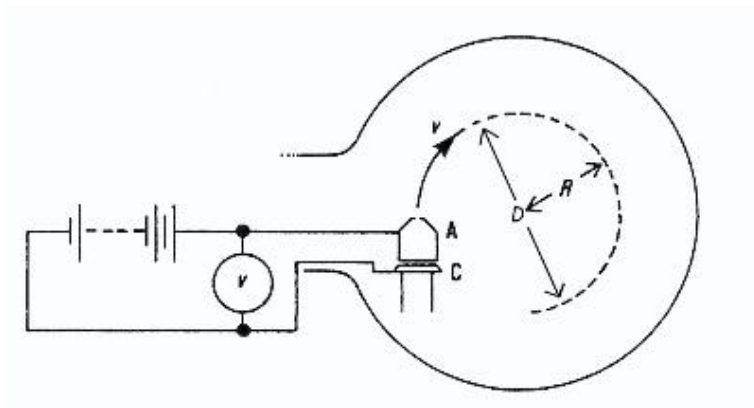
3. A magnetic field (field strength, B) is applied at right angles to the E field until electron motion is again horizontal.

At this point magnetic force=Electric force

$$Bev = eE \quad v = \frac{E}{B}$$

$$\frac{e}{m} = \frac{1}{2V_a} \left(\frac{E}{B} \right)^2$$

3.2 Method 2



Thermionic electrons are accelerated through a p.d. V_a

A magnetic field is applied perpendicular to the motion, causing the electrons to feel a force.

Magnetic force $F = Bev$

This is the centripetal force, $\frac{mv^2}{R}$

$$\frac{e}{m} = \frac{v}{BR} \quad v = \frac{e}{m}BR$$

From accelerating p.d. $eV_a = \frac{1}{2}mv^2$

$$\frac{e}{m} = \frac{2V_a}{(BR)^2}$$

4 Milikan's experiment

Upthrust+Viscous drag

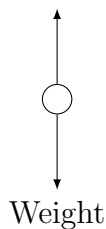


Figure 1: No electric field

Upthrust+Electric force

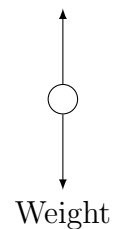


Figure 2: Electric field

4.1 With electric field

$$\text{Electric field} = \frac{QV}{d}$$

$$\text{Weight} = mg$$

$$\frac{QV}{d} = mg$$

4.2 Without electric field

$$F_D = 6\pi r\eta v$$

$$\text{Weight} = mg$$

$$\text{Mass} = \text{Density} \times \text{Volume}$$

$$\text{Mass} = \frac{4}{3}\pi r^3 \rho$$

$$6\pi r\eta v = \frac{4}{3}\pi r^3 \rho g$$

$$r^2 = \frac{9\eta v}{2\rho g}$$

4.3 Significance of results

These results were significant because it introduced the idea of quantisation of charge

Questions from past papers

5 Milikan's experiment

Why does an oil droplet reach a constant speed when the plate voltage is switched off in Milikan's experiment

Weight pulls droplet down, reaches terminal velocity

Derive $r^2 = \frac{9\eta v}{2\rho g}$

$$F_D = 6\pi r \eta v$$

$$\text{Weight} = mg$$

$$\text{Mass} = \text{Density} \times \text{Volume}$$

$$\text{Mass} = \frac{4}{3}\pi r^3 \rho$$

$$6\pi r \eta v = \frac{4}{3}\pi r^3 \rho g$$

$$r^2 = \frac{9\eta v}{2\rho g}$$

Determine the mass or radius of a droplet in Milikan's experiment

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

$$r = \sqrt{\frac{9\eta v}{2\rho g}}$$

$$m = \frac{4}{3}\pi r^3 \rho$$

Charge from mass

$$Q = \frac{mgd}{V}$$

Determine the sign of the charge carried by a stationary droplet in Milikan's experiment

Opposite to the charge of the top plate to ensure forces are balanced

Comment on the significance of a charge calculated in Milikan's experiment

It will be a multiple of the charge of an electron

6 Electron Guns

Speed of electrons from the voltage they are accelerated through a Voltage

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

$$v = \sqrt{\frac{eV}{\frac{1}{2}m}}$$

Why are there two power supplies in an electron gun?

One to cause thermionic emission, one to accelerate the electrons

7 Electrons in magnetic fields

Does the speed of an electron change in a magnetic field

No as force is perpendicular to velocity, meaning no work is done

Specific charge from radius of curvature, magnetic flux density and accelerating voltage

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

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

$$\frac{e}{m} = \frac{2V}{B^2r^2}$$

What is the velocity of an electron when magnetic and electric fields are equal

$$EQ = BQv$$

$$v = \frac{E}{B}$$

Velocity of electrons in a magnetic field

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

$$v = \frac{Ber}{m}$$

Why do electrons undergo circular motion in a magnetic field

Force perpendicular to motion, does not change speed, causes direction of motion to change

8 Electrons in electric fields

Draw the path of an electron beam in an electric field

Curves up while between plates, straight line continuing up after leaving plates

Specific charge of an electron from curving in an electric field

$$ma = \frac{eV}{d}$$

Calculate acceleration using SUVAT

$$\frac{ad}{V} = \frac{e}{m}$$

Specific charge from electric field strength

$$EQ = mg$$

$$\frac{Q}{m} = \frac{g}{E}$$

Why does an electron beam in an electric field curve at an increasing angle to the horizontal

The electrons feel a constant force, meaning they have constant vertical acceleration, causing the vertical component of the velocity to increase, while the horizontal component is constant, causing an increasing angle.

9 Thermionic emission

Explain thermionic emission

The current heats the wire, meaning the electrons in the filament gain sufficient k.e. to leave the filament

Why must the filament be in an evacuated tube for thermionic emission

So that there are no collisions

Why is thermionic emission negligible when the filament current is too low

If the current is too low there is little heating effect, meaning that the electrons don't gain enough kinetic energy to be released

10 Discharge Tubes

Why is light emitted in a Crooke's tube

Electrons present, collide with atoms, excitation occurs, emit photon as they return to the ground state

Why can a glow not be seen until the pressure is low enough in a Discharge tube

The electrons can't gain enough kinetic energy as there are too many molecules present