CHAPTER # 14
ELECTROMAGNETISM

S/A

MAGNETISM

The study of the properties associated with a magnet is called magnetism.

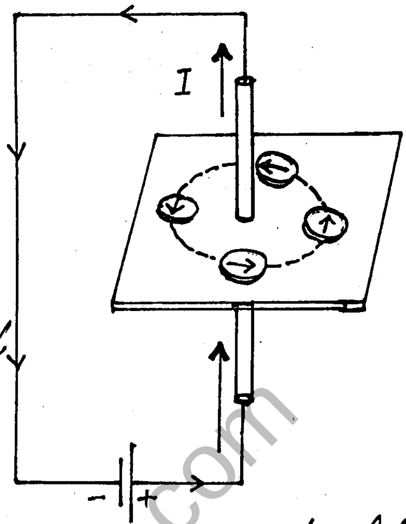
ELECTROMAGNETISM

It is defined as the study of the magnetic field associated with the moving charges or current.

MAGNETIC FIELD DUE TO CURRENT IN A LONG STRAIGHT WIRE

Prof. Hans Oersted was the first Scientist who discovered a magnetic field around a moving charge (current) in 1820. He showed that an electric current deflects a nearby Compass needle.

In order to investigate about the existance of magnetic field due to moving charges, Let us Consider a straight thick Copper wire that is passed vertically through a hole inside a Cardboard. place some Compass needles around this Conductor along a circular path with the centre at the wire. All of them will point the direction of N-S. When a heavy Current is passed through the wire, the needles are deflected along the tangent to the circle. If the direction of current in the wire is reversed, then the direction of needles is also reversed. If the current through the wire is stopped, the needles regain their original N-S position.



On the basis of above experiment, following conclusions can be made.

CONCLUSION

1# Magnetic field is setup in a space around a current carrying conductor.

2# The magnetic lines of force are circular and their direction depends upon the direction of current.

3# The magnet field lasts only as long as the current is flowing through the wire.

The direction of field lines can be found by right hand rule.

RULE # If the wire is grasped in the fist of right hand with erected thumb points the direction of current, then the encircling fingers indicate the direction of the magnetic field.

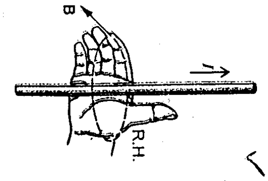


Fig. 14.1 (b)

FORCE ON A CURRENT CARRYING CONDUCTOR IN A UNIFORM MAGNETIC FIELD

As we already know that a current carrying conductor develops its own magnetic field. If such a conductor is placed inside an external magnetic field then it will experience a magnetic force due to interaction b/w its own field and applied external field.

To explain this fact, Let us consider a current carrying wire that is moving on a pair of conducting copper rails lying b/w the poles of a horse shoe magnet inside a field pointing vertically upward. When current is passed through the copper rod, it starts moving under the effect of a magnetic force which is always perpendicular to the plane containing rod and magnetic field B as shown in the fig. The results obtained from above experiments are

RESULTS

1 # Copper rod experiences no force when it is placed parallel to the magnetic field B.

and it experiences max force when it is placed at right angle to the magnetic field Hence force varies directly with $\sin\alpha$ i.e.

$$F \propto \sin\alpha$$

2# The force increases with the rise in magnitude of Current and vice versa. Thus force is directly related with the magnitude of Current I

$$F \propto I$$

3# Force is directly proportional to the length of the Conductor.

$$F \propto L$$

4# Copper rod experiences a greater force in strong magnetic field B. Hence it varies directly with B

$$F \propto B$$

By Combining all the above factors.

$$F \propto BIL\sin\alpha$$

$$F = K\,BIL\sin\alpha$$

In S.I units the value of Constant K is one or unity. Therefore

$$F = BIL\sin\alpha$$

$$\Rightarrow B = \frac{F}{IL\sin\alpha} \quad \text{———} (A)$$

DEFINATION OF B

In above equation (A)

if $I = 1A$, $L = 1m$ and $\alpha = 90°$ then

$$F = B$$

Def # Magnetic field or magnetic induction is defined as the force acting on 1m length of Conductor placed at right angle to the magnetic field when a current of 1Amp is passing through it

#UNIT OF B # From equation $B = \frac{F}{IL\sin\alpha}$

$$\text{unit of } B = \frac{N}{A\ m}$$
$$= N A^{-1} m^{-1} = \text{Tesla}$$

Hence the unit of B is called Tesla denoted by T.

#TESLA #

Magnetic field strength is said to be one tesla if it exerts a force of 1N on 1meter length of Conductor placed right angle to the magnetic field when 1Ampere Current passes through it

#VECTOR REPRENTATION #

In vector form magnetic force is given as $\vec{F_m} = F_m\,\hat{n}$

$$= ILB\sin\alpha\,\hat{n}$$
$$= I(\vec{L}\times\vec{B})$$

where $\hat{n}$ represents the direction of magnetic force at right angle to the plane containing $\vec{L}$ and $\vec{B}$ and is found by right hand rule

#RULE # Rotate $\vec{L}$ to concide with $\vec{B}$ through the smaller angle. Curl the fingers of right hand along the direction of rotation. The Thumb points the direction of force.

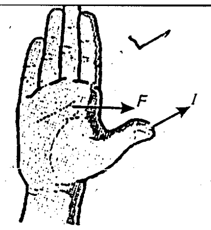


Fig. 14.3

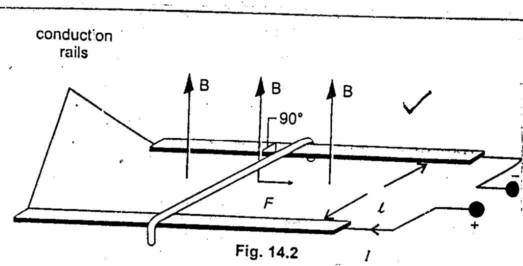
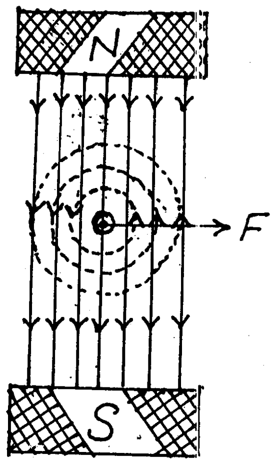


Fig. 14.2

ALTERNATIVE METHOD FOR DETERMINING THE DIRECTION OF MAGNETIC FORCE

In order to determine the direction of magnetic force convinently, let us consider a conductor is placed inside the magnetic field acting vertically downward. The current flowing inside the conductor is out of the page towards the reader represented by ⊙ but if it flows in to the page i.e. away from the reader then it will be represented by ⊗



It is clear from the figure that the line of forces are reinforcing on right hand side of the conductor produce a strong magnetic field while they cancel on the left side to produce a weak field. Hence the conductor tends to move towards right (weaker part) with a force F in a direction at right angle to both the conductor and the magnetic field B just satisfying the direction of $(\vec{L} \times \vec{B})$

EXAMPLE # 14.1

A 20.0 cm wire carrying a current of 10.0 A is placed in a uniform magnetic field of 0.30 T. If the wire makes an angle of 40° with the direction of magnetic field, find the magnitude of magnetic force acting on the wire.

 # SOLUTION # **Data :-**

length of the wire $= L = 20\,cm = 0.2\,m$

Current $= I = 10\,A$

$B = 0.30\,T$, $\theta = 40^\circ$

$F_m = ?$

$\because F_m = ILB\sin\alpha$

$= 10 \times 0.2 \times 0.3 \times \sin 40^\circ$

$= 0.386\,N \simeq 0.39\,N$

MAGNETIC FLUX AND FLUX DENSITY

MAGNETIC FLUX

Def:- The number of magnetic lines of force passing through a surface held perpendicular to the field lines is called magnetic flux

OR

It is the dot product of magnetic field $\vec{B}$ and area vector $\vec{A}$. Mathematically

$$\phi = \vec{B}\cdot\vec{A} = BA\cos\theta$$

where $\vec{A}$ is the vector area whose magnitude is equal to the area of surface element and direction is normal to the surface of the

UNIT

$$\phi = BA$$

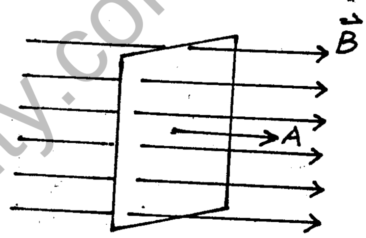
$$\text{unit of } \phi = \frac{N}{Am} \times A^2$$
$$= N\,m^{-1}A$$
$$= \text{weber}$$

Hence S.I unit of ϕ is $Nm^{-1}A$ or weber.

CASES

(a) MAXIMUM FLUX

The magnetic flux through a surface element is maximum when it is held perpendicular to the magnetic field lines i.e $\theta = 0$

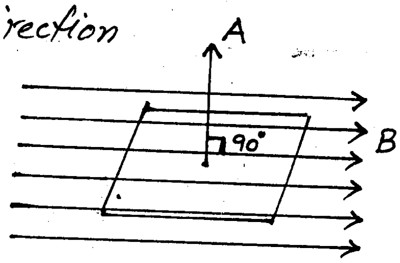


Hence $\phi = \vec{B}\cdot\vec{A} = BA\cos 0$

$\phi_{max} = BA \quad (\because \cos 0 = 1)$

(b) MINIMUM FLUX

when the surface element is placed parallel to the field lines then the direction of $\vec{B}$ and $\vec{A}$ are mutually perpendicular i.e. $\theta = 90°$



$\phi = \vec{B}\cdot\vec{A} = BA\cos 90°$

$\phi_{min} = 0$

FLUX THROUGH A CURVED SURFACE

For a curved surface placed in a non uniform magnetic field, the surface is divided in to large number of small flat patches. The flux through all these patches is individually calculated. The total flux is equal to the sum of flux through elements of the surface.

FLUX DENSITY

From equation $\phi = BA$

$$B = \frac{\phi}{A}$$

Def:- Flux density B is defined as the flux passing through a unit surface area held perpendicular to B. It is also called magnetic induction.

UNIT The unit of flux density is $\frac{\text{weber}}{m^2}$ which is also Called Tesla

EXAMPLE # 14.2

The magnetic field in a Certain region is given by $\vec{B} = (40\hat{i} - 18\hat{k})\ Wb\ m^{-2}$. How much flux passes through a 5.0 cm^2 area loop in this region if the loop lies flat in the xy-plane?

-: SOLUTION :- Data

$$\vec{B} = (40\hat{i} - 18\hat{k})\ Wb\ m^{-2}$$

$$\vec{A} = 5.0\ cm^2\ \hat{k} = 5.0 \times 10^{-4}\ m^2\ \hat{k}$$

$$\phi = ?$$

As
$$\phi = \vec{B} \cdot \vec{A}$$
$$= (40\hat{i} - 18\hat{k}) \cdot 5 \times 10^{-4}\ \hat{k}$$
$$= 200 \times 10^{-4} (\hat{i} \cdot \hat{k}) - 90 \times 10^{-4} (\hat{k} \cdot \hat{k})$$
$$= -90 \times 10^{-4}\ Wb.$$

AMPERE'S LAW AND DETERMINATION OF FLUX DENSITY B

A. M. Ampere was the first one who found the magnetic field quantatively around a long straight conductor. After performing so many experiments he concluded that magnetic field around a current carrying conductor is

(i) directly proportional to the current flowing through the conductor i.e.

$$B \propto I \quad \text{——— (1)}$$

(ii) inversly proportional to the distance r from the conductor

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

By combining the above two equations

$$B \propto \frac{I}{r}$$

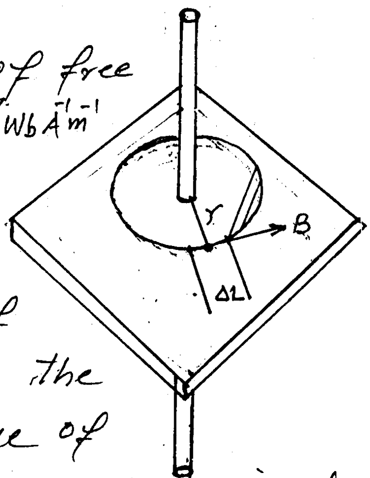
$$B = K\frac{I}{r}$$

where K is the constant of proportionality and its value is $\mu_0/2\pi$

μ_0 is called permeability of free space and its value is $4\pi \times 10^{-7}\ Wb\,A^{-1}m^{-1}$

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

$$B \times 2\pi r = \mu_0 I \quad \text{——— (A)}$$



where r is the distance of point on the circle around the conductor on which the value of B is to be determined. Let this circular path is divided in to n number of small patches of length $\Delta L_1, \Delta L_2 \cdots\cdots \Delta L_n$. Then the value of $\sum_{r=1}^{n}(\vec{B}\cdot\vec{\Delta L})_r$ is

$$\sum_{r=1}^{n}(\vec{B}\cdot\vec{\Delta L})_r = (\vec{B}\cdot\vec{\Delta L})_1 + (\vec{B}\cdot\vec{\Delta L})_2 + \cdots\cdots + (\vec{B}\cdot\vec{\Delta L})_n$$
$$= B\Delta L_1 \cos\theta + B\Delta L_2 \cos\theta + \cdots\cdots + B\Delta L_n \cos\theta$$

As the Component $B\cos\theta$ for all these patches is parallel to their lengths Hence $\theta = 0$ & $\cos\theta = 1$

So $$\sum_{r=1}^{n}(\vec{B}\cdot\vec{\Delta L})_r = B\Delta L_1 + B\Delta L_2 + \cdots\cdots + B\Delta L_n$$
$$= B(\Delta L_1 + \Delta L_2 + \cdots\cdots \Delta L_n)$$
$$= B\,(\text{length of closed circular path})$$
$$\sum_{r=1}^{n}(\vec{B}\cdot\vec{\Delta L})_r = B \times 2\pi r \quad \text{------ } (B)$$

Comparing eq (A) and equation (B)

$$\sum_{r=1}^{n}(\vec{B}\cdot\vec{\Delta L})_r = \mu_0 I \quad \text{— } (C)$$

STATEMENT

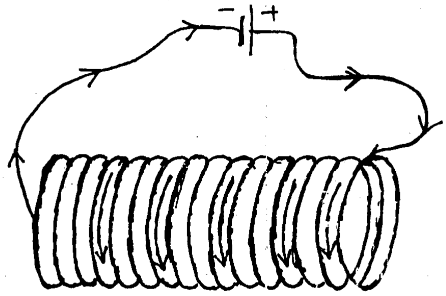
It can be stated that the dot product of magnetic field and path length of any closed path around a Conductor is equal to the product of μ_0 and the total current enclosed by the path

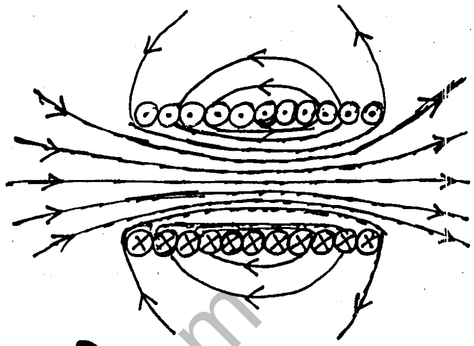
FIELD DUE TO A CURRENT CARRYING SOLENOID

Def:- A solenoid is a long insulated Copper wire wound closely and evenly on a cylindrical frame of some non magnetic material.

The magnetic field inside the

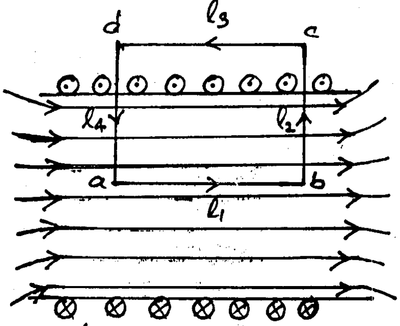
Solenoid is uniform and much stronger while it is so weak outside the solenoid that it can be neglected as compared to the field inside.





DETERMINATION OF B

In order to determine the value of B, consider a rectangular closed path abcd containing faces of lengths l_1, l_2, l_3 and l_4 respectively as shown in the fig. By applying Ampere's law to all these elements of the closed path i.e.



$$\sum_{r=1}^{4} (\vec{B}\cdot\vec{\Delta L})_r = \mu_o \times I'$$

where I' is the total current enclosed by the path.

On expanding the above equation.

$$(\vec{B}\cdot\vec{\Delta L})_1 + (\vec{B}\cdot\vec{\Delta L})_2 + (\vec{B}\cdot\vec{\Delta L})_3 + (\vec{B}\cdot\vec{\Delta L})_4 = \mu_o I' \quad (1)$$

For element ab length l_1 is parallel to the magnetic field B therefore

$$\vec{B}\cdot\vec{\Delta L_1} = B\cdot\Delta l_1 \cos 0$$

$$= B\Delta L_1$$

$$\text{but} \quad \Delta l_1 = l_1$$

$$\therefore \quad \vec{B}\cdot\vec{\Delta L_1} = Bl_1$$

For element $cd = l_3$ that lies outside the solenoid, the field B is equal to zero hence

$$\vec{B} \cdot \Delta\vec{L}_3 = B\Delta L_3 \cos 180^\circ = 0 \times \Delta L_3 \cos 180$$
$$= 0$$

For elements $bc = l_2$ and $da = l_4$, magnetic field is perpendicular to the lengths of the elements i.e. $\theta = 90^\circ$

$$\therefore \quad \vec{B} \cdot \Delta L_2 = B\Delta L_2 \cos 90^\circ = 0$$
$$\vec{B} \cdot \Delta L_4 = B\Delta L_4 \cos 90^\circ = 0$$

Hence by using these values in equation we have

$$Bl_1 + 0 + 0 + 0 = \mu_o I'$$
$$\text{or} \quad Bl_1 = \mu_o I' \quad \text{———} (2)$$

In order to find the Current enclosed, we Consider a rectangular surface bounded by the loop abcda. If n be the number of turns per unit length of solenoid, then the number of turns intercepted by the rectangular surface of length l_1 will be nl_1. Let I be the Current passing through each turn then the total current enclosed by the loop is $nl_1 I$ i.e. $I' = nl_1 I$

using the value of I' in equation (2) we have

$$Bl_1 = \mu_o n l_1 I$$
$$\text{or} \quad B = \mu_o n I$$

The direction of B inside the solenoid is found by right hand rule

RULE # Hold the solenoid in the right hand with fingers curling in the direction of the current, The thumb will point in the direction of the field.

EXAMPLE # 14.3

A Solenoid 15 cm long has 300 turns of wire. A Current of 5A flows through it. What is the magnitude of magnetic field inside the Solenoid?

-: SOLUTION :-

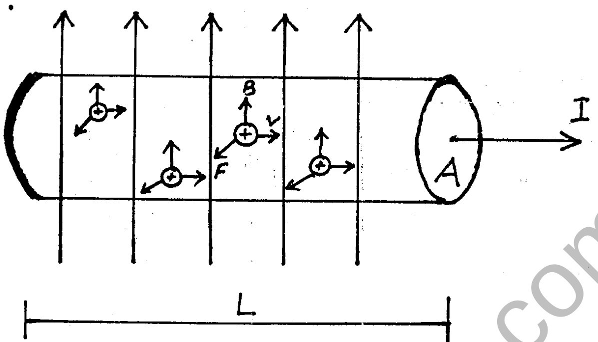
length of solenoid = $l = 15cm = 0.15m$
number of turns = $N = 300$
Current = $I = 5A$
Permeability of free space = $\mu_o = 4\pi \times 10^{-7}\ Wb\,m^{-1}A^{-1}$
$B = ?$

$$\because B = \mu_o n I$$
$$= \mu_o \frac{N}{l} I \quad (\because n = \frac{N}{l})$$
$$= 4\pi \times 10^{-7} \times \frac{300}{.15} \times 5$$
$$= 1.256 \times 10^{-2}$$
$$\simeq 1.3 \times 10^{-2}\ weber/m^2$$
$$= 1.3 \times 10^{-2}\ Tesla$$

FORCE ON A MOVING CHARGE IN A MAGNETIC FIELD

A current carrying Conductor experiences a force inside the magnetic field due to interaction b/w field of moving charges and that of applied external field. When the current is flowing inside the Conductor, we are interested in Calculating the force exerted on the moving charges.

Let us consider a wire segment of length L having area of cross-sectional area A is placed inside a magnetic field B pointing vertically upward. Let I be the current flowing inside the wire segment and n be the number of charge carriers per unit wire of the wire.



DETERMINATION OF MAGNETIC FORCE

The magnitude of the magnetic force experienced by the wire segment can be computed as under.

Volume of wire of length L and area of cross-section A $= AL$

number of charge carriers in unit volume $= n$

Total number of charge carriers in AL volume $= nAL$

charge on a single charge carrier $= q$

Total charge moving due to nAL carriers $= \Delta Q = nALq$

Assuming v be the velocity of single charge q and Δt be the time by the charge in moving b/w the two ends of wire segment. then

$$\Delta t = \frac{L}{v} \qquad (\because t = \frac{S}{v})$$

If a charge ΔQ exit from right end face in time Δt then the current I flowing inside the wire segment is

$$I = \frac{\Delta Q}{\Delta t} = \frac{nALq}{L/v}$$

$$I = nAvq$$

As force on a Conductor L Carrying a Current I is

$$\vec{F}_L = I\,\vec{L}\times\vec{B}$$

$$\vec{F}_L = nAqv\,\vec{L}\times\vec{B}$$

Since the direction of segment L is along the direction of velocity of charge carriers therefore $\hat{L} = \hat{v}$ Hence

$$v\vec{L} = vL\hat{L} = vL\hat{v} = Lv\hat{v} = L\vec{v}$$

So $$F_L = nAqL\,\vec{v}\times\vec{B}$$

This is the magnetic force acting on the conductor due to nAL charge carrier. The force experienced by a single charge carrier is

$$\vec{F} = \frac{\vec{F}_L}{nAL} = \frac{nALq\,\vec{v}\times\vec{B}}{nAL}$$

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

The force experienced by -ively charge carrier electron is

$$\vec{F} = -e(\vec{v}\times\vec{B}) \qquad (\because q_{elec} = -e)$$

The force experienced by +ively charge carrier proton is

$$\vec{F} = +e(\vec{v}\times\vec{B}) \qquad (\because q_{Pro} = +e)$$

DIRECTION OF MAGNECTIC FORCE

Direction of magnetic force on proton is Obtained by rotating $\vec{v}$ through smallest possible angle untill it Concides with $\vec{B}$. The proton is deflected vertically upward to plane Containing $\vec{v}$ and $\vec{B}$

As far as the electron is Concerned, it is deflected vertically downward in to the magnetic field $\vec{B}$ due to its reverse charge.

CASES (a) MAXIMUM FORCE :-

Since magnetic force on a charge carrier is

$$F = qvB\sin\theta$$

where θ is the angle b/w v and B
if the particle is projected at right angle to B then $\theta = 90°$ and it will experience max. force.

$$F = qvB\sin 90° = qvB \quad (\because \sin 90° = 1)$$

b) MINIMUM FORCE:

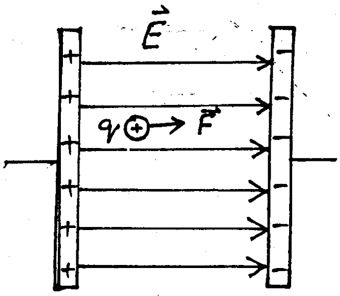
when charge carrier is moving parallel to the magnetic field i.e. $\theta = 0°, 180°$ then it remains undeflected

$$F = qvB\sin 0° = 0 \quad (\because \sin 0° = 0)$$

$$F = qvB\sin 180° = 0 \quad (\because \sin 180° = 0)$$

MOTION OF CHARGE PARTICLE IN ELECTRIC AND MAGNETIC FIELD

When a charge q is placed inside a field $\vec{E}$ b/w the two oppositly charged plates then it experiences an electric force along the direction of field and is given by



$$F = qE$$

If mass of charge particle is m then the acceleration acquired by it under the effect of electric force is

$$a = \frac{F}{m} = \frac{qE}{m}$$

The acceleration will be uniform due to uniform field between the two plates.
If now the charge particle q is moving with

velocity v inside a space where an electric and magnetic fields are existed, then the total force acting on a charge q is equal to the sum of electric and magnetic forces therefore

$$\vec{F} = \vec{F_e} + \vec{F_m}$$
$$= q\vec{E} + q(\vec{V} \times \vec{B})$$

work is done only by the electric force while magnetic force is used to deflect the charge particle.

DETERMINATION OF e/m OF AN ELECTRON

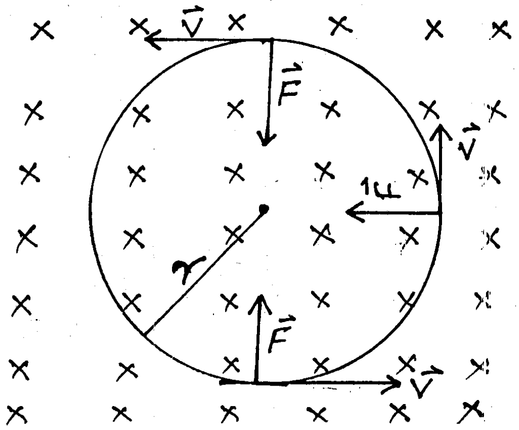
J.J. Thomson was the first scientist who found the e/m of an electron in 1897.

:EXPERIMENT:-

Consider an electron is projected with velocity v at right angle to the magnetic field B directed in to the plane of the paper. It experiences a force given by

$$\vec{F_m} = -e(\vec{V} \times \vec{B})$$

The direction of this force is perpendicular to the plane containing $\vec{V}$ and $\vec{B}$ as shown in the fig.



As the force F is at right angle to v therefore it tends to change the direction of velocity by keeping its magnitude constant. As the charge is projected at right angle to $\vec{B}$, therefore it will be under the influence of magnetic force which is given as

$$F_m = qvB\sin\alpha$$

Here $q = e$, $\alpha = 90°$ ($\because V \perp B$)

$$\therefore \quad F_m = evB\sin 90$$

$$F_m = evB \quad \text{—— (A)}$$

As the magnitude of $\vec{V}$ and $\vec{B}$ doesn't vary. therefore the electron follows a circular path under the effect of constant magnetic force. This force deflects the charge particle to move along a circular path of radius r by providing it a necessary Centripetal force. Hence

$$F_m = F_c$$

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

$$\Rightarrow e/m = \frac{v}{Br} \quad \text{—— (B)}$$

By knowing the values of v and r, e/m of electron can be determined.

DETERMINATION OF R

The radius of the circular path followed by electron can be measured by making its path visible. For this electron beam is projected inside a Leybold Tube filled with hydrogen at a very low pressure. This beam is deflected along a circular path by applying a uniform magnetic field of known value. The beam of electron collides with the hydrogen atom due to which they are excited. On dexcitation these atoms emit light to make the path of electrons visible and it looks like a glowing circle. The diameter and hence radius of this circle is determined.

DETERMINATION OF VELOCITY V BY POTENTIAL DIFFERENCE METHOD

In this method, the electron is accelerated through a potential difference V before entering in to the magnetic field. The energy acquired by the electron is equal to eV and it appears as its K.E. Hence

$$K.E. = eV$$

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

$$v^2 = \frac{2eV}{m}$$

$$v = \sqrt{\frac{2eV}{m}} \qquad \text{(C)}$$

By using the value of v in equation (B)

$$e/m = \sqrt{\frac{2eV}{m}} \Big/ Br$$

Squaring both sides

$$e^2/m^2 = \frac{2eV}{m\, B^2 r^2}$$

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

By using the values of V, B and r, e/m of electron can be computed.

The most accurate value of e/m of an electron is 1.7588×10^{11} C/Kg.

EXAMPLE 14.4

Find the radius of an orbit of electron moving at a rate of $2.0\times10^{7}\,ms^{-1}$ in a uniform field of $1.20\times10^{-3}\,T$.

#SOLUTION #

$e = 1.6\times10^{-19}\,C$

$V = 2.0\times10^{7}\,ms^{-1}$

$B = 1.20\times10^{-3}\,T$

$m = 9.11\times10^{-31}\,Kg$

$r = ?$

Since we know that $F_{Cen} = F_{mag}$

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

$$r = \frac{mv}{eB} = \frac{9.1\times10^{-31}\times2.0\times10^{7}}{1.6\times10^{-19}\times1.20\times10^{-3}}$$

$$r = 9.47\times10^{-2}\,m$$

EXAMPLE 14.5#

Alpha particles ranging in speed from $1000\,ms^{-1}$ to $2000\,ms^{-1}$ enter in to a velocity selector where the electric intensity is $300\,Vm^{-1}$ and the magnetic induction is $0.20\,T$ which particle will move undeviated

#SOLUTION #

$E = 300\,Vm^{-1}$

$B = 0.20\,T \qquad V = ?$

For the particle to remain undeflected in cross electric and magnetic fields, The electric force must be equal to the magnetic force i.e.

$$F_m = F_e$$

$$qVB = qE$$

$$VB = E$$

$$\Rightarrow V = \frac{E}{B} = \frac{300}{0.20}$$

$$V = 1500\ ms^{-1}$$

Hence the alpha particle having a speed of $1500\ ms^{-1}$ will move undeviated through the field.

CATHODE RAY OSCILLOSCOPE

 # DEFINATION # An electronic device which is used to display graphs of different functions which rapidly vary with time. As it traces the desired waveform by using an electronic beam (Cathode rays) Hence it is also called Cathode ray oscilloscope or CRO

 # PRINCIPLE #

It works on the principle of deflecting an electronic beam through a uniform electric field b/w the two set of parallel plates to produce a variety of electrical signals in visual form.

 # CONSTRUCTION #

The basic unit of CRO is electron gun which comprises the following main parts.

 # CATHODE # To produce an electronic beam when heated.

 # GRID # It controls the number of accelerated electrons which inturn controls the brightness of lighted spot formed on the screen.

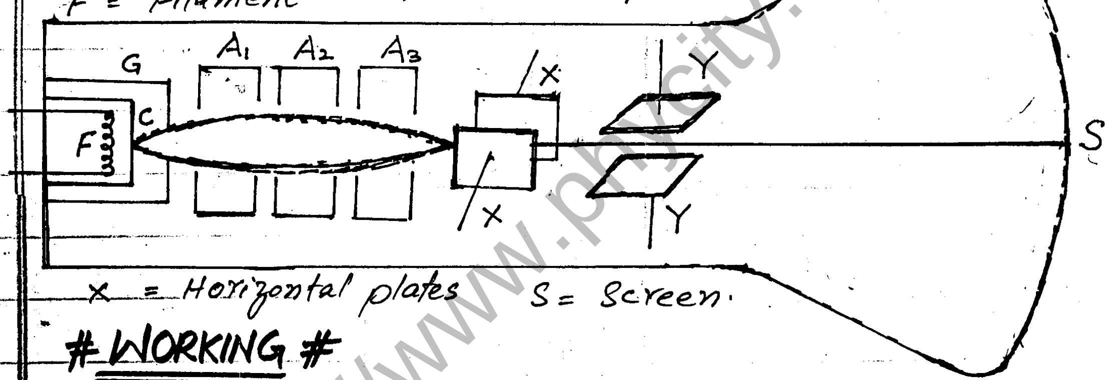
 # ANODES # High potential electrodes which are positive w.r.t Cathode and Cause the electronic beam to accelerate.

HORIZONTAL AND VERTICAL PLATES

These set of plates deflect the electronic beam along horizontal and vertical directions respectively.

#SCREEN# It Converts and focus the beam of electrons in to visible light according to the elec. signals either done electrostatically or electromagnetically or by a Combination of both methods.

G = Grid
C = cathode
F = Filament
A_1, A_2, A_3 = Anodes
Y = vertical plates



X = Horizontal plates S = Screen.

WORKING

The beam of electron emitted from the heated filament is accelerated by the highly potential anodes and is passed through a uniform electric field b/w the two set of plates. The deflected beam falls on the flourescent screan where it makes a visible spot.

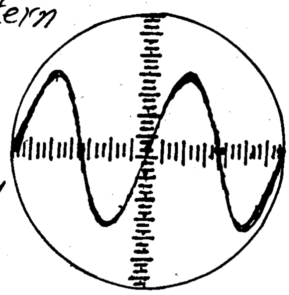
Now we shall see how the wave form of different voltages can be generated in CRO.

PRODUCTION OF SAW TOOTH WAVE

The voltage that is applied to x-plates deflects the electronic beam horizontally and is provide by a circuit called sweep or time base generator inside the CRO. Its output waveform is a sawtooth wave of time period T. The voltage increases linearly for a time period T and then drops to zero. As this voltage is impressed across the x plates. The spot is deflected linearly with time T along x-axis. The spot of light returns to its starting position very quickly on the falling of sawtooth wave to its initial value after time T. In case of short time period we just see a bright line on the screen.

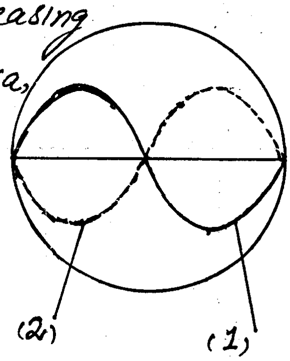
PRODUCTION OF SINUSOIDAL (SINE) WAVE

When the sinusoidal voltage is applied on Y plates (Vertical plates) and time base voltage is applied on x plates (Horizontal plates). The sinusoidal voltage along y-axis expands along x-axis to produce a sinusoidal trace on the screen. The wave pattern will become stationary if the time T become equal or some multiple of time period of the voltage applied on y plates. For this the frequency of time base generator matches with the frequency of voltage on y plates. It can be done by adjusting the synchronization control provided on the front panel of CRO.



USES OF CRO

(1) It can be used to display the wave pattern of a given voltage.
(2) The voltage, frequency and the phase of displayed wave form can be found by CRO.
(3) Time period of a wave can be determined by time caliberation of x-axis
(4) we can easily calculate the instantaneous value and peak value of voltage due to caliberation of volts along y-axis and that of time along x-axis
(5) The phase difference b/w the two voltages can be measured by displaying their waveform simultaneously. e.g. If the voltage 1 is increasing and that of 2 is decreasing vice versa, then the phase difference between these two voltages is 180°

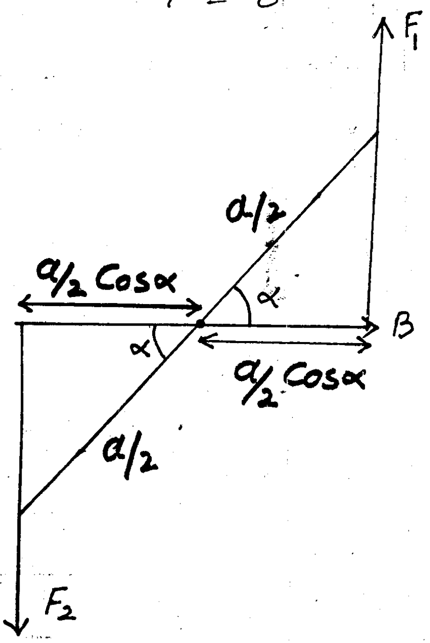


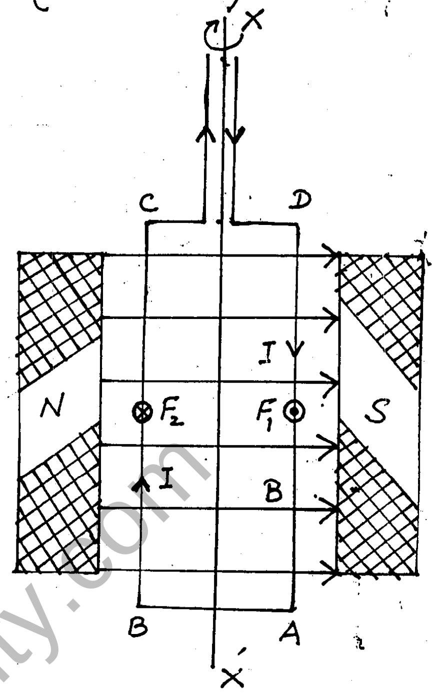
TORQUE ON A CURRENT CARRYING COIL

Consider a rectangular coil of length L and breadth a carrying a current I and is placed inside a magnetic field B with its plane parallel to B. Due to interaction b/w its own field and field of external magnet, it experiences a magnetic force F. The fig shows that its two faces AB and CD are parallel to the magnetic field and hence experiences no force i.e.

$F = BIL \sin 0 \quad (\because L \parallel B)$

$F = 0$





But the faces BC and DA being right angle to the field B experiences equal and opposite force of magnitude $F_1 = F_2 = ILB \sin 90^\circ = ILB$ and constitute a couple which tends to rotate the coil in the counter clockwise direction. The torque due to couple is

$$\tau = \text{Force} \times \text{Arm of Couple}$$

$$\tau = F \times a$$

$$= BIL \times a$$

$$= BIA \qquad (\because A = La)$$

This is the case when the plane of the coil is parallel to the field.

If now at any instant the coil makes an angle α to the magnetic field B then the couple produced in this particular case is

$$\tau = \tau_{DA} + \tau_{BC}$$
$$= BIL \times \frac{a}{2} \cos\alpha + BIL \times \frac{a}{2} \cos\alpha$$
$$= 2 BIL \frac{a}{2} \cos\alpha$$
$$= BIL a \cos\alpha$$
$$\tau = BIA \cos\alpha$$

GALVANOMETER

#Def# An electromechanical device which is used to detect the passage of very small current is called galvanometer.

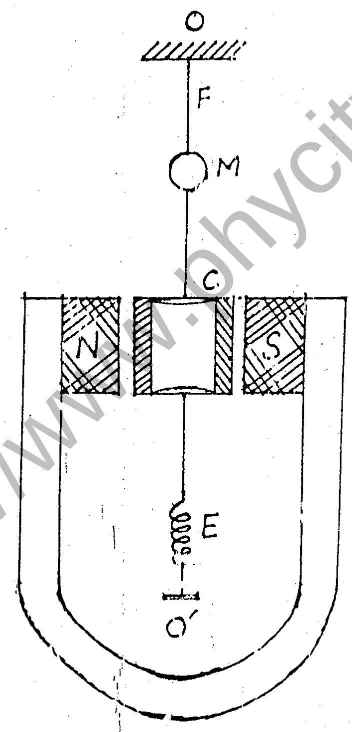
Moving coil galvanometer was originally developed by a French scientist D'Arsonval. The modern moving coil galvanometer is the result of work of Dr. Edward Weston.

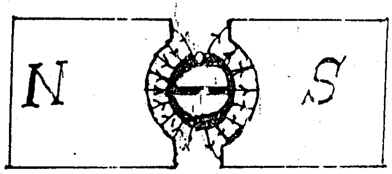
Principle

Its working is based on the fact that a current carrying coil inside a magnetic field always experiences a torque which tends to rotate it about its axis.

Construction

It consists of a rectangular coil C suspended b/w the concave pole pieces of a U shaped magnet by means of a suspension wire F. The coil is made of an enameled Copper wire wound on a frame of some non magnetic material. The suspension wire F acts as one Current lead while the other terminal of the Coil is Connected to a loosely wound spiral E which Serves as a Second Current lead. The mirror M attached with the suspension wire used to determine the deflecting angle θ. The pole pieces of the magnet are made Concave to make the field radial and stronger.





Working

Let N be the number of turns of the coil and A be its area of cross-section. When I current is passed through the coil placed in a magnetic field B then the coil is deflected through an angle α. The deflecting torque experienced by the coil is given as

$$\tau_{Def} = NBIA \cos\alpha \quad \text{——— (A)}$$

where α is the angle b/w the plane of the coil and magnetic field.

Due to this deflecting torque, the suspension wire is twisted that give rise to a torsional couple. This couple tends to untwist the suspension wire to restore its original position hence it is also called restoring torque. It is experimently observed that if the coil obey the Hook's Law then restoring torque (couple) is directly proportional to the deflecting angle θ

i.e. $\tau_{rest} \propto \theta$

$$\Rightarrow \tau_{rest} = C\theta \quad \text{——— (B)}$$

where C is constant and is called torsional couple and is defined as couple for unit twist. Under the effect of both these couple, the coil comes in to its state of rest or equilibrium if

$$\tau_{Def} = \tau_{rest}$$

$$NBIA \cos\alpha = C\theta$$

$$I = \frac{C}{NBA\cos\alpha}\theta$$

As the coil is placed in a radial field Hence the plane of the coil will be parallel to the magnetic field B i.e. $\alpha = 0$

$$\therefore \quad I = \frac{C}{NBA}\theta \quad (\because \cos 0 = 1)$$

If $\frac{C}{NBA}$ is constant then $I \propto \theta$

Thus the current passing through the coil is directly proportional to the angle of deflection.

METHOD FOR MEASURING ANGLE OF DEFLECTION

There are two methods commonly used for observing the angle of deflection of coil

1- Lamp and scale method (arrangement)
2- pivoted type galvanometer

#1# LAMP AND SCALE ARRANGEMENT

In this method a beam of light from the lamp is directed towards the mirror M attached to the coil of galvanometer. After reflecting from the mirror, it produces a spot on a translucent scale placed at a distance of one meter from the galvanometer. When the coil rotates, the mirror attached to the coil also rotates and spot of light moves along the scale. The displacement of the spot of light on the scale is proportional to the angle of deflection provided that the displacement is very small.

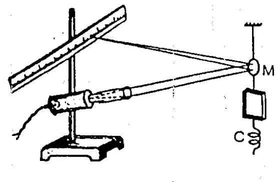


Fig. 14.17

PIVOTED TYPE GALVANOMETER

The galvanometer used inside the scientific laboratories is called pivoted type galvanometer. In this type of galvanometer, the coil is pivoted b/w two jewelled bearings. The restoring torque is provided by two hair springs which also serve as current leads. A light aluminium pointer is attached to the coil which moves over a scale and gives the angle of deflection of coil. This type of galvanometer is less sensitive but portable than suspended coil type galvanometer.

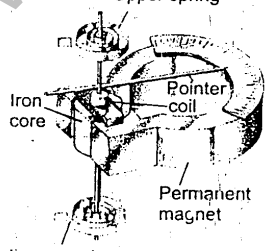


Fig. 14.1

SENSITIVITY OF A GALVANOMETER

#Def# A very small current in mA that produces a deflection of 1mm on a scale held at a distance of 1m from a galvanometer is called sensitivity of the galvanometer.

HOW TO MAKE GALVANOMETER MORE SENSITIVE

Since we know that

$$I = \frac{C}{BNA}\,\theta$$

The galvanometer will be more sensitive if the angle θ is very large. For this the factor $\frac{C}{BNA}$ should be very small. It can be done by

(i) increasing the number of turns N, but it makes the coil heavy

(ii) increasing the area of cross-section of coil that affects the dimensions of coil and makes it less portable.

(iii) decreasing the value of C which makes the suspension wire very thin and less durable.

(iv) increasing the intensity of magnetic field B which is convinient and appropriate method to make the galvanometer more sensitive. It doesn't affect the dimensions of the coil and can be done by inserting an iron cylinder inside the coil and by making the field radial.

#N.B# It is often observed that when current is passed through the coil of a galvanometer, it keeps on oscillating and will not come to rest as soon as the current flowing through the coil is stopped. A lot of time is consumed to wait for the coil to come in to its equilibrium state.

STABLE OR DEAD BEAT GALVANOMETER

#Def# A galvanometer in which the coil comes to rest quickly after the current passed through it is stopped is called stable or a dead beat galvanometer.

AMMETER

Def:-

A device used for measuring current in amperes is called ammeter. It is the modified form of moving coil galvanometer.

Meter movement

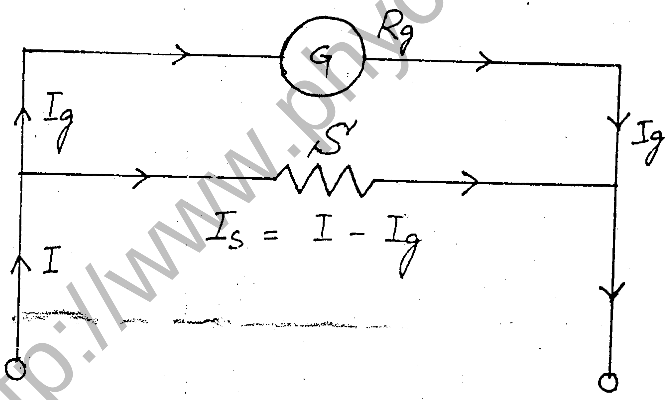
The portion of the galvanometer whose motion causes the needle of the device to move across the scale is usually called meter movement.

Many meter movements are very sensitive and gives full scale deflection for a very small current in milliampare. Hence a need of modification arises in such devices for measuring large currents.

CONVERSION OF GALVANOMETER IN TO AMMETER:

Suppose we have a galvanometer whose meter movement (coil) has a resistance R_g and which gives a full scale deflection when a current I_g is passed through it. The potential difference V_g across it's ends according to Ohm's law is given as

$$V_g = I_g R_g$$



In order to convert a galvanometer in to an ammeter to measure a maximum current I, such value of bypass resistance or shunt S is connected in parallel with the galvanometer so that I_g current for full deflection of galvanometer passes through the galvanometer. As meter movement is parallel to the shunt

Therefore

$$V_s = V_g$$

$$I_s R_s = I_g R_g$$

$$\Rightarrow R_s = I_g R_g / I_s.$$

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

Shunt resistance is so small that only a piece of copper wire can serve the purpose. As low resistance (shunt) is connected in parallel to the galvanometer, hence ammeter is called low resistance galvanometer. Due to its low resistance, it doesn't disturb the circuit. It is always connected in series inside the electrical circuit.

VOLTMETER

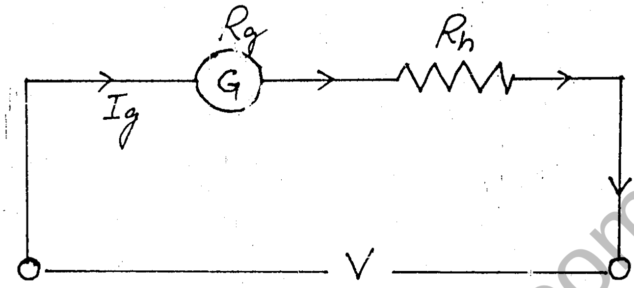
#Def# An electrical device used to measure the potential difference b/w the two points is called voltmeter.

It is also the modified form of moving coil galvanometer and is always connected in parallel inside the electrical circuit.

CONVERSION OF GALVANOMETER IN TO VOLTMETER#

Suppose we have a meter movement (coil) of resistance R_g which gives a full scale deflection when a current I_g is passed through it.

In order to convert it in to a voltmeter, a high resistance R_h is connected in series with the meter movement which gives a full scale deflection when connected across a potential difference V.



As same current I_g is flowing through R_g and R_h. Hence by applying Ohm's Law

$$V = I_g(R_g + R_h)$$

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

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

$$\Rightarrow \quad R_h = \frac{V}{I_g} - R_g$$

By connecting a proper value of R_h in series with the meter movement, any voltage can be measured. Before connecting a voltmeter in a circuit, it should be assured that its resistance should be very high as compare to the resistance of the circuit otherwise it will load the circuit and will vary the required voltage to be measured. As a high resistance is connected in series along with the galvanometer, hence it is also called a high resistance galvanometer.

EXAMPLE # 4.6

What shunt resistance must be connected across a galvanometer of $50.0\,\Omega$ resistance which gives full scale deflection with $2.0\,mA$ current, so as to convert it in to an ammeter of range $10.0\,A$?

SOLUTION

Data

Resistance of galvanometer $= R_g = 50.0\,\Omega$

Current for full scale deflection $= I_g = 2.0\,mA$
$= 2.0 \times 10^{-3}\,A$

Current to be measured $= I = 10.0\,A$

Shunt Resistance $= R_s = ?$

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

$$= \frac{2.0 \times 10^{-3}\,A}{10.0\,A - 2.0 \times 10^{-3}\,A} \times 50.0\,\Omega$$

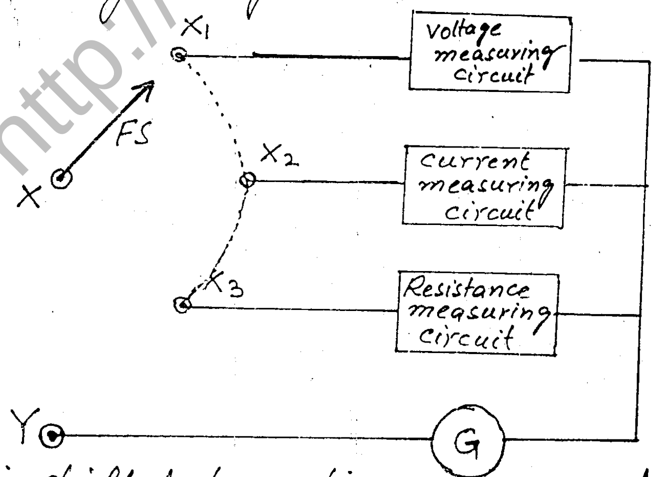
$$= 0.01\,\Omega$$

AVO METER – MULTIMETER

Def:- An electrical device which can measure current in amperes, potential difference in volts and resistance in ohms is called Avometer.

#CONSTRUCTION#

Avometer basically consists of a sensitive moving coil galvanometer which can be converted in to a multirange Ammeter, Voltmeter or Ohmmeter accordingly as a current measuring circuit or a voltage measuring circuit or a resistance measuring circuit connected with the galvanometer with the help of a switch called function switch F_S. X & Y are the main terminals of the Avometer connected with the circuit in which the measurement is required. For measuring voltage, current and resistance, the function

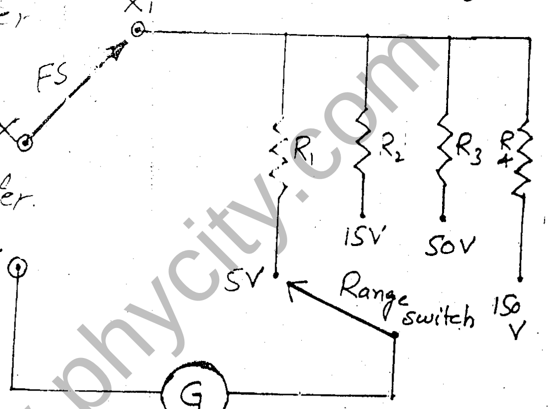


switch is shifted to positions X_1, X_2 and X_3 respectively.

VOLTAGE MEASURING PART OF AVOMETER#

In order to use Avometer as a voltmeter

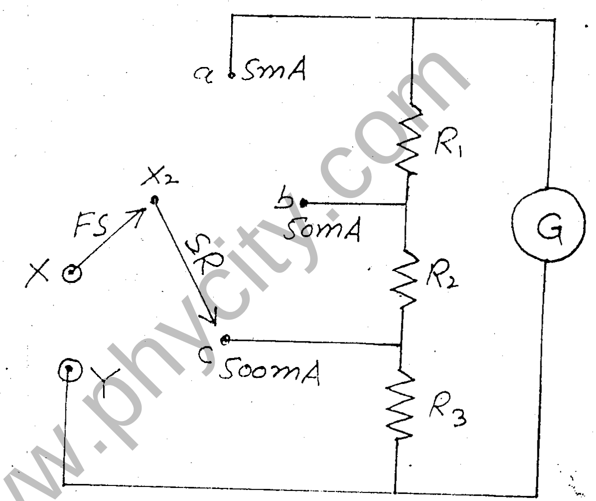
The function switch FS is shifted to position X_1. Since we know that a galvanometer can be converted in to a voltmeter by connecting a high resistance in series with the galvanometer. In multirange voltmeter, a series of high resistance called multiplier is connected in series with the galvanometer. Avometer has several voltage ranges. A desired range is selected by range switch. Greater will be the multiplier resistance, greater will be the range of voltmeter.



Avometer can also have an ability to measure the AC voltage but for this AC voltage is firstly converted in to DC voltage by using diode as a rectifier and then employed to the device for measurement.

CURRENT MEASURING PART OF AVOMETER

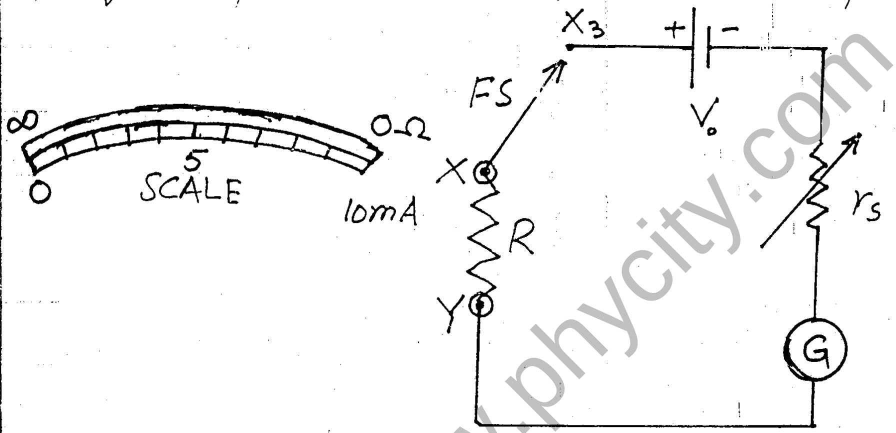
Since we know that a galvanometer can be converted in to an ammeter by connecting a low resistance (shunt) in parallel with the galvanometer. For using Avometer as an ammeter the function switch FS is shifted to the point X_2. For multirange Ammeter, The current measuring circuit consists of a series of shunt (low) resistances called Aryton or universal shunt that is connected in parallel with the galvanometer. Larger will be the value of shunt, smaller will be the range of an ammeter as selected by a range switch SR.



RESISTANCE MEASURING PART OF AVOMETER

To use Avometer as an Ohmmeter for measuring resistance, a galvanometer along with a controlling resistance r_s is connected in series with a cell (Internal Battery).

Before measuring the unknown resistance, the function switch FS is switched on to position X_3. Also the circuit in which resistance R is to be tested is switched off. The value of Controling resistance r_s is adjusted in such a way that the terminals X and Y are short circuited i.e. when $R=0$ the galvanometer gives full scale deflection and is marked as 0 for resistance measurement. When terminals X and Y are not joined, no current flows through the galvanometer. Thus the zero of the scale is marked as infinity ∞.



when the resistance R is not infinite, the galvanometer deflects to some intermediate point depending upon the value of resistance R. The amount of deflection on scales shows directly the magnitude of the resistance. The measurement of resistance is independent of the polarity of the internal cell. Avometers Can measure resistance from less than one ohm up to many megaohms.

DIGITAL MULTIMETER

 # Def # A device which displays the values of current, voltage and resistance in the form of numbers composed of digits is called digital multimeter.

Its accuracy is much higher as compared to an ordinary Avometer because it eliminates the human error that often occurs in reading the dial of Avometer. It also displays the polarity and the unit of V, A and Ω. A portable digital multimeter (DMM) is shown in the fig.