Bismah Noor
Batch-I FSc
@SochbadlobyMAK

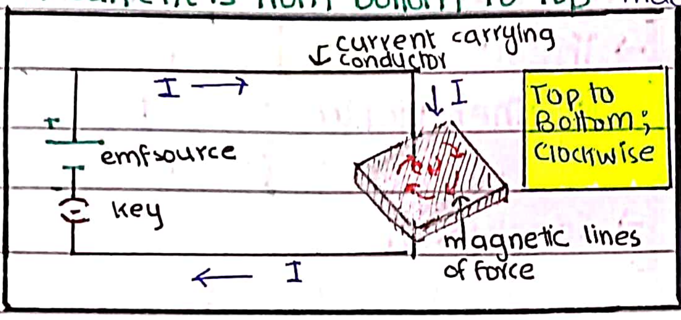
ELECTROMAGNETISM

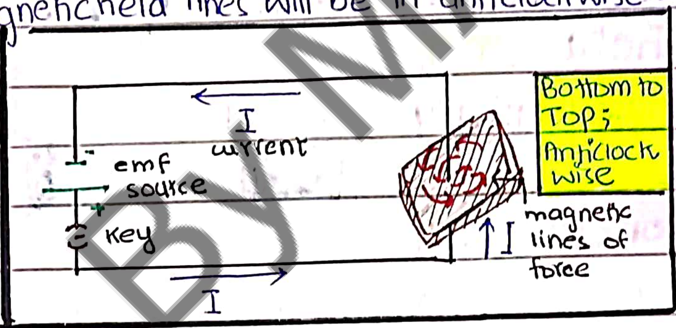
magnetic effect of electric field

Introduction:

Ampere discovered when a current passes through a conductor, it produces a magnetic field around it.

→ If current is from top to bottom magnetic field lines will be in clockwise direction
→ If current is from bottom to top magnetic field lines will be in anticlockwise direction





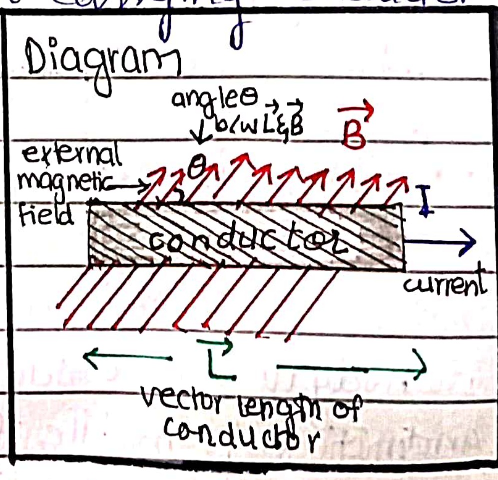
→ Temporary magnet will be made as the current carrying conductor's magnetism is dependent on current.

→ **Right Hand rule:** Put your thumb in the direction of current and curl your fingers around the wire. The curled fingers will show the direction of magnetic field. This is valid for conventional current.

→ For direct current follow the same procedure but with your left hand.

force on a current carrying conductor:

→ **External Magnetic field's effect:** A current carrying conductor acts like a temporary magnet, when it's placed in uniform external magnetic field, it will experience a force F_B.



→ **Factors affecting force F_B:**

- $F_B \propto I$ (current) | $F_B \propto L$ (length) | $F_B \propto B$ (magnetic field)
- $F_B \propto \sin\theta$ (angle between conductor and magnetic field)

Mathematically $F_B \propto ILB\sin\theta$, $F_B = KILB\sin\theta$ $(K=1)$

PKMZ

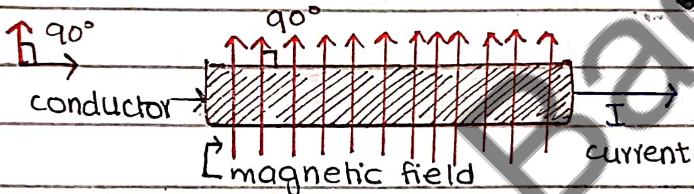
→ **Why do we take 'sin θ'** : We take sinθ for vector product in this specific case, the length of conductor is considered vector. Reason behind this is that if the conductor's position is altered, the system alters aswell thus the position length of conductor is not a scalar. In simpler words we can also say that length is basically displacement which is also a vector. thus,

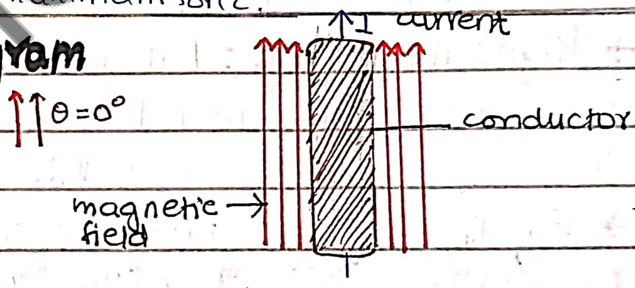
$$\vec{F}_B = I(\vec{L} \times \vec{B})$$

↑ vector ↖↗ vectors

minimum force $\vec{B} \parallel \vec{L}$	**maximum force** $\vec{B} \perp \vec{L}$
→ **Theta** 0° (b/w $\vec{B}$ and $\vec{L}$)	→ **Theta** 90° b/w $\vec{B}$ and $\vec{L}$
→ **Mathematically** $F_B = ILB\sin(0)$ $F_B = ILB(0) = 0 = min$	→ **Mathematically** $F_B = ILB\sin(90)$ $F_B = ILB(1) = max$
→ **Conclusion** when conductor and magnetic field are parallel to each other, conductor will experience minimum force	→ **Conclusion** when conductor and magnetic field are perpendicular to each other, conductor will experience maximum force.

Diagram

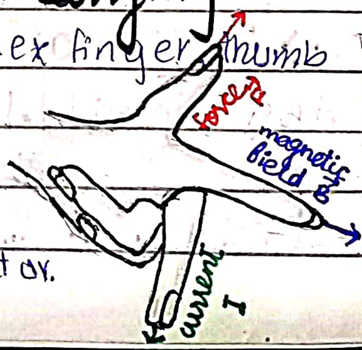




→ **Units for magnetic induction** : As we know that $F_B = ILB$ thus bey re-arranging we get $F/IL = B$ where F = Newton, I = Ampere and L = m thus $1NA^{-1}m^{-1} = B$, $1NA^{-1}m^{-1} = 1Tesla$

$B = 1T = NA^{-1}m^{-1}$ In CGS $1G = 10^{-4}$ Tesla $1T = 1N/Am$

→ **Fleming's left hand rule for the force on current carrying conductor** : Physics Gangster Rule Stretch your index finger, thumb and middle finger mutually perpendicular to each other such that your index finger points in the direction of magnetic field and middle finger in current's direction. This way your thumb will give direction of force on current carrying conductor.



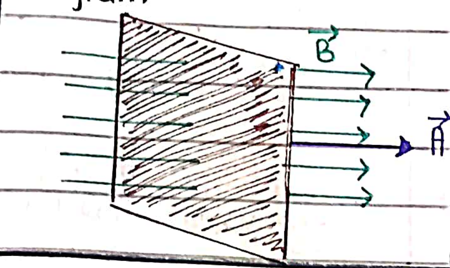
11. Magnetic Flux: "The scalar product of magnetic induction $\vec{B}$ and the area $\vec{A}$ is called magnetic flux ϕ_B".

→ Number of magnetic field lines passing through a surface (vector area) is called magnetic flux

Mathematically $\phi = \vec{B} \cdot \vec{A} = BA\cos\theta$ where θ is some arbitrary angle.

↳ maximum flux — $\vec{A} \parallel \vec{B}$

Diagram



$\phi_B = \vec{A} \cdot \vec{B}\cos\theta$

$\vec{A}$, $\vec{B}$ (parallel), $\theta = 0°$

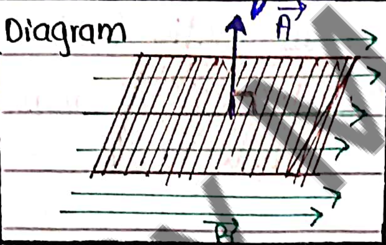
$\phi_B = \vec{A} \cdot \vec{B}\cos(0)$

$\phi_B = AB = max$

Conclusion: When vector area $\vec{A}$ and magnetic field $\vec{B}$ are parallel, $\phi_B = max$

minimum flux — $\vec{A} \perp \vec{B}$

Diagram



$\phi_B = \vec{A}\vec{B}\cos\theta$

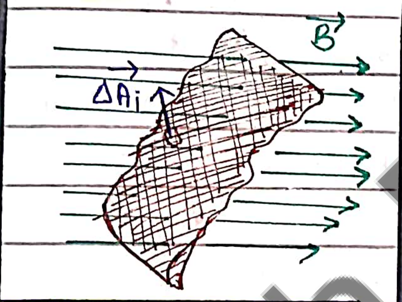
$\vec{A} \perp \vec{B}$, $\theta = 90°$

$\phi_B = AB\cos 90$

$\phi_B = 0 = min$

Conclusion: When vector area $\vec{A}$ and magnetic field $\vec{B}$ are perp. $\phi_B = min$

magnetic flux through curved or non uniform magnetic f



$\phi_B = \sum_{i=1}^{n} B_i \Delta A_i \cos\theta$

Suppose that the area is curved thus magnetic field will not be uniform. In this case divide the vector area in many small patches i.e., $\Delta\vec{A}_i$ such that magnetic field becomes uniform.

For one of these small patches, $\phi_B = \vec{B} \cdot \Delta\vec{A}_i = B\Delta A_i\cos\theta$

To calculate flux through whole surface, we add the flux from each patch

$\phi_B = \sum_{i=1}^{n} \Delta\phi_B = \sum \vec{B}_i \cdot \Delta\vec{A}_i = \sum_{i=1}^{n} B_i \Delta A_i \cos\theta$ $\quad \phi_B = B\cos\theta \sum \Delta A$

→ **flux density:** Amount of magnetic flux passing through vector area.

→ **unit** SI unit of magnetic flux density is Tesla or Wbm^{-2}

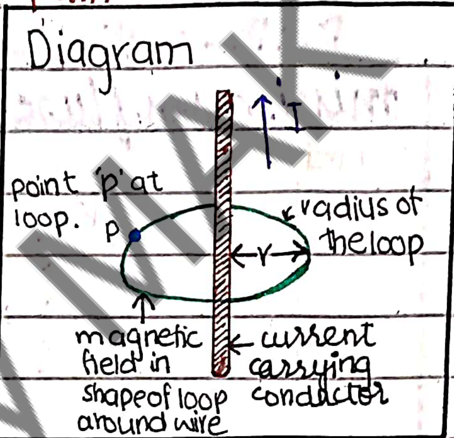
SI unit of magnetic flux is **weber (Wb)**. When magnetic induction of 1 Tesla passes through area of $1m^2$, the magnetic flux is 1 Weber.

$1Wb = 1Tm^2$
$1Wb = 1NA^{-1}m^{-1}m^2$
$1Wb = 1NA^{-1}m$

Tesla = $1N / 1A : 1m$, $1 Tesla = 1NA^{-1}m^{-1}$

4) Ampere Circuital Law:

"Ampere's circuital law states that for any closed loop the sum of the length elements multiplied by the component of magnetic field parallel to each element is proportional to the current enclosed by the path"



→ **Magnetic field around conductor:** Magnetic field is in the shape of loop around current.

→ **Factors affecting magnetic field of current:**

- $\uparrow B \propto I \uparrow$ More the current, more the strength of B
- $\uparrow B \propto 1/r \downarrow$ More the radius of the loop, mor will be the strength of magnetic field i.e., near the conductor magnetic field will be strong, radially far away from conductor, magnetic field will be weak.

→ **length elements of circumference of loop:** The whole loop is composed of small length elements ΔL, all these length elements together give the whole loop $\Sigma \Delta L$. As the loop is circular, $\Sigma \Delta L = 2\pi r$

Mathematically

$$B = \frac{\mu_0}{2\pi} \times \frac{1}{r} \times I \quad ①$$

where $\frac{\mu_0}{2\pi}$ = constant of proportionality

$$\Sigma \Delta L = 2\pi r \quad ②$$

where $2\pi r$ = circumference.

multiplying ① and ②

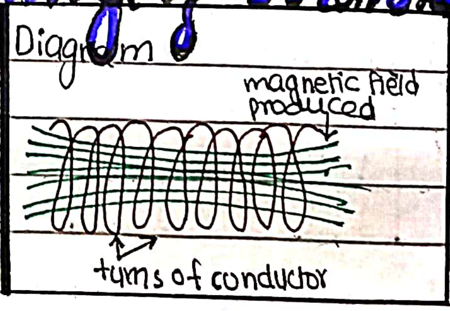
$$\Sigma B \cdot \Delta L = B \Sigma \Delta L = \frac{\mu_0}{2\pi r} \times 2\pi r$$

$$\Sigma B \cdot \Delta L = \mu_0 I$$

→ **permeability 'μ':** Permeability refers to the ability of a substance to allow another substance pass through it. permeability of vacuum $\mu_0 = 4\pi \times 10^{-7}\ Wb/At.m$ (webers/ampere turn meter) relative permeability $\mu_r = \mu/\mu_0$

4) Magnetic field due to current carrying solenoid

"A coil wounded in the form of a spiral helix forms a solenoid"



→ **Factors affecting strength of magnetic field for solenoid:**

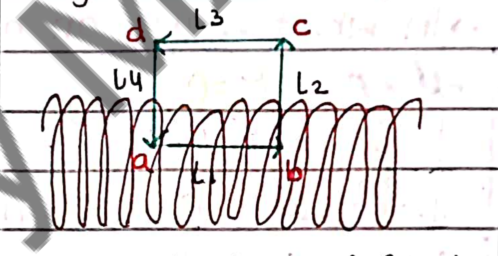
- Number of turns $\propto$ current $\propto$ strength of magnetic field
- Spacing between loops $\propto$ 1/magnetic field strength.

- Inside the solenoid field is very strong and uniform
- More close the turns of solenoid, more uniform the magnetic field will be.

→ **Ideal solenoid :** Ideal solenoid is achieved when the turns are closely packed and length of solenoid is much greater than the radius of the turns. In this case external field around solenoid is zero and internal field is very uniform and strong.

→ applying Ampère's law:

Diagram



▲ Magnetic field of ideal solenoid

consider the amperian path or loop a-b-c-d-a with lengths l_1, l_2, l_4, l_3 where l_1 is inside solenoid and l_3 is outside.

- Total length elements = 4

Mathematically $\Sigma B \cdot \Delta l = \mu_0 I$

since there are 4 length elements thus

$B \cdot L_1 + B \cdot L_2 + B \cdot L_3 + B \cdot L_4 = \mu_0 I$

or $BL_1 \cos\theta_1 + BL_2 \cos\theta_2 + BL_3 \cos\theta_3 + BL_4 \cos\theta_4 = \mu_0 I$

$BL_1 \cos 0 + BL_2 \cos 90 + BL_3 \cos 180 + BL_4 \cos 270° = \mu_0 I$

where $\cos 90 = 0$, $\cos 270 = 0$ and B for $l_3 = 0$ (since it's outside)

thus $BL_1 + 0 + 0 + 0 = \mu_0$ or $BL = \mu_0 I$

→ loop angles

L1 → B	$\theta = 0°$
L2 ↑ B	$\theta = 90°$
L3 ← B	$\theta = 180°$
270° L4 ↓ B	$\theta = 270°$

For 'N' number of turns in solenoid, $BL = N\mu_0 I$ or $B = \frac{N}{l}\mu_0 I$

where number of turns per unit length is called N/l

$B = N/l \, \mu_0 I$ implies that as number of turns per unit length increase, 'B' increases

→ **right hand rule for solenoid :** curl your fingers in direction of current around the coil, extended thumb will point in North pole's direction of magnet. This is for elec. current, for electronic current use left hand. side opposite to thumb will be south pole.

↳ Motion of Charged Particle in magnetic field:

External forces acting on current carrying conductor are in actual those which act on individual charge particles which may cause the particles to deviate from their path. The charge particle may or may not be restricted to a conductor but it will experience a force in both cases.

A. → magnetic force on a point charge:

→ under what conditions will external magnetic field affect a charge?

- When the charge is moving ('static charges don't produce magnetic field and hence won't be affected by external magnetic field)
- when angle between velocity and magnetic field is not 0.

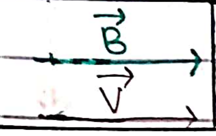
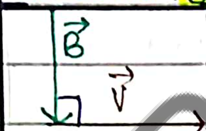
Mathematically

$$\vec{F_B} = q(\vec{v} \times \vec{B})$$

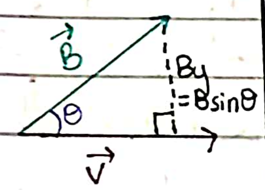
- $\vec{B}$ → strength of magnetic field
- q → magnitude of charge
- $\vec{v}$ → velocity of moving charge $\propto F_B$

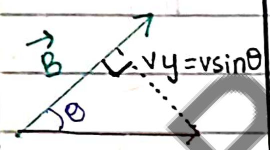
{PKM2}

→ In what ways can angle between $\vec{v}$ and $\vec{B}$ effect the $\vec{F_B}$?

when $\theta = 0°$	when $\theta = 90°$
 $F_B = qVB\sin\theta$, $\sin 0° = 0$; $F_B = 0$ = minimum	 $F_B = qVB\sin\theta$, $\sin 90° = 1$; $F_B = qVB$ = maximum
• Conclusion: When velocity of charge particle is parallel to magnetic field, the magnetic force will be minimum	• Conclusion: When velocity of charge particle is perpendicular to magnetic field, the magnetic force will be maximum

when $0 < \theta < 90°$





$$\vec{F_B} = q(\vec{v} \times \vec{B})$$
$$F_B = qVB\sin\theta$$
$$F_B = qBV\sin\theta$$

as force is a vector quantity thus on the other side of equation cross product needs to be taken. It doesn't matter wether '$\sin\theta$' is considered in terms of $\vec{v}$ or $\vec{B}$.

B. → the force on current carrying conductor and motion of charge particle in magnetic field:

- When charge is dependent on conductor, The force F_B is given by $F_B = BIL\sin\theta$
- When moving charge particle is not dependent on conductor, force F_B is given by $F_B = qVB\sin\theta$

Mathematically $F_B = BIL\sin\theta$

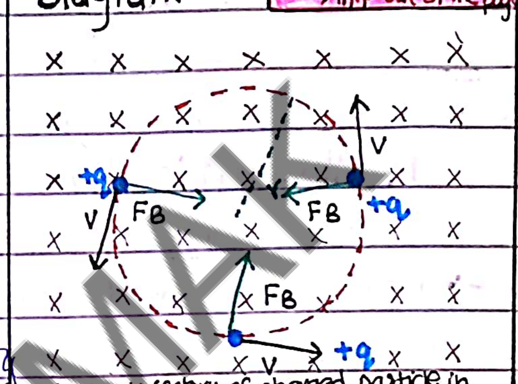
where $I = Nq/t$ (for N number of charge particles) and $L = v \times t$ $(v = L/t)$

Thus $F_B = B\,\frac{Nq}{t} \times v \times t$, $F_B = BNqv\sin\theta$

For single particle	$N = 1$	$F_B = Bqv\sin\theta$	or	$\vec{F_B} = qVB\sin\theta\,\hat{n}$
For N particles		$F_B = NBqV\sin\theta$	or	$\vec{F_B} = NqVB\sin\theta\,\hat{n}$

c. → circular motion of charge particle in uniform magnetic field :

Diagram



circular trajectory of charged particle in magnetic field.

→ **When does a charged particle revolve in uniform magnetic field?** When magnetic field and velocity of charged particle are perpendicular to each other, the magnetic field will constantly pull upon the charge from it's otherwise straight path. The constantly changing direction of charged particle causes it to move in a circle.

→ **What provides the centripetal force FB?** $\vec{F_B}$, $\vec{B}$ and $\vec{v}$ should be mutually perpendicular to each other. Primarily $\vec{B}$ being perpendicular to $\vec{v}$ provides centripetal force $\vec{F_B}$.

→ **Direction of revolution with respect to charge:** Positive charge will perform circular motion in anticlockwise direction while for -ve charge, direction will be clockwise.

Mathematically Fc (centripetal force) = FB (magnetic force) ①

$F_c = mv^2/r$ ② , $F_B = qvB$ ③

putting ② and ③ in eq ① $mv^2/r = qvB$ where $v = r\omega$

$m(r\omega)/r = qB$

angular velocity → $\omega = \frac{qB}{m}$

frequency = $\omega/2\pi$ putting value of frequency

angular frequency → $f = qB/m2\pi$

Time period = $1/f$ thus equation becomes

time period → $T = \frac{2\pi m}{qB}$

→ **cyclotron:** cyclotron is a machine that accelerates charged particles or ions to high energies.

D. → Determination of charge to mass ratio for an electron:

→ **What does charge to mass ratio tell us?** Charge to mass ratio i.e., 'q_e/m_e' tells us about how much charge is contained by a certain mass of electrons. Where q_e = charge of $\bar{e}$, m_e = mass of $\bar{e}$.

mathematically we know that $F_c = F_B$ or $\frac{m_e v^2}{r} = q_e v B$

$m_e v/r = q_e B$ rearranging $q_e/m_e = v/Br$ ①

→ here value of 'B' can be easily determined from apparatus. The radius of revolving charge can be calculated by making the revolving electrons glow, making a visible circle.

→ **How to determine velocity 'v'?** According to Heisenberg's uncertainty principle, both velocity and position of charge particle can not be determined simultaneously thus we will substitute velocity for another factor equal to it.

mathematically Potential 'V' is applied to make $\bar{e}$ enter the magnetic field. The potential energy will be converted into kinetic energy which will inturn provide $\bar{e}$ with velocity v. thus $K.E = q_e V$ or $\frac{1}{2} m_e v^2 = q_e V$

$v^2 = 2 q_e V / m_e$, $v = \sqrt{2 q_e V / m_e}$ ② putting value of 'v' from ② in ①.

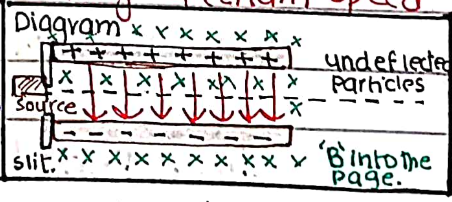
$\frac{q_e}{m_e} = \frac{1}{Br}\sqrt{\frac{2 q_e V}{m_e}}$ squaring b.s $\left(\frac{q_e}{m_e}\right)^2 = \frac{2V}{B^2 r^2}\left(\frac{q_e}{m_e}\right)$

$$\frac{q_e}{m_e} = \frac{2V}{B^2 r^2}$$

→ **Conclusion:** we know all factors of R.H.S. Thus we get the value of e/m which is $1.7588 \times 10^{11}\ C\,kg^{-1}$

E. → Velocity Selector:

"Device which permits particles having a certain speed through it is called velocity selector."



→ **Adjusting magnetic and electric fields:** If both fields are applied ⊥ to each other such that they have equal magnitudes but opposite directions the particle will be permitted through the apparatus.

Mathematically $F_{electric} = F_{magnetic}$, $qE = qvB$ $v = E/B$

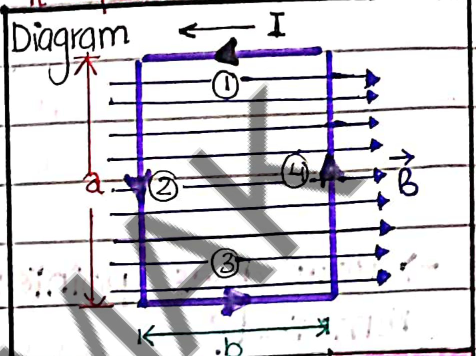
→ **Particles having 'v' slower than E/B:** will be deflected in $F_{electric}$'s direction.

→ **Particles having 'v' greater than E/B:** will be deflected in $F_{magnetic}$'s direction.

→ **Particles having 'v' equal to E/B:** will pass straight through velocity selector.

↳ Torque on a Current Carrying Coil:

"When a current carrying loop or coil is placed in uniform magnetic field it experiences a force, this force can exert torque on the coil or loop of wire."



→ **Magnetic Force on sides of loop:** [where θ is b/w Length 'L' and $\vec{B}$]

Side 1	Side 2	Side 3	Side 4
$F_1 = BIb\sin\theta_1$	$F_2 = BIa\sin\theta_2$	$F_3 = BIb\sin\theta_3$	$F_4 = BIa\sin\theta_4$
$F_1 = BIb\sin 180$	$F_2 = BIa\sin 90$	$F_3 = BIb\sin 0°$	$F_4 = BIa\sin 90°$
$F_1 = 0$	$F_2 = BIa$	$F_3 = 0$	$F_4 = BIa$

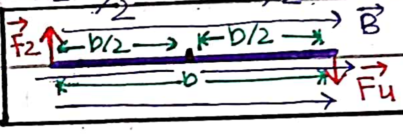
θ_1	180°	θ_4	90°
θ_3	0°	θ_2	90°

→ **Direction of force on '2' and '4' sides:** By applying fleming's left hand rule, we get to know that $\vec{F_2}$ and $\vec{F_4}$ separated by a length 'b' are equal in magnitude but opposite in direction. F_2 is out of page whereas F_4 is into the page.

→ **What will cause the coil to rotate?** $\vec{F_2}$ and $\vec{F_4}$ produce a couple. net torque of this couple rotates the coil.

Mathematically magnitude of torque of couple $\tau = F_2\frac{b}{2} + F_4\frac{b}{2}$

where values of F_2 and F_4 are, $\tau = IBa\,b/2 + IBa\,b/2$



$\tau = 2IBa\frac{b}{2}$ $\tau = IBab$ where $a \times b$ = Area of coil

$\tau = IBA$
$\tau = NIAB$ } maximum torque when θ = 90°

$\tau = NIAB\sin\theta$ } Torque at arbitrary angle θ

→ **Factors affecting torque on loop:**

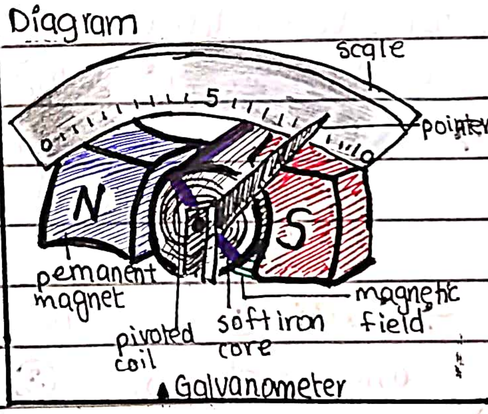
$\tau = N\ I\ A\ B\ \sin\theta$

N: number of turns of coil; I: magnitude of current; A: area of coil; B: magnitude of m.f; θ: angle between coil and magnetic field

→ **Minimum and Maximum torque angles:** $\theta_{max\,torque} = 90°$ $\theta_{min\,\tau} = 0/180°$

↳ Galvanometer:

"A device used for detection and measurement of small electric currents is called galvanometer."



→ **Working Principle:** Principle of moving coil galvanometer is the torque on current carrying conductor coil in the magnetic field.

→ **Construction:** A pivoted coil wrapped around soft iron core is placed in concave poles of permanent magnet. A light pointer is used to measure angular displacement which is placed on a calibrated scale. The poles are made concave because this provides a strong and radial magnetic field making magnetic force perpendicular and producing maximum torque. Iron core is made soft because this helps to concentrate magnetic field giving more inertia to coil.

→ **How does pointer retain rest position after current is removed?** The coil is connected to a spring which provides restoring torque for the pointer to attain back its rest point.

→ As pointer moves away from zero, restoring force goes on increasing because angular displacement is increasing.

→ We can also say that greater the current greater will be; angular displacement, distance of pointer from zero and restoring force

Mathematically $\vec{\tau}_{mag} + (-\vec{\tau}_{res}) = \vec{\tau}_{net}$

at equilibrium when pointer is at rest, $\vec{\tau}_{mag} = \vec{\tau}_{res}$.

where $\vec{\tau}_{mag} = NIAB$ and $\vec{\tau}_{res} = C\varphi$ ($\vec{\tau}_{res}$ depends on angular displacement)

eq. ① becomes: $NIAB = C\varphi$ or $I = \frac{C\varphi}{NAB}$, $I \propto \varphi$

→ **Sensitivity of galvanometer:** small current causes large angular displacement thus $I \propto \varphi$ tells us that this device is used to detect very small current values.

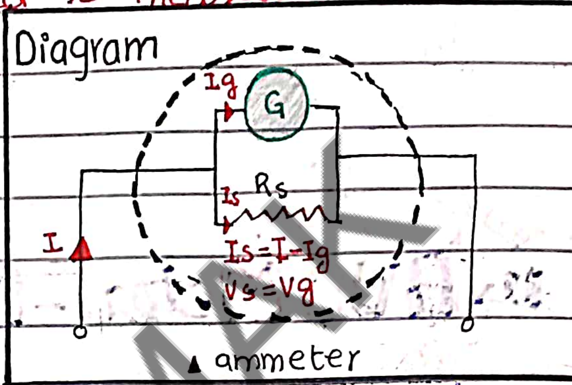
→ **What happens if current is very large?** Very large current will cause very large angular displacement which will not be supported by the spring of the device. Thus it may make the device out of order

→ If torque greater than threshold value is produced, the spring will break thus needle will not come back to zero as not restoring force is available.

→ **Uses** ① To measure small amount of current. ② To detect small amount of current ③ To determine wether two points in a circuit are at same potential or not.

A. → Conversion of galvanometer into ammeter:

"An ammeter is a measuring instrument used to measure electric current in the circuit."



→ Drawback of a galvanometer: in presence of large current, galvanometer will show full scale deflection. It will indicate the current but not measure it.

→ How to convert it into ammeter? Connect a low (shunt) resistance in **parallel** with galvanometer to convert it into ammeter.

→ Why are galvanometer and ammeter connected in parallel? In parallel combination unequal distribution of current takes place. Current takes that path prefferiably which offers less resistance. Thus more current flows through Rs (shunt resistance) and less flows through Rg (galvanometer resistance) as $R_s << R_g$. This whole apparatus is ammeter which will show full scale deflection measuring the current correctly.

→ Connection of ammeter in circuit: Ammeter is always connected in **series** as in series connection current is not divided.

Mathematically: In parallel combination $V_s = V_g$

Applying ohm's law → $I_s R_s = I_g R_g$

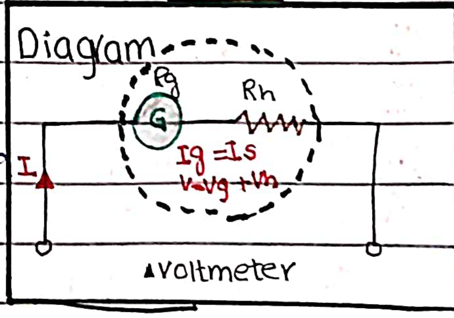
$R_s = \frac{I_g R_g}{I_s}$ Total current through ammeter $I = I_g + I_s$ or $I_s = I - I_g$

$$R_s = \frac{I_g R_g}{I - I_g}$$

B. → Conversion of galvanometer into voltmeter:

"Voltmeter is a measuring instrument used to measure potential difference in the circuit."

→ How to convert? Connect a high resistance 'Rh' in **series** with the galvanometer.



→ Connection of voltmeter in circuit: Voltmeter should be connected in parallel across load resistance. This is because in **parallel** combination, **voltage** remains same.

Mathematically:

$I_g = I_R$

Resistance of galvanometer = R_g

current = I_g (same through R_h and G)

Applying ohm's law

$V = I_g R$ where $R = R_g + R_h$

$V = I_g(R_h + R_g)$

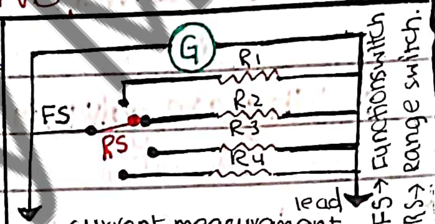
$V = I_g R_h + I_g R_g$ or $R_h = \frac{V}{I_g} - R_g$

AVO Meter - Multimeter:

(Ampere, Volt, Ohm)

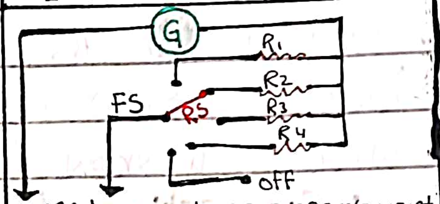
"A single device which can measure current, voltage and resistance is called AVO"

A. → Current Measurement: This circuit contains resistors R_1, R_2 etc connected in parallel across -G-. Any shunt can be used to measure current without making excessive current to flow through -G-



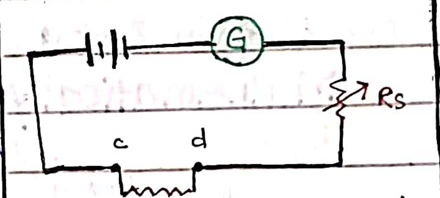
▲ current measurement

B. → Voltage Measurement: This part of AVO meter consists of number of resistances connected in series with galvanometer. These series resistances are called multipliers.



▲ voltage measurement

C. → Resistance Measurement: Circuit contains -G- connected with variable resistance in series. leads are connected to the resistance which is to be measured. The amount of current through -G- now depends upon external resistance.



▲ resistance measurement

Digital Multimeter:

"It is an electronic instrument which is used to measure current, resistance and voltage in a circuit."

→ **Important features of a multimeter (digital) DMM:**

(i) It is a digital version of AVOmeter

(ii) It is a very accurate device

(iii) It is very easy to operate

(iv) It is much easy to read

(v) It removes reading error parallax

(vi) It shows the digital values with decimal point, polarity and the unit of V, A or Ω