Magnetic field lines: ① Come out of N pole & go into S pole.
② direction of a field line at any point in the field shows the direction of the force that a 'free' magnetic N pole would experience at that point.
③ Field is strongest where lines are closest.

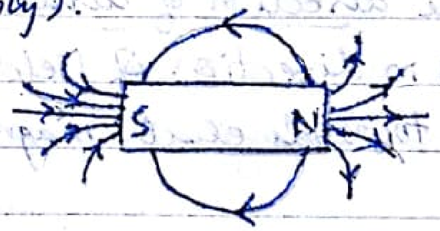
ELECTROMAGNETISM

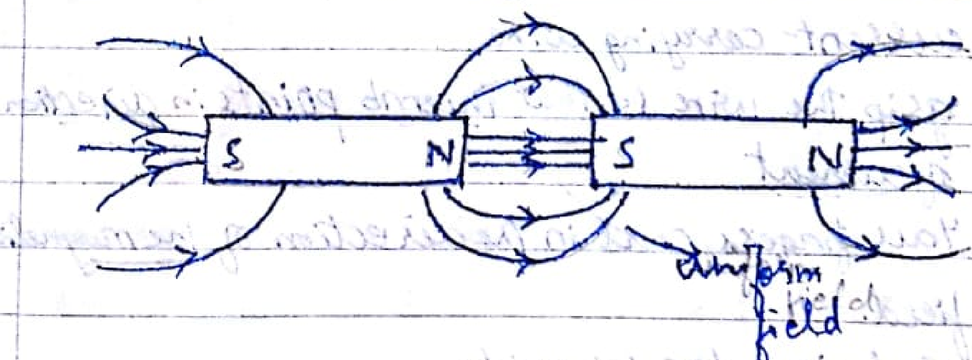
* Law of magnets : Like poles repel
Unlike poles attract.

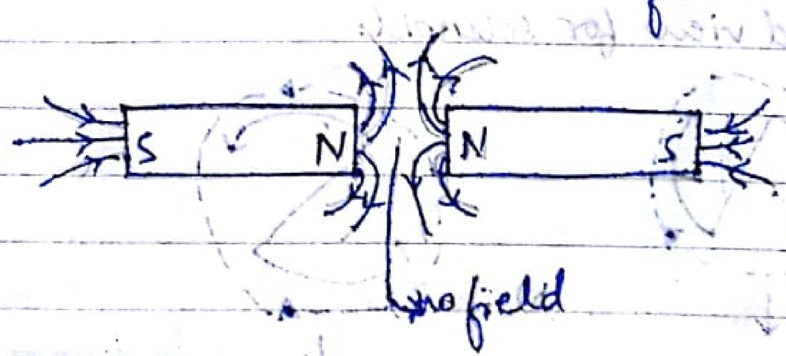
→ This implies that there is a magnetic field - A region of space where a magnetic pole will experience a force.

→ Magnetic fields are not visible but are represented by lines of magnetic force / magnetic field lines / magnetic flux

- Field lines start at N pole & end at S pole
- They are smooth curves that never touch / cross.
- Strength of magnetic field is indicated by the distance between the lines - closer lines means a stronger field (flux density).







* All magnetic fields are created by moving charges.

→ Current-carrying conductor – e⁻

→ Permanent magnet – magnetic field is produced by the movement of e⁻ within the atoms of the magnet. Each e⁻ represents a tiny current as it circulates around within the atom, & this current sets up a magnetic field.

* Field direction:

1. Right-hand grip rule

a) solenoid

R-H grip rule ⇒

- grip the coil so that your fingers go around it, following the direction of current.
- thumb points in direction of field lines inside the coil. (i.e. towards electromagnet's N-pole).

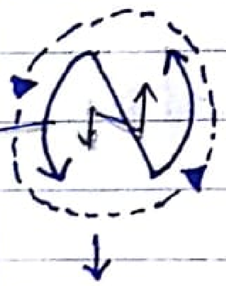
b) current-carrying wire

Right-hand rule ⇒

- grip the wire so that thumb points in direction of current
- Your fingers curl in the direction of the magnetic field.

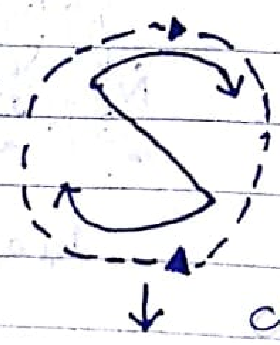
2. End view for solenoid:

direction of current



antichockwise

N pole



clockwise

S pole

* Magnetic forces arises due to the interaction between 2 magnetic fields such as between wire & permanent magnetic.

→ Use Flemming's left-hand rule aka motor rule

→ Production of force is known as the <u>motor effect</u>. because this force is used in electric motors.

→ BIF of which B & I are known.

* Magnetic field strength = magnetic flux density (no. of magnetic field lines passing through a region per unit area.)

→ greater near pole, reduces further away from pole.

→ Flux density : symbol = B
unit = Tesla (T)

→ Flux density is analogous to gravitational & electric field strength. So,

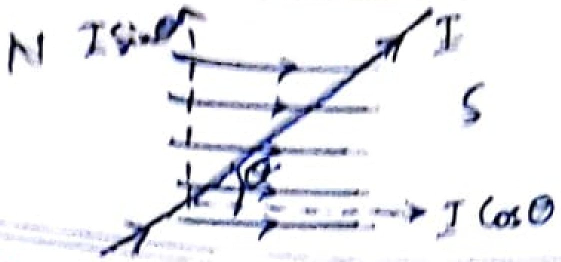
"The magnetic flux density at a point in space is the force experienced per unit length by a long straight conductor carrying unit current and placed at right angles to the field at that point."

$$\boxed{B = \frac{F}{Il}}$$

"The magnetic flux density is 1 T when a wire carrying a current of 1 A placed at right angles to the magnetic field experiences a force of 1 N per metre of its length."

$$\boxed{1\,T = 1\,N\,A^{-1}\,m^{-1}}$$

$T = Wb\,m^{-2}$ (Weber)



$I \sin\theta \perp$ to B

$$B = \frac{F}{I \sin\theta \times l}$$

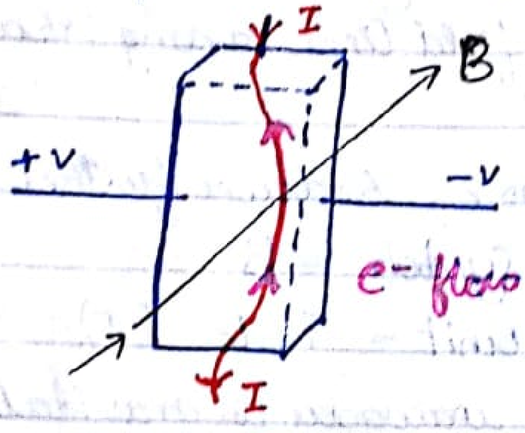
The component of current that is ⊥ to the field is important.

∴ $F = BI\sin\theta\, l$ or $F = B \cdot I \cdot l \cdot \sin\theta$

When $\theta = 90°$ ∴ $\sin\theta = 1$

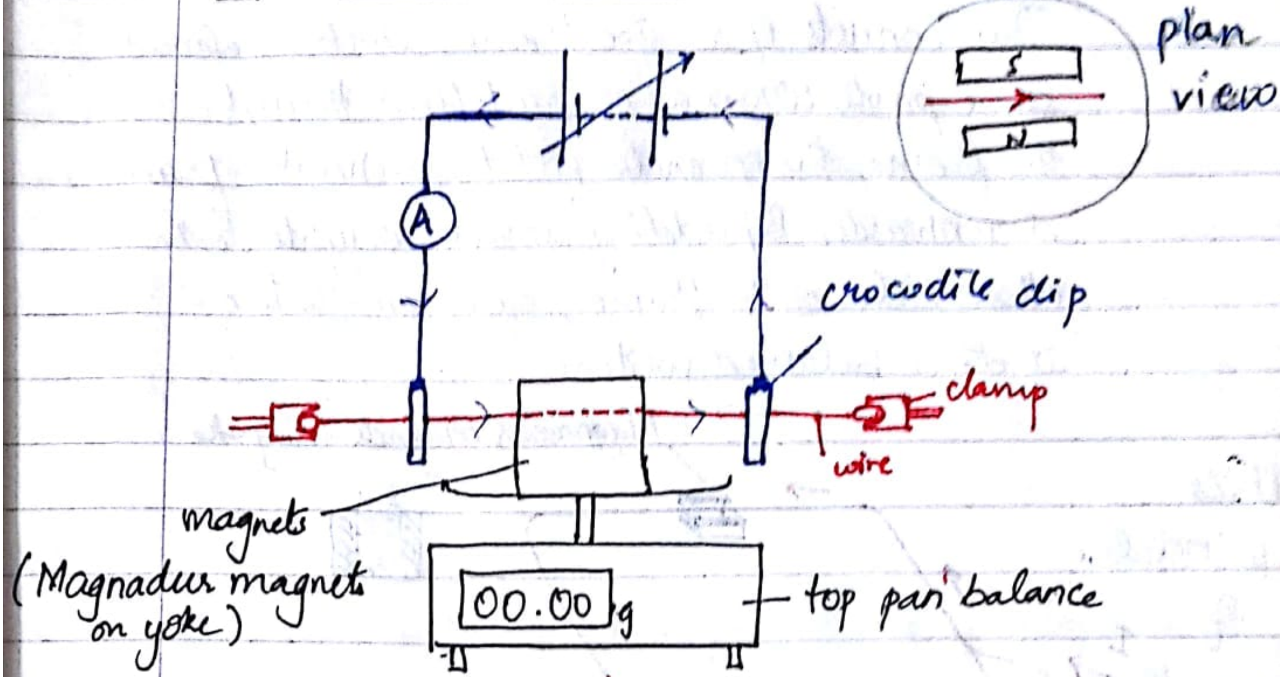
∴ $F = BIl$ when current is ⊥ to field.

* Using Hall probe to measure B:



e− are deflected as they move through the Hall probe ⇒ accumulate on one side ⇒ create small p.d.

THE CURRENT BALANCE [to determine B]



- When there is no current in the wire, the magnet arrangement is placed on the top pan balance & the balance is zeroed.
- Now, when a current I flows in the wire, its value is shown by the ammeter.
- The wire experiences an upward force (FLR) & according the Newton's third law of motion, there is an equal & opposite force on the magnets.
- The magnets are pushed downwards & a reading appears on the scale of the balance. The force $F = mg$ where m is indicated on the balance & $g = 9.81\ ms^{-2}$
- ∴ F, I & l are known. B can be calculated.

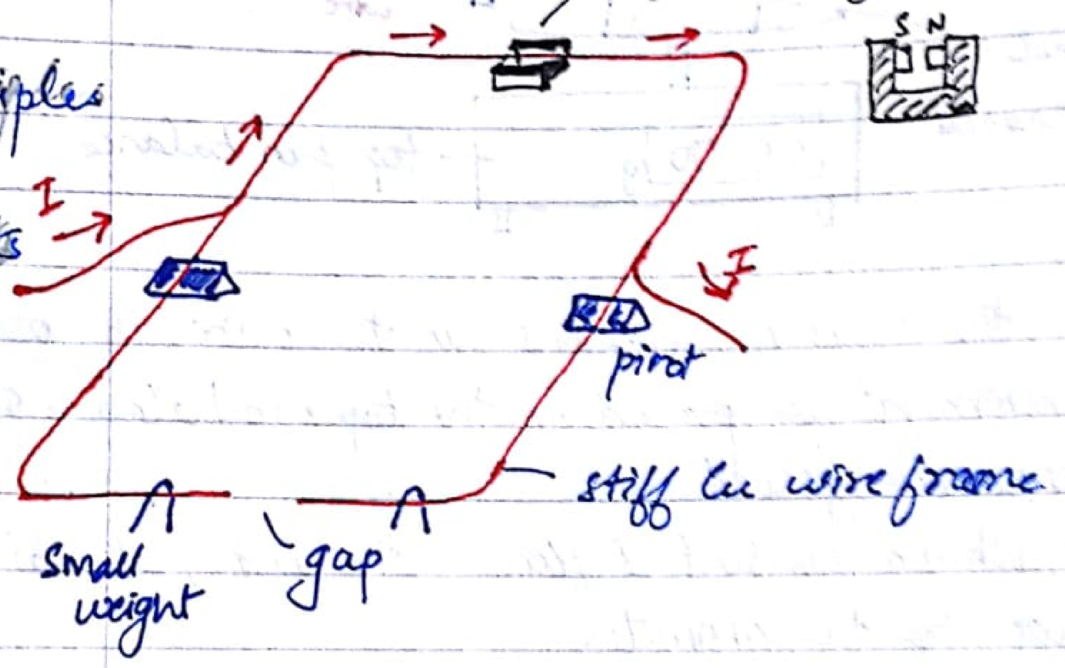
A system like this in effect 'weighs' the force on the current-carrying conductor & is an example of a current balance.

version of current balance

Another ~~method to show~~ $F \propto I$

This consists of a wire frame which is balanced on 2 pivots. When a current flows through the frame, the magnetic field pushes the frame downwards. By adding small weights to the other side of the frame, you can restore it to a balanced position.

Uses principles of moments



$F = B \times I \times l \times \sin\theta$

But $I = \frac{Q}{t}$

$\therefore F = B \times \frac{Q}{t} \times l \times \sin\theta$

But $\frac{l}{t} = \frac{\text{distance}}{\text{time}}$ = speed = velocity = v

$\therefore F = B \times Q \times v \times \sin\theta$

$$\boxed{F = BQv \sin\theta}$$

If there are 'n' charged particles in a length 'l' of the conductor, each carrying a charge 'q', which pass a point in the conductor in time 't', then the current in the conductor is given by

$I = \frac{nq}{t}$ & the speed of charged particle $v = \frac{l}{t}$

$\therefore F = B \frac{nq}{t} l \sin\theta$ & $F = Bnqv \sin\theta$

This force is the force on 'n' charged particles. ∴

The force on a particle of charge q, moving at a speed v at an angle θ to a uniform magnetic field of flux density B is given by

$F = Bqv \sin\theta$

direction of force given by FLHR. Second finger gives direction of conventional current i.e. +ve particles.

∴ direction of finger = direction of velocity.

If particles are −ve (e−), the finger points in the opp. direction to the velocity.

* The field due to a solenoid may be influenced (made stronger) by:

1. Introducing a ferrous core in the centre
2. Increasing the turns of coils of wire
3. Increasing the current

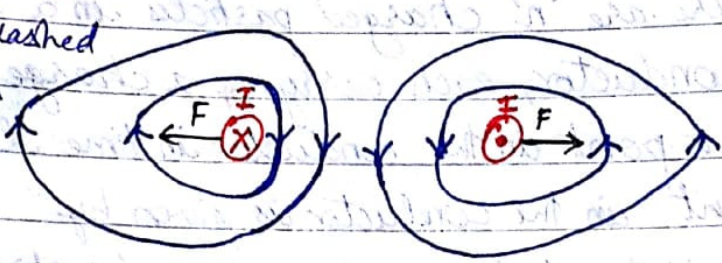
* Forces between current-carrying conductors:

Opposite to magnetic law.

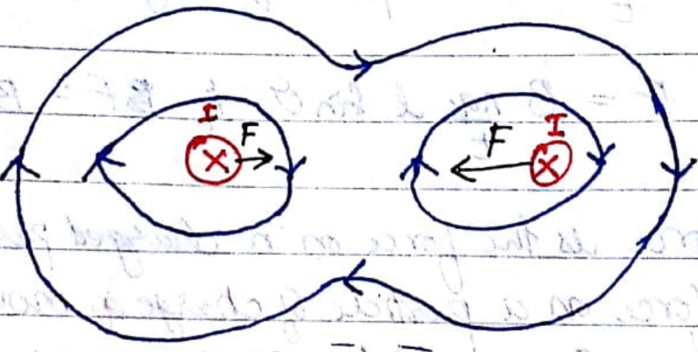
Parallel currents ATTRACT (like attract)

Anti-parallel currents REPEL (unlike repel)

Field lines squashed together ∴ push wires apart. (same direction)

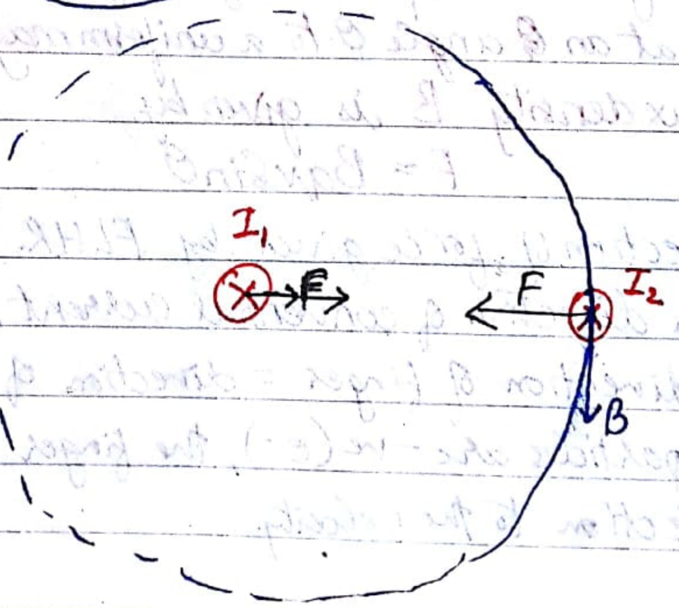


Fields cancel out each other ∴ wires pushed together (opp. direction).



Motor Effect explanation

F & F: action-reaction pair (Newton's 3rd law).



* Comparing the forces on mass, charge & current in gravitational, electric & magnetic fields as appropriate.

1. Gravitational field effect on mass
Because masses always attract each other, a mass placed in a gravitational field will always move in the direction of the field, from a position of higher potential to a lower potential.
For a field produced by a point mass, the field strength obeys an inverse square law relationship and the potential obeys a reciprocal relationship with distance from the source of the field.

2. Electric fields are like gravitational fields in that, for a field produced by a point charge, the field strength is given by the inverse square law & the potential by a reciprocal relationship.
However, we can have both +ve & −ve charges.
A +ve electric charge (like a mass) moves in the direction of the field, from a position of higher potential to a lower potential. But a −ve charge does just the opposite, against the direction of the field & from a low potential to a high potential.

3. Electric charges in a magnetic field.
A stationary charge is unaffected but a moving charge experiences a force ($F = Bqv \sin\theta$). The direction of F is given by FLHR (for +ve charges).

Finally, a current-carrying conductor in a magnetic field does <u>not</u> experience a force is the conductor is parallel to the field direction, but for all other directions it experiences a force given by $F = BIl \sin\theta$. The direction of F is again given by FLHR.

* B around a long, straight wire

Flux density, B (tesla) $\propto$ $\frac{\text{current, I (amperes)}}{\text{distance, r (meters)}}$

OR $B = k\frac{I}{r}$ where k is a constant. It depends on the material round the wire.

If the wire is in vacuum:

$$B = \frac{\mu_0 I}{2\pi r}$$

where μ_0 is a constant called the 'permeability of free space'.

(*) The permeability μ of a material is the measure of its effect on the strength of the magnetic field.
For a vacuum, $\mu_0 = 4\pi \times 10^{-7}$ tesla metre ampere^{-1} (TmA^{-1})

* B inside a solenoid

B is uniform inside the solenoid and:
Magnetic flux density, B (tesla) $\propto$ turns per metre, n $\times$ current, I (amperes)

If the solenoid is in vacuum:

$$B = \mu_0 n I$$