PRACTICAL CENTRE KARACHI

PRACTICAL CENTRE

PHYSICS

UNIT#18

MAGNETIC FIELD

2024-25

MAGNETIC FIELD 18

S.No.	CONTENTS	Page#

18.1 MAGNETIC FIELD:

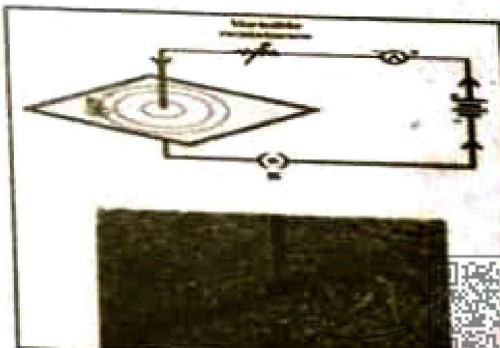
An area around a permanent magnet or a current carrying conductor, where they generate a magnetic force is called magnetic field.

Magnetic field can be generated through two primary methods:

- From permanent magnet
- From current carrying conductor, also known as electro magnet

In 1819, Hans Christian Oersted made a significant discovery that revealed how a current Carrying conductor generates a magnetic field.

Experiment



Take a straight thick copper wire and pass it vertically through a hole in a horizontal piece of cardboard. When current flow through the wire, a iron fillings are scattered on to the cardboard, they become magnetized and arrange themselves in a circular pattern around the current-carrying wire.

Conclusions

- A magnetic field is set up around current carrying conductor.
- The lines of force are circular and their direction depends upon the direction of current.
- The magnetic field lasts only as long as the current is flowing through the wire.

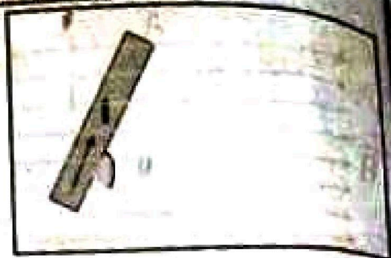
Direction of lines of force:

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

Right hand Rule:

If the wire is grasped in the fist of right hand with the thumb pointing in the direction of current, then t curled fingers indicate the direction of magnetic field.

FORCE ON CURRENT CARRYING CONDUCTOR IN A UNIFROM MAGNETIC FIELD



Consider a consider a current carrying conductor of length $\vec{L}$ is placed in the magnetic field of strength $\vec{B}$. Experimentally, it is seen that the force acting on the conductor depends upon the following factors.

- The magnetic force is directly proportional to the magnitude of current I.
  $F \propto I$ ⟶ (i)
- The magnetic force is directly proportional to the magnitude of length of conductor L.
  $F \propto L$ ⟶ (ii)
- The magnetic force is directly proportional to the strength of magnetic field $\vec{B}$.
  $F \propto B$ ⟶ (iii)
- The magnetic force is directly proportional to the sine of angle between length of conductor and strength of magnetic field B.
  $F \propto \sin\theta$ ⟶ (iv)

Combining relations i, ii, iii and iv, we get

$$F \propto ILB\sin\theta$$

$$F = ILB\sin\theta$$

This equation gives another definition of B. In this equation if $l = 1m$, $I = 1A$, and $F = 1N$, then also B is called 1 tesla (1T). Hence,

$$B = \frac{F}{IL\sin\theta}$$

$$1\ tesla = \frac{1N}{1A \times 1m}$$

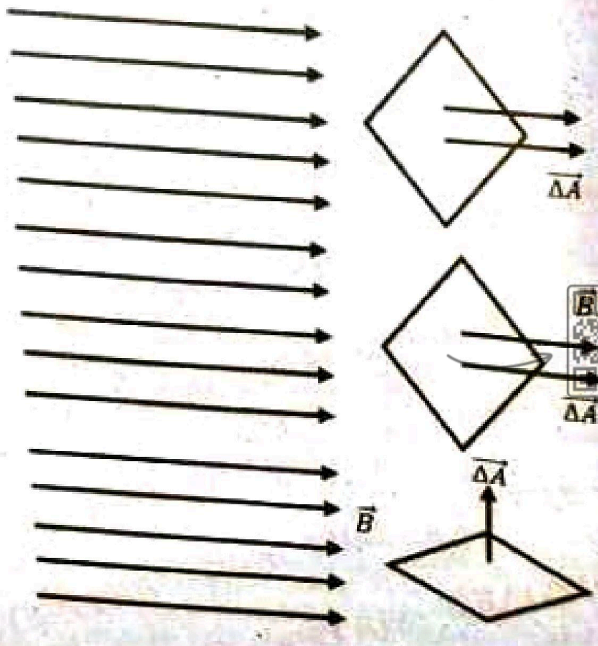
If a wire of length 1 meter, carrying a current of 1 ampere, is held perpendicular to a magnetic field and it experiences a force of 1 newton, then the magnetic induction of magnetic field is said to be 1 Tesla.

18.2 MAGNETIC FLUX:

Total number of magnetic lines of force emitting from a magnet and passing through a certain area, is called magnetic flux. OR It may be defined as "the scalar product of strength of magnetic field $\vec{B}$. and vector area $\Delta\vec{A}$.

i.e $\Delta\phi = \vec{B}.\Delta\vec{A}$

or $\Delta\phi = B\Delta A\cos\theta$



where θ is the angle between $\vec{B}$ and $\Delta\vec{A}$.
Magnetic flux is a scalar quantity.

(i) MAXIMUM FLUX:
Flux passing through an area will be maximum when angle between $\vec{B}$ and $\overrightarrow{\Delta A}$ is 0°

$\Delta\phi = B\Delta A\cos 0^\circ = B\Delta A \times 1 = B\Delta A \quad \therefore \cos 0^\circ = 1$

(ii) MINIMUM FLUX:
Flux passing through an area will be minimum when angle between $\vec{B}$ and $\overrightarrow{\Delta A}$ is 90°.

i.e $\Delta\phi = B\Delta A\cos 90^\circ = B\Delta A \times 0 = 0 \quad \therefore \cos 90^\circ = 0$

UNIT OF MAGNETIC FLUX:

$\phi = BA$

$= \frac{N}{A\,m}\, m^2$

$= N\text{-}mA^{-1}$

$N\text{-}mA^{-1}$ is known as weber

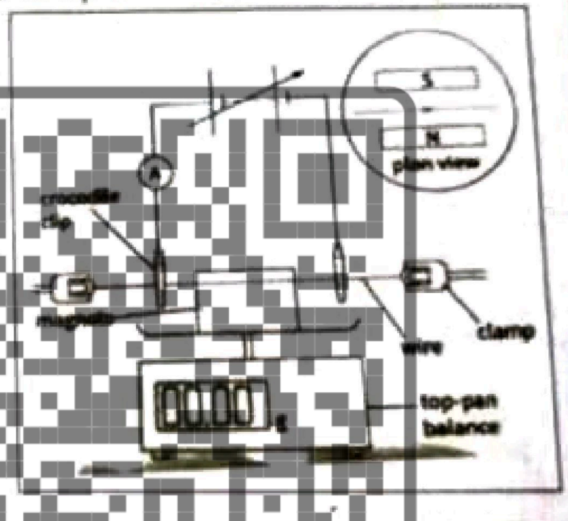
MAGNETIC FLUX DENSITY:

The magnetic flux per unit area is known is known as magnetic flux density. It is denoted by B. Its units are weber per meter square or Tesla.

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

Measurement of Magnetic Flux density by current balance:

A simple experimental setup for the measurement of flux density between two magnets, As shown in fig. The magnetic field within this magnet configuration is uniform. To measure the length (L) of the current marrying wire within this uniform magnetic held, a ruler can be used. When the wire carries no current, the magnet arrangement is positioned on top of balance, and the Subsequently, when an electric current (I) flows through the wire, the ammeter displays its magnitude. The wire experience an upward force, and in accordance with Newton's third law of motion, an equal and opposite force acts upon the magnets. Consequently, the magnets are pushed down wards, causing the balance to indicate a reading. The force (F) can be calculated as F= mg, with 'm' representing the mass indicated on the balance in kilograms and 'g' representing the acceleration due to gravity (9.81ms⁻²).

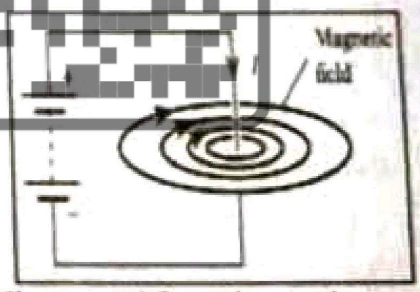


With the knowledge of F, I and L, determine the magnetic flux density (B) between the magnets using the following equation.

$$B = \frac{F}{IL}$$

18.3 AMPERE'S LAW

Consider a long straight wire carrying a current " I " and closed curve containing of a circle of radius ' r ' with wire at the center as shown in figure.



The magnetic field ' B ' around a long straight current carrying conductor is directly proportional to the twice of current ' I ' passing through the conductor and is inversely proportional to the distance 'r' from the conductor.

$$B \propto 2I \longrightarrow (i)$$

$$B \propto \frac{1}{r} \longrightarrow (i)$$

Combining (i) and (ii)

$$B \propto \frac{2I}{r}$$

$$B = \frac{\mu_o}{4\pi} \times \frac{2I}{r}$$

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

Where μ_o is the constant called the permeability of free space and its value is $4\pi \times 10^{-7}$ web m^{-1}.

Consider a closed circular path shown around a current carrying wire. The closed path is referred as Amperean path. Divide this path into large no. of elements each of vector length $\overrightarrow{\Delta L}$ remains the same. The direction of $\vec{B}$ at each point is tangent to the curved part. Then

$$B_{||}\Delta L = B\cos\theta \Delta L = B\Delta L\cos\theta$$
$$= \vec{B}.\overrightarrow{\Delta L}$$

Where $B_{||} = B\cos\theta$ = component of $\vec{B}$ parallel to $\overrightarrow{\Delta L}$

Where θ is the angle between $\vec{B}$ and $\overrightarrow{\Delta L}$.

The sum of all quantities $\vec{B}.\overrightarrow{\Delta L}$ for all path elements in a closed path is equal to μ_o times the current enclosed by the Loop. It can be represented as

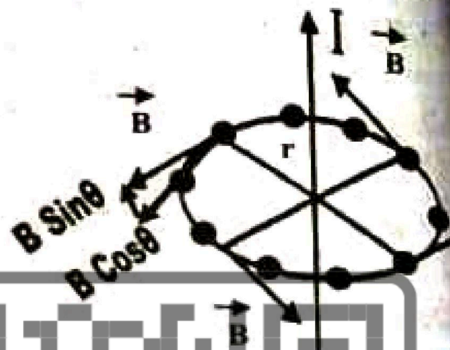
$$(\vec{B}.\overrightarrow{\Delta L})_1 + (\vec{B}.\overrightarrow{\Delta L})_2 + \dots + (\vec{B}.\overrightarrow{\Delta L})_N = \sum \vec{B}.\overrightarrow{\Delta L}$$

$$\sum \vec{B}.\overrightarrow{\Delta L} = \sum B\Delta L\cos 0^o$$

$$\sum \vec{B}.\overrightarrow{\Delta L} = B\sum \Delta L$$

$$\sum \vec{B}.\overrightarrow{\Delta L} = \frac{\mu_o I}{2\pi r} \times 2\pi r$$

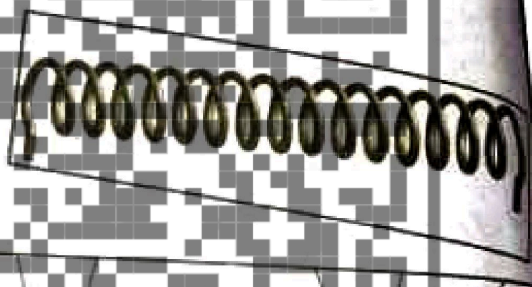
$$\sum \vec{B}.\overrightarrow{\Delta L} = \mu_o I$$



This is known as Ampere's circuital law.

Solenoid:

A solenoid is a long, tightly wound, cylindrical coil of wire. When current passes through the winding of the solenoid, a magnetic field is produced and solenoid behaves a bar magnet



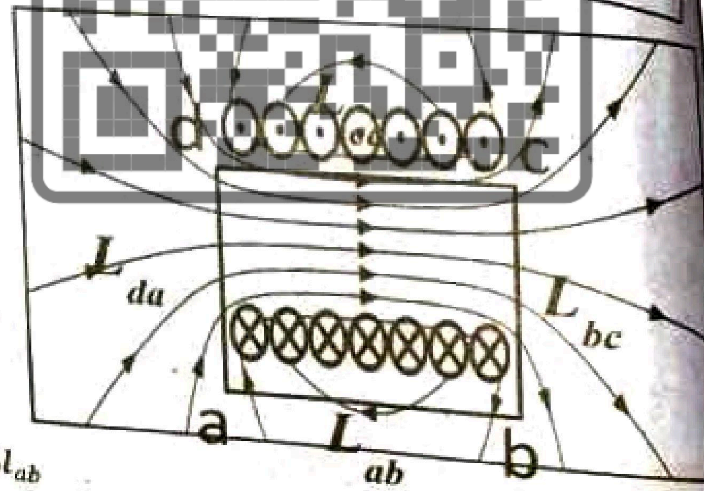
Calculation of B:

Consider a rectangular loop 'abcd'. It is divided into four elements of lengths l_{ab}, l_{bc}, l_{cd} and l_{da}

Applying Ampere's law,

$$\sum \vec{B}.\overrightarrow{\Delta L} = \mu_o \times \textit{Current enclosed}$$

$$(\vec{B}.\overrightarrow{\Delta L})_{ab} + (\vec{B}.\overrightarrow{\Delta L})_{bc} + (\vec{B}.\overrightarrow{\Delta L})_{cd} + (\vec{B}.\overrightarrow{\Delta L})_{da} = \mu_o \times \text{Current enclosed}$$



Consider the element l_{ab} that lies inside the solenoid. Field inside the solenoid is uniform and parallel to l_{ab}. Then.

$$(\vec{B}.\overrightarrow{\Delta L})_{ab} = \vec{B}.\vec{l}_{ab} = B\,l_{ab}\cos 0^0 = Bl_{ab}\,(1) = Bl_{ab}$$

For the element l_{cd}, that lies outside the solenoid, for which $\vec{B} = 0$

$$(\vec{B}.\overrightarrow{\Delta L})_{cd} = \vec{B}.\vec{l}_{cd} = B\,l_{cd}\cos 180^0 = (0)\,l_{cd}\,(-1) = 0$$

For the elements l_{bc} and da = l_{da} are inside the solenoid and perpendicular to $\vec{B}$. Then,

$$(\vec{B}.\overrightarrow{\Delta L})_{bc} = \vec{B}.\vec{l}_{bc} = B\,l_{bc}\cos 90^o = Bl_{bc}\,(0) = 0$$

$$(\vec{B}.\overrightarrow{\Delta L})_{da} = \vec{B}.\vec{l}_{da} = B\,l_{da}\cos 90^o = Bl_{da}\,(0) = 0$$

$$\sum \vec{B}.\overrightarrow{\Delta L} = (\vec{B}.\overrightarrow{\Delta L})_{ab} + (\vec{B}.\overrightarrow{\Delta L})_{bc} + (\vec{B}.\overrightarrow{\Delta L})_{cd} + (\vec{B}.\overrightarrow{\Delta L})_{da}$$

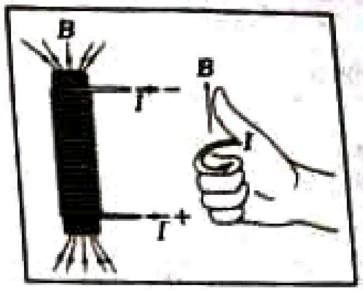
$\sum \vec{B}.\overrightarrow{\Delta L} = Bl_{ab} + 0 + 0 + 0 = Bl_{ab}$

To find the current enclosed, consider n is the number turns per unit length of the solenoid, then total number of turns in rectangular surface will be nl_{ab}, each carrying a current I. So the current enclosed by the loop will be nl_{ab} I. Then according to Ampere's law, equation reduces to

$\sum \vec{B}.\overrightarrow{\Delta L} = \mu_o \times$ Current enclosed

$$Bl_{ab} = \mu_o \times nl_{ab} I$$

$$B = \mu_o nI$$



The field $\vec{B}$ is along the axis of the solenoid.

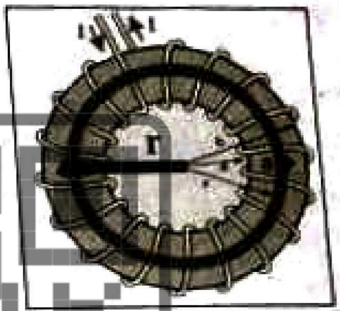
Its direction is given by right hand rule. Hold the solenoid in the right hand with fingers curling in the direction of the current and thumb will point in the direction of the field.

TOROID:

A toroid is a circular solenoid.

OR

It is a coil of insulated copper wire wound on a circular core with close turns.



Consider a toroid having N turns and carrying current I. To find $\vec{B}$ within the core of the toroid, imagine a circular curve of radius r within the core of the toroid. It is clear that $\vec{B}$ at every point on the circular curve has the same magnitude.

The direction of $\vec{B}$ at every point is along tangent.

The area bounded by this circular curve of radius r has current NI passing through it. Using Ampere's Law, for this circular curve, we have

$\Sigma \vec{B}.\overrightarrow{\Delta l} = \mu_o$ (current enclosed by the curve)

$\Sigma \vec{B}.\overrightarrow{\Delta l} = \mu_o NI$

($\vec{B}$ is parallel to each element $\overrightarrow{\Delta l}$ and angle between them is zero.)

$\Sigma B\Delta l \cos 0° = \mu_o NI$ $\quad\because \cos 0° = 1$

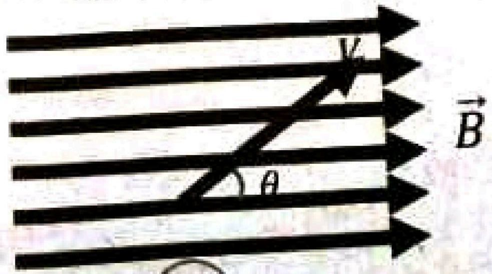
$B\, \Sigma\Delta l = \mu_o NI$

$\because \vec{B}$ at every point on the circular curve has the same magnitude

$B \times 2\pi r = \mu_o NI$ $\quad\because \Sigma\Delta l = 2\pi r$

$B = \frac{\mu_o NI}{2\pi r}$

FORCE ON A CHARGE PARTICLE MOVING UNIFORM MAGNETIC FIELD:



Consider a charge particle "q" is projected in a magnetic field of magnetic induction "B" with velocity "v". It experience magnetic force "F" is given by

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

The magnitude of force is given by

$$F = qvB \sin\theta \longrightarrow \text{(ii)}$$

The magnitude of magnetic force depends upon the following factors

i) Magnitude charge (ii) Magnitude and direction of velocity

iii) Magnetic induction

DIRECTION OF FORCE:

According to right hand rule the direction of force perpendicular to the plane formed by velocity $\vec{v}$ and magnetic induction $\vec{B}$.

A force which acts perpendicular to the direction of motion it does not change magnitude of velocity it only changes direction of velocity. The force given by equation (i) perpendicular to the direction of motion provide centripetal force to the charge "q" for moving in a circular path.

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

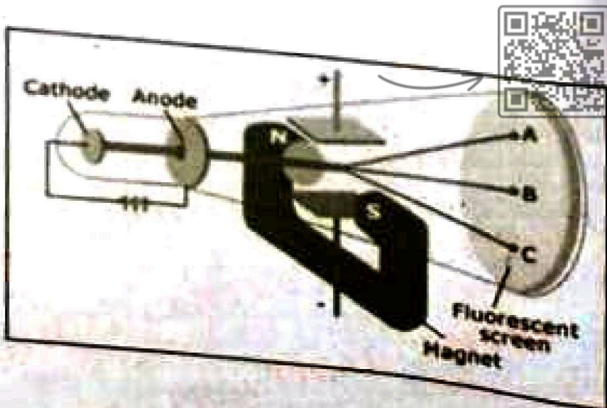
$\vec{F} = q(\vec{v} \times \vec{B})$
$q = e$
$\vec{F} = e(\vec{v} \times \vec{B})$
$(\vec{v} \times \vec{B})$

18.4 CHARGE TO MASS RATIO OF AN ELECTRON:

Measuring the charge-to-mass ratio (e/m) of an electron is a classic experiment in the field of electromagnetism and particle physics. This experiment, known as the " $\frac{e}{m}$ experiment "involves applying both a magnetic field and an electric field to a beam of electrons.

Apparatus and Materials:

1. **Cathode Ray Tube (CRT):**
   This is a vacuum tube that produces a beam of electrons. It consists of an electron gun, focus in, deflection plates, and a fluorescent screen as shown in figure.



2. **Magnetic Field Source:**
   We'll need a strong and uniform magnetic field source, such as a Helmholtz coil or a solenoid.
3. **Voltage Source:**
   A variable voltage source to create an electric field.

4. **Fluorescent Screen:**
   A screen coated with a phosphorescent material to visualize the electron beam.
5. **Rulers and Measurement Devices:**
   To measure the radius of the electron beam's circular path and the electric potential applied.

Experimental Procedure:

1. Setup:

- Set up the CRT in a vacuum chamber to ensure the electron beam doesn't interact with air molecules.
- Position the Helmholtz coil (or solenoid) around the CRT, providing a uniform magnetic field parallel to the beam path.
- Connect the voltage source to the focusing and deflection plates to create an electric field perpendicular to the magnetic field.

2. Calibration:

- Calibrate the magnetic field by measuring its strength at the location of the electron beam. We can do this using a magnetic field strength meter.

3. Electron Beam Production:

- Apply a high voltage across the cathode and anode of the CRT to generate a beam of electrons from the cathode (electron gun).
- Use the focusing and deflection plates to control and direct the electron beam.
- Observe the Electron Beam:
- Turn off the magnetic field and electric field to observe the electron beam's straight- line path on the fluorescent screen.

5. Apply the Magnetic Field:

- Turn on the magnetic field, which causes the electron beam to bend in a circular path due to the Lorentz force (the interaction between the magnetic field and the moving electrons).
- Measure the Radius(r):
- Measure the radius of the circular path formed by the electron beam on the screen. Ensure the screen is marked with a scale for accurate measurement.

CALCULATION:

If "V" is the accelerating potential applied between cathode and anode. "e" is the charge on an electron then the K. E gained by the electron is

$$\frac{1}{2}m v^2 = Ve$$

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

$$v = \sqrt{\frac{2Ve}{m}} \longrightarrow \text{(i)}$$

A magnetic field is applied perpendicular to the path of fast moving electrons. The electron experience a force perpendicular to there path, due to this force electrons move a circular path.

Magnetic force = e B v $\sin\theta$

Magnetic force = eBv $\sin\theta$

Magnetic force = eBv $\sin 90^0$

Magnetic force = eBv $\longrightarrow$ **(ii)**

This force provide centripetal force to electron for moving in a circle of radius "r"

$$F_c = \frac{mv^2}{r} \longrightarrow \text{(iii)}$$

Comparing eq. (ii) and eq. (iii)

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

$$\frac{e}{m} = \frac{v}{Br}$$

From eq (i)

$$\frac{e}{m} = \frac{\sqrt{\frac{2ve}{m}}}{Br}$$

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

$$\frac{e^2}{m^2} = \frac{2Ve}{mB^2r^2} \longrightarrow \text{(iv)}$$

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

Using the measured value for the radius (r), magnetic field strength (B), and electric potential (V), we calculate the $\frac{e}{m}$ ratio of the electrons which was found to be 1.7588×10^{11} C/kg

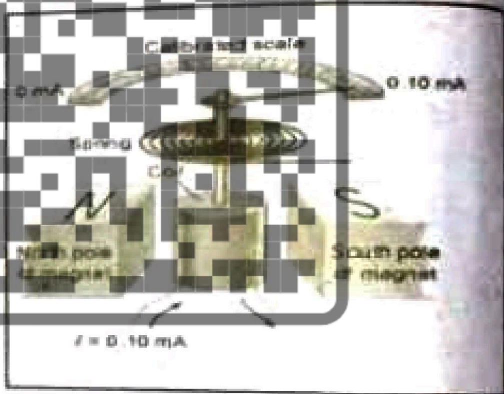
18.5 GALVANOMETER:

A Galvanometer is an instrument used to detect and measure electric currents. It is a highly sensitive electromagnetic apparatus capable of measuring even very small currents, such as those on the order of a few micro amperes.

PRINCIPLE:

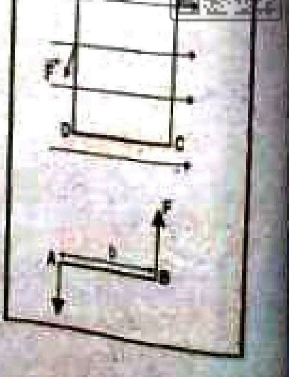
It works based on the principle of electromagnetic induction. When a coil carrying an electric current is positioned within an external magnetic field, it undergoes magnetic torque. The degree of deflection observed in the coil, caused by this magnetic torque, is directly proportional to the current's magnitude flowing through the coil.

CONSTURACTION:



1. **Coil**
   The key component of a Galvanometer is a coil of wire (usually wound around as oft iron core) suspended within a magnetic field. The coil is mounted on a spindle so that it can rotate freely.
2. **Magnet**
   A permanent magnet or an electromagnet is placed around the coil. The magnetic field lines from the magnet pass through the coil.
3. **Spring**
   A delicate torsion spring is attached to the coil, providing a restoring torque when the coil is deflected.
4. **Pointer**
   A thin pointer or needle is attached to the coil, allowing for the measurement of the deflection.

WORKING:



➤ When a small electric current flow through the coil, it generates a magnetic field around the coil. This magnetic field interacts with the external magnetic field (provided by the permanent magnet or electromagnet) to exert a torque on the coil.

➤ The torque causes the coil to rotate, and the amount of rotation is proportional to the current passing through it. This rotation is indicated by the deflection of the pointer on a calibrated scale.

➤ The coil continues to rotate until the restoring torque from the spring equals the torque due to the current-induced magnetic field. At this point, the pointer comes to rest, and its position on the scale indicates the magnitude of the current.

➤ Consider a rectangular coil consisting of N turns, each with a current I flowing through them and across-sectional area A. When this coil is situated within a uniform radial magnetic field B, it undergoes a torque as shown in figure.

➤ Let's examine a single turn ABCD of the rectangular coil, characterized by a length' L 'and breadth' b' as shown in figure. This turn is suspended within a magnetic field with strength of B, arranged so that the coil's plane is parallel to the magnetic field lines. As sides AB and DC are aligned parallel to the magnetic field, they do not experience any discernible force due to the magnetic field. However, sides AD and BC, which are perpendicular to the field's direction, encounter an effective force denoted as F. given by the equation

$$F= BIL$$

By employing Fleming's left-hand rule, we can recognize that the forces acting on sides directions to each other. When a pair of equal and opposite Magnetic Fields forces, denoted as F and collectively referred to as a couple, act on the coil, they generate a torque. This torque induces a deflection in the coil.

➤ The torque (τ) is calculated as the product of the force(F) and the perpendicular distance (b) between these forces:

$$\text{Deflecting torque} = \tau = F\times b$$

➤ Substituting the known value of F, we have:

Torque (τ) acting on a single-loop ABCD of the coil

$$\text{Deflecting torque} = \tau = BIL \times b$$

Where L x b represents the area (A) of the coil. Consequently, the torque acting on a coil with nturnsis given by:

$$\text{Deflecting torque} = \tau = NIAB$$

This magnetic torque causes the coil to rotate, leading to the twisting of the phosphor bronzestrip. Simultaneously, the spring (S) attached to the coil exerts a counter-torque, known as there storing torque.

$$\text{Restoring torque} = \tau = k\theta$$

k is termed the torsional constant of the spring, representing the restoring couple per unit twist. Under equilibrium conditions,

$$\text{Restoring torque} = \text{Deflecting torque}$$

$$k\theta = NIAB$$

$$\theta = \frac{NIAB}{k}$$

$$\theta = \left(\frac{NAB}{k}\right) I$$

$$\theta = (Constant) I$$

The quantity ($\frac{NAB}{k}$) is a constant for a given galvanometer.

$$\theta \propto I$$

It is evident that the deflection observed in the galvanometer is directly proportional to the current flowing through it.

18.6 AMMETER:

An electrical device which is used for the measurement of current is called ammeter. Ammeter is a modified form of a moving coil galvanometer. It is also called a low resistance galvanometer.

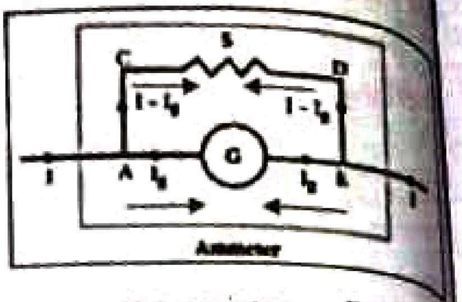
PRINCIPLE AND CONSTRUCTION:

Its principle and construction is similar to the moving coil galvanometer.

CONVERSION OF GALVANOMETER INTO AMMETER:

To convert a galvanometer into an ammeter, a very small resistance is connected in parallel with the galvanometer. This resistance is called shunt resistance (Rs).

CALCULATION OF R_s:



Ammeter is basically a galvanometer in which suitable modification has been made.

Suppose we have a galvanometer that gives full scale deflection when a current I_g is passed through it. Let R_g be the resistance of the galvanometer and voltage across galvanometer is given by:

$$V_g = I_g R_g$$

In order to convert it into ammeter which measure a current I, we connect a resistance R_s called shunt resistance parallel to the galvanometer so that excess current I reaches at point A. It has two paths to flow: through galvanometer or through R_s. If current I_g flows through galvanometer, then current through R_s will be $I_s = I - I_g$. According to Ohm's law

$V_s = R_s I_s$ or $V_s = R_s (I - I_g)$

As shunt resistance R_s and galvanometer are connected in parallel, then potential difference across them will be same.

$$V_s = V_g$$

$$I_s R_s = I_g R_g$$

$$(I - I_g) R_s = I_g R_g$$

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

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

A piece of copper wire can be used as shunt. To measure current through wire, ammeter is always connected in series.

18.7 VOLTMETER:

An electrical device which is used for the measurement of potential difference between two points is called voltmeter.

Voltmeter is a modified form of a moving coil galvanometer. It is also called a high resistance galvanometer.

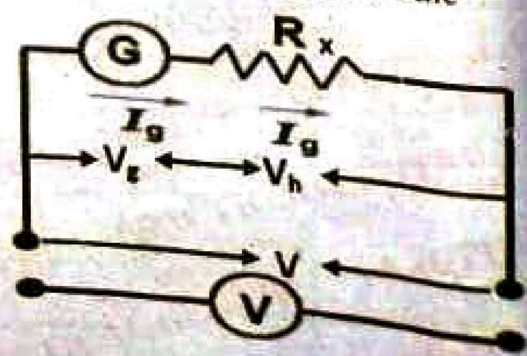
PRINCIPLE AND CONSTRUCTION:

Its principle and construction is similar to the moving coil galvanometer.

CONVERSION OF GALVANOMETER INTO VOLTMETER:

To convert a galvanometer into an voltmeter, a high resistance is connected in series with the galvanometer.

Calculation of R_x:



A galvanometer is converted into a voltmeter upto a range 'v' by connecting a high resistance 'R_x' in series. Due to which most of the potential drop on it. If Ig is the current for full deflection of galvanometer then some current from R_x due to the series connection.

$$V = V_x + V_g$$

$$V = I_g R_x + I_g R_g$$

$$V - I_g R_g = I_g R_x$$

$$R_x = \frac{V - I_g R_g}{I_g}$$

$$R_x = \frac{V}{I_g} - R_g$$

To measure voltage, voltmeter is always connected in parallel with the two points whose potential is to be measured.

18.8 CRQs (Short Answered Questions)