CHARGED PARTICLES

* Millikan's Oildrop experiment

- American physicist Robert Millikan devised a way to measure the charge of an electron in 1913.
- The principle of the method to measure e-charge involved the balancing of the gravitational force on a tiny, charged sphere (oil drop) by an electric force in the opposite direction, so that the sphere remains stationary.

gravitational force downwards = electric force upwards

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

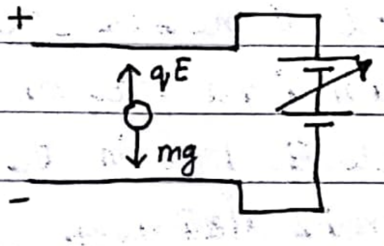
$$\therefore Q = q = \frac{mgd}{V} \quad \text{and} \quad \frac{q}{m} = \frac{gd}{V} \text{ (charge-mass ratio).}$$

- Procedure:

1. He used an atomiser spray to produce a small number of tiny oil ~~droplets~~ drops in the chambers. These drops were charged by friction with the nozzle of the spray.
2. With ~~the~~ electric field switched off, he observed a single drop falling. If its velocity was constant, he knew it was falling at terminal velocity. By timing its fall against a scale, he could determine its velocity and from this he could work out its mass (heavier drops fall with a greater terminal velocity).
3. He then switched on the electric field and adjusted it until the drop remained stationary. Then he knew that the drop's weight

was balanced by the electric force on it.

4. To alter the charge on an oil drop, Millikan included a source of β-radiation in his apparatus. An oil drop which absorbed a β-particle (fast-moving e^-) would gain -ve charge & so the electric force on it would change.



- He found that the charge q was always an integral multiple of a fundamental quantity of charge e equal to 1.6×10^{-19} C. This fundamental charge was ascribed to the charge of an e^-.
- The experimental result that the charges on the droplets seem to be only in integral multiples of e means that charge is quantised, or exists only in discrete amounts.
- Particles such as protons & many others from the 'particle zoo' of sub-atomic particles have charges which are multiples of e. The exception is quarks, which have charges which are multiples of $\frac{1}{3}e$.

* The electron mass

- A particle of mass 'm' and charge 'q' moving with speed 'v' at right angles to a uniform magnetic field of flux density 'B' experiences a force F_B given by $F_B = Bqv$
- The direction of this force is given by Flemming's Left Hand Rule (FBI).

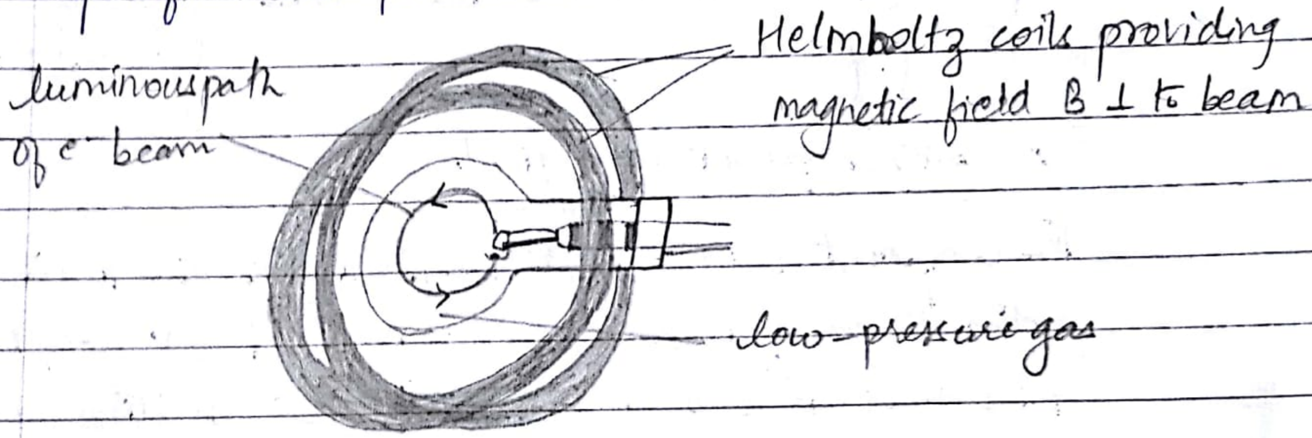
- There is a constant force which is normal to the direction of motion is the condition necessary ~~force~~ for circular motion and ∴ F_B provides the centripetal force.

∴ $F_B = F_C$

$$Bqv = \frac{mv^2}{r} \quad \therefore \frac{q}{m_e} = \frac{v}{B\cancel{q}r}$$

- The ratio e/m for an e^- is called "specific charge". & can be determined using a fine beam tube.

"Specific" means 'per unit mass'.



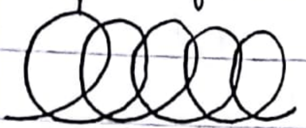
The path of e^- is made visible by having low pressure gas in the tube & thus the radius of the orbit may be measured.
It is difficult to measure 'r' from outside using a rule due to parallax error. Also 'v' needs to be measured. This can be done using cathode-anode voltage V_{ca}. This p.d. causes each e^- to accelerate as it moves from the cathode to the anode.

Work done on e^- = K.E.

$$qV_{ca} = \frac{1}{2} m_e v^2 \quad \text{eliminating } v \Rightarrow \frac{e}{m_e} = \frac{2V_{ca}}{r^2B^2}$$

- By accelerating e⁻ through ~~pot~~ p.d., their speed (v) on entry into the region of magnetic field may be calculated.

- The magnetic field is provided by a pair of current-carrying coils called ~~Helmboltz~~ Helmholtz coils which give a very uniform field in the space between them.
- It is of interest to rotate the tube slightly, so that the velocity of the e⁻ is not normal to the magnetic field. In this case, the path of the e⁻ is seen to be a helix.



→ velocity component along field

The component of v normal to the field gives rise to circular motion. However, there is also a component of v along the direction of the field. There is no force on the e⁻ resulting from this component of v. Consequently, e⁻ execute circular motion & move in a direction normal to the plane of the circle (i.e. along field). The ~~a~~ circle is "pulled out" into a helix.
- The helical path is an imp. aspect of the focusing of e⁻ beams by magnetic fields in an e⁻ microscope.

Centripetal force provided by magnetic force ∴ $Bqv = mv^2/r$

∴ $\boxed{r = \frac{mv}{Bq}}$ ∵ $mv = p$ ∴ $\boxed{p = Bqr}$

→ faster-moving particles move in bigger circles ($r \propto v$)

→ ~~&~~ heavier particles move in bigger circles (more inertia ∴ $r \propto m$)

→ a stronger field makes particles move in tighter circles ($r \propto 1/B$)

Application: particle accelerators & mass spectrometers.

* Velocity selection of charged particles.

→ If the e⁻ beam passing through an electric & magnetic field remains straight, it follows that the electric & magnetic forces on each e⁻ must have the same magnitude & act in opposite directions.

electric force = magnetic force
(upward) (downward)

$$qE = Bqv$$

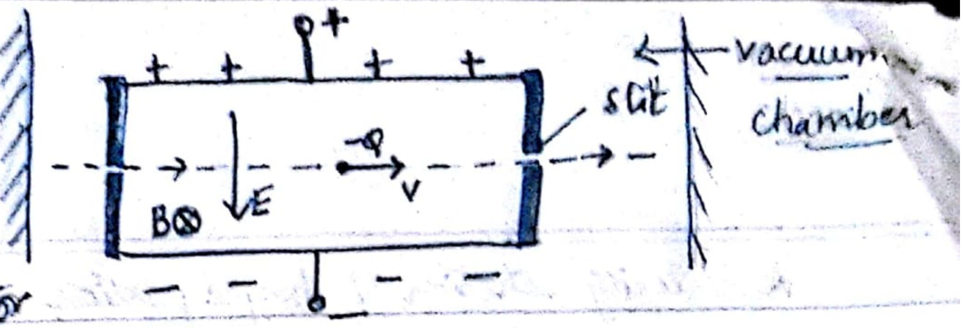
$$\therefore \boxed{v = \frac{E}{B}}$$

electric field =
(down plane of paper)
magnetic field =
(into paper ⊗)

but $E = \frac{V}{d}$ $\therefore v = \frac{V}{Bd}$

→ Balancing the effect of electric & magnetic fields is also used in a device called a "velocity selector".
This is used in devices for investigations on ions such as mass spectrometers where it is desired to produce a beam of charged particles all moving with the same velocity.

→ For the value of the velocity given by E/B, the particles will not be deflected. Particles with any other velocities will be deflected (upwards by E if faster; downwards by B if slower).
If a parallel beam of particles enters the field then all the particles passing undeviated through the slit will have the same velocity, irrespective of their mass. (but same charge).

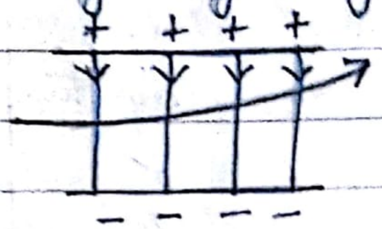


1. Velocity selector

FLHR

2. Negatively charged particles

a)



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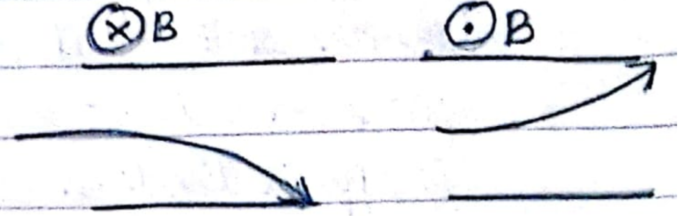
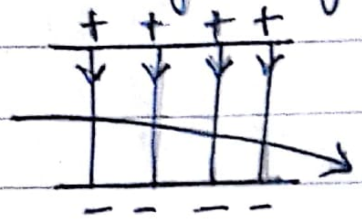


3. Positively charged particles

a)



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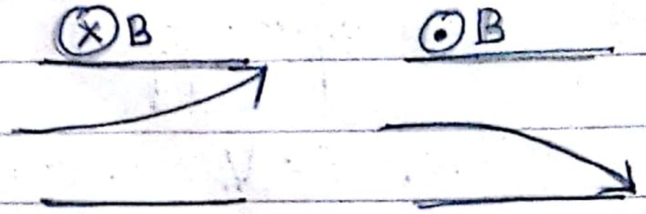

FLHR: Flemming's Left Hand Rule.