CHAPTER 4
MOVING CHARGES AND MAGNETISM

INTRODUCTION

- Earlier it was thought that there is no connection between electricity and magnetism.
- in 1820 Christian Oersted observed that, When a compass needle brings very close to a current carrying conductor , the compass needle deflects. ie, just as a static charges produces an electric field , a current or moving charges produces a magnetic field (in addition)

MAGNETIC FIELD

It is the region around a magnetic dipole or a current carrying conductor where which other magnetic dipoles or current carrying conductor experiences a force of attraction or repulsion.

MAGNETIC INDUCTION VECTOR
(Or)
MAGNETIC FLUX DENSITY
(Or)
MAGNETIC FIELD (B)

The strength and the direction of the magnetic field is specified by a quantity called magnetic induction , $\vec{B}$

- Unit : weber/metre^2 (Or) tesla

MAGNETIC FIELD LINES

These are the imaginary lines in a magnetic field in which a hypothetical north pole would move.

MAGNETIC FLUX (ϕ_B)

It is the total number of magnetic field lines passing through a unit area in a direction perpendicular to the area.

$$\boxed{\phi_B=\int \vec{B}.\vec{da}}$$

MAGNETIC LORENTZ FORCE

When a charge q moves with a velocity $\vec{V}$ in a magnetic field $\vec{B}$, then the magnetic force experienced on the charge is given by

$$\boxed{\vec{F}_B=q(\vec{V}\,X\,\vec{B})}$$

This is the magnetic Lorentz force.

<u>NOTE</u>

1) It depends on $q,\vec{V},\vec{B}$ and it's direction is perpendicular to both V and B (it is obtained by right hand thumb rule)
2) Force on a negative charge is opposite to that on a positive charge.
3) $\vec{F}_B=0$ if $V=0$ or $B=0$
4) $\vec{F}_B=0$ if V and B are parallel or antiparallel

<u>Lorentz Force</u>

It is the total force acting on a charged particle moving in a combined electric and magnetic fields.

$$\vec{F}=\vec{F}_E+\vec{F}_B=q\vec{E}+q(\vec{V}\,X\,\vec{B})$$

=> $$\boxed{\vec{F}=q(\vec{E}+\vec{V}\,X\,\vec{B})}$$

WORK DONE BY MAGNETIC FORCE ON A CHARGED PARTICLE

We know the magnetic force

$$\vec{F}_B=q(\vec{V}\,X\,\vec{B})$$

Also the work done by the magnetic force

$$dw=\vec{F}_B.\vec{dr}$$

Since $\vec{V}$ and $\vec{dr}$ are in the same direction and which is perpendicular to $\vec{F}_B$, the work done by the magnetic force $\boxed{dw=\vec{F}_B.\vec{dr}=0}$

ie. magnetic force doesn't do work

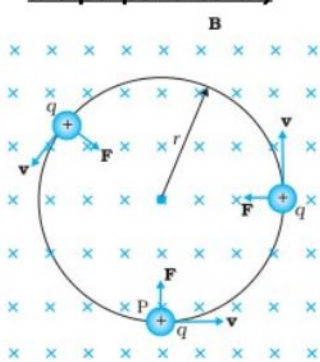
MOTION OF A CHARGED PARTICLE IN A MAGNETIC FIELD

<u>Case 1 : If the charged particle moves parallel to the field</u>
($\vec{V}$ <u>and</u> $\vec{B}$ <u>are parallel)</u>

$$\vec{F}_B=q(\vec{V}\,X\,\vec{B})=qVB\sin 0=0$$

No force acting on the particle, it continues in its own path along a straight line.ie, the particle is uneffected by the field.

<u>Case 2 : If the charged particle moves perpendicular to the field</u>
($\vec{V}$ <u>and</u> $\vec{B}$ <u>are perpendicular)</u>



$$\vec{F}_B=q(\vec{V}\,X\,\vec{B})=qVB\sin 90=qVB$$,

perpendicular to both $\vec{V}$ and $\vec{B}$

This perpendicular force acts as a centripetal force and the particle executes a circular motion perpendicular to the magnetic field(Above Fig)

If m- Mass of the particle and r-Radius of the particle. Then,

$$\frac{mV^2}{r}=qVB \quad => \quad \boxed{r=\frac{mV}{qB}} \quad ....(1)$$

If T is the time period of rotation. Then,

$$T=\frac{2\pi r}{V}=\frac{2\pi\frac{mV}{qB}}{V} \quad => \quad \boxed{T=\frac{2\pi m}{qB}} \quad ....(2)$$

If υ is the frequency of rotation. Then,

$$\boxed{\upsilon=\frac{1}{T}=\frac{qB}{2\pi m}} \quad ....(3)$$

NOTE

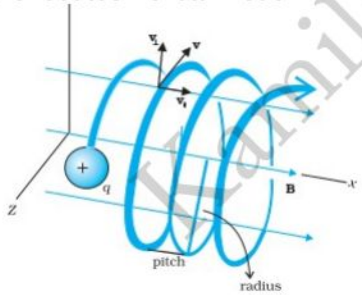
1) As the momentum 'mV' increases 'r' increases. Ie, For particle having larger momentum, larger is the radius. (Eqn(1))

2)Frequency is independent of velocity (Eqn(3)). This independence of velocity of υ can be applid in the design of cyclotron.

Case 3 : If the charged particle enters at an angle θ with the field

Here $\vec{V}$ will have a component perpendicular to the field , $V_{per}=V\sin\theta$ and a component parallel to the field , $V_{par}=V\cos\theta$.

The perpendicular component rotates the particle and the parallel component translates. So the particle executes helical motion.



$$\boxed{T=\frac{2\pi m}{qB}} \quad \text{And} \quad \boxed{\upsilon=\frac{qB}{2\pi m}}$$

Pitch (P)

It is the distance moved along the magnetic field in one rotation.

$$P=TV_{par}=TV\cos\theta$$

Or $$\boxed{P=\frac{2\pi mV\cos\theta}{qB}} \quad ....(4)$$

Example 4.3 NCERT

What is the radius of the path of an electron (mass 9 × 10 $^{-31}$ kg and charge 1.6 × 10 $^{-19}$ C) moving at a speed of 3 ×10 ^{7} m/s in a magnetic field of 6 × 10 $^{-4}$ T perpendicular to it? What is its frequency? Calculate its energy in keV. (1 eV = 1.6 × 10 $^{-19}$ J).

Soln

$$r=\frac{mV}{qB}=\frac{9.1x10^{-31}x3x10^{7}}{1.6x10^{-19}x6x10^{-4}}=26x10^{-2}m$$

$$\upsilon=\frac{qB}{2\pi m}=2x10^{6}Hz$$

$$E=\frac{1}{2}mV^2=40.5x10^{-17}J=2.5keV$$

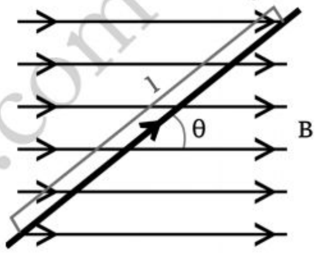
MAGNETIC FORCE ACTING ON A CURRENT CARRYING CONDUCTOR PLACED IN A UNIFORM MAGNETIC FIELD

Let A- Area of cross section of wire

l - Length of the wire

B - External magnetic field

n – Free electron density in the wire



The total charge in the wire, $q=nAle$

The average velocity of the electron= The drift velocity , V_d.

Then $\vec{F}_B=q(\vec{V}_d X\vec{B})=nAle(\vec{V}_d X\vec{B})$

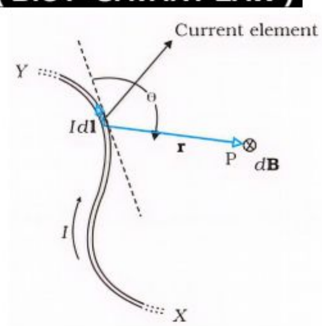
=> $$\boxed{\vec{F}_B=I(\vec{l}X\vec{B})} \quad ....(5)$$

(Since $I=neAV_d$ and $\vec{l}$ is of magnitude l and direction identical to the current)

This equation hold for a straight conductor.

If the wire has an arbitrary shape, we can use the equation $\boxed{\vec{F}_B=I(\vec{dl}X\vec{B})}$

MAGNETIC FIELD DUE TO A CURRENT ELEMENT (BIOT -SAVART LAW)



The magnetic field at a point due to the small element of a current carrying conductor is **directly proportional to the current flowing through the conductor (I),the length of the element (dl), sine of the angle between 'r' and 'dl' and inversely proportional to the square of the distance of the point from dl.**

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

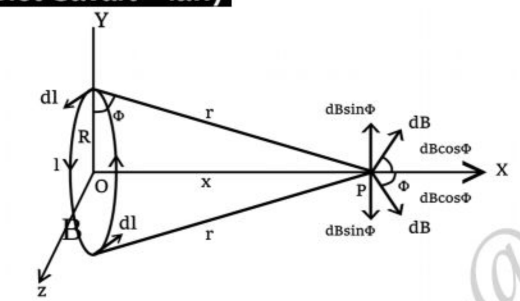
Where $\frac{\mu_0}{4\pi}=10^{-7}T\,m/A$ is a constant

In vector form, $$\boxed{\vec{dB}=\frac{\mu_0 I}{4\pi}\frac{\vec{dl}\,X\,\hat{r}}{r^2}}$$ ....(10)

Or $$\boxed{\vec{dB}=\frac{\mu_0 I}{4\pi}\frac{\vec{dl}\,X\,\vec{r}}{r^3}}$$ ....(11)

Do Example 4.5 NCERT

MAGNETIC FIELD ON THE AXIS OF A CIRCULAR CURRENT LOOP (Finding out using Biot-Savart law)



- The figure shows a circular loop carrying a steady current I
- The loop is placed in YZ plane with it's centre at origin O and has a radius 'R'.
- X-axis is the axis of the loop.

The magnetic field at P due to the current element dl , at A is $\vec{dB}=\frac{\mu_0 I}{4\pi}\frac{\vec{dl}\,X\,\hat{r}}{r^2}$

=> $$dB=\frac{\mu_0}{4\pi}\frac{I\,dl\sin 90}{r^2}$$

=> $$dB=\frac{\mu_0}{4\pi}\frac{I\,dl\sin 90}{r^2}$$

=> $$dB=\frac{\mu_0}{4\pi}\frac{I\,dl}{(x^2+R^2)}$$

- The direction of dB is perpendicular to the plane formed by $\vec{dl}$ and $\vec{r}$
- It has an x component (dBcosΦ) and a perpendicular component (dBsinΦ).
- When summed over the perpendicular components cancels out and only x component survives.

The net contribution along x direction can be obtained by integrating $dB_x=dB\cos\phi$

where $$\cos\phi=\frac{R}{r}=\frac{R}{(x^2+R^2)^{1/2}}$$

Therefore, $B=\int dB_x=\int dB\cos\phi$

=> $$B=\int\frac{\mu_0}{4\pi}\frac{I\,dl}{(x^2+R^2)^2}\frac{R}{(x^2+R^2)^{1/2}}$$

=> $$B=\frac{\mu_0 I R}{4\pi(x^2+R^2)^{3/2}}\int dl$$

=> $$\boxed{B=\frac{\mu_0 I R(2\pi R)}{4\pi(x^2+R^2)^{3/2}}=\frac{\mu_0 I R^2}{2(x^2+R^2)^{3/2}}}$$

In vector form $$\boxed{\vec{B}=\frac{\mu_0 I R^2}{2(x^2+R^2)^{3/2}}\hat{i}}$$ ....(12)

Special Case

1) For a coil of N turns, $$\boxed{\vec{B}=\frac{\mu_0 N I R^2}{2(x^2+R^2)^{3/2}}\hat{i}}$$

2) Field at the centre of the loop $$\boxed{\vec{B}=\frac{\mu_0 I}{2R}\hat{i}}$$

Example 4.7

Consider a tightly wound 100 turn coil of radius 10 cm, carrying a current of 1 A. What is the magnitude of the magnetic field at the centre of the coil?

Solution

$$\vec{B}=\frac{\mu_0 N I}{2R}=\frac{4\pi x 10^{-7} x 100 x 1}{2 x 10 x 10^{-2}}=6.28 x 10^{-4}T$$

AMPERE'S CIRCUITAL LAW

The line integral of magnetic field around a closed loop is μ_0 times times the current enclosed by the loop.

$$\boxed{\oint\vec{B}.\vec{dl}=\mu_0 I_{enc}}$$

APPLICATIONS OF AMPERE'S LAW

(1) TO FIND THE MF PRODUCED BY A LONG STRAIGHT CURRENT CARRYING CONDUCTOR

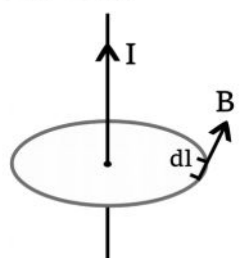
Consider a straight conductor carrying a current 'I' . We have to find out the magnetic field at a distance 'r' from the straight conductor.

Apply Ampere's law

$$\oint\vec{B}.\vec{dl}=\mu_0 I_{enc}$$

$$\vec{B}.\vec{dl}=B\,dl\cos 0=B\,dl$$

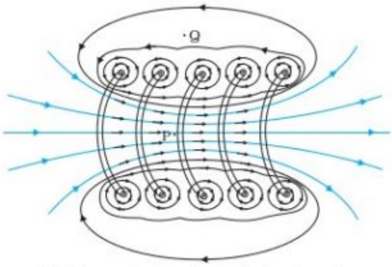
=> $$B\oint\vec{dl}=\mu_0 I$$



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

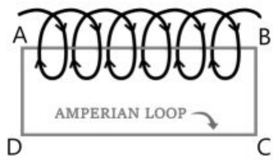
=> $$B=\frac{\mu_0 I}{2\pi r}$$ ....(13)

(2) B DUE TO A LONG SOLENOID



- A
  Solenoid is a long insulated wire wound in the form of a helix where the neighbouring turns are closely spaced.
- When current flows through the solenoid, it behaves as a bar magnet.
- For a long solenoid, the field outside is nearly zero. The field inside is everywhere parallel to the axis.

Expression for MF



According to Ampere's law,

$$\oint \vec{B}.\vec{dl}=\mu_0 N I_{enc}$$

Where N is the total no of the turns of the solenoid.

=>

$$\int_A^B \vec{B}.\vec{dl}+\int_B^C \vec{B}.\vec{dl}+\int_C^D \vec{B}.\vec{dl}+\int_D^A \vec{B}.\vec{dl}=\mu_0 N I_{enc}$$

=> $$\int_A^B B\,dl\cos 0+\int_B^C B\,dl\cos 90+\int_C^D 0\,dl$$

$$+\int_D^A B\,dl\cos 90=\mu_0 N I$$

=> $\int_A^B B\,dl=\mu_0 N I$ => $B\int_A^B dl=\mu_0 N I$

=> $B l=\mu_0 N I$ => $B=\frac{\mu_0 N I}{l}$

=> $$B=\mu_0 n I$$ ....(14)

Where $n=\frac{N}{L}$ is the turns per unit length.

NOTE

We can increase the MF of a solenoid by
- Increasing the number of turns
- increasing the current
- Inserting a soft iron core

Example 4.9

A solenoid of length 0.5 m has a radius of 1cm and is made up of 500 turns. It carries a current of 5 A. What is the magnitude of the magnetic field inside the solenoid?

Solution

$l=0.5\,m$, $R=1\,x\,10^{-2} m$, $N=500$

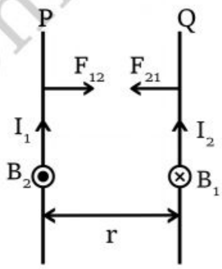
$$B=\mu_0 n I$$

$$n=\frac{N}{l}=\frac{500}{0.5}=1000$$

Therefore $B=4\pi\,x\,10^{-7}x\,10^{3}x\,5$

$B=6.28\,x\,10^{-3} T$

FORCE BETWEEN TWO PARALLEL STRAIGHT CURRENT CARRYING CONDUCTORS(The Ampere Force)



Consider two straight parallel conductors P and Q of lengths l_1 , l_2 and carrying currents I_1 and I_2 placed at a separation 'r'.

MF at a distance r from P, $B_1=\frac{\mu_0 I_1}{2\pi r}$

The conductor Q is placed in this magnetic field. Therefore the force (Lorentz force) acting on Q by this field, $\vec{F_{21}}=I_2(\vec{l_2}\,X\,\vec{B})$

=> $\vec{F_{21}}=I_2(l_2 B_1)$ (since angle $\theta=90^0$)

=> $$F_{21}=\frac{\mu_0 I_1 I_2}{2\pi r} l_2$$

Similarly $$F_{12}=\frac{\mu_0 I_1 I_2}{2\pi r} l_1$$

Therefore force per unit length can be written as

$$f=\frac{\mu_0 I_1 I_2}{2\pi r}$$ ....(16)

NOTE
- When currents are in same direction ,the force is attractive.
- If the currents are in opposite direction ,

the force is repulsive.

- Definition of I ampere: An ampere is defined as the constant current which if maintained in two straight parallel conductors of infinite lengths placed one metre apart in vacuum will produce a force per unit length of $2x\,10^{-7}\,N/m$ between them.

MAGNETIC DIPOLE MOMENT DUE TO A CURRENT LOOP

Magnetic dipole moment of a current loop,

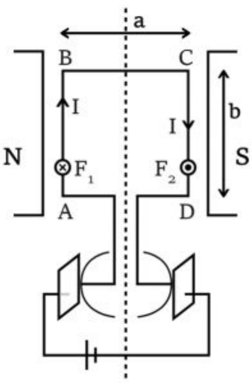
$$\boxed{m = Current \times Area\,of\,the\,loop}$$

$$\boxed{m = I\,A}$$

For a coil having N turns

$$\boxed{m = N\,I\,A} \quad ....(17)$$

TORQUE ON A CURRENT LOOP IN A UNIFORM MAGNETIC FIELD



The force on AB due to the MF , B be F_1. This force is directed into the plane of the loop. $F_1 = I\,b\,B$

Similarly The force' on CD due to the MF , B be F_2. This force is directed out of the plane of the loop. $F_2 = I\,b\,B$

These two forces are equal in magnitude but opposite in direction. So net force is zero, but there is a torque(τ) due to these pair of forces.

$$\tau = \left(\frac{a}{2}\,X\,F_1\right) + \left(\frac{a}{2}\,X\,F_2\right)$$

=> $\tau = \frac{a}{2}\,I\,b\,B\sin\theta + \frac{a}{2}\,I\,b\,B\sin\theta$

=> $\tau = I\,b\,B\,a\sin\theta$ => $\tau = I\,A\,B\sin\theta$

If the loop has N turns, $\tau = N\,I\,A\,B\sin\theta$

=> $\boxed{\tau = m\,B\sin\theta}$ Where $m = N\,I\,A$

In vector form $\boxed{\vec{\tau} = \vec{m}\,X\,\vec{B}}$ ....(18)

<u>NOTE</u>

The above equation is analogous to the equation of torque on an electric dipole in a uniform electric field

CIRCULAR CURRENT LOOP AS A MAGNETIC DIPOLE (Prove that the circular current loop act as a magnetic dipole)

We know the magnetic field at the axis of a circular current loop, $B = \frac{\mu_0 I\,R^2}{2(x^2 + R^2)^{3/2}}$

The MF at large distance($x \gg R$) at the axis of the circular current loop,

$$B = \frac{\mu_0 I\,R^2}{2x^3}$$

Multiplying and dividing by π

$$B = \frac{\mu_0 I\,\pi\,R^2}{2\pi\,x^3} \quad => \quad B = \frac{\mu_0 IA}{2\pi\,x^3}$$

=> $B = \frac{\mu_0 m}{2\pi\,x^3}$ where $m = I\,A$

=> $\boxed{B = \frac{\mu_0}{4\pi}\frac{2m}{x^3}}$ ....(19)

This equation is similar to the EF due to an electric dipole at a distance x from the centre of the dipole on it's axial line,

$$\boxed{E = \frac{1}{4\pi\epsilon_0}\frac{2p}{x^3}} \quad ....(20)$$

Comparing (19) and (20) we get

$$B \rightarrow E \qquad \mu_0 \rightarrow \frac{1}{\epsilon_0} \qquad m \rightarrow p$$

Similarly we know for an electric dipole ,electric field at a point on the equitorial line at a distance x from the centre of the dipole is

$$\boxed{E = \frac{1}{4\pi\epsilon_0}\frac{p}{x^3}} \quad ....(21)$$

From this equation ,we get equation for B for a point in the plane of the loop at a distance x from it's centre $x \gg R$

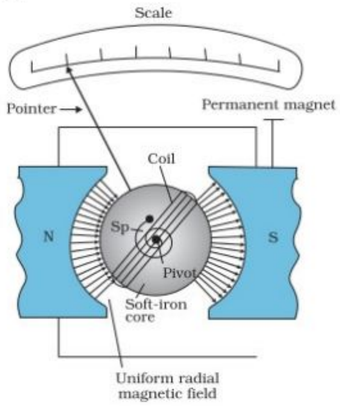
$$\boxed{B = \frac{\mu_0}{4\pi}\frac{m}{x^3}} \quad ....(22)$$

Thus circular current loop acts as a magnetic dipole with dipole moment m=I A

MOVING COIL GALVANOMETER

Moving coil galvanometer is used to detect the presence of small electric current and to give its direction.

Construction



The galvanometer consists of a light rectangular coil of N turns each having area A wound on an a soft iron cylinder. The cylinder is free to rotate between two concave shaped magnetic poles, which produce radial magnetic field. field. One end of the cylinder is attached to a spring,which produces a restoring couple. At the other end a pointer is pivoted.

Principle

When current flows through the coil, a torque acts on it. In the radial magnetic field , magnetic field is always parallel to the plane of the coil and the torque experienced will be maximum.

The torque, $\tau = m X B = m B \sin\theta = mB$
(since $\vec{m}$ and $\vec{B}$ is perpendicular. Ie, $\theta = 90^0$)

Therefore $\tau = N I A B$ ....(26)
This produces a restoring torque in the spring,
$\tau = k\phi$ ....(27)
where k is the restoring torque per unit deflection.

Comparing (26) and (27)
$$N I A B = k\phi$$
=> $\boxed{I = (\frac{k}{N A B})\phi}$ => $\boxed{I \alpha \phi}$

Current sensitivity

It is the deflection produced for unit current.
$$\boxed{\frac{\phi}{I} = (\frac{N A B}{k})}$$

Voltage sensitivity

It is the deflection produced for unit voltage.
$$\boxed{\frac{\phi}{V} = (\frac{N A B}{k R})}$$

NOTE

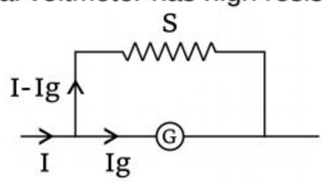
Increasing the current sensitivity may not necessarily increase the voltage sensitivity (eg: If we double N , $\frac{\phi}{I}$ doubles. Since resistance also doubles, voltage sensitivity remains the same)

AMMETER

- To measure current
- It connects in series in a circuit
- When it connects current should not change. So resistance of an ammeter should be very low

CONVERSION OF A GALVANOMETER TO AN AMMETER

- The galvanometer is very sensitive and withstand only a small current.
- A galvanometer can be converted into an ammeter by connecting a small resistance , S (shunt resistance) in parallel to the galvanometer.
- This reduces the instrument resistance and allows only the required current to flow through the galvanometer.
- An ideal voltmeter has high resistance



G - Galvanometer resistance
I_g - Maximum current that can be flow through the galvanometer
I - Current to be measured
S - Shunt resistance

Applying kirchoff's law to the loop,
$$-I_g G + (I - I_g) S = 0$$
=> $$(I - I_g) S = I_g G$$
=> $$\boxed{S = \frac{I_g G}{(I - I_g)}}$$

Total resistance of the ammeter, $\boxed{R = \frac{G S}{G + S}}$

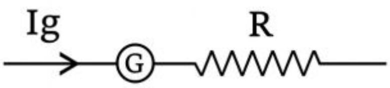
Note:
1. An ammeter is a low resistance instrument and it is always connected in series to the circuit
2. An ideal ammeter has zero resistance

VOLTMETER

- To measure pd across two points
- It connects parallel to the points
- When it connects , it should not affect the pd across the points.

CONVERSION OF A GALVANOMETER TO A VOLTMETER

- A galvanometer can be converted into a voltmeter by connecting a high resistance R in series with the galvanometer.



$V = I_g G + I_g R$ => $I_g R = V - I_g G$

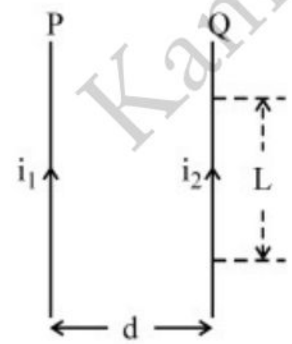
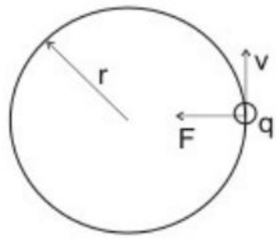
=> $\boxed{R = \frac{V}{I_g} - G}$

Thus R can be calculated for any given value of V.

<u>Note:</u>
1. Voltmeter is a high resistance instrument
2. It is always connected in parallel with the circuit element across which the potential difference is to be measured.
2. An ideal voltmeter has infinite resistance

PREVIOUS YEAR QUESTIONS

1. a) b)	A rectangular loop of area A and carrying a steady current I is placed in a uniform magnetic field. Derive the expression of torque, $\vec{\tau} = \vec{m} \times \vec{B}$ acting on the loop. Increasing the current sensitivity may not necessarily increase the voltage sensitivity of a galvanometer. Justify	 2.5 1.5
2.	What is the magnitude of the equatorial and axial fields due to a bar magnet of length 5.0 cm at a distance of 50 cm from its mid-point ? The magnetic moment of the bar magnet is 0.40 Am^2.	2
3. a) b)	Ampere's theorem helps to find the magnetic field in a region around a current carrying conductor. Write the expression of Ampere's theorem. Draw a graph showing the variation of intensity of magnetic field with the distance from the axis of a current carrying conductor.	 1 2
4.	The path of a charged particle entering parallel to uniform magnetic field will be (a) circular (b) helical (c) straight line (d) none of these	1
5.	A particle of charge q is moving with a velocity **v** through a region, where an electric field **E** and a magnetic field **B** are present. Write an equation for total force on charge.	2
6.	Unit of magnetic field intensity is	1
7.	A circular coil of radius R and N turns carries a current I. Show that the intensity of magnetic field at an axial point distant x from the centre is $B = \frac{\mu_0 N I R^2}{2(x^2+R^2)^{3/2}}$	4
8.	With a circuit diagram explain how a moving coil galvanometer can be converted to an ammeter.	4
9.	Using Ampere's circuital law show that the intensity of magnetic field at an axial point near the centre of a current carrying solenoid is $B = \mu_0 n I$.	3
10.	State Biot - Savart law and express it mathematically.	2
11.a) b)	Using Biot-Savarts law, obtain the expression for the magnetic field due to a circular loop of radius r carrying a current I at a point on its axis distant x from the centre of the coil. What is the value of B at the centre ?	3 1
12.	State Biot-Savart's law and express it in the vector form.	3
13.	State Ampere's circuital law. Use this law to obtain the expression for the magnetic field inside a current carrying solenoid at an axial point near the centre.	2 3
14.	Write the expression for Lorentz force acting on a moving charge.	2
15.a) b)	Which law help us to find the magnetic field on the axis of a circular current loop? Consider a tightly wound I 00 turn coil of radius 10 cm, carrying current of I A. What is the magnitude of the magnetic field at the centre of the coil ?	1 3

16.a)	What is a solenoid ?	1
b)	Write down the equation for magnetic field inside a solenoid.	1
17.	Name the force experienced by a charge q moving through a uniform magnetic field with a velocity V.	1
18.a)	Force experienced on a charge 'q' moving with a velocity 'v' in a direction parallel to the direction of a magnetic field of intensity B is	1
b)	What is the value of magnetic field at the centre of a circular coil of 'n' turns and radius 'a' carrying a current of I ampere ?	1
19.a)	Derive the expression for the torque on a rectangular current loop in a uniform magnetic field with the help of a diagram.	2
b)	A 100 turn closely wound circular coil of radius 10 cm carries a current of 3.2 A. What is the magnetic moment of this coil ?	2
20.a)	State Biot-Savart law.	1
b)	Obtain the expression for the magnetic field on the axis of a circular current loop.	2
21.	Current loop behaves as a .... (Magnetic dipole/Electric dipole)	1
22.	Figure shows the two current carrying conductors. Derive the expression for force between the conductors. 	2
23.a)	The direction of magnetic field around a current carrying conductor is given by	1
b)	State Biot-Savart law.	1
c)	Derive the expression for magnetic field on the axis of a circular coil carrying current.	3
MARCH 2025		
24.a)	What is the working principle of a moving coil galvanometer ?	1
b)	How will you convert a galvanometer into an ammeter ?	1
c)	An ammeter is always connected in series with a circuit. Why ?	1
25.a)	What is Lorentz force ?	1
b)	The figure shows the path of motion of a charged particle (+q) in a uniform magnetic field : 	
i)	What will be the direction of magnetic field with respect to the velocity of the charged particle ?	1
ii)	Show that frequency of revolution of the charged particle is independent of the radius (2)	2
iii)	Is there any change in kinetic energy of the charged particle? Explain.	1