20/7/16

Magnetic Field & Its Effect

Physical quantities		Symbol
Pole Strength	–	m
Length	–	l
Magnetic field	–	B (vector)
Magnetic flux	–	ϕ
Energy	–	E
Inductance	–	L
Resistance	–	R
force	–	F (vector)
Current	–	I

Magnetic field in the Sense of Magnet —

- In the sense of magnet the space around a magnet when iron like material comes in field it feels an attractive force.

Magnetic field in the sense of current —

- When the current passing through a conductor a field is develop around it when an another conducting wire is place it feels a magnetic force this field is

known as magnetic field of a conducting wire.
Its unit is Tesla or weber/m^2

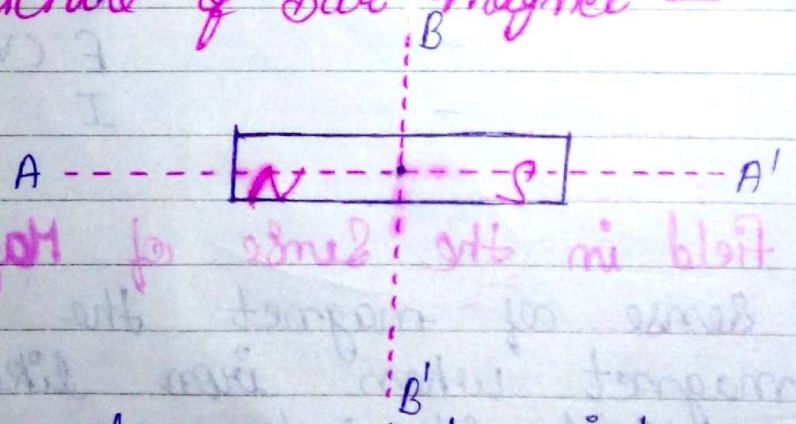
✯ Magnetic lines of force —

- The imaginary closed curve originate from north pole and ending at South pole. Any tangent at that curve shows the direction of magnetic field.
- **Properties —**

(i) It start from North externaly.
(ii) It Start from South internaly.
(iii) It is a close curve.

✯ Magnetic field due to a bar magnet —

(i) Structure of Bar magnet —



The poles are that point where the max. attraction of force exists.
North pole are generally +ve and South pole are generally -ve.

✯ Magnetic lines of force —

- **Properties —**

(iv) They never intersect each other.

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(v) Place where force field is strong the density of field lines is more while at the place of weak field lines force is not strong.

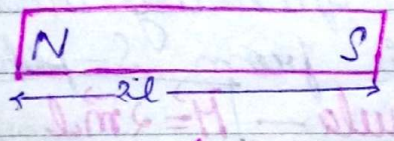
(vi) They can enter in North pole from any angle and can come out from South pole from angle.

(2) Pole strength — The strength of the attraction of the poles of the magnet is called pole strength.

- It is a Scalar quantity.
- Its unit is Ampere Metre.

(3) Geometrical length or Actual length of the magnet —

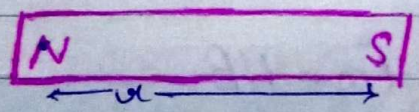
- The distance between the two opposite ends of a magnet is called the magnetic length of the magnet.



(4) Magnetic / effective length →

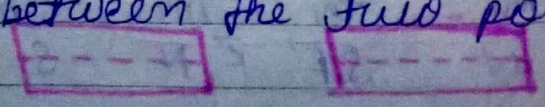
The distance between the two poles of a magnet is called Magnetic / effective length.

Magnetic length is $\frac{5}{6}$ of Geometrical length



(5) Axial line

The distance between the two poles of a magnet is called



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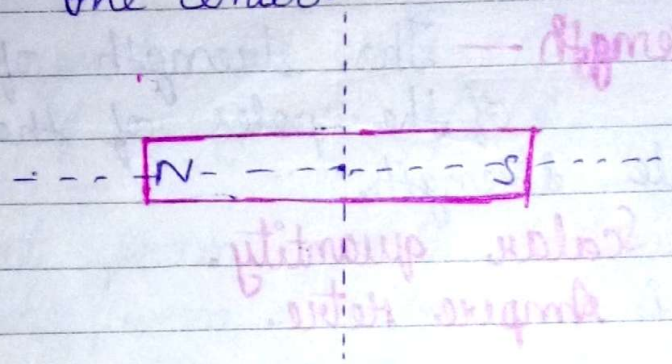
(5) Axial line —

- The line passing through the poles of a magnet is called axial line and we can also say that the line passing through the centre.
- The line perpendicular to the axis and passing through the center.



Magnetic dipole moment —

- The product of the strength of the either pole and effective length is called dipole moment.
- It is a vector quantity and denoted by $\vec{M}$.
- Its direction is from S-pole to N-pole.

formula — $\boxed{\vec{M} = 2\vec{m}l}$

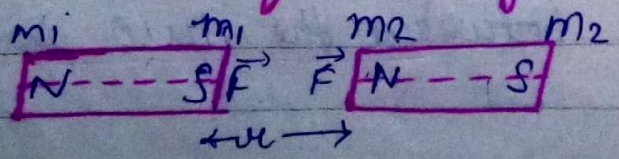
unit → Ampere m²

Dimension → $[L^2 T^0 A^1]$

Relation between Magnetic field and Magnetic force →

$$\boxed{F_m = MB}$$

Coloumb's law for Magnetic field —



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According to this law attractive or repulsion force between two magnetic poles is proportional to the square of the distance between them.

If the pole strength are m_1 and m_2 and distance between them is r the force betw. them.

$$f \propto m_1 m_2 \quad \text{—(A)}$$

$$f \propto \frac{1}{r^2} \quad \text{—(B)}$$

Therefore, $f \propto \frac{m_1 m_2}{r^2}$ —(C) [from (A) & (B)]

$$f = K \frac{m_1 m_2}{r^2}$$

$$f = \frac{\mu_0}{4\pi} \frac{m_1 m_2}{r^2}$$

but, $f = mB$

$$mB = \frac{\mu_0}{4\pi} \frac{m_1 m_2}{r^2}$$

assumption $\longrightarrow M = 1$

$$B = \frac{\mu_0}{4\pi} \frac{m_1 m_2}{r^2}$$

★ Magnetic field due to a bar magnet at an axial point —

If magnetic moment of a bar magnet is M then at a point P which is at r distance from its mid point, magnetic field can be determined as follows →

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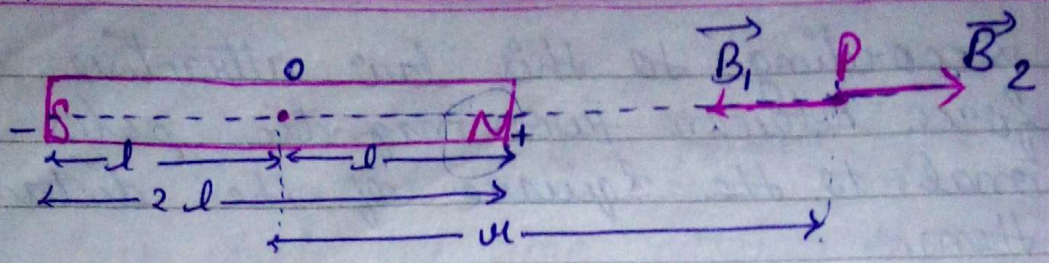

If magnetic field at point P due to S & N pole are $\vec{B_1}$ and $\vec{B_2}$ respectively.
Then,

$$\vec{B_1} = \frac{\mu_0}{4\pi}\frac{m}{(r+l)^2} \quad \text{—— (A)}$$

$$\vec{B_2} = \frac{\mu_0}{4\pi}\frac{m}{(r-l)^2} \quad \text{—— (B)}$$

Resultant, magnetic field at point P.

$$B = B_2 - B_1 \quad \text{—— (C)}$$

by eq^n (A) (B) & (C)

$$B = \frac{\mu_0}{4\pi}\frac{m}{(r-l)^2} - \frac{\mu_0}{4\pi}\frac{m}{(r+l)^2}$$

$$B = \frac{\mu_0}{4\pi} m \left[\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2}\right]$$

$$B = \frac{\mu_0 m}{4\pi}\left[\frac{\cancel{r^2} + \cancel{l^2} + 2rl - \cancel{r^2} - \cancel{l^2} + 2rl}{(r^2-l^2)^2}\right]$$

$$B = \frac{\mu_0 m}{4\pi}\left[\frac{4rl}{r^4}\right]$$

$$= \frac{\mu_0}{4\pi}\frac{2ml}{r^3}$$

$$\boxed{B = \frac{\mu_0}{4\pi}\frac{2M}{r^3}} \quad \text{—— (i)}$$

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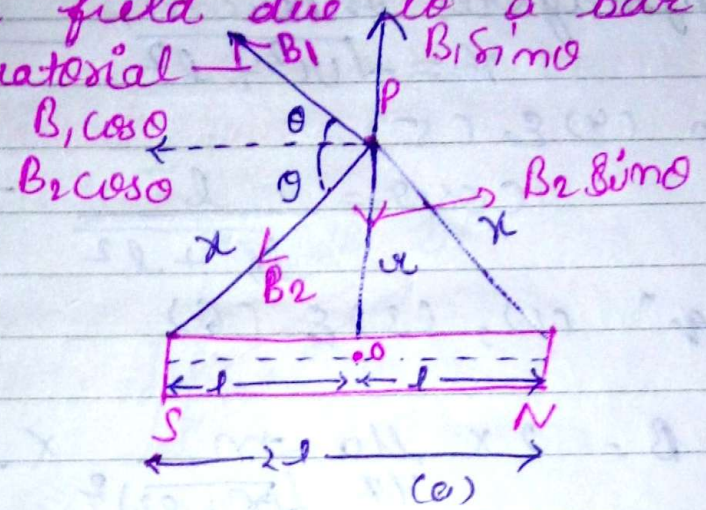
In Vector Notation —

$$\vec{B} = \frac{\mu_0}{4\pi} \frac{2\vec{M}}{r^3}$$

* Magnetic field due to a bar magnet at an equatorial —



Let us consider a bar magnet NS of length 2l and pole strength m. Suppose the magnetic field is to be determined at point P lying on the equatorial of the magnet NS at a distance r from its centre, as shown in fig (a). Let distance betw. PN & PS is x.

force exert on point P from N pole is B_1

$$B_1 = \frac{\mu_0}{4\pi} \frac{m}{x^2} \quad \text{—— (1)}$$

force exert on point P from S pole is B_2

$$B_2 = \frac{\mu_0}{4\pi} \frac{m}{x^2} \quad \text{—— (2)}$$

As the vertical components get cancelled $B_1 \sin\theta$ and $B_2 \sin\theta$ equal and opposite in direction, whereas horizontal components add up.

$$B = B_1 \cos\theta + B_2 \cos\theta$$

from eqn (1) & (2) $B_1 = B_2$

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$$B = 2B_1 \cos\theta \quad \text{——} \quad (3)$$

Now,

$$\cos\theta = \frac{l}{x} \quad \text{——} \quad (4)$$

from pythagores theorem,

$$x = \sqrt{r^2 + l^2} \quad \text{——} \quad (5)$$

from (4) & (5)

$$\cos\theta = \frac{l}{\sqrt{r^2 + l^2}} \quad \text{——} \quad (6)$$

from eq^n (1), (3) & (6)

$$B = 2 \times \frac{\mu_0}{4\pi} \frac{m}{(\sqrt{r^2 + l^2})^2} \times \frac{l}{\sqrt{r^2 + l^2}}$$

$$B = 2 \frac{\mu_0}{4\pi} \frac{m \quad l}{(r^2 + l^2)(r^2 + l^2)^{1/2}}$$

$$B = 2 \frac{\mu_0}{4\pi} \frac{ml}{(r^2 + l^2)^{3/2}}$$

As per the condition,

$$r >> l$$

So,

$$B = \frac{\mu_0}{4\pi} \frac{2ml}{(r^2)^{3/2}}$$

$$B = \frac{\mu_0}{4\pi} \frac{2ml}{r^3}$$

We know that, $2ml = M$

$$\boxed{B = \frac{\mu_0}{4\pi} \frac{M}{r^3}} \quad \text{——} \quad (ii)$$

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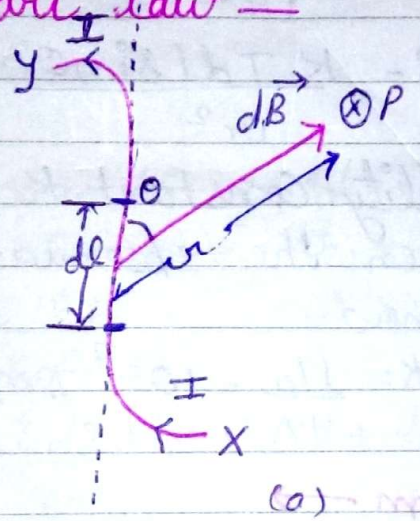
→ On comparing (i) & (ii), we note that the magnetic field at a point at a certain distance on the axial line of short magnet is twice of that at the same distance on its equatorial line.

✡ Biot - Savart law —



(a)

As shown in fig (a), consider a current carrying wire xy. A current element $d\vec{l}$ of a conductor xy carrying current I.
Let P be the point where the magnetic field $d\vec{B}$ due to the current element $d\vec{l}$ is to be calculated.
Let the position vector of point P relative to element $d\vec{l}$ be $\vec{r}$.
Let θ be the angle between $d\vec{l}$ and $\vec{r}$.
Now, Acc. to Biot Savart law, the magnitude of the field $\boxed{d\vec{B}}$ is

1. directly proportional to the current I through the conductor. $dB \propto I$ —— (1)
2. directly proportional to the length dl of the current element, $dB \propto dl$ —— (2)
3. directly proportional to angle $\sin\theta$.
$dB \propto \sin\theta$ —— (3)

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4. Inversly proportional to the Square of the distance 'r' of the point 'P' from the current element. $dB \propto \frac{1}{r^2}$ — (4)

Then, from eq^n (1), (2), (3) & (4)

$$dB \propto \frac{I\,dl \sin\theta}{r^2}$$

or

$$dB = \frac{K\,I\,dl \sin\theta}{r^2}$$

The proportionality Constant K depends on the medium between the observation point P and the current element.

Here, $K = \frac{\mu_0}{4\pi} = 10^{-7}\ T.m.A^{-1}$ (or $wbm^{-1}A^{-1}$)

In vecter form →

As we know that $\hat{r} = \frac{\vec{r}}{|\vec{r}|}$

So, $dB = \frac{\mu_0}{4\pi} \frac{I\,dl \sin\theta}{r^2} \hat{r}$

$$dB = \frac{\mu_0}{4\pi} \frac{I\,r\,dl \sin\theta}{r^3}$$

$$\vec{dB} = \frac{\mu_0 I}{4\pi} \frac{\vec{dl} \times \vec{r}}{r^3}$$

There are Some special cases →

(i) when, $\theta = 90°$

So, $dB = \frac{\mu_0}{4\pi} \frac{I\,dl \sin 90}{r^2}$ [$\sin 90° = 1$]

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{I\,dl}{r^2}$$

In this case dB is max.

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It means the magnetic field due to a current element is maximum in a plane passing through the element and perpendicular to its axis.

(2). When, $\theta = 0^\circ$

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dl \sin\theta}{r^2}$$

$$\sin\theta = 0$$

$$dB = 0$$

i.e., the magnetic field is 0 at points on the axis of the current element.

(3) When, $\theta = 180^\circ$

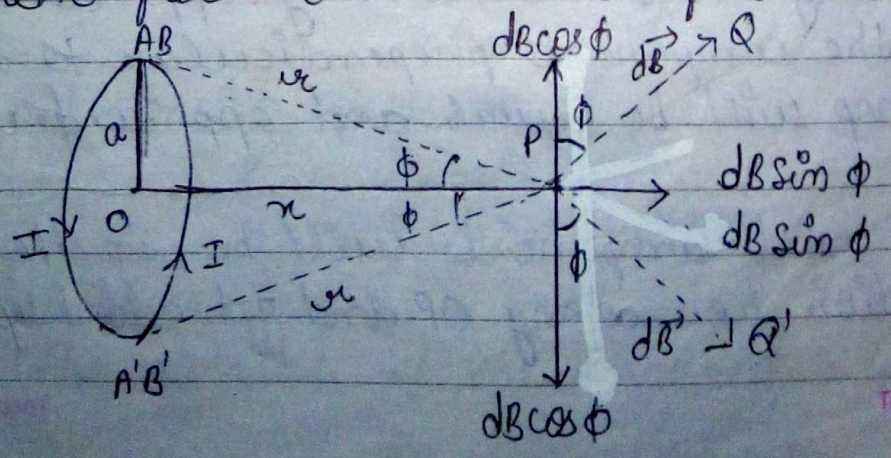
$$\sin 180^\circ = -1$$

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dl \sin 180}{r^2} \rightarrow dB = \frac{\mu_0}{4\pi} \frac{I\,dl(-1)}{r^2}$$

$$\rightarrow d\vec{B} = -\frac{\mu_0}{4\pi} \frac{I\,dl}{r^2}$$

It means dB is minimum, It means the magnetic field due to a current element is minimum in a plane passing through the element and perpendicular to its axis.

☆ Magnetic field on the axis of a circular loop -



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Consider a circular loop of wire of radius a and carrying current I, as shown in digram. Let the plane of the loop be perpendicular to the plane of the paper.
We wish to find field $\vec{B}$ at an axial point P at a distance x from the centre O.
Consider a current element $d\vec{l}$ at the top of the loop. It has an outward coming current.
If $\vec{r}$ be the position vector of point P relative to the element $d\vec{l}$, then from Biot-Savart law, the field at point P due to the current element is

$$dB = \frac{KI\, dl \sin\theta}{r^2}$$

Since $d\vec{l} \perp \vec{S}$, i.e., $\theta = 90°$, therefore

$$dB = \frac{\mu_0}{4\pi} \frac{I\, dl}{r^2}$$

The field $d\vec{B}$ lies in the plane of paper and is perpendicular $\vec{r}$, angle between OP and CP. Then dB can be resolved into two rectangular components—

1. $dB \sin\phi$ along the axis
2. $dB \cos\phi$ to the axis.

For any two diametrically opp. elements of the loop, the components perpendicular to the axis of the loop will be equal and opp. and will cancel out.
Their axial components will be in the same direction, i.e., along OP and get added up.

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∴ Total magnetic field at the point P in the dir^n OPis,

$$B = \int dB \sin\phi$$

But $\sin\phi = \frac{a}{r}$ and $dB = \frac{\mu_0}{4\pi} \cdot \frac{I\,dl}{r^2}$

Since $\frac{\mu_0}{4\pi}$ and I are constant, and r and a are same^n for all points on the circular loop, we have

$$B = \int \frac{\mu_0}{4\pi} \frac{I\,dl\,a}{r^3}$$

$$B = \frac{\mu_0}{4\pi} \frac{I\,a}{r^3} \int dl$$

$$B = \frac{\mu_0 \times I\,a}{\cancel{4\pi}_{2}\,r^3} \times \cancel{2\pi}\,a \quad [\because dl = \text{circumference} = 2\pi a]$$

$$B = \frac{\mu_0 I a^2}{2r^3}$$

By pythagores theorem —

$$r = (a^2 + x^2)^{1/2}$$

$$B = \frac{\mu_0 I a^2}{2\,[a^2 + x^2]^{3/2}}$$

As the dir^n of the field is along +ve x-dir^n, we can write,

$$\vec{B} = \frac{\mu_0 I a^2}{2\,(x^2 + a^2)^{3/2}}\,\hat{i}$$

If coil consists of N no. of turns,

$$\vec{B} = \frac{\mu_0 N I a^2}{2\,(x^2 + a^2)^{3/2}}$$

→ Special Cases —

(i) At the centre of the current loop,

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$x = 0$, therefore,

$$B = \frac{\mu_0 N I a^2}{2a^3} = \frac{\mu_0 N I}{2a}$$

2. At the axial points lying far away from the coil, $x >> a$, so that

$$B = \frac{\mu_0 N I a^2}{2x^3}$$

3. At an axial point at a distance equal to the radius of the coil i.e., $x = a$, we have

$$B = \frac{\mu_0 N I a^2}{2(a^2+a^2)^{3/2}} = \frac{\mu_0 N I}{2^{5/2} a}$$

☆ Ampere's circuital law -

Ampere's circuital law states that the line integral of the magnetic field $\vec{B}$ around any closed circuit is equal to μ_0 (permeability constant) times the total current I threading or passing through this closed circuit.

Mathematically,

$$\oint B \cdot dl = \mu_0 I$$

☆ Application of Ampere's law to a straight conductor →

Circular loop of a radius r around an infinitely long straight wire carrying current. Draw a perpendicular on straight wire OP. Consider a circular path of radius r.

~~Acc~~.

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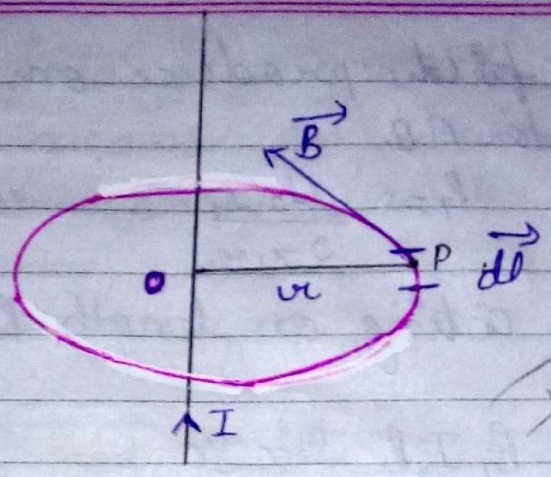


$r = 10 \times 10^{-2}$

$I = 3 \times 10^{-3}$

$n = 100$

$\frac{4\pi \times 10^{-7} \times 100 \times 3 \times 10^{-3}}{2\pi \times 10 \times 10^{-2}}$

According to Ampere's law.

$$\oint B \cdot dl = \mu_0 I$$

$$\oint B\,dl \boxed{\cos 0^\circ} = \mu_0 I$$

$$\oint B\,dl = \mu_0 I$$

$$B \oint dl = \mu_0 I$$

$$B\, 2\pi r = \mu_0 I$$

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

$10^{-2} \times 10^{-7} \times 10^{2} \times 10^{-3} \times 3$

$10^{-3} \times 10^{3} \times 3$

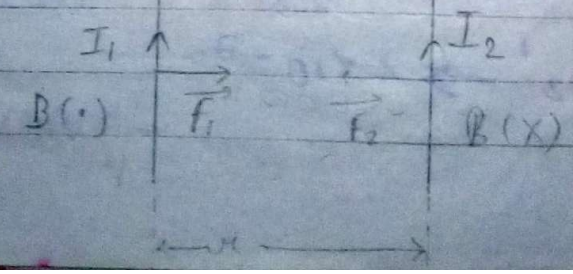
3

Both $\vec{B}$ and $\vec{dl}$ are tangential to the circle so the angle b/w them is zero.

- As the field lines are circular, the field $\vec{B}$ at any point of loop is directed along the tangent to the circle at the point.

☆ Forces: between two parallel current carrying conductor —

- As shown in fig. consider two long parallel wires AB and CD carrying currents I_1 and I_2. Let r be the seperation between them.



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Magnetic field produce on conductor CD due to conductor AB.

$$B_1 = \frac{\mu_0 I_1}{2\pi r} \quad \text{--- (1)}$$

The force acting on length l of the wire CD will be,

$$F_2 = B_1 I_2 l \sin 90$$

$$F_2 = B_1 I_2 l \quad \text{--- (ii)}$$

from eq^n (i) & (ii)

$$F_2 = \frac{\mu_0 I_1 I_2 l}{2\pi r}$$

force applied on per unit length of conductor CD.

$$F_2' = \frac{F_2}{l} = \frac{\mu_0 I_1 I_2 \cancel{l}}{\cancel{l}\, 2\pi r} = \frac{\mu_0 I_1 I_2}{2\pi r} \quad \text{--- (iii)}$$

Similarly, force applied on per unit length of conductor AB.

$$F_1' = \frac{F_1}{l} = \frac{\mu_0 I_1 I_2}{2\pi r} \quad \text{--- (iv)}$$

from eq^n (iii) & (iv)

$$F_1' = F_2' = \frac{\mu_0 I_1 I_2}{2\pi r}$$

If, $I_1 = I_2 = 1$ Amp and $r = 1m$

Then,

$$F_1' = F_2' = \frac{\mu_0}{2\pi}$$

$$F_1' = F_2' = \frac{\cancel{4}^{2}\pi \times 10^{-7}}{\cancel{2}\pi}$$

$$F_1' = F_2' \rightarrow 2 \times 10^{-7}$$

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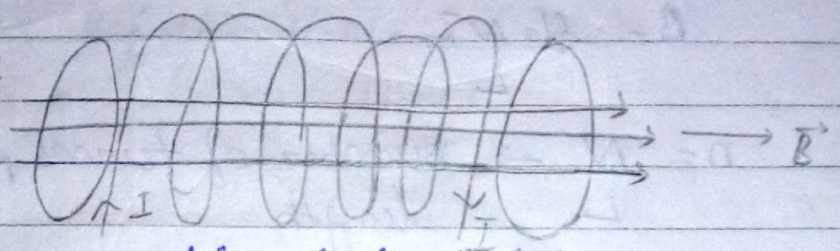
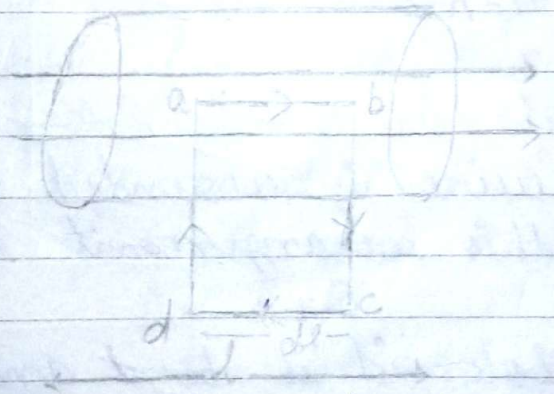
Magnetic field in a Solenoid

A solenoid means an insulated copper wire wound closely in the form of a heli



The magnetic field inside a closely wound long solenoid is uniform everywhere and zero outside it.

To determine the magnetic field $\vec{B}$ at any inside point, consider a rectangular closed patch abcd as the Amperean loop.



Ampere loop for closed loop abcd

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 \Sigma I$$

$$\oint_{ab} \vec{B}\cdot d\vec{l} + \oint_{bc} \vec{B}\cdot d\vec{l} + \oint_{cd} \vec{B}\cdot d\vec{l} + \oint_{da} \vec{B}\cdot d\vec{l} = \mu_0 N I$$

N → Number of turns

$$\oint_{ab} B\,dl\cos 0^\circ + \oint_{bc} B\,dl\cos 90^\circ + 0 + \oint_{da} B\,dl\cos 90^\circ$$

outside the solenoid

$$= \mu_0 N I$$

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$$\oint_{ab} B\,dl + 0 + 0 + 0 = \mu_0 N I$$

$$B\int dl = \mu_0 N I$$

$$B L = \mu_0 N I$$

$$B = \frac{\mu_0 N I}{L}$$

$n = \frac{N}{L}$ → number of turns per unit length

$$B = \mu_0 n I$$

So, Magnetic field for a solenoid is $B = \mu_0 n I$

If magnetising field is H,

$$B = \mu_0 H$$

$$\cancel{\mu_0} H = \cancel{\mu_0} n I$$

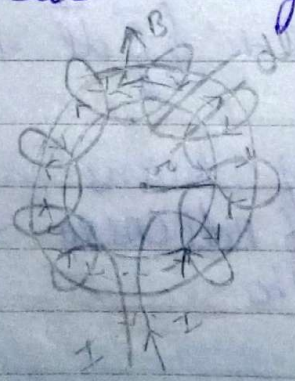
$$H = n I$$

Magnetic field in a toroid —

- If copper wire is wounded over a circular ring then this arrangement is called toroid.

Or

If a long solenoid is bend and its both ends made joint together then it is called toroid. In the figure one toroid is shown which is made by a circular ring of radius r.



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According to Ampere's law →

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 \Sigma I$$

$$\oint B\,dl \cos 0^\circ = \mu_0 N I$$

N is number of turns

$$B \oint dl = \mu_0 N I$$

$$B\, 2\pi r = \mu_0 N I$$

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

$\frac{N}{2\pi r} = n$ → no. of turns per unit length

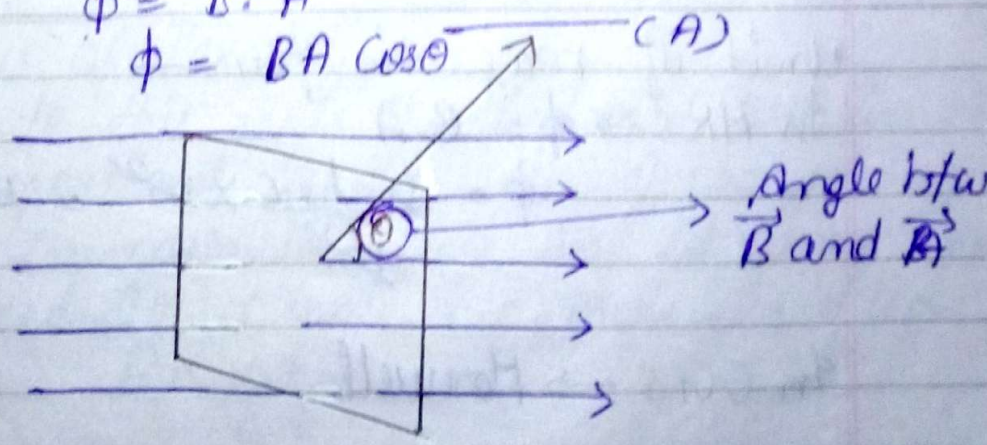
$$B = \mu_0 n I$$

✱ Magnetic flux →

- Number of magnetic field lines passing through a surface area placed normal to the magnetic field is known as magnetic flux
- Denoted by ϕ.
- It can also be defined as the Scalar product of magnetic field $\vec{B}$ and area vector $\vec{A}$.

$$\phi = \vec{B}\cdot\vec{A}$$

$$\phi = BA\cos\theta \quad (A)$$



✱ There are some special cases related to magnetic flux →

(1.) Case I →

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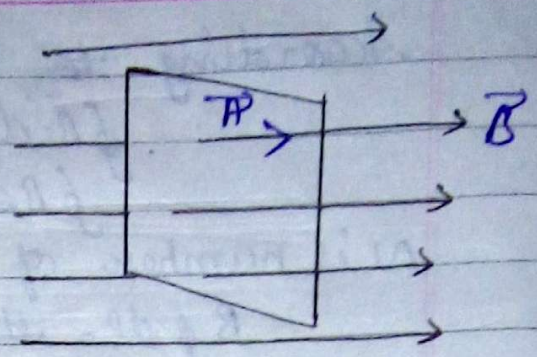
If $\theta = 0°$

then from eq^n (A)

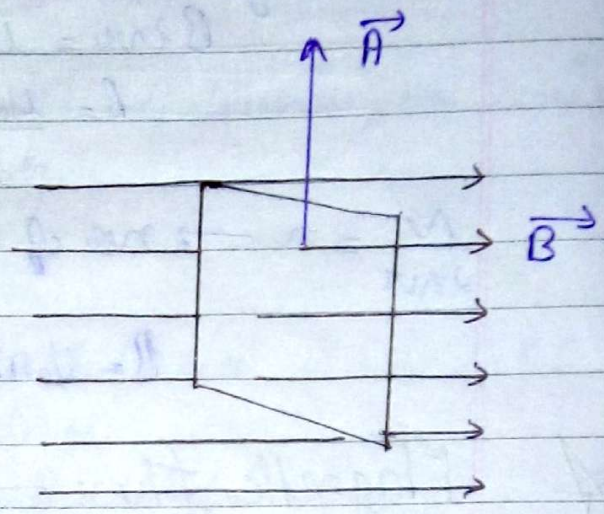
$$\phi = BA\cos\theta$$
$$\phi = BA\cos 0°$$
$$\phi = BA_{max}$$



If, $\theta = 90°$

Then, from eq^n (A)

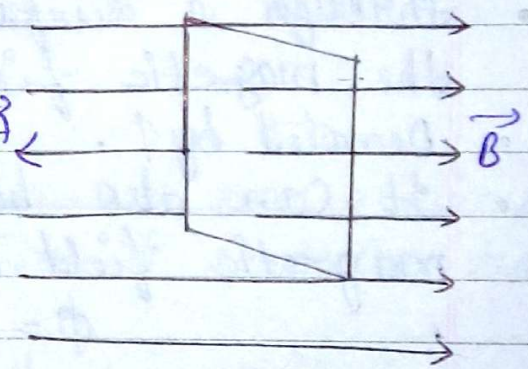
$$\phi = BA\cos\theta$$
$$\phi = BA\cos 90°$$
$$\phi = 0_{min}$$



If $\theta = 180°$

Then, from eq^n (A)

$$\phi = BA\cos\theta$$
$$\phi = BA\cos 180°$$
$$\phi = -BA$$



Unit of magnetic flux —

In MKS $\rightarrow \phi = B.A$

$$\phi = \frac{\text{Weber}}{m^2} \times m^2 = \text{Weber}$$

In CGS $\rightarrow$ Maxwell

Ques→ Length and breadth of rectangular coil are 20 cm and 10 cm. If its plane makes an angle of 30° to the dir^n of magnetic field 0.3 T. Calculate the magnetic flux.

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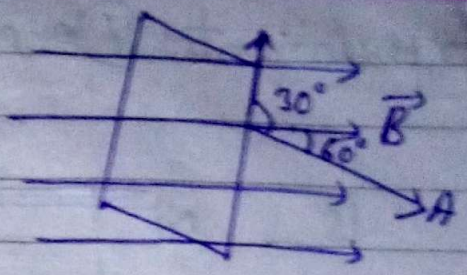
Sol^n → Acc. to Question →

$\theta = 60°$

$\phi = BA\cos\theta$

$\phi = 3\times10^{-1} \times 2\times10^{-2} \times \frac{1}{2}$

$\phi = 3\times10^{-3}$ wb Ans



☆ Faraday's Law :—

(1) First law of faraday →

- According to this law " When there is change in magnetic flux linked with any coil EMF and current are induced in the coil." The EMF is induced upto the direction the flux is changes.

" Or "

- The magnetic flux changes with time in a circuit it produced an electromotive force (EMF).

(2) Second law of faraday —

"According to this rule the induced EMF in the coil is proportional to the rate of change in flux". If change in magnetic flux in Δt time is $\Delta\phi$ then induced EMF $\propto$ rate of change in flux.

$$E \propto \frac{\Delta\phi}{\Delta t}$$

$$E = K\frac{\Delta\phi}{\Delta t}$$

" Or "

The induced EMF is equal to the rate of change of magnetic flux. $E = \frac{d\phi}{dt}$ or $-\frac{d\phi}{dt}$

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☆ Faraday's Experiments —

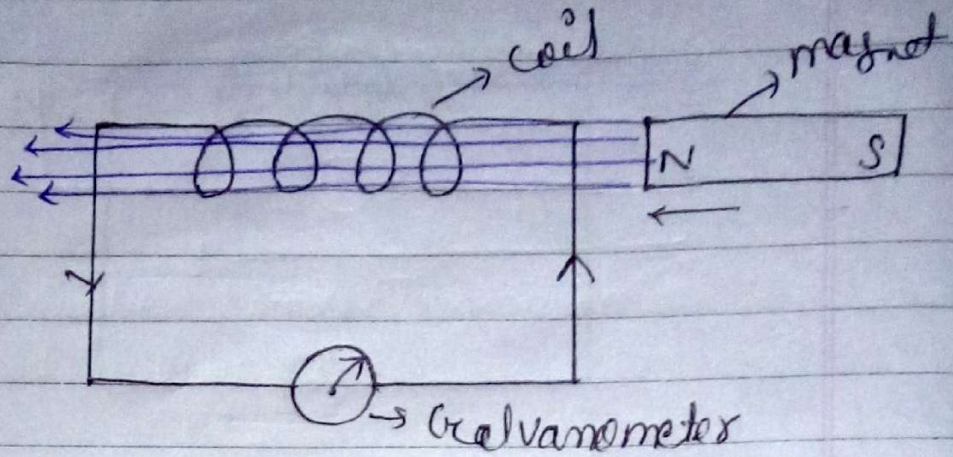

fig → Magnet is moving towards coil

(i) When the North pole of a strong bar magnet is moved towards the coil, then the deflection in galvanometer is towards right side.

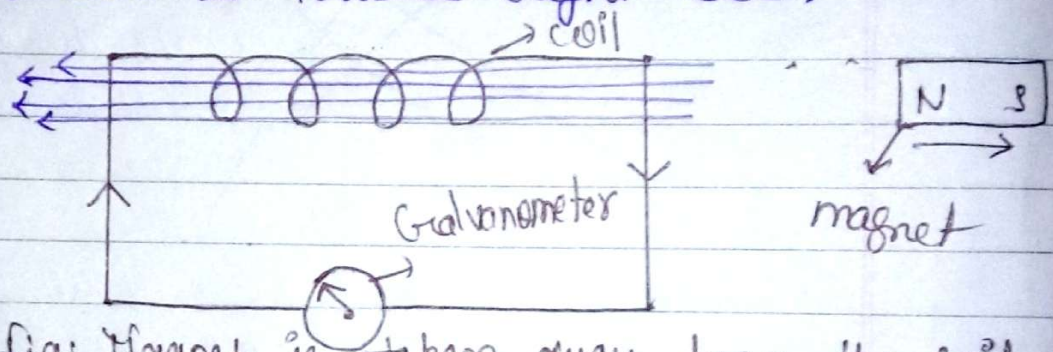

fig: Magnet is taken away from the coil

(ii) When the N-pole of the bar magnet is moved away from the coil, then the deflection in galvanometer is in opposite direction.

(iii) If the above experiments are repeated by bringing the S-pole of the magnet towards or away from the coil, then the direction of current in the coil is opposite to that obtained in the case of N-pole.

(iv) When the magnet is held stationary anywhere near or outside the coil, the galvanometer does not show any deflection.

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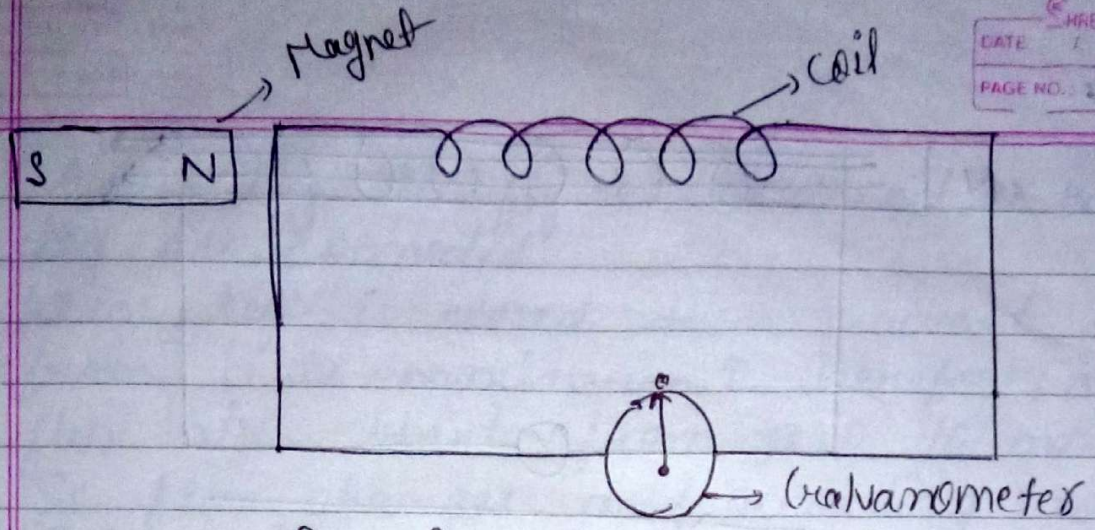

fig → Stationary position of magnet

Explanation → When a bar magnet is placed near a coil, a number of lines of force pass through it.

- As the magnet is move closer to the coil, the magnetic flux (the total number of line of force) linked with coil increases, then the induced current is set up in the coil in one direction.
- As the magnet is move away from the coil, the magnetic flux linked with the coil decreases, an induced EMF & an induced current is set up in the coil in opposite direction.
- When the relative motion in coil and magnet is stop, the magnetic flux linked with the coil stops therefore the induced current through the coil is 0.

(b) Induced EMF with the stationary magnet and moving coil →

- Now, in this condition, when the relative motion between the coil and magnet is fast, the deflection in the galvanometer is large and when the relative motion is slow, the galvanometer deflection is small.

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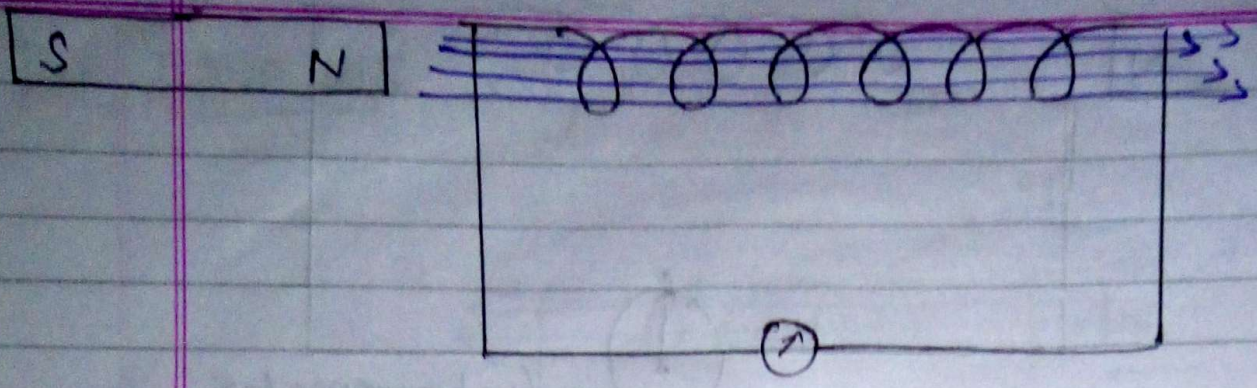


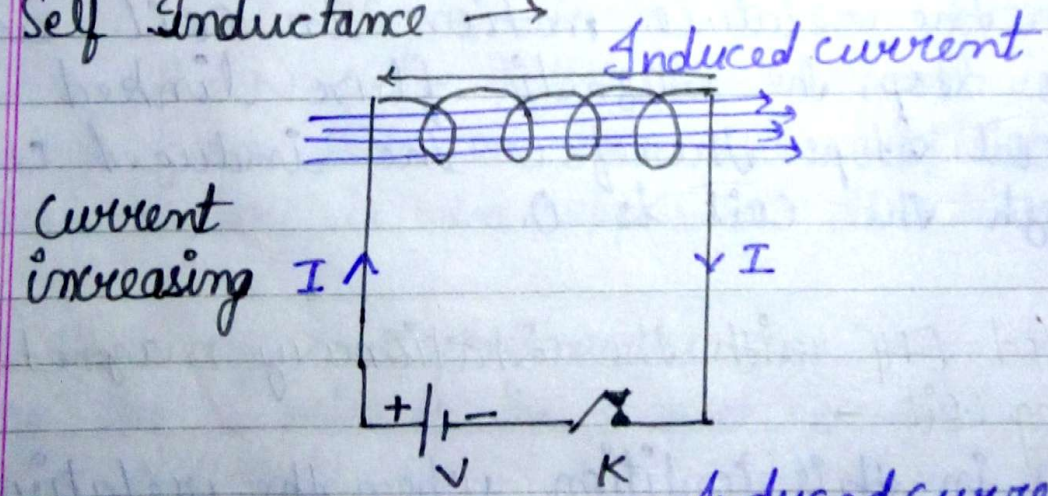
Electromagnetic induction with a stationary magnet and moving coil

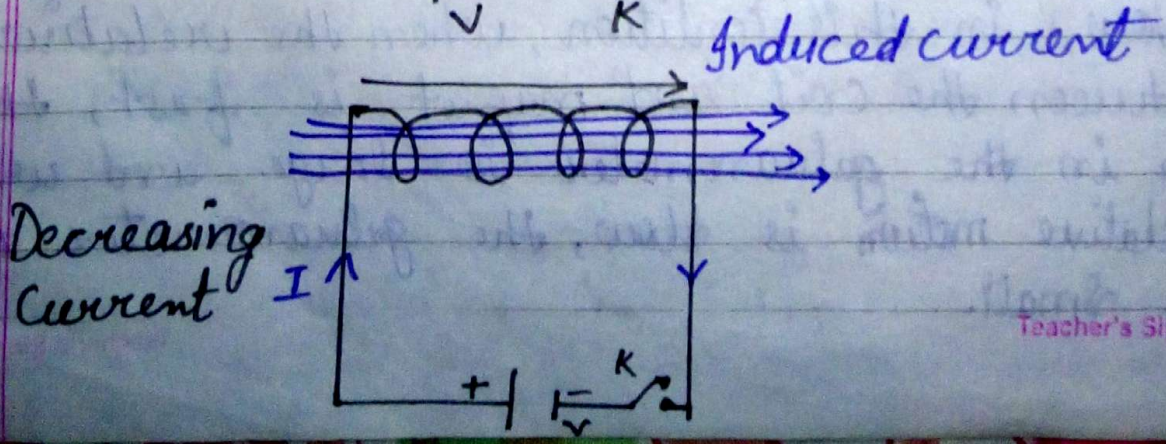
✱ Lenz's Law →

Acc. to this rule → In each case of electromagnetic induction, the direction of induced EMf and induced current as such that they always oppose the reasons behind their origin.

$$E = -\frac{d\phi}{dt}$$

✱ Self Inductance →





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- According to fig (a), in a coil a battery and key are connected.
- When key is closed then current starts from 0 to maximum ↑. Therefore, magnetic flux also starts from zero to maximum.
- So, flux changes and according to Faraday's law EMF is induced in the coil.
- When key is opened then current and hence flux changes from maximum to 0 and once again EMF is induced but in opp. dir^n
- Self inductance →
- Phenomenon of arising induced EMF or induced current in the same coil in which flux changes (increase or decrease) is called Self inductance.

Coefficient of Self induction L.

Magnetic flux in the coil is directly to induced EMF.

$$\phi \propto I$$

$$\phi = LI \quad \text{—(1)}$$

from eq^n (1),

$$\boxed{L = \frac{\phi}{I}} \quad \text{—(2)}$$

If in eq^n (2) $I = 1$ Ampere, then we will find that

$$\boxed{\phi = L}$$

is such that they always oppose the

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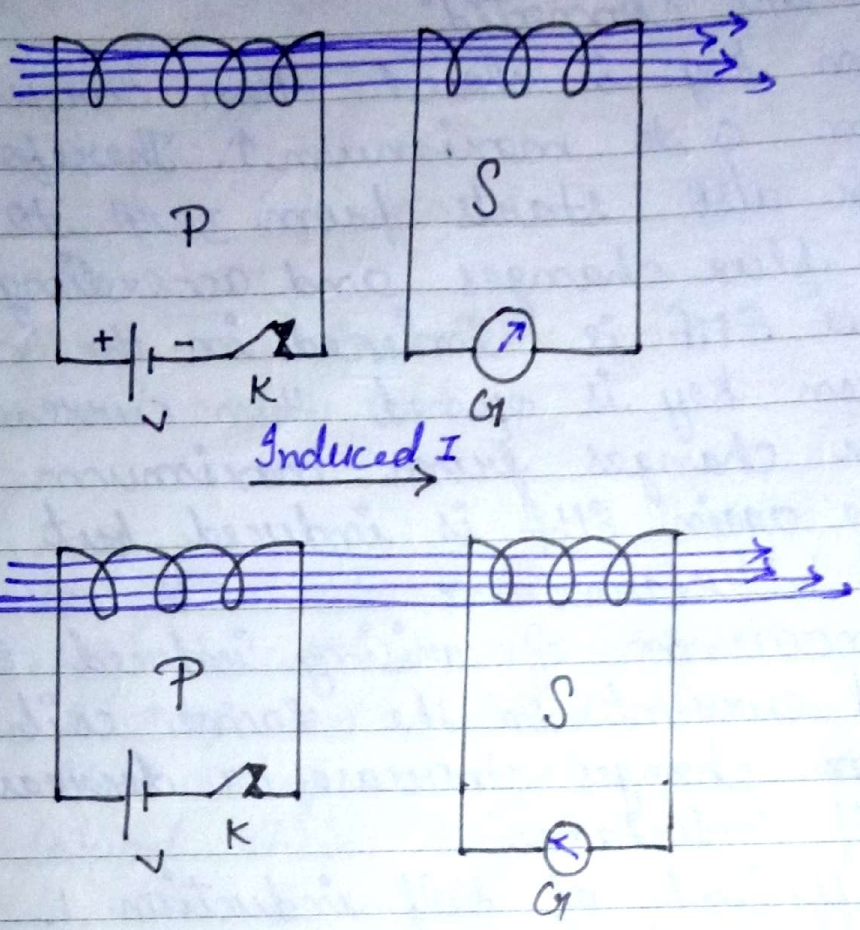
✡ Mutual Induction →



- As shown in fig. there are two coils.
- A cell and key is connected between the ends of the primary coil and a galvanometer is connected between the ends of the secondary coil.
- When key K is closed then magnitude of current get increased from 0 to maximum
- Then flux associated with primary and secondary coil is ~~produced~~ changed & induced current EMF developed in the secondary coil.
- When key is open then magnitude of current get decreases from maximum to 0.

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- Induced current flow in secondary coil but in opposite direction from.

Mutual Induction The phenomenon of arising induced current in a coil due to change in current in a ~~no~~ nearby coil is called Mutual induction.

- flux associated with secondary coil ϕ_2 is directly $\propto$ to current P coil I_1.

$$\phi_2 \propto I_1$$

$$\boxed{\phi_2 = M I_1} \quad \text{—— (A)}$$

- Here M is a constant and known as mutual constant.

from eq^n (A) $\rightarrow M = \frac{\phi_2}{I_1}$

Let, $I_1 = 1$ Ampere, so. $M = \phi_2$

✱ Types of Magnetic property of Material →

There are three types of Magnetic property of Materials

- Diamagnetic Substances
- Paramagnetic Substances
- ferromagnetic Substances

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S.No.	Property	Diamagnetic Substances	Paramagnetic Substances	Ferromagnetic Sub.
1.	Effects of magnets →	They are feebly repelled by magnets.	They are feebly attracted by magnets.	They are strongly attraced by magnets.
2.	In External magnetic field →	Acquire feeble magnetisation in opposite direction of the magnetising field.	Acquire feeble magnetisation in the direction of the magnetising field.	Acquire strong magnetisation in the direction of the magnetising field.
3.	In a non-uniform magnetic field →	Tend to move slowly from stronger to weaker parts of the field.	Tend to move slowly from weaker to stronger parts of the field.	Tend to move quickly from weaker to stronger parts of the field.
4.	In a uniform magnetic field →	A freely suspended diamagnetic rod aligns itself perpendicular to the field	A freely suspended paramagnetic rod aligns itself parallel to the field.	A freely suspended ferromagnetic rod aligns itself parallel to the field.
5.	Susceptibility (χ_m)	Susceptibility is small and negative $-1 \le \chi_m < 0$	Susceptibility is small and +ve, $0 < \chi_m < \varepsilon$, where ε is small number	Susceptibility is very large and positive. $\chi_m > 1000$
6.	Permeability value (μ) →	$\mu < \mu_0$	$\mu > \mu_0$	$\mu >> \mu_0$
7.	Relative Permeability value (μ_r)	Slightly less than 1. $0 \le \mu_r < 1$	Slightly greater than 1 $1 < \mu_r < 1+\varepsilon$	of the order of thousands $\mu_r > 1000$
8.	Effect of temperature	Susceptibility is independent of temperature.	Susceptibility varies inversely as temperature : $\chi_m \propto \frac{1}{T}$.	Susceptibility decreases with temperature in a complex manner. $\chi_m \propto \frac{1}{T-T_c}$ $(T > T_c)$
9.	Removal of magnetising field →	Magnetisation lasts as long as the magnetising field is applied.	As soon as the magnetisating ~~is lost~~ field is removed magnetisation is lost.	Magnetisation is retained even after the magnetisation field is removed.
10.	Variation of M with H →	M changes linearly with H.	M changes linearly with H and attains saturation at low temperature and in very strong fields.	M changes with H non linearly and ultimately attains saturation.
11.	Hysteresis effect →	B-vector shows no hysteresis.	B-vector shows hysteresis	B-vector shows hysteresis.
12.	Physical state of material	Solid, liquid or gas.	Solid liquid or gas.	Normally solids only.
13.	Examples	Bi, Cu, Pb, Si, N_2 (at STP), H_2O, NaCl	Al, Na, Ca, O_2 (At STP), $CuCl_2$	Fe, Ni, Co, Gd, Fe_2O_3, Alnico.

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Ques → Diff. betw. magnetic field and magnetising field? L.R. Circuit?

✱ Intensity of Magnetisation →

- When a magnetic material is placed in a magnetising field, it gets magnetised. The magnetic moment developed per unit volume of a material when placed in a magnetising field is called intensity of magnetisation or simply magnetisation.

$$I = \frac{M}{V}$$ → magnetic moment

✱ Magnetising field →

If B_0 is magnetic induction in vaccum and μ_0 is magnetic permeability of vaccum then the ratio of B_0 to μ_0 is known as magnetising field.

$$\boxed{\vec{H} = \frac{\vec{B_0}}{\mu_0}}$$

magnetising field

✱ Magnetic Susceptibility →

- Magnetic susceptibility measures the ability of a substance to take up magnetisation when placed in magnetic field.

"It is define as the ratio intensity of magnetisation M to the magnetising field intensity H. It is denoted by . Thus,

$$\boxed{\chi_m = \frac{M}{H}}$$

→ intensity of magnetisation

χ_m → magnetic susceptibility

H → magnetising field intensity

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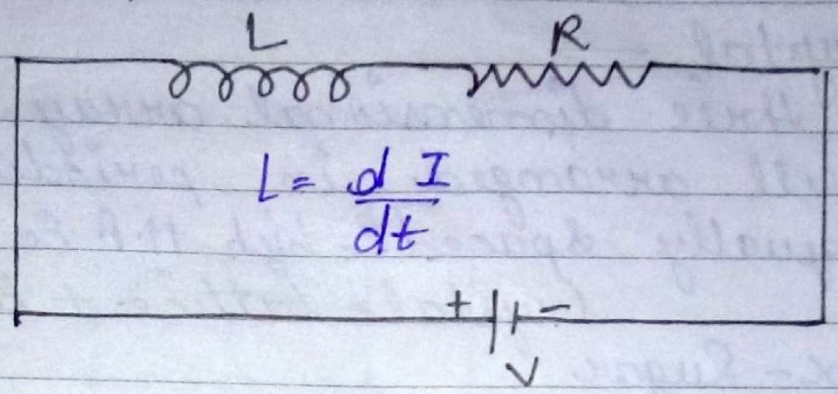
✱ LR-Circuit →



growth of current →
when K is closed –

$$E = L\frac{dI}{dt} + IR \quad \text{—(1)}$$

when $\frac{dI}{dt} = 0$, $I = I_0$

$$E = I_0 R \quad \text{—(2)}$$

$$(I_0 - I)R = L\frac{dI}{dt} \Rightarrow \frac{R}{L}\int dt = \int \frac{dI}{(I_0 - I)}$$

$$\int \frac{dI}{(I_0 - I)} = \frac{R}{L}\int dt$$

$$\log_e (I_0 - I) = \frac{R}{L}t + c$$

At, $t = 0$ $\quad I = 0$

$$c = -\log_e I_0$$

$$I = I_0 (1 - e^{R/L t})$$

when $\frac{dI}{dt} = 0$, $I = I_0$

$$E = I_0 R \quad \text{—(3)}$$

$$(I_0 - I)R = L\frac{dI}{dt}$$

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Electrostatics

Physical Quantity	units
Electric (q, Q)	Coulomb (C)
Electric (I)	Ampere
Resistance (R)	Ohm (Ω)
Capacitance (C)	Farad (F)
Inductance (L)	Henry
Magnetic Induction (B)	Tesla or weber
frequency	Hertz (Hz)
force (F)	Newton (N)
Power (P)	watt (W)
Potential	Volt

Electrostatics —

- Electrostatics is a branch of physics in which we study electric charges at rest. The charges at rest are produced due to friction between two insulating bodies which are rubbed against each other.
- which gives electrons are basically +ve.
- which take electrons are basically -ve.

Electric charge —

- when a glass rod rubbed with silk is bringed near to another glass rod which is already rubbed with silk then these two rods are repel each other similarly.
- Two ebonite rods rubbed with fur and

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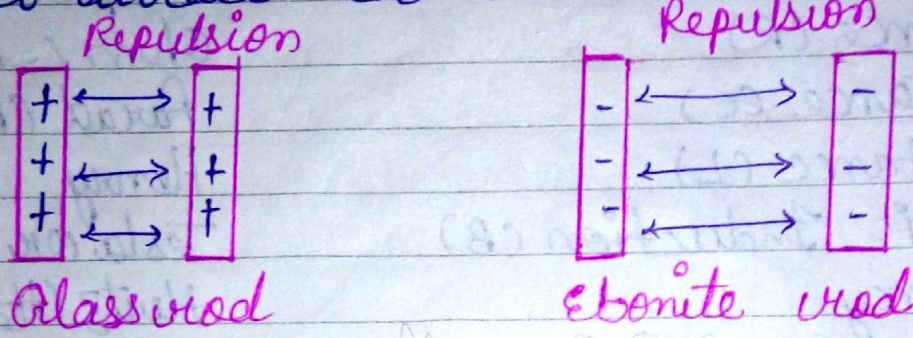
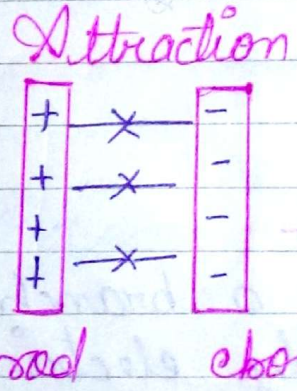
bring them near to each other then we will observe that they will repel each other.
But a glass rod rubbed with silk and a ~~glass~~ ebonite rod rubbed with fur get attract each other.





- The object which transfer a quantity during the friction is called the electric charge.
- Same charges repel each other and diff. charges attract each other.

Conductors, Insulators & Semi-Conductors

(1) Conductors →

- The materials in which electrons are loosely bound and are capable to move from one

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place to another are called conductors.
- Flow of electrons in a conductor causes flow of charges and the flow of charge is termed as electric current.
- Ex - Silver, gold, aluminium, iron etc.

(2) Insulators —
- The materials in which electrons are tightly bound that they are not capable to move freely in such materials current and heat cannot flows. These materials are called insulator.
- Ex - wood, platic, rubber etc.

(3) Semi-Conductors —
- There are some substances which are neither good conductors of electricity nor good insulators. These substances are called semi-conductors.
- Ex - Germanium, Silicon etc.
- In semiconductors there are small free electrons & by increasing temperature electrons can be made free from atoms so conductivity increases by increasing temperature.

Dielectric Constants —
- Some insulators are called dielectric. It can't conduct electricity but when an external electric field is applied it induced charge appear on the outer surface of dielectric.
- Ex - Mica sheet.

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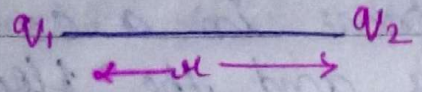
✱ Coulomb's Law —



Acc. to this law the force of interaction betw. any two charges is directly proportional to the product of the magnitude of charges and inversly proportional to the square of the distance between them.

$$F \propto q_1 q_2 \quad \text{—— (A)}$$

$$F \propto \frac{1}{r^2} \quad \text{—— (B)}$$

from eq^n (A) & (B)

$$F \propto \frac{q_1 q_2}{r^2}$$

then,

$$\boxed{F = \frac{K q_1 q_2}{r^2}} \quad \text{(C)}$$

K → electrostatic force constant

(C) → Coulomb's law for free space

Here K is $\frac{1}{4\pi\varepsilon_0}$

where ε_0 is permitivity in free space or dielectric constant

$$K = 9 \times 10^9$$

unit of K is $\frac{Nm^2}{C^2}$.

$\varepsilon_0 = 8.85 \times 10^{-12}$

unit → C^2/Nm^2

$$\boxed{F_m = \frac{1}{4\pi\varepsilon_m} \frac{q_1 q_2}{r^2}} \quad \text{—— (D)}$$

Coloumb's law for medium ← (D)

ε_m → Permitivity in medium

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from eq^n (C) & (D)

$$\frac{F}{F_m} = \frac{\frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}}{\frac{1}{4\pi\epsilon_m}\frac{q_1 q_2}{r^2}}$$

$$\frac{F}{F_m} = \frac{\epsilon_m}{\epsilon_0} = \epsilon_r \rightarrow \text{Relative permitivity}$$

Ex (1) → Calculate force between two charges of 1C. each seperated by 1m in vacuum.

Sol^n → formula → $F = \frac{Kq_1q_2}{r^2}$

Given → $q_1 = q_2 = 1C$

$r = 1m$

$$F = \frac{9\times10^9 \times 1\times1}{(1)^2}$$

$$F = 9\times10^9 N$$

Ex (2) → Two equal charges are placed at a distance 'r'm exerting force 'F'N on each other what will be the new force F_1 when—

(1) The distance between charges is double
(2) The magnitude of both charges are halved
(3) The magnitude of each charge is doubled but distance betw. charge is halved.

Sol^n → Let, $q_1 = q_2 = q$

$$F = \frac{Kq_1q_2}{r^2}$$

$$F = \frac{Kq^2}{r^2} \quad \text{—(A)}$$

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(i) Distance betw. charges → $2r$

$$F_1 = \frac{Kq^2}{(2r)^2}$$

$$F_1 = \frac{Kq^2}{4r^2}$$

from eq^n (A)

$$F_1 = \frac{F}{4} N$$

(ii) Magnitude of both charges,

$$q_1 = q_2 = \frac{q}{2}$$

$$F_1 = \frac{K\left(\frac{q}{2}\right)\left(\frac{q}{2}\right)}{r^2}$$

$$F_1 = \frac{Kq^2}{4r^2}$$

$F_1 = \frac{F}{4} N$ — from eq^n (A)

(iii) Magnitude of charges, $q_1 = q_2 = 2q$

distance → $\frac{r}{2}$

Then, $$F_1 = \frac{K(2q)(2q)}{\left(\frac{r}{2}\right)^2}$$

$$F_1 = \frac{K4q^2}{\frac{r^2}{4}}$$

$$F_1 = 16\frac{Kq^2}{r^2}$$

$F_2 = 16 F N$ — from eq^n (A)

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✡ Conservation & quantization of charges—

(1) Quantization of charge —

- charge exists only in discrete manner or in the packets form. This is called Quantisation of charge.

$q = ne \rightarrow 1.6 \times 10^{-19} C$

$\rightarrow n = 0, \pm 1, \pm 2, \ldots \infty$

$q = 0$

→ $q = \pm 1e = \pm 1 \times 1.6 \times 10^{-19} C = \pm 1.6 \times 10^{-19}$

→ $q = \pm 2e = \pm 2 \times 1.6 \times 10^{-19} C$

→ $q = \pm 3e = \pm 3 \times 1.6 \times 10^{-19} C \ldots \infty$

The value of charge lying between these values are not possible

(2) Conservation of charge —

- The charge can niether be created nor be destroyed. Charges always develop in equal and opposite pairs.
- So, the total charge remain conserved.

✡ Electric field (E) →

- Electric field of a charge is the space around the charge in which any other charge experiences the electrostatic force of attraction or repulsion.

$$E = \frac{F}{q}$$

Unit → $\frac{N}{C}$ or NC^{-1}

→ $E = \frac{F}{q_1} \rightarrow F = \frac{k q_1 q_2}{r^2 q_1} \rightarrow \boxed{E = \frac{k q_2}{r^2}}$

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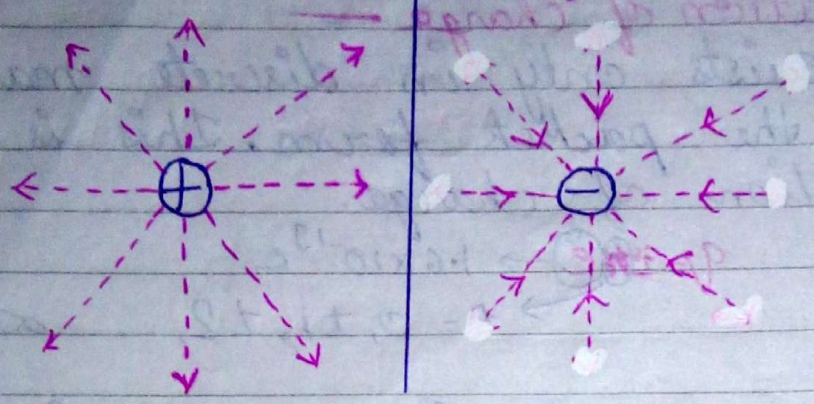
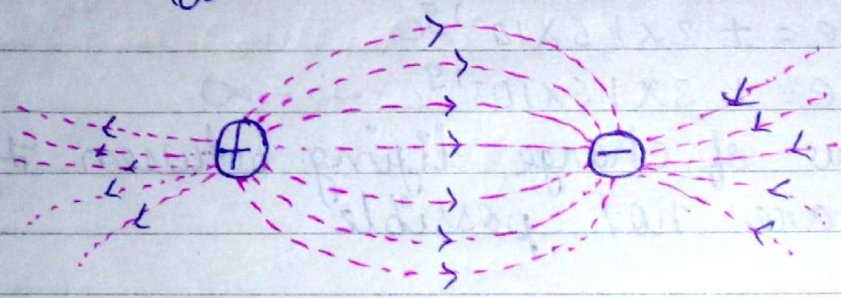
Electric lines of force —



(a) (b)



(c)

- In dig (a) → Some lines of force due to single +ve charge these are directed towards outwards. These lines are extended to ∞
- In dig (b) → Some lines of force due to single −ve charge these are directed towards inwards.
- In dig (c) → If +ve charge and −ve are placed near them electric lines of force are directed from +ve charge to −ve charge.

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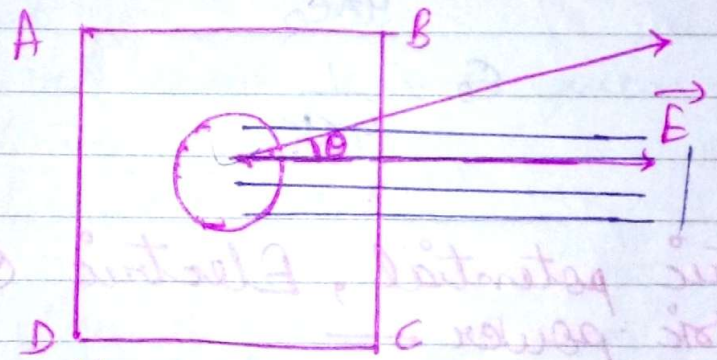
✯ Properties of Electric lines of force —

(1) These are imaginary curves.
(2) Tangent to the line of force at any point gives the direction of electric field at that point.
(3) No two lines of force can intersect each other.
(4) These lines start from a +ve charge and end at −ve charge.

✯ Electric flux (ϕ) —



- Electric flux over an area in an electric field is the total No. of electric line of force passing in area.
- It is represented by ϕ.

Electric flux for ~~an~~ small area

$$d\phi = \vec{E} \cdot d\vec{s}$$
$$d\phi = E\,ds\cos\theta \quad \text{—— (1)}$$

E → electric field, ds → small area

- Total flux —

$$\phi = \oint d\phi \quad \text{—— (2)}$$
$$\phi = \oint \vec{E} \cdot d\vec{s} \quad [\text{from eqn (1)}]$$

unit → Nm^2C^{-1}

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✯ Gauss Law —

- Acc. to Gauss Law electric flux, passing through a electric is equal to the product of total charge Q and of $\frac{1}{\epsilon_0}$.

$$\phi = Q \times \frac{1}{\epsilon_0}$$

from eqⁿ (2)

$$\boxed{\phi = \frac{Q}{\epsilon_0} = \oint E \cdot ds}$$

from Coulomb's law →

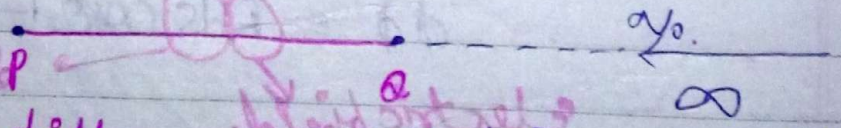
$$K = \frac{1}{4\pi\epsilon_0}$$

$$\epsilon_0 = \frac{1}{4\pi K}$$

✯ Electric potential, Electric energy, Electric Electric power —

Electric potential → Electric potential at a point in the electric field is the amount of work done in moving a +ve charge from ∞ to that point

$$V = \frac{W}{q_0}$$



Potential difference → Electric potential diff. betw. two point Q & P in an electric field is the amount of work done in moving +ve charg from Q to P.

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$$V_P - V_Q = \frac{W}{q_0}$$

$$V = \frac{Kq}{r}$$

Electrical energy —

Electrical energy is denoted by U.

$$U = Vq$$

$$U = \frac{Kq_1 q_2}{r}$$

we take q_1 & q_2 bec. two charges are present

$$U = \frac{Kq_1 q_2}{r}$$

Total work done for a given time is called electric energy.

$$\boxed{U = W = Vq}$$

✱ Electric Power —

- Electric power is denoted by P.
- Work done per unit time is called power.

$$P = \frac{W}{T} \quad \Big| \quad P = VI$$

$$P = IRI \rightarrow P = I^2R$$

- unit of power is watt or Joule/Sec

or

$$P = V \times \frac{V}{R} \rightarrow P = \frac{V^2}{R}$$

✱ Capacitance & Capacitors —

- The ability of conductor to store charge in it is called Capacitance.

$$Q \propto V$$

$$C = \frac{Q}{V} \text{ or } Q = CV \quad \text{—— (1)}$$

C → Capacitance of Conductor

unit → Farad (F)

$1\,\mu F = 10^{-6} F$

$1\,PF = 10^{-12} F$

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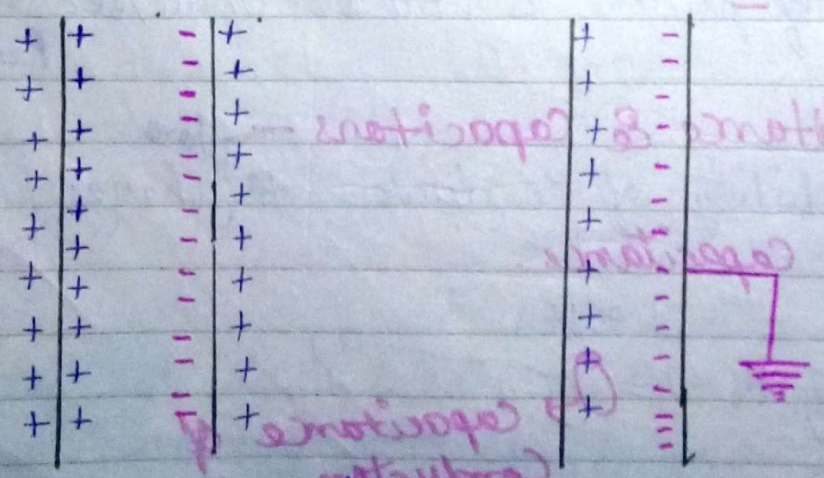
- Capacitors are the arrangement by which a large amount of charge can be stored in small place.

Let, us consider a plate A which is charged with some +ve charge
from eqⁿ — (1) it is clear that by decreasing the value of V capacity of conductor can be increased.
So, the value of potential can be decreased if another plate B is taken near to plate A, then negative charge is developed on plate B towards the plate A. and equal +ve charge is developed on the other side of plate B. which move into the ground when it is connected to earth.
So, potential reduces and capacity of conductor A increases



Capacitor and Condensor are same.

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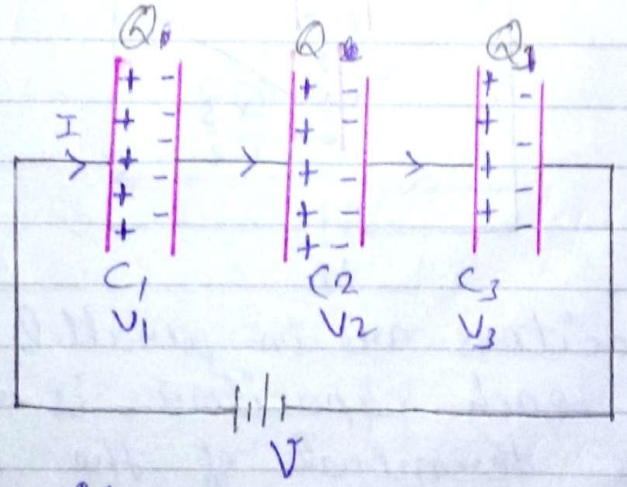
There are various types of capacitors

- Spherical capacitor
- Parallel capacitor
- Cylindrical capacitor

COMBINATIONS OF CAPACITOR -

(1) Series combination
(2) Parallel Combination

(1) Series Combination :-



The capacitors are in series when IInd plate of first capacitor is ~~called~~ connected with the first plate of its following ~~characters~~ capacitors in a row.

$Q = C_1V_1$, $Q = C_2V_2$ and $Q = C_3V_3$

$V_1 = \frac{Q}{C_1}$, $V_2 = \frac{Q}{C_2}$, $V_3 = \frac{Q}{C_3}$

Total potential → $V = V_1 + V_2 + V_3$

$\frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$

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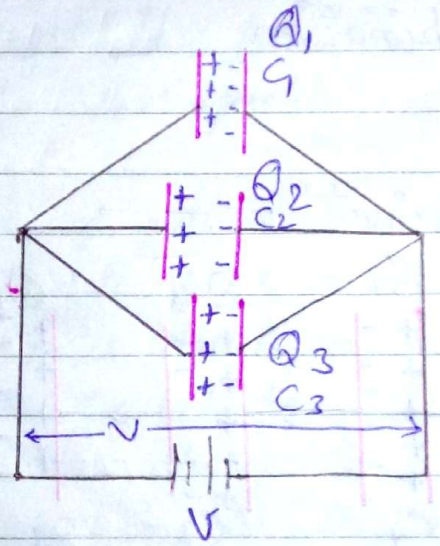
$$\frac{Q}{C} = Q\left[\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right]$$

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

So, in series combination ~~rep~~ reciprocal of total capacitance is equal to the sum of the reciprocals of individual capacitance connected in series.

(2) Parallel Combination —



The capacitors are in parallel when first plate of each capacitor is connected with the one terminal of the battery and the second plate is connected with the another terminal of the battery.

$$Q_1 = C_1 V, \quad Q_2 = C_2 V, \quad Q_3 = C_3 V$$

$$Q = Q_1 + Q_2 + Q_3$$

$$CV = C_1 V + C_2 V + C_3 V$$

$$C\cancel{V} = \cancel{V}(C_1 + C_2 + C_3)$$

$$C_{se} = C_1 + C_2 + C_3$$

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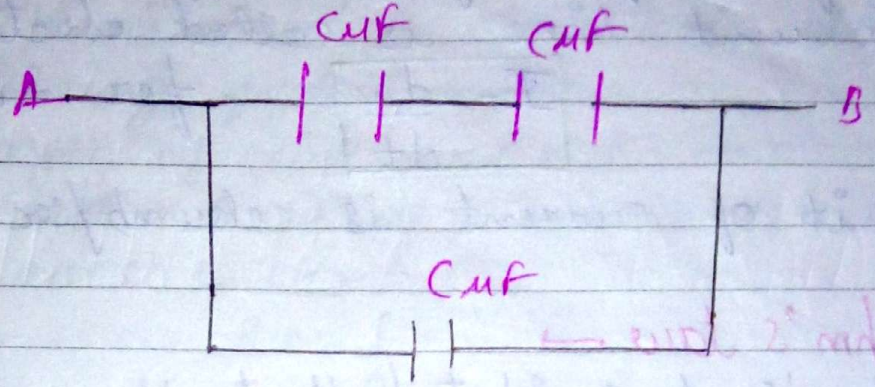
So, in parallel combination total capacitance is equal to the sum of individual capacitances connected in the circuit.



Ques → Find equivalent capacitor?

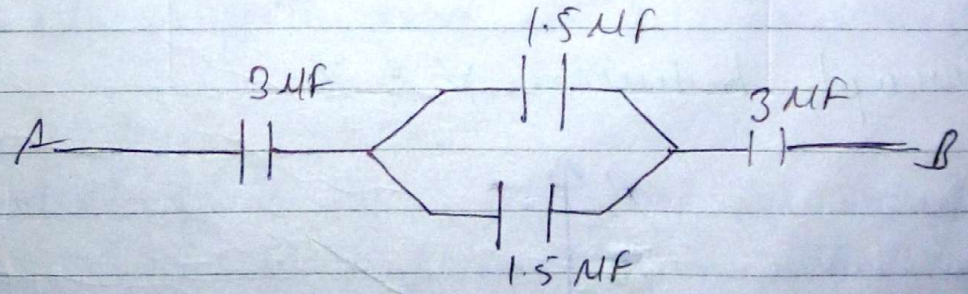
$$\rightarrow \frac{1}{C_s} = \frac{1}{C} + \frac{1}{C}$$

$$C_s = \frac{C}{2}\ \mu f$$

Then, $C_{eq.} = \frac{C}{2} + C$

$$\boxed{C_{eq} = \frac{3C}{2}\ \mu f}$$

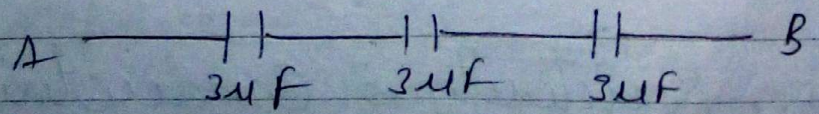
Ques →



$C = C_1 + C_2$

$C = 1.5 + 1.5$

$C = 3\ \mu f$



$$\frac{1}{3} + \frac{1}{3} + \frac{1}{3} = \frac{1+1+1}{3} = 1\ \mu f$$

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✯ Electric current →

The electric current is define as the rate of flow of charges through a conductor per unit time is called electric current.

$$\boxed{I = \frac{dq}{dt}} \longrightarrow \text{for small part}$$

unit of current is coloumb/sec or Ampere (A)

✯ Ohm's law →

Ohm's law stated that the potential difference of the conductor is directly proportional to the current flowing through the conductor.

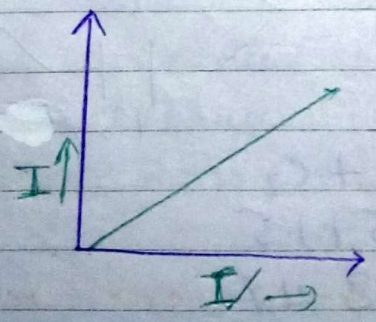
$$V \propto I$$

$$V = RI \quad \text{or} \quad V = IR$$

$$R = \frac{V}{I}$$

R is a constant called resistor
unit of R is volt/A or Ω (ohm).

Graph between V & I.



✯ Resistance, Resistivity & Conductivity —
(R) (ρ) (σ)

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- Obstruction produce by the conductor to the flow of charges (flow of current) is called resistance of the conductor.
- The resistance of conductor depends upon following factors —

(1) length of wire → $R \propto l$. —— (i)

(IA) (2) Crossection area of wire → $R \propto 1/A$. —— (ii)

from (i) & (ii)

$$R \propto \frac{l}{A}$$

$$R = \frac{\rho l}{A}$$

ρ is a constant is called Resistivity or specific resistance

$$\rho = \frac{RA}{l}$$

→ unit of ρ → $\frac{\text{Ohm } m^2}{m}$ ⇒ Ohm m

- Thus, electrical resistivity of the material is equal to the resistance of wire of unit length and unit cross-section area

☆ Conductivity → (σ)

Conductivity is the reciprocal of resistivity

$$\sigma = \frac{1}{\rho} = \frac{1}{\text{Ohm-m}} = \text{Ohm}^{-1} m^{-1} \text{ or mho } m^{-1}$$

☆ Electromotive force and Terminal potential difference —

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Electromotive force →
Electromotive force of a cell is the maximum potential difference between the cells when it is in the open circuit. i.e. when no current is drawn from the cell

Terminal potential difference →
The potential difference between the cell in a closed circuit i.e. when current is drawn from the cell is called terminal potential difference

$$E = V + Ir \quad (E > V)$$

Series and Parallel Combination of Resistance

(1) Series Combination :-

In diagram three Resistances R_1, R_2 and R_3 are connected in series. V_1, V_2, V_3 are the potential difference across R_1, R_2, R_3, Respectively
Acc. to ohm's law -

$$V = IR$$
$$V_1 = IR_1$$
$$V_2 = IR_2$$
$$V_3 = IR_3$$

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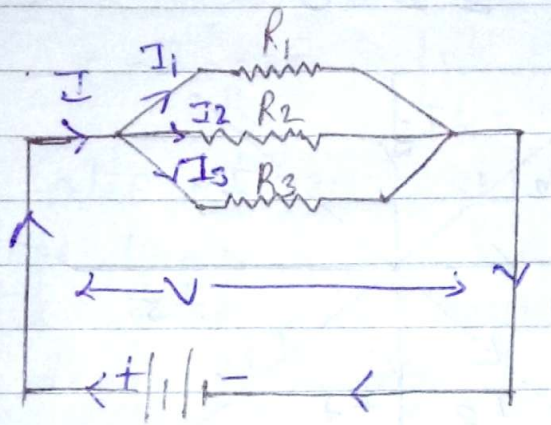
$$V = V_1 + V_2 + V_3$$
$$IR = IR_1 + IR_2 + IR_3$$
$$\cancel{I}R = \cancel{I}(R_1 + R_2 + R_3)$$
$$R_s = R_1 + R_2 + R_3$$

Resistance in series is equal to the sum of the individual resistance.

(2) Resistance in parallel –



$V = IR \rightarrow I = V/R$

Resistance of $V = I_1R_1 \longrightarrow I_1 = V/R_1$

Resistance of $= I_2R_2 \longrightarrow I_2 = V/R_2$

Resistance of $= I_3R_3 \longrightarrow I_3 = V/R_3$

$$I = I_1 + I_2 + I_3$$
$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$
$$\frac{\cancel{V}}{R} = \cancel{V}\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]$$
$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

If n resistance are connected in parallel,

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \cdots\cdots + \frac{1}{R_n}$$

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☆ Kirchoff's law →

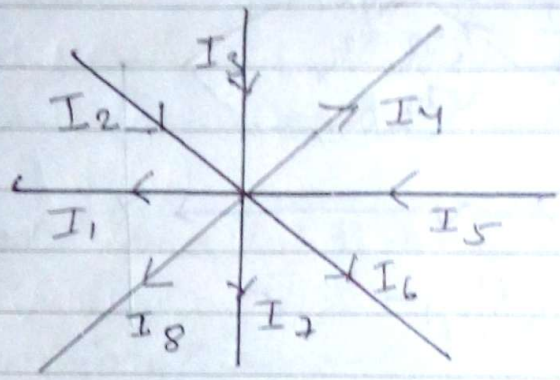
(1) first law →

In an electric circuit, the algebric sum of currents at any junction is zero.

OR.

The sum of currents entering a junction is equal to the sum of currents leaving that junction.

$$\Sigma I = 0$$



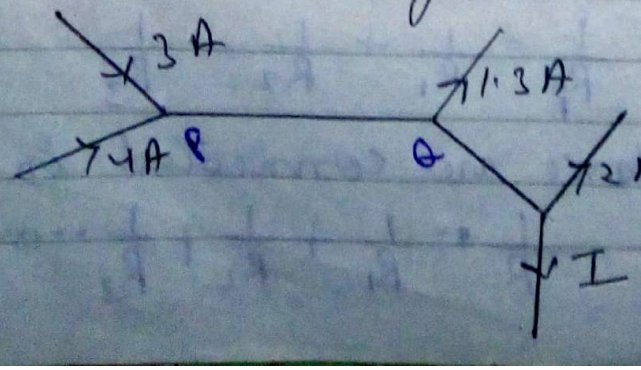
$$-I_1 + I_2 + I_3 - I_4 + I_5 - -I_6 - I_7 - I_8$$

$$\rightarrow \quad I_2 + I_3 + I_5 = I_1 + I_6 + I_7 + I_8$$

- Sign Convention →

(i) The current flowing in a circuit towards the junction is taken as positive and current flowing away from the junction is taken as negative.

Ques → 1. The following diagram find the value of current I in given branch?



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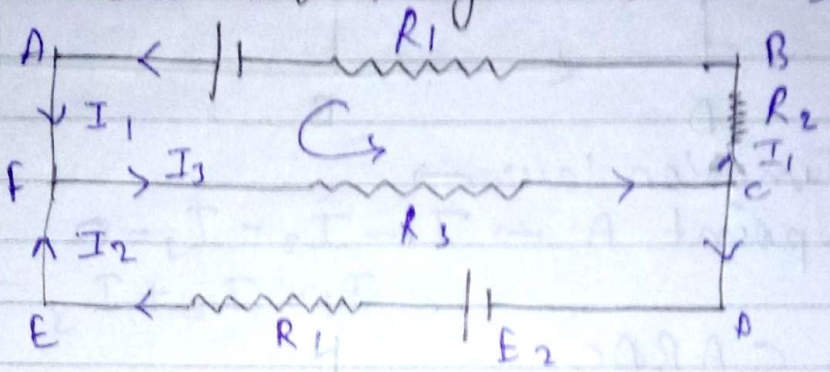
Sol^n →

$$I = 3 + 4 - 1.3 - 2$$
$$I = 7 - 3.3$$
$$I \Rightarrow 3.7\ A$$

(2) Second law → or Voltage law or loop law →



This is also known as Kirchoff's loop law and voltage law.

It states that in any close path of an circuit, the algebric sum of voltage is equal to the sum of E.M.F. in that loop.

$$\Sigma E = \Sigma V$$
$$\Sigma E = \Sigma IR$$

(A) If the direction of current is along the path then E.M.F. of cell is taken +ve otherwise -ve.

(B) The voltage drop on resistance is taken positive if one moves in the direction of current and is taken -ve if one move in the opp. dir^n of current.

Closed loop AFCBA

$$I_3 R_3 + I_1 R_2 + I_1 R_1 = E_1 \quad \text{—— (1)}$$

Closed loop AEDBA

$$-I_2 R_4 + I_1 R_2 + I_1 R_1 = E_1 - E_2 \quad \text{—— (2)}$$

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Parallel plate Capacitor →

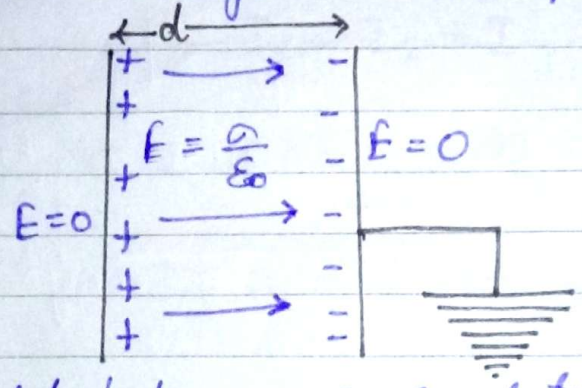
The simplest and the most widely used capacitor is the parallel plate capacitor. It consists of two large plane parallel conducting plates, seperated by a small distance.

A = Area of each plate

d = Distance between the two plates

$\pm\sigma$ = uniform charge densities on the two plates

$\pm Q$ = Total charge on each plate.



Electric field between two plates. $E = \frac{\sigma}{\varepsilon_0}$ —(1)

Sigma is surface charge densities. $\sigma = \frac{Q}{A}$ —(2)

from eq^n (1) & (2)

$$E = \frac{Q}{\epsilon_0 A} \quad \text{—(3)}$$

potential difference between these plates is

$$V = E\,d$$

$$V = \frac{Q\,d}{\epsilon_0 A} \quad \text{— [from eq}^n\text{(3)]}$$

capacity. $C = \frac{Q}{V} \rightarrow C = \frac{Q}{\frac{Q\,d}{\epsilon_0 A}}$

$$C = \frac{\cancel{Q} \times \epsilon_0 A}{\cancel{Q}\,d} \rightarrow \boxed{C = \frac{\epsilon_0 A}{d} \text{ Farad}}$$

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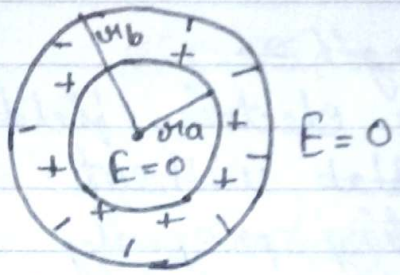
✡ Spherical plate capacitor →

A Spherical capacitor consist of two concentric Spheric Spherical ~~Shells~~ shells of inner and outer radii r_a and r_b.

The two shells carry charges $+Q$ and $-Q$ respectively.

Inside a hollow conductor, E is 0.

Outside the outer shell electric field is also 0.



$$V = \frac{KQ}{R}$$

$$V = V_A - V_B$$

$$V = \left[\frac{KQ}{r_a} - \frac{KQ}{r_b}\right]$$

$$V = KQ\left[\frac{1}{r_a} - \frac{1}{r_b}\right]$$

$$V = KQ\left[\frac{r_b - r_a}{r_a r_b}\right]$$

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

$$C = \frac{Q}{KQ\left[\frac{r_b - r_a}{r_a r_b}\right]}$$

$$C = \frac{r_a r_b}{K(r_b - r_a)} \rightarrow C = \frac{r_a r_b}{\frac{1}{4\pi\epsilon_0}(r_b - r_a)}$$

$$C = 4\pi\epsilon_0 \cdot \frac{r_a r_b}{r_b - r_a}$$

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✡ Dielectric →

- A dielectric substance is a substance which does not allow the flow of charges through it but permits them to exert electrostatics forces on one another through it.
- A dielectric is essentially an insulator which can be polarised through small localised displacements of its charges.

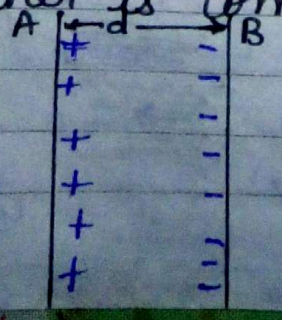
✡ Dielectric Strength →

The maximum electric field that can exist in a dielectric ~~stab~~ without causing the breakdown of its insulating property is called dielectric strength of the material.

✡ Capacitors with dielectric →

- when capacitor is completely filled with dielectric
- when capacitor is partially with dielectrics
- When capacitor is completely filled with two or more dielectric

(i) when capacitor is completely with dielectric —



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Capacity of parallel plate capacitor is —

$$C_0 = \frac{\epsilon_0 A}{d} \quad \text{—(1)}$$

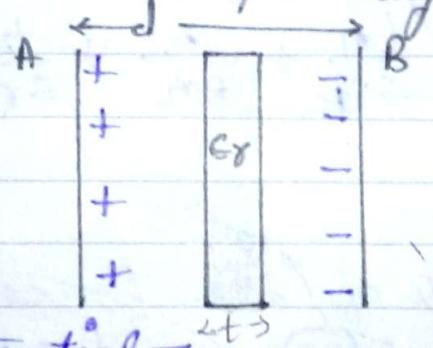
$$C_m = \frac{\epsilon_0 \epsilon_r A}{d} \quad \text{—(2)} \quad [\epsilon_m = \epsilon_0 \epsilon_r]$$

$$C_m = C_0 \epsilon_r$$

from eq^n (1) & (2)

$$\frac{C_0}{C_m} = \frac{\frac{\cancel{\epsilon_0} \cancel{A}}{\cancel{d}}}{\frac{\cancel{\epsilon_0} \epsilon_r \cancel{A}}{\cancel{d}}} \Rightarrow \epsilon_r$$

(ii) When capacitor is partially filled with dielectric s —



potential —

$$V = E_0 (d-t) + E_m t$$

$$V = \frac{Q}{\epsilon_0 A}(d-t) + \frac{Qt}{\epsilon_0 \epsilon_r A}$$

$$V = \frac{Q}{\epsilon_0 A}\left[d - t + \frac{t}{\epsilon_r}\right]$$

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

$$C = \frac{\cancel{Q}}{\frac{\cancel{Q}}{\epsilon_0 A}\left[d - t + \frac{t}{\epsilon_r}\right]} \rightarrow \boxed{C = \frac{\epsilon_0 A}{d - t + \frac{t}{\epsilon_r}}}$$

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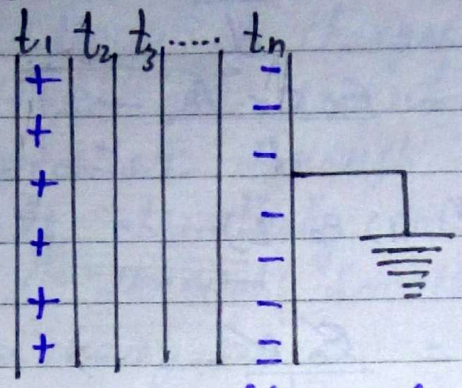
(iii) When capacitors is filled with two or more dielectrics



Let, the capacitor is filled with the dielectric constant $\epsilon_{r1}, \epsilon_{r2}, \epsilon_{r3}, \ldots \epsilon_{rn}$ with thickness $t_1, t_2, t_3 \ldots t_n$ respectively

$$C_m = \frac{\epsilon_0 A}{\left(\frac{t_1}{\epsilon_{r1}} + \frac{t_2}{\epsilon_{r2}} + \frac{t_3}{\epsilon_{r3}} \cdots \frac{t_n}{\epsilon_{rn}}\right)} \text{ farad}$$

Ques → find the ratio of the forces when two charges of $1.5\,\cancel{m}\,10^{-3}C$ and $0.2\,mC$ are placed at a distance of $1\,m$ in free space two inner medium having permitivity $2\epsilon_0$?

Solution → Given $\begin{cases} q_1 = 1.5\,mC = 1.5 \times 10^{-3} C, & r = 1\,m \\ q_2 = 0.2\,mC = 0.2 \times 10^{-3} C \end{cases}$

$$F = \frac{K q_1 q_2}{r^2}, \quad F_m = \frac{K q_1 q_2}{r^2}$$

$$F_0 = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}, \quad F_m = \frac{1}{4\pi 2\epsilon_0} \frac{q_1 q_2}{r^2}$$

$$\frac{F_0}{F_m} = \frac{\frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}}{\frac{1}{4\pi 2\epsilon_0} \frac{q_1 q_2}{r^2}}$$

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$$\frac{F_0}{F_m} = \frac{2\epsilon_0}{\epsilon_0} \rightarrow 2:1$$

Ratio of the forces is 2:1

Ques If the area of parallel plate capacitor is doubled and the distance between plates is half then what will be the effect of capacitance?

Ans- formula = $C = \frac{\epsilon_0 A}{d}$

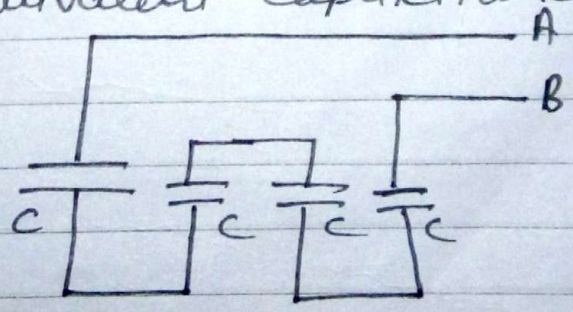
Given $\begin{cases} A = 2A \\ d = d/2 \end{cases}$

$$\Rightarrow C_1 = \frac{\epsilon_0 A \times 2 \times 2}{d}$$

$$\Rightarrow C_1 = \frac{4\epsilon_0 A}{d}$$

$$\Rightarrow C_1 = 4C$$

Ques → find equivalent capacitance between A & B?



Solution →

$$\frac{1}{C_S} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C} + \frac{1}{C}$$

$$\frac{1}{C_S} = \frac{4}{C}$$

$$C_S = \frac{C}{4}$$

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