Chapter: 13

"ELECTROMAGNETISM"

Introduction:

Electromagnetic is made up of two words.

1- Electro, which has something to do with electricity

2- Magnetic, which has something to do with magnetism

"Electromagnetism is the branch of physics that deals with the study of electricity and magnetism and the interaction between them"

OR

"Electricity induced magnetism is called electromagnetism"

(Read)

Magnetism	Electromagnetism
Magnetism is defined as a force or property that can cause two objects to attract or repel each other due to the motion of electric charges.	Electromagnetism is the branch of physics that deals with the study of electricity and magnetism and the interaction between them.
It refers to the phenomena associated with magnetic fields or magnetic forces.	It refers to the phenomena associated with both magnetic fields and electric fields.

➔ The study of magnetism started with the discovery of the **lodestone (a piece of magnetite, Fe_3O_4),** which has property attract iron and other magnetic materials. Today, much is known of this mineral, also called iron ore or iron oxide.

History of Electromagnetism (Read)

During a lecture demonstration in the summer of 1820, the Danish **physicist Hans Christian Oersted** noticed that a current in a straight wire caused a noticeable deflection in a nearby magnetic compass needle. He concluded that **moving charges or currents produced a magnetic field** in the surrounding space. Later the name oersted was adopted for the physical unit of magnetic field.

A naturally occurring Lodestone was (Read) first mined at magnesia, Anatolia in Turkey. This is the reason that this **lodestone is named as "Magnet".**

For your information (Read)

Recording media and swipe cards:

Magnetic recording media:

VHS(Video Home System) tapes contains a reel of magnetic tape. The information that makes up the video and sound is encoded on the magnetic coating on the tape. Common audio cassettes also rely on magnetic tape. Similarly, in computers, floppy disks and hard disks record data on a thin magnetic coating.

Credit, debit and ATM cards:

All of these cards have a magnetic strip on one side. This strip encodes the information to contact an individual's financial institution and connect with their account(s).

13.1 MAGNETIC FIELD

"Magnetic Field is the region around a magnetic material or a moving electric charge within which the force of magnetism acts"

➔ The region of space surrounding any moving electric charge (current), in addition to containing an electric field also contains a magnetic field.

➔ When charges are at rest, no such magnetic field is observed.

➔ In general, we can say that current through a conducting wire creates a magnetic field around the wire.

➔ If a suspended bar-shaped magnet is free to rotate, it will rotate until its one end points to the earth's geographic north pole. This end is called north (N) pole of bar magnet. The other end points to earth's geographic south Pole called south (S) pole.

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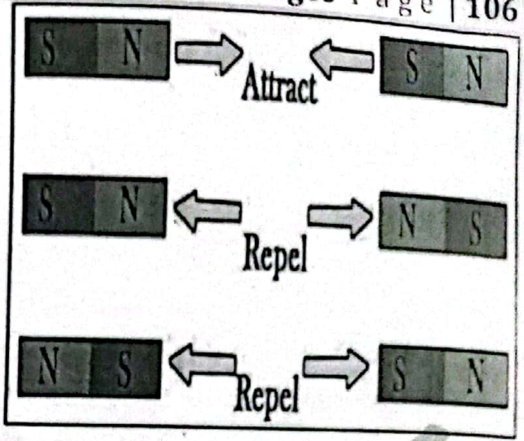
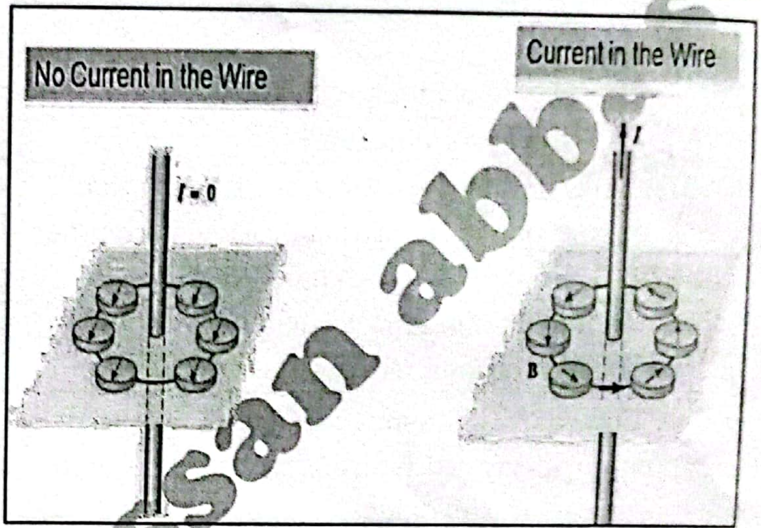


→ The like poles repel and unlike poles attract each other with a force, such force of attraction or repulsion between unlike or like poles is known as magnetic force.

→ Magnetic field is a vector quantity and represented by $\vec{B}$ called magnetic induction.

MAGNETIC FIELD DUE TO CURRENT IN A LONG STRAIGHT WIRE

1- Take a straight, thick copper wire and pass it vertically through a hole in a horizontal piece of cardboard.



2- Place small compass needles on the cardboard along a circle with the center at the wire. All the compass needles will point in the direction of N-S of earth's magnetic field.

3- Now pass a heavy current through the wire. It will be seen that the needles will rotate and will set themselves tangential to the circle.

4- On reversing the direction of current, the direction of needles is also reversed.

5- As the current is stopped, all the needles again point along the N-S direction.

Following conclusion can be drawn from the above mention experiment:

a. A magnetic field is set up in the region surrounding a current carrying wire.

b. The lines of force are circular (in the form of concentric circles) and their direction depends upon the direction of current.

c. The magnetic field lasts only as long as the current is flowing through the wire.

Similar observations can be made through a cardboard on which iron fillings are sprinkled. These iron fillings form concentric circles around the wire.

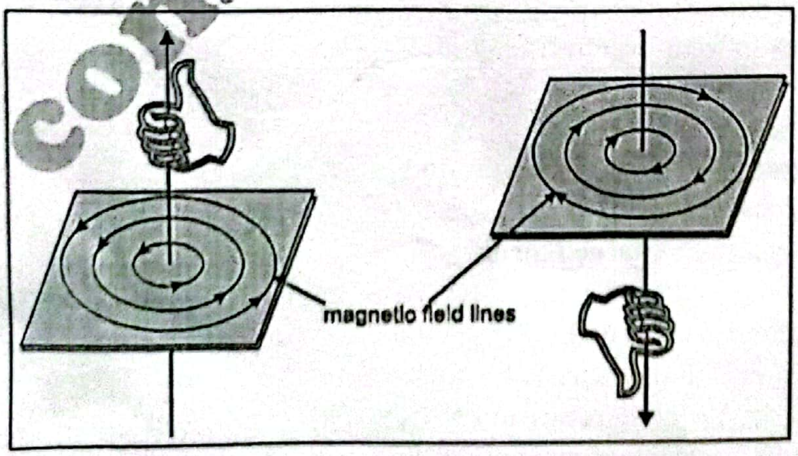
The direction of the lines of force can be found by a rule known as **Right Hand Rule** concluded directly from the above experiment which is stated as follows:

Right Hand Rule-I

"If the wire is grasped in fist of right hand with the thumb pointing in the direction of the current, the fingers of the hand will circle the wire in the direction of the magnetic field"

→ This rule is for direction of conventional current or flow of positive charges.

→ For electronic current flow the same rule is applied but with left hand.



Magnetic Monopoles doesn't exist!
Although the force between two magnetic poles is otherwise similar to the force between two electric charges, electric charges can be isolated (witness the electron and proton) whereas a single magnetic pole has never been isolated. That is, magnetic poles are always found in pairs. All attempts thus far to detect an isolated magnetic pole have been unsuccessful. No matter how many times a permanent magnet is cut in two, each piece always has a north and a south pole.

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13.2 FORCE ON A CURRENT CARRYING CONDUCTOR IN UNIFORM MAGNETIC FIELD (for long)

Introduction

We know that current carrying wire sets up its own magnetic field. If such a current carrying wire is placed at right angle to an external uniform magnetic field 'B', then these two magnetic fields i.e. the magnetic field due to current carrying wire and the applied external uniform magnetic field interact with each other, as a result of which wire experience a force 'F_B'.

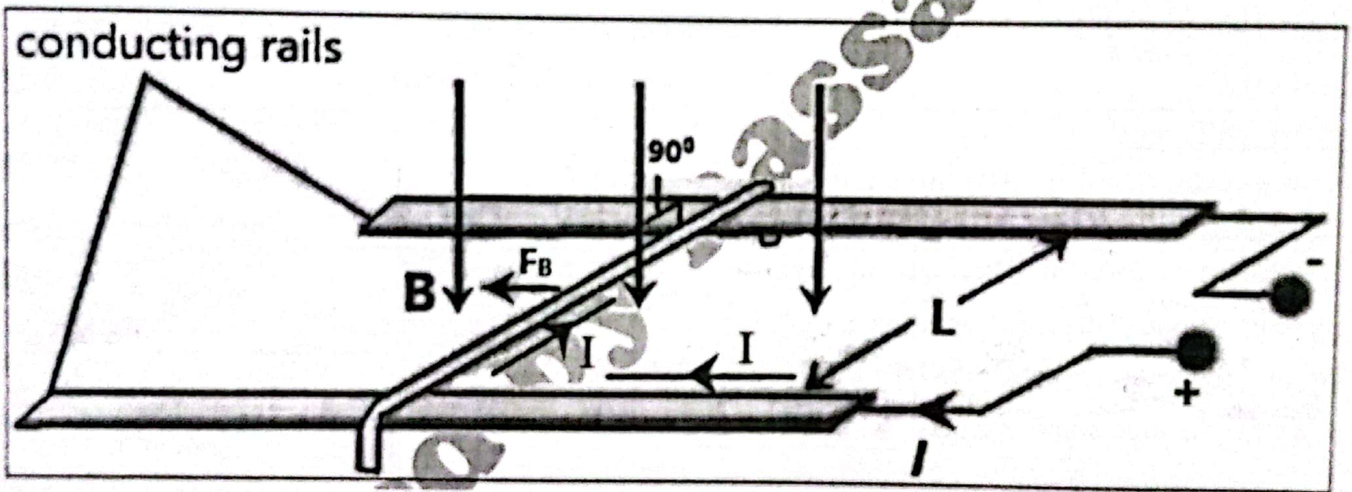
The Origin of the Magnetic Force on a Wire

When a magnetic field is applied at some angle to a wire carrying a current, a magnetic force is exerted on each moving charge in the wire. The total magnetic force on the wire is the sum of all the magnetic forces on the individual charges producing the current.

Explanation

- Consider a rod of copper, capable of moving on a pair of copper rails. The whole arrangement is placed between the pole pieces of a horseshoe magnetic so that the copper rod is subjected to a magnetic field directed inwards(into the page).
- When a current is passed through the copper rod from a battery, the rod moves on the rails.

We adopt the following convention: A current or a field (electric or magnetic) emerging out of the plane of the paper is depicted by a dot (⊙). A current or a field going into the plane of the paper is depicted by a cross (⊗)



Factors on which the force acting on current carrying conductor depends imp

The magnitude of the force depends upon the following four factors:

i. **Current:**

The force 'F' is directly proportional to the current 'I' flowing through the conductor.

$$F \propto I$$

The more the current, greater is the force and vice versa.

ii. **Direction of conductor in magnetic field:**

If the length of the conductor is perpendicular to the direction of the applied field then a maximum force acts on the conductor. However, if the length is parallel to the direction of field, the conductor experiences no force. It means, the magnitude of force depends upon the factor of sinθ (angle θ that the current carrying wire makes with the magnetic field i.e. between $\vec{L}$ & $\vec{B}$).

$$F \propto \sin\theta$$

iii. **Strength of the magnetic field:**

The force 'F' is directly proportional to the strength of the applied/external magnetic field 'B'.

$$F_B \propto B$$

The stronger the external field, the greater is the force and vice versa.

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iv. **Length of the conductor:**

The force 'F' is directly proportional to the length 'L' of the conductor inside the magnetic field.

$$F_B \propto L$$

Combining all these factors,

$$F_B \propto ILB\sin\theta$$

$$F_B = k\,ILB\sin\theta$$

Where k is constant of proportionality. It is dimensionless and its numeric value is 1 in SI units. Thus

$$\boxed{F_B = ILB\sin\theta} \text{ ----(i)}$$

This equation shows that the magnitude of the force 'F' on a current carrying wire.

In Vector Form

$$\boxed{\vec{F_B} = I\vec{L} \times \vec{B}}$$

Where θ is the angle between vector $\vec{L}$ & $\vec{B}$ and **the vector $\vec{L}$ is in the direction of current flow.**

Maximum force:	**Minimum force:**
This force is maximum when angle θ between length of wire (l) and magnetic field (B) is 90°.	Force will be minimum when angle between l and B is zero.
F_B = ILBsinθ	F_B = ILBsinθ
$F_{B(max)}$ = ILbsin (90°)	$F_{B(min)}$ = ILBsin0°
$F_{B(max)}$ = ILB	$F_{B(min)}$ = 0

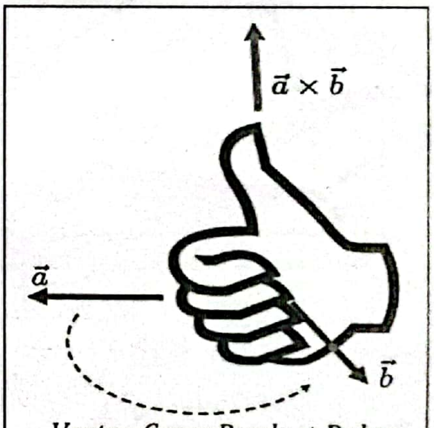
Direction of Force

As force is a vector quantity so its direction should also be determined.

(i) Right Hand Cross Product Rule II

The direction of the force 'F' is given by the right-hand rule of the cross product of vectors $\vec{L}$ & $\vec{B}$ i.e. "Open the fingers of right hand in the direction of $\vec{L}$(current) and then curl the fingers of right hand in the direction of $\vec{B}$ through smaller angle. The thumb points in the direction of force"

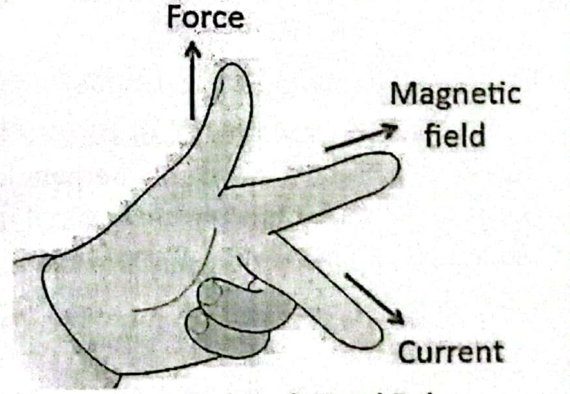
→This rule is for direction of conventional current or for flow of positive charges. For electronic current the same rule is applied but with left hand.



Vector Cross Product Rule

(ii) The direction of the force 'F' is also determined by Fleming's left-hand rule, which states that

"The thumb and the first two fingers of the left hand are set at right angle to each other, with the first finger pointing in the **direction of the magnetic field** and second finger pointing in the **direction of current**, the thumb gives the **direction of force**"



Fleming's Left-Hand Rule

Magnetic Induction (B)

Definition

Equation (i) provides a definition of strength of magnetic field(B).

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

If $I = 1A$, $L = 1m$, $\theta = 90°$

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$$B = F$$

"If current of 1A passing through a wire of length 1m placed perpendicular to the magnetic field, then the force exerted on it will be equal to Magnetic Induction."

Unit of B:

$$B = \frac{F}{IL\sin\theta} \rightarrow \frac{N}{A.m}$$

$$\boxed{B \rightarrow NA^{-1}m^{-1}} \rightarrow \text{Tesla}$$

$$\boxed{B \rightarrow Tesla}$$

One Tesla:

Tesla is the unit of magnetic induction. 1 Tesla is defined as:

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

$$1\text{Tesla} \rightarrow \frac{1N}{(1A)(1m)}$$

$$\boxed{1\text{Tesla} \rightarrow 1NA^{-1}m^{-1}}$$

"If current of 1A passing through a wire of length 1m placed perpendicular to the magnetic field, experiences a force of 1 Newton, then magnetic induction is said to be one tesla"

Strengths of magnetic fields

Conventional laboratory magnets can produce magnetic fields as large as about **25,000 G** or **2.5 T**. Superconducting magnets that can generate magnetic fields as great as **3 x 10⁵ G** or **30 T**, have been constructed. These values can be compared with the small value of Earth's magnetic field near its surface, which is only about **0.5 G** or **0.5 x 10⁻⁴ T**.

***Gauss*:**

Tesla is the bigger unit, other unit is "Gauss"

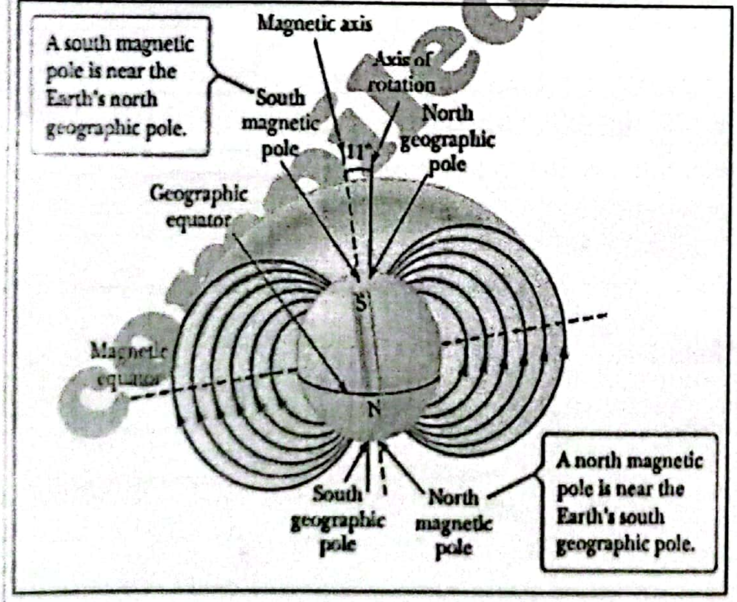
$1\ G = 10^{-4}$ Tesla

or **$1\ T = 10^{4}$ Gauss**

Example 13.1

A wire carrying current 2 A current and has length of 10 cm between the poles of a magnet is kept at angle of 30⁰ to the uniform field of 0.6 T. Find the force acting on the wire? ($F_B = 0.06$ N)

Earth's Magnetic Field



Pattern of Earth's Magnetic field

The magnetic field pattern of Earth is similar to the pattern that would be set up by a bar magnet placed at its center.

Source of Earth's Magnetic field

It's considered more likely that the true source of Earth's magnetic field is electric current in the liquid part of its core.

Strength of Earth's Magnetic field

The magnitude of the Earth's Magnetic field at its surface ranges from 25 to 65 μT (0.25 to 0.65 G).

Planet's rate of rotation

There is some evidence that the strength of a Planet's magnetic field is related to the planet's rate of rotation. For example, Jupiter rotates faster than Earth, and recent space probes indicate that Jupiter's magnetic field is stronger than Earth. Venus, on the other hand, rotates more slowly than Earth, and its magnetic field is weaker.

Direction of Magnetic field

An interesting fact concerning Earth's magnetic field is that its direction reverses every few million years.

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13.3 Magnetic Flux (Φ_B) and Magnetic Flux Density (B)

Introduction:

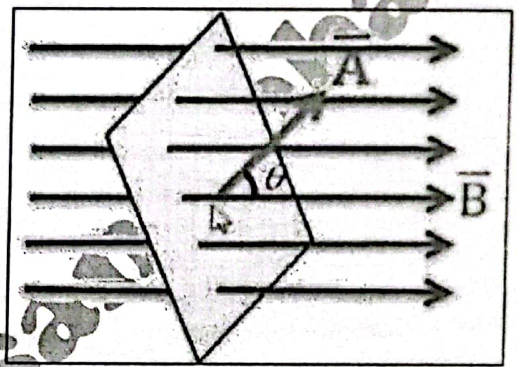
A magnetic field can be represented by imaginary lines of force called magnetic field lines.
As, electric field lines are close together where Electric field is strong and vice versa, just like it **magnetic induction tells us how close magnetic field lines are, as it tells us the strength of the magnetic field.**

Definition:

Magnetic flux is defined as:

"The number of magnetic field lines passing through a surface placed perpendicularly to the magnetic field is called Magnetic Flux"

- It is represented by Φ_B
- Magnetic flux is a scalar quantity.



Mathematical form:

Magnetic flux is the scalar(dot) product of magnetic induction $\vec{B}$ and vector area $\vec{A}$.

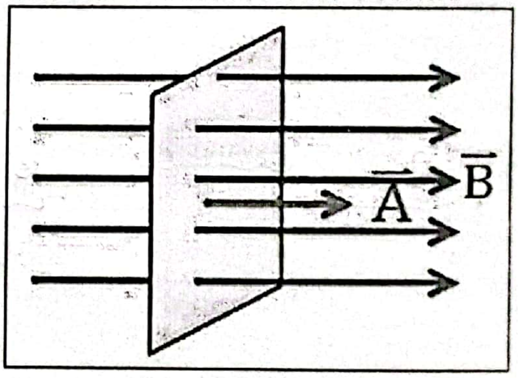
$$\Phi_B = \vec{B} \cdot \vec{A}$$

$$\Phi_B = BA\cos\theta$$

Where **θ is angle between magnetic field $\vec{B}$ and vector area $\vec{A}$.**
Direction of vector area $\vec{A}$ is normal to the surface area.

Maximum Flux:

If area is held perpendicular to the direction of magnetic field 'B' then the direction of vector area $\vec{A}$ is parallel to the direction of $\vec{B}$ and angle θ between them is 0^0. In this case then maximum number of field lines will pass through the surface. Therefore, magnetic flux will be maximum,



$$\Phi_B = BA\cos\theta$$

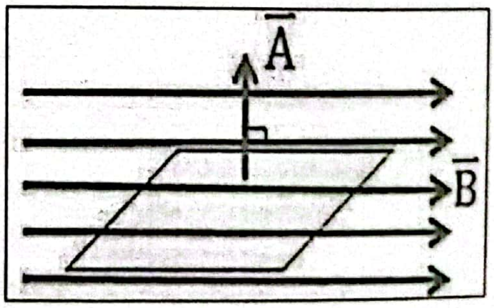
$$\Phi_B = BA\cos(0°) \quad \because \theta = 0^0 \text{ because magnetic field B is parallel to the area vector } (\vec{A})$$

$$\Phi_B = BA(1)$$

$$\Phi_B = BA$$

Zero Flux:

If area is placed parallel to the direction of magnetic field 'B' then the direction of vector area $\vec{A}$ is perpendicular to the direction of $\vec{B}$ and angle 'θ' between them is 90^0. In this case then minimum ~~maximum number~~ no of field lines will pass through the surface. Therefore, magnetic flux will be ~~minimum~~ 0.



$$\Phi_B = BA\cos\theta$$

$$\Phi_B = BA\cos(90°) \quad \because \theta = 90^0 \text{ because magnetic field B is perpendicular to the area vector } (\vec{A})$$

$$\Phi_B = BA(0)$$

$$\Phi_B = 0$$

Unit of Magnetic Flux:

$\Phi = BA$ $\Phi \rightarrow (Tesla)(m^2)$ $\boxed{\Phi \rightarrow Tm^2 \rightarrow Wb(weber)}$	$\Phi = BA$ $\Phi \rightarrow (NA^{-1}m^{-1})(m^2)$ $\boxed{\Phi \rightarrow Nm^{+1}A^{-1} \rightarrow Wb(weber)}$

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Magnetic Flux Density (B)

Definition:

"Magnetic flux per unit area of a surface placed perpendicular to magnetic field"

Mathematical form:

$$B = \frac{\Phi_B}{A} = \frac{Magnetic\ flux}{Surface\ Area}$$

Units of Magnetic Flux Density:

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

$$B = \frac{\text{weber}}{\text{m}^2}$$

$$\boxed{B = \text{Wbm}^{-2} = Tesla}$$

∴ Magnetic flux does not hold for curved or non-uniform magnetic field.

calculate (for short)

MAGNETIC FLUX THROUGH CURVED OR NON-UNIFORM MAGNETIC FIELD

If the magnetic field is non-uniform or the surface is curved. Then we divide the whole curved path into 'n' number of small patches each of area ΔA such that **area of each patch becomes approximately flat or magnetic field is almost uniform over it.** (for short)

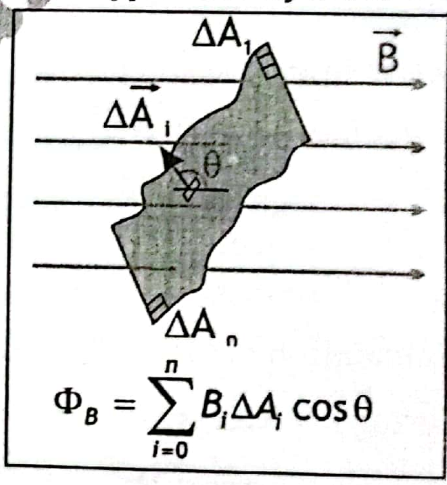
For one of these small patches the magnetic flux is

$$\Delta\Phi_B = \vec{B_i} \cdot \vec{\Delta A_i} = B_i \Delta A_i \cos\theta_i$$

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

$$\Phi_B = \sum_{i=1}^{n} \Delta\Phi_B = \sum_{i=1}^{n} \vec{B_i} \cdot \vec{\Delta A_i}$$

$$\boxed{\Phi_B = \sum_{i=1}^{n} B_i \Delta A_i \cos\theta_i}$$



Homework:

A hemispherical surface of radius 5cm is placed in a magnetic field of strength 0.6T. If the direction of the surface is along the direction of the field then calculate the flux through the hemispherical surface.

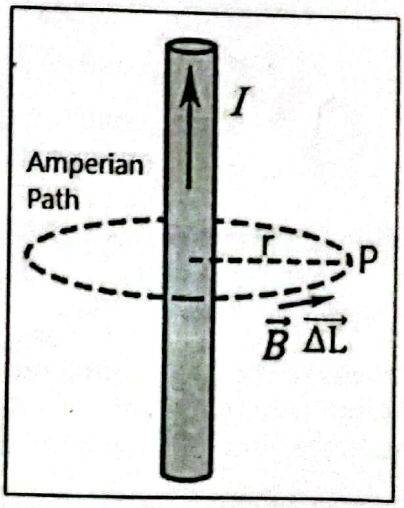
($\Phi_B = 4.7 \times 10^{-3}$ Wb)

13.4 AMPERE CIRCUITAL LAW (for long)

imp.

Background:

We know that an electric current produces a magnetic field, in 1826 **Marie Ampere** after carrying a series of experiments, generalized his results into a law known as **Ampere circuital law.** By this law the magnetic field strength 'B' at any point due to a current-carrying conductor can be easily computed.



Explanation and Derivation:

In order to find magnetic field due to current carrying wire at a distance "r" we apply the following steps.

Steps:

1. Take a point P at some distance r at which B has to be calculated.
2. Draw an **Amperian path** (an imaginary closed path in the form of circle of radius 'r'), which passes through point P.

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3. Divide the Amperian path into 'n' small segments of length like $\overrightarrow{\Delta L}$ and let $\vec{B}$ be the value of magnetic field strength at the site of $\overrightarrow{\Delta L}$
4. Determine the value of $\vec{B}.\overrightarrow{\Delta L}$

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

where θ is the angle between $\vec{B}$ & $\overrightarrow{\Delta L}$

Definition:

Ampere's law states that,

"The sum of all such product,($\vec{B}.\overrightarrow{\Delta L}$) over the closed path is equal to μ_o times the total current that passes through the closed path"

→ μ_o is a constant known as **permeability of free space** and in SI units its value is **4π x 10-7 $WbA^{-1}m^{-1}$**

Mathematical form of Ampere's Law:

Ampere's law can be mathematically expressed as

$$(\vec{B}.\overrightarrow{\Delta L})_1 + (\vec{B}.\overrightarrow{\Delta L})_2 + \cdots + (\vec{B}.\overrightarrow{\Delta L})_n = \mu_o I \text{ ----(i)}$$

OR

$$\sum_{i=1}^{n}(\vec{B}.\overrightarrow{\Delta L})_i = \mu_o I$$

Where 'n' is the number of elements into which the loop has been divided.

Calculation of $(\vec{B}.\overrightarrow{\Delta L})_1$

$(\vec{B}.\overrightarrow{\Delta L})_1 = B_1\Delta L_1\cos\theta$

$= B_1\Delta L_1\cos 0^0 \quad \because \theta = 0^0$ *because* $\vec{B}$ & $\overrightarrow{\Delta L_1}$ are parallel to each other.

$= B_1\Delta L_1 \quad \because \cos 0^0 = 1$

Calculation of $(\vec{B}.\overrightarrow{\Delta L})_2$

$(\vec{B}.\overrightarrow{\Delta L})_2 = B_2\Delta L_2\cos\theta$

$= B_2\Delta L_2\cos 0^0 \quad \because \theta = 0^0$ *because* $\vec{B}$ & $\overrightarrow{\Delta L_2}$ are parallel to each other.

$= B_2\Delta L_2 \quad \because \cos 0^0 = 1$

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Calculation of $(\vec{B}.\overrightarrow{\Delta L})_n$

$(\vec{B}.\overrightarrow{\Delta L})_n = B_n\Delta L_n\cos\theta$

$= B_n\Delta L_n\cos 0^0 \quad \because \theta = 0^0$ *because* $\vec{B}$ & $\overrightarrow{\Delta L_2}$ are parallel to each other.

$= B_n\Delta L_n \quad \because \cos 0^0 = 1$

Putting all values of $\vec{B}.\overrightarrow{\Delta L}$ in equation (i)

$$B_1\Delta L_1 + B_2\Delta L_2 + \cdots + B_n\Delta L_n = \mu_o I \text{ ----(ii)}$$

$$|B_1|=|B_2|=|B_3|\ldots\ldots\ldots|B_n|=|B|$$

The **magnetic field is tangent to this circle at every point**, and its magnitude has the same value B over the entire circumference of a circle of radius r because all the length segments are equidistant from the center(current carrying conductor).

But remember $\vec{B}_1 \neq \vec{B}_2 \neq \vec{B}_3 \neq \ldots\ldots\ldots \neq \vec{B}_n$

$B\Delta L_1 + B\Delta L_2 + B\Delta L_3 + \ldots + B\Delta L_n = \mu_o I$

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$$B(\underbrace{\Delta L_1 + \Delta L_2 + \cdots + \Delta L_n}_{Circumference\ of\ amperian\ path}) = \mu_o I$$

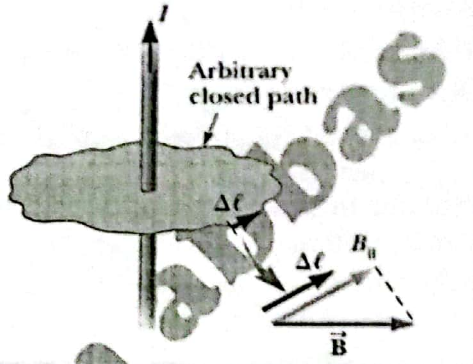
$$B(2\pi r) = \mu_o I$$

because Amperian path is in the form of circle and circumference of circle = $2\pi r$

Rearranging above equation gives,

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

In general Ampere's law can be applied to any arbitrary closed path around a uniform magnetic field.



For any other medium apart from vacuum or air the permeability μ of that material is used in the equation of Ampere's law.

$$\boxed{B = \frac{\mu I}{2\pi r}}$$

Units of μ_o:

$\mu_o = \frac{B\,(2\pi r)}{I}$ $\mu_o = \frac{(Tesla)(m)}{(A)}$ $\mu_o = TmA^{-1}$	$\mu_o = \frac{B\,(2\pi r)}{I}$ $\mu_o = \frac{(Wbm^{-2})(m)}{(A)}$ $\mu_o = Wbm^{-1}A^{-1}$	$\mu_o = \frac{B\,(2\pi r)}{I}$ $\mu_o = \frac{(Nm^{-1}A^{-1})(m)}{(A)}$ $\mu_o = NA^{-2}$

PERMEABILITY (μ)

Permeability is the measure of magnetization that a material obtains in response to an applied magnetic field. The permeability of a vacuum μ_o is $4\pi \times 10^{-7}$ Wb/At.m (webers/ampere-turn meter) and is used as a reference. The relative permeability μ_r of a material is the ratio of its absolute permeability to the permeability of a vacuum.

$$\mu_r = \frac{\mu}{\mu_o}$$

As, it is a ratio of permeabilities, μ_r is dimensionless. Typical magnetic materials, such as iron have relative permeability of few hundred.

Factors upon which B depends

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

$B \propto \frac{I}{r}$ As, μ_o & 2π are constants

There are two factors upon which B depends:

i- $\boxed{B \propto I}$

Strength of Magnetic field at any point is directly proportional to current passing through wire.

If more current passes the strength of B at that point increases and vice versa.

ii- $\boxed{B \propto \frac{1}{r}}$

Strength of Magnetic field strength at any point is inversely proportional to its distance from the current carrying wire.

Farther the point from the current carrying wire weaker will be magnetic field at that point and vice versa.

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Example 13.2

Two long parallel wires 6cm apart carry current of 8A and 2A in the same direction. What is magnitude of magnetic field B midway between then? **($B_{net} = 4 \times 10^{-5}$ T)**

Assignment 13.1 $B = \mu_0 I / 2\pi r$ $B = \frac{4\times3.14\times10^{-7}\times1}{2(3.14)(5\times10^{-3})}$

A long straight wire carries a current of 1 A. Find the magnitude of the magnetic field at a distance of 1 m from it. **($B = 2 \times 10^{-5}$ T)**

Magnetic Force between two parallel current carrying conductors

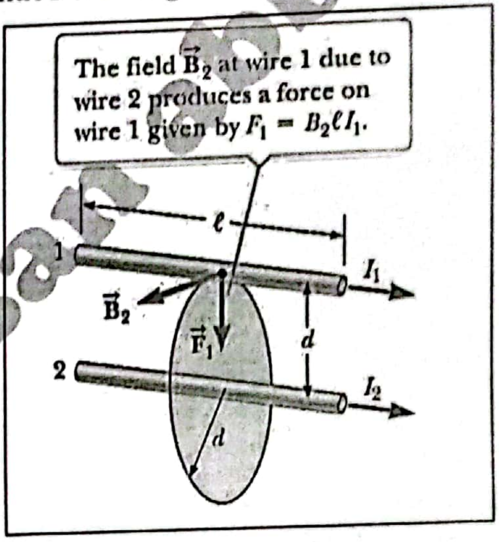
(Self-understanding)

Introduction: imp

When two current-carrying wires placed close together, they exert magnetic forces on each other.

Explanation:

Consider two long, straight, parallel wires separated by the distance d and carrying currents I_1 and I_2 in the same direction, as shown in Figure. Wire 1 is directly above wire 2. **What's the magnetic force on one wire due to a magnetic field set up by the other wire?**



In this calculation we are finding the force on wire 1 due to the magnetic field of wire 2. The current I_2 sets up magnetic field $\vec{B}_2$ at wire 1. Using Ampere's law, we find that the magnitude of this magnetic field is

$$B_2 = \frac{\mu_0 I_2}{2\pi d}$$

the magnitude of the magnetic force on wire 1 in the presence of field $\vec{B}_2$ due to I_2 is

$$\boxed{F_1 = B_2 I_1 \ell = \left(\frac{\mu_0 I_2}{2\pi d}\right) I_1 \ell = \frac{\mu_0 I_1 I_2 \ell}{2\pi d}}$$

The direction of $\vec{F}_1$ is downward, toward wire 2, as indicated by right-hand rule. This calculation is completely symmetric, which means that the force $\vec{F}_2$ on wire 2 is equal to and opposite $\vec{F}_1$, as expected from Newton's third law of action–reaction.

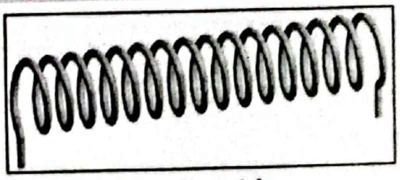
We have shown that **parallel conductors carrying currents in the same direction attract each other.** We can also show that by applying same steps that **parallel conductors carrying currents in opposite directions repel each other.**

MAGNETIC FIELD DUE TO CURRENT CARRYING SOLENOID

imp

Solenoid:

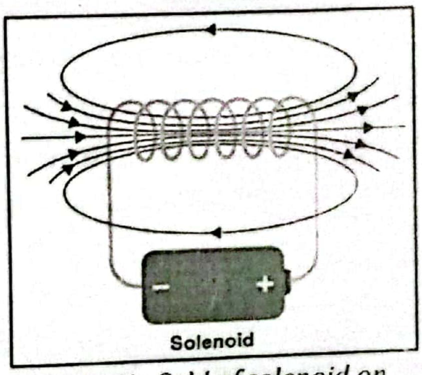
"A coil wounded in the form of a spiral (helix) with many turns forms a solenoid"



solenoid

Properties of solenoid:

1. When current passes through solenoid, it produces magnetic field 'B' along its axis and behaves like a **"Bar Magnet"** i.e. one end of solenoid becomes north pole while end becomes south pole.
2. Solenoid is also called **'Electromagnet'** (a temporary magnet whose magnetism is produced by an electric current).
3. Inside the tightly wound solenoid magnetic field lines are closer and parallel to each other which means **magnetic field is strong and very uniform inside the solenoid** along its axis i.e. the field inside the solenoid has a constant magnitude at all points.



Magnetic field of solenoid on passing current

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4. Outside the solenoid magnetic field lines are farther and not parallel to each other which means magnetic field is weak and non-uniform and it is so weak that it can be neglected as compared to the field inside.

$$B_{outside} << B_{inside}$$

$$\therefore \; B_{outside} \approx 0$$

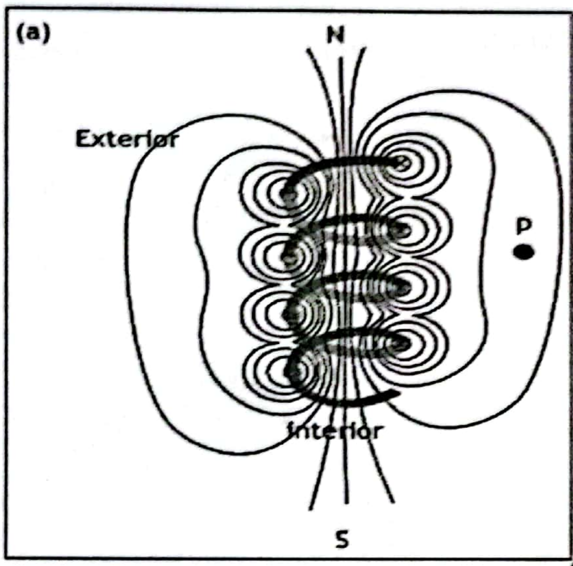
Direction of B outside the solenoid = North➔South

Direction of B inside the solenoid = South ➔ North

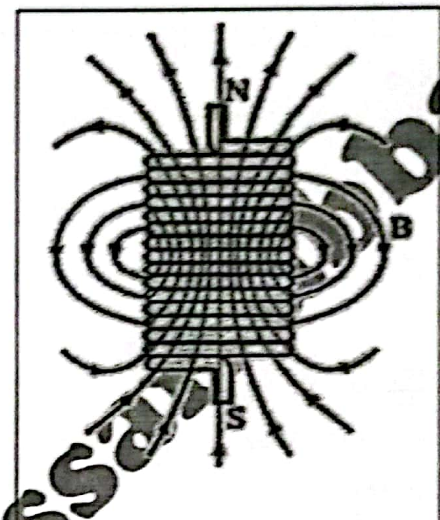
Ideal solenoid

An ideal solenoid is approached **when the turns are closely packed** and the **length is much greater than the radius of the turns.**

As the length of the solenoid increases, the interior field becomes more uniform and the exterior field becomes weaker.



For loosely wound solenoid



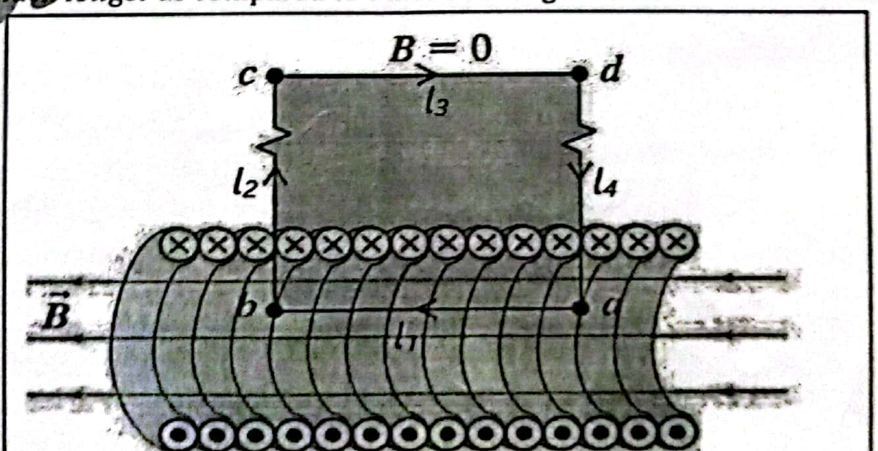
(b) Tightly wound solenoid

5. The magnetic field lines surrounding a **loosely wound solenoid,** shows that these lines in the interior are nearly parallel to one another, are uniformly distributed and are close together.
6. For a **tightly wound solenoid** the field in the interior of the solenoid is very uniform and strong.
7. An **ideal solenoid** is approached when the turns are closely packed and length of coil much greater than its diameter of the turns i.e. $l >> d$ (approaching ideal solenoid), In this case, the external field is close to zero and the interior field is uniform over a great volume.

Calculation of *B* inside current carrying solenoid:

The value of magnetic field $\vec{B}$ i.e. quantitative expression for the interior magnetic field in an ideal solenoid can be easily determined by applying Ampere's circuital law.

- Consider a closed Amperian path in the form of rectangular path(loop) abcd. Divide it into four elements of length ab = l_1, bc = l_2, cd = l_3 and da = l_4 where l_1 is inside the solenoid and l_3 outside the solenoid.
- Lengths l_1 and l_3 much longer as compared to other two lengths l_2 and l_4



Central part of solenoid

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- Applying Ampere's law, we have

$$\sum_{n=1}^{4}(\vec{B}.\vec{l})_n = \mu_o \times \text{current enclosed}$$

$$(\vec{B}.\vec{l})_1 + (\vec{B}.\vec{l})_2 + (\vec{B}.\vec{l})_3 + (\vec{B}.\vec{l})_4 = \mu_o \times \text{current enclosed ----(i)}$$

- Now we will calculate the value of $\vec{B}.\vec{l}$ for each of the elements.

Calculation of $(\vec{B}.\vec{l})_1$

The element ab = l_1 that lies inside the solenoid. Magnetic field inside the solenoid is uniform and is parallel to l_1 ($\theta = 0^0$)

$\vec{B}.\vec{l}_1 = Bl_1\cos\theta_1$

$\vec{B}.\vec{l}_1 = Bl_1\cos(0^o)$

$\vec{B}.\vec{l}_1 = Bl_1(1)$

$\vec{B}.\vec{l}_1 = Bl_1$

Calculation of $(\vec{B}.\vec{l})_2$

The element bc = l_2 is perpendicular to B inside the solenoid, so ($\theta = 90^0$)

$\vec{B}.\vec{l}_2 = Bl_2\cos\theta_2$

$\vec{B}.\vec{l}_2 = Bl_1\cos(90^o)$

$\vec{B}.\vec{l}_2 = Bl_2(0)$

$\vec{B}.\vec{l}_2 = 0$

Calculation of $(\vec{B}.\vec{l})_3$

For the element cd = l_3 that lies outside the solenoid, the magnetic field **B** is approx. zero i.e. B=0

$\vec{B}.\vec{l}_3 = Bl_3\cos\theta$

$\vec{B}.\vec{l}_3 = (0)l_3\cos\theta$

$\vec{B}.\vec{l}_3 = 0$

Calculation of $(\vec{B}.\vec{l})_4$

The element da = l_4 is perpendicular to B inside the solenoid, so ($\theta = 270^0$)

$\vec{B}.\vec{l}_4 = Bl_4\cos\theta_4$

$\vec{B}.\vec{l}_4 = Bl_4\cos(270^o)$

$\vec{B}.\vec{l}_4 = Bl_4(0)$

$\vec{B}.\vec{l}_4 = 0$

so, equation(i)

$$(\vec{B}.\vec{l})_1 + (\vec{B}.\vec{l})_2 + (\vec{B}.\vec{l})_3 + (\vec{B}.\vec{l})_4 = \mu_o \times \text{current enclosed}$$

becomes

$$Bl_1 + 0 + 0 + 0 = \mu_o \times \text{current enclosed}$$

$$Bl_1 = \mu_o \times \text{current enclosed ----(ii)}$$

To find the current enclosed by the rectangular surface bounded by the loop abcda.

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–If 'n' is the number of turns per unit length of the solenoid, i.e. $n = \frac{Total\ number\ of\ turns}{Total\ length\ of\ solenoid} = \frac{N}{l}$

$Total\ number\ of\ turns\ of\ solenoid\ 'l'\ is\ N = nl$

So, **total number of turns in length l_1 is 'nl_1'**

So, the total current enclosed by the closed path abcda = **total number of turns in length l_1 x *current flowing in solenoid***

Total current enclosed by the closed path abcda = $nl_1 \times I$

so, equation (ii) becomes

$$Bl_1 = \mu_o \times nl_1 I$$

$$\boxed{B = \mu_o nI}$$

A closely wound solenoid has greater value of n as compared to loosely wound solenoid.

This equation holds for solenoid containing air/vacuum, when some magnetic material is inserted inside the solenoid its magnetic field increased many times.

If magnetic material is inserted inside the solenoid:

If magnetic material of absolute permeability 'μ' is inserted inside the solenoid, then

$$B = \mu nI \quad ----(a)$$

$$As, \mu_r = \frac{\mu}{\mu_o} \rightarrow \mu = \mu_o \mu_r$$

So, above equation (a) becomes

$$\boxed{B = \mu_o \mu_r nI}$$

Point to Ponder
By what factor will the magnetic field inside a solenoid increase if both the number of turns and the current are doubled?

Factors affecting magnetic field of a Solenoid:

$$B = \mu_o \mu_r nI$$

1. $B \propto \mu_r$

Magnetic field directly depends on the relative permeability of material. When a ferromagnetic material says **soft iron** is inserted $\mu_r = 600$ ($B \propto \mu_r$). Hence, magnetic field increases 600 times as compared to air/vacuum.

2. $B \propto n$

Number of turns per unit length of solenoid has direct influence on B.

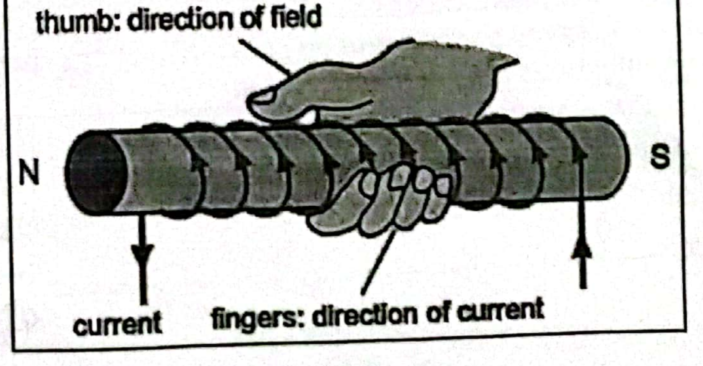
$As, n = \frac{N}{l}$ **'n' will be greater when more turns are wound on smaller length of solenoid.**

3. $B \propto I$

When current increases, the magnetic field created due to current also increases and vice versa.

Right Hand Rule III for solenoid direction of 'B':

To find the direction of magnetic field **Right hand grip rule** is applied which states that **"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 magnetic field/north pole".**



Direction of current in solenoid can be reversed by changing,
1. Pattern of wounding of wire.
2. Polarity of battery.

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$n_1 = N_1/L \Rightarrow n_1 = 500$ | $n_2 = N_2/L$, $n_2 = 400$ | $B = B_1 + B_2 = \mu_0 n_1 I + \mu_0 n_2 I$ | $= \mu_0 I (n_1 + n_2) = 4 \times 3.14 \times 10^{-7} \times 3 (500 + 400)$ | $= 3.4 \times 10^{-3}$ T.

Example 13.3

A solenoid is 10cm long and is wound with two layers of wire. The inner layer has 50turns and the outer layer has 40turns. A current of 3A flows in both layers in same direction. What is the magnitude of magnetic flux density along the axis of solenoid?
($B_{net} = 3.4 \times 10^{-3}$ T)

Assignment 13.2 imp $B = \mu_0 n I$, $n = \frac{B}{\mu_0 I}$, $n = \frac{0.10}{4 \times 3.14 \times 10^{-7} \times 10}$, $n = 7.96 \times 10^3\ m^{-1}$

You are asked to design a solenoid that will give a magnetic field of 0.10 T, yet the current must not exceed 10.0A. Find the number of turns per unit length that the solenoid should have.
($n = 7.96 \times 10^3\ m^{-1}$)

13.6 FORCE ON A MOVING CHARGED PARTICLE IN UNIFORM MAGNETIC FIELD

Introduction:

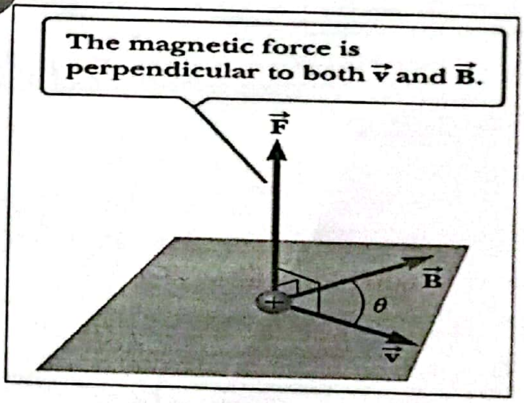
In electrostatics, we know that when a **charged particle is placed in an electric field it** experiences a force called electric force in the direction of electric field or against the electric field, depending on the sign of the charge.

Similarly, a **charged particle in a magnetic field** would experience a force called magnetic force, provided that the following two conditions must met.

1. **The charge must be moving because no force acts on a stationary charge.** The force on the charged particle results from the interaction of the external magnetic field and the magnetic field created by the moving charge.
2. **The velocity of the moving charge is neither parallel nor antiparallel to the direction of the magnetic field.**

(A) FORCE ON POINT (POSITIVE) CHARGE

For a positive charge 'q' moving with velocity 'v' in a magnetic field of strength 'B', the force acting on the charge is given by the expression



$$\vec{F}_B = q(\vec{v} \times \vec{B})$$
$$\vec{F}_B = q\,v\,B \sin\theta\, \hat{n}$$

where **θ is the angle between velocity and magnetic field** and $\hat{n}$ is the unit vector, use to express the direction of magnetic force on moving charge.

Magnitude form:

$$F_B = qvB \sin\theta$$

Maximum force:

Force on charge particle will be maximum when charge particle moves perpendicularly to the magnetic field i.e. θ = 90°

As, $F = q\,v\,B \sin\theta$ ∴ θ = 90°

Putting θ = 90° → F = F_{max}

$F_{max} = q\,v\,B \sin 90^0$ (+) → (v ∥ B)

$F_{max} = q\,v\,B$

Minimum/Zero force:

Force on charge particle will be zero when charge particle is moving either parallel or antiparallel to the magnetic field i.e. θ = 0° or 180°

$F = q\,v\,B \sin\theta$ Putting θ = 0° → F = F_{min} $F_{min} = q\,v\,B \sin 0^0$ $F_{min} = 0$	$F = q\,v\,B \sin\theta$ Putting θ = 180° → F = F_{min} $F_{min} = q\,v\,B \sin 180^0$ $F_{min} = 0$

θ = 180° (v ∥ B)

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$F_B = qvB\sin\theta$ / 1- Particle → neutral $q=0 \Rightarrow F_B=0$ 2nd particle → rest $v=0$, $F_B=0$ 3rd particle pass through region where $B=0$ 4th V-(||) charge

Direction of force:

moving parallel or antiparallel to B $\theta = 0°$, $\theta = 180°$

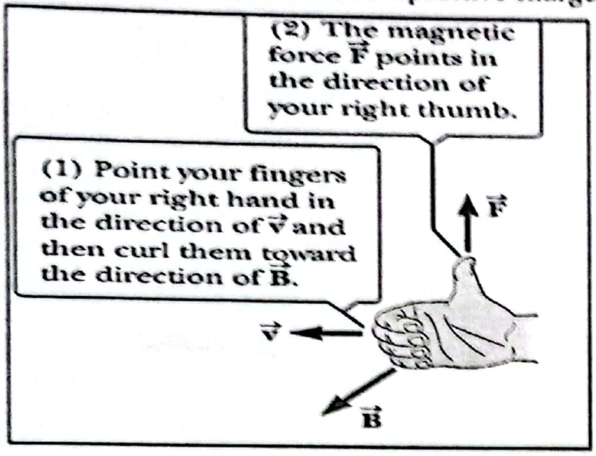
For a positive charge, the **Right-Hand Rule II or Flemings Left Hand Rule** for force on a current carrying conductor are used to determine the direction of force. Where the **direction of current is replaced by velocity of charged particle.**

(i) Right Hand Cross Product Rule

1- Point the fingers of your right hand in the direction of the velocity $\vec{v}$.

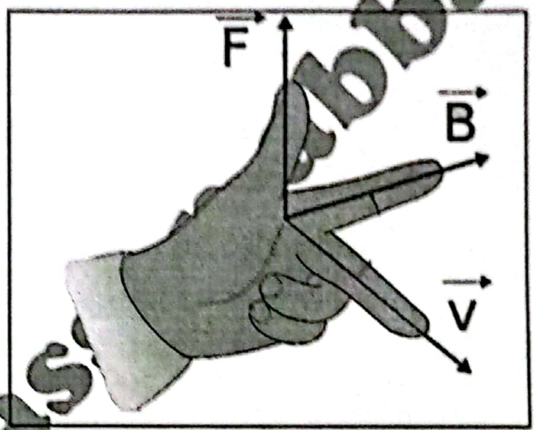
2- Curl the fingers in the direction of the magnetic field $\vec{B}$, moving through the smallest angle.

3- The erected thumb points in the direction of the magnetic force 'F' exerted on a positive charge.



(ii) Fleming's Left-Hand Rule

"The thumb and the first two fingers of the left hand are set at right angle to each other, with the first finger pointing in the direction of magnetic field and second finger pointing in the direction of velocity of the charged particle, then thumb gives the direction of the force"



Force on negative charge:

If the moving particle is negatively charged such as an electron simply use the right-hand cross product or Fleming's Left-Hand Rule to find the direction for positive q and then reverse that direction for the negative charge. Figure illustrates the effect of a magnetic field on charged particles with opposite signs.

Q:- Mass of proton is 1836 times greater than electron, both particles enter with same velocity in B, which particle experiences greater force (Boom)

Force on electron, putting q = -e

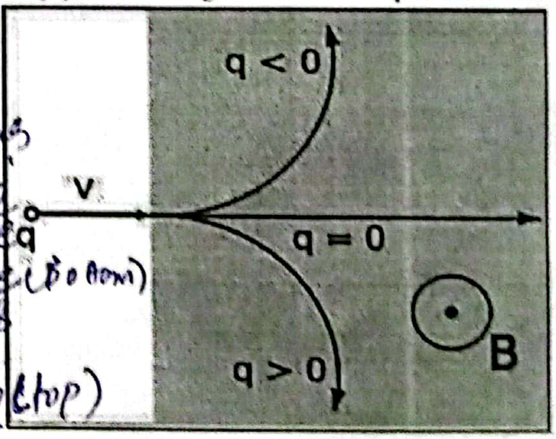
$$\vec{F} = -e\,(\vec{v} \times \vec{B})$$

Force on proton, putting q = +e

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

Q:- Under what conditions negative force on a particle can be zero (stop)

$$\boxed{\therefore\ \vec{F}_{proton} = -\vec{F}_{electron}}$$



(b) THE FORCE ON CURRENT CARRYING CONDUCTOR AND MOTION OF CHARGE PARTICLE IN MAGNETIC FIELD

- We have seen that a current carrying wire experiences a force when placed in a magnetic field. Since a current in a wire consists of moving electric charges, we might expect that freely moving charged particles would also experience a force when passing through a magnetic field. The force on current carrying conductor is

$$F_B = ILB\sin\theta \;----(i)$$

- If 'N' particles, each particle having charge 'q' pass by a given point in time 't', they constitute a current, they by definition of current

$$I = \frac{total\ charge\ flows\ by\ a\ point}{time\ taken} = \frac{Nq}{t} ----(ii)$$

Both experience same forces b/z they don't depend upon mass
$F_B = qVB\sin\theta$

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- As 'L' represents length of conductor and time 't' represents time taken by charge particles to pass through conductor of length 'L'. Then by definition the velocity by which the charge particles pass through conductor is,

$$velocity = \frac{distance\ covered}{time\ taken} = \frac{L}{t}$$

$$v = \frac{L}{t} \rightarrow L = vt \quad ----(iii)$$

Putting equation (ii) & (iii) in equation (i)

$$F_B = \left(\frac{Nq}{t}\right)(vt)B\sin\theta$$

$$F_B = (Nq)(v)B\sin\theta$$

Here F_B represents total force on conductor having 'N' charge carriers.
Force on single charged particle,

$$Force\ on\ single\ charged\ particle = \frac{Total\ force\ on\ conductor}{Total\ no\ of\ charge\ carriers}$$

$$= \frac{NqvB\sin\theta}{N}$$

$$\boxed{F_B = qvB\sin\theta}$$

In vector form,

$$\boxed{\vec{F}_B = q\vec{v} \times \vec{B} \text{ or } \vec{F}_B = qvB\sin\theta\hat{n}}$$

Where $\hat{n}$ is unit vector and it represents the direction of force on the charged particle.

Quiz

Q- Why wheat flour is usually passed near a magnet before being packed?

- A lot of food is passed through metal detectors/ magnetic fields to ensure that no metal has ended up in there during the manufacturing process.
- When wheat is drawn from the silos prior to milling, it is thoroughly cleaned. Powerful magnets extract tiny pieces of steel or any remaining ferrous metal objects.
- If they ended up in the finished product you could end up eating them and be injured.

Q- Why a steel ship becomes magnetized as it is constructed?

1 - A ship *does* get magnetized slightly during construction, because working on steel shakes it up enough to let the 'domains' (that give it its magnetic properties) align themselves a bit in the direction of the existing field.
2 - A ship is built from number of plates joined together as a group of panels and block by welding.
- A huge amount of welding is done for the construction of ships. During this a high ampere of current is required. **As steel is a ferromagnetic substance, it has magnetic dipoles which tends to acquire magnetic behavior once being passed through electric current.**
- Hence when huge amount of current is passed through steel plates for the formation of ship, it becomes magnetized.

Homework

An ion (q = +2e) enters into a magnetic field of strength 1.2T with a velocity 2.5 x 10^5 ms^{-1} perpendicular to the field. Determine the force that acts on the ion.

($F = 9.6 \times 10^{-14}$ N)

$F_B = qvB\sin\theta$.
$= (2e)(2.5\times10^5)(1.2T)\sin(90)$
$= (2\times1.6\times10^{-19})(2.5\times10^5)(1.2)\sin 90$
$= 9.6\times10^{-14} N$

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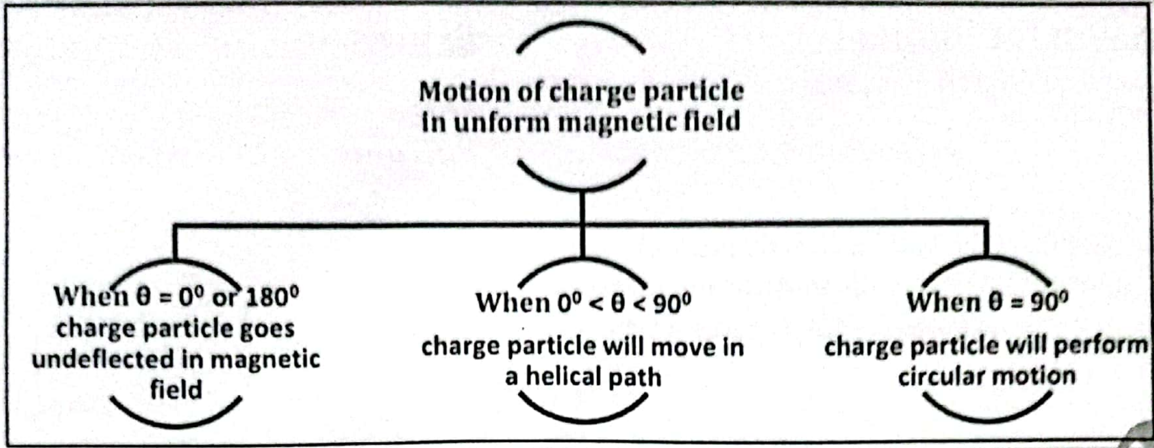


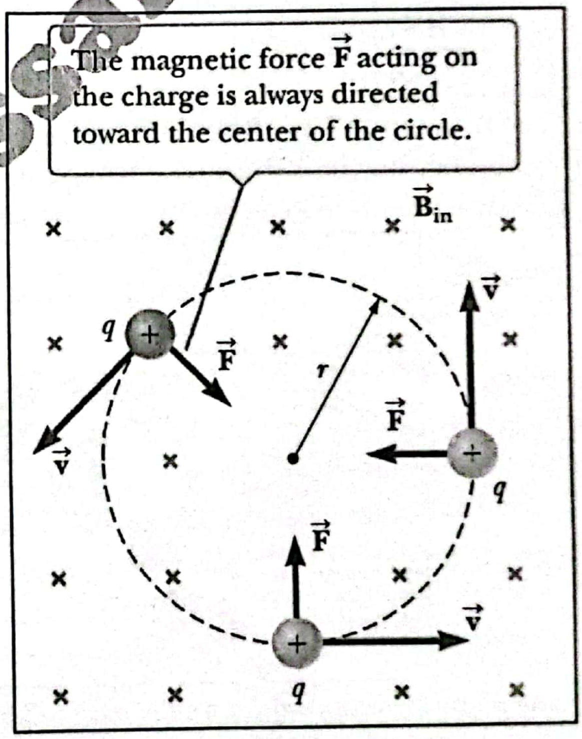
(c) CIRCULAR MOTION OF CHARGE PARTICLE IN UNIFORM MAGNETIC FIELD (mcqs)

The charge particle will perform circular motion if its velocity is perpendicular to uniform magnetic field.

Let us consider a positive charge particle 'q' moving with velocity 'v' perpendicular to the magnetic field. Let us assume the direction of the magnetic field 'B' directed into the page. We know that charged particle will experience magnetic force which is

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

The direction of the force is perpendicular to both 'v' and 'B'.



Effect of magnetic force on motion of charge particle:

- As charged particle is experiencing a force that acts at right angle to its velocity, so charge will change the direction of the velocity (magnitude of velocity remains unchanged).
- The magnitude of force is $qvB\sin\theta$ as $\theta = 90^0$, so $F_B = qvB$. As both v and B are constant in magnitude so the magnitude of F is also constant. Thus, the charged particles are subjected to a constant force 'qvB' at right angle to their direction of motion.
- Under the action of this force, the charged particles will move along a circle as shown in figure.
- The magnetic force $F_B = qvB$ provides the necessary centripetal force $\frac{mv^2}{r}$ to the charge particle.

Mathematical calculations:

Centripetal force due to charge particle is provided by magnetic force.

$$F_c = F_B$$

$$\frac{mv^2}{r} = qvB\sin\theta$$

$$\frac{mv^2}{r} = qvB\sin 90^0 \qquad \because v \text{ and } B \text{ are perpendicular to each other } \theta = 90^0$$

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

$$\frac{mv}{r} = qB \; ----(i)$$

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Expression for Radius(r):

Rearranging equation (i) gives

$$\boxed{r = \frac{mv}{qB}}$$

That is, the radius of the path is directly proportional to the linear momentum 'mv' of the particle and inversely proportional to the magnitude of the charge on the particle.

Expression for Angular velocity(ω):

Putting $v = r\omega$ in equation (i)

$$\frac{m(r\omega)}{r} = qB$$

$$m\omega = qB$$

$$\boxed{\omega = \frac{qB}{m}} --- (ii)$$

Expression for frequency(f):

As, $\omega = \dfrac{qB}{m}$

substituting $\omega = 2\pi f$ in above eq.

$$2\pi f = \frac{qB}{m}$$

$$\boxed{f = \frac{qB}{2\pi m}}$$

The frequency 'f' is often referred to as the cyclotron frequency because this is the frequency at which particles revolve in a cyclotron (particle accelerator)

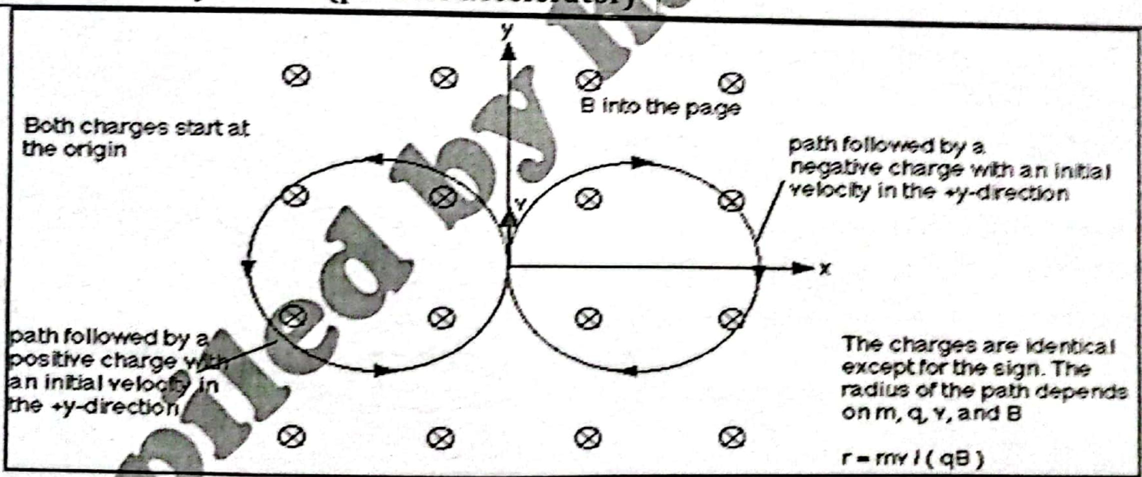
Calculation of Time Period(T):

$$T = \frac{1}{f}$$

Substituting $f = \dfrac{qB}{2\pi m}$

$$T = \frac{1}{\frac{qB}{2\pi m}} \Rightarrow \boxed{T = \frac{2\pi m}{qB}}$$

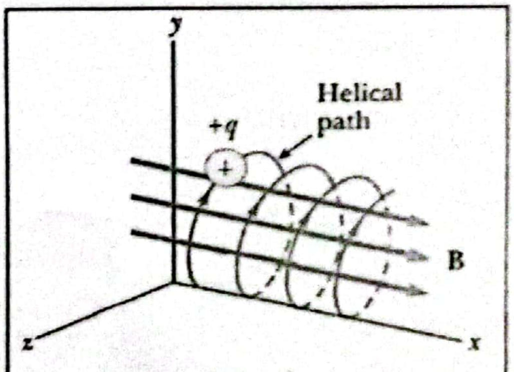
This time period of the motion is the time interval the particle requires to complete one revolution.



The following diagram shows the path followed by two charges, one positive and one negative, in a magnetic field that points into the page

Helical motion of charged particle:

If a charged particle moves in a uniform magnetic field with its velocity at some arbitrary angle (**between 0⁰ and 90⁰**) with respect to B, its path is a helix/spiral.



A charged particle having a velocity vector that has a component parallel to a uniform magnetic field moves in a helical path.

Example 13.4

The path of an electron in a uniform magnetic field of flux density 1.0×10^{-2} T in a vacuum is a circle of radius 1 cm. Calculate the period of its orbit?

(Ans: 3.57×10^{-9} s = 3.57 ns)

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Imp for longs (4times)

(D) DETERMINATION OF CHARGE TO MASS RATIO(e/m) FOR AN ELECTRON

- To determine the charge to mass ratio (q_e/m_e) for an electron. The beam of electron is projected perpendicularly in a uniform magnetic field, such that the electron will perform circular motion (this uniform magnetic field is provided by Helmholtz rings.
- The centripetal force (F_c) it needed is provided by magnetic force (F_B).

$$F_c = F_B$$

$$\frac{mv^2}{r} = qvB\sin\theta$$

As, v and B are perpendicular to each other $\theta=90^0$ & q = e

$$\frac{mv}{r} = eB\sin(90^0)$$

$$\frac{mv}{r} = eB$$

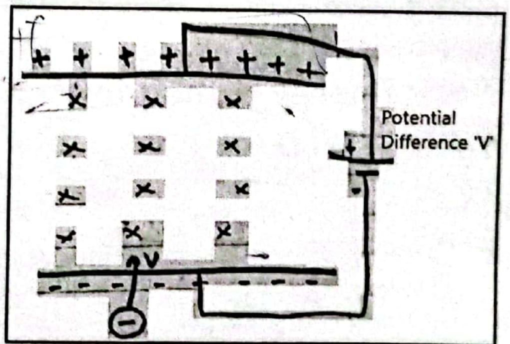
Rearranging for $\frac{e}{m}$ gives $\boxed{\frac{e}{m} = \frac{v}{Br}}$ - - - (i)

Helmholtz rings
Two similar coils with radius R are placed at the same distance R. When the coils are so connected that the current through the coils flows in the same direction, the Helmholtz coils produce a region with a nearly uniform magnetic field.

Estimation of radius 'r'

1) Practically we shot beam of electrons into a magnetic field of known value.
2) Radius of the electrons can be measured by making their path visible through ionization and de-excitation of the gas molecules.
3) This is done by filling a glass tube with a gas such as hydrogen or helium at low pressure.
4) This tube is placed in a region of uniform magnetic field. As electrons are shot into this tube, they begin to move along a circle under the action of magnetic force.
5) As the electrons move, they collide with the atoms of the gas.
6) When electrons collide with the atoms of the gas, they excite them and their de-excitation causes emission of visible blue light.
7) Due to emission of blue light, their path becomes visible as a circular ring of light and diameter of the ring can be easily measured.

Measurement of velocity 'v'



- In order to measure the velocity 'v' of the electrons, we should know the potential difference through which the electrons are accelerated before entering into the magnetic field.
- If 'V' is the potential difference, the energy gained by electrons during their acceleration is 'Ve'.
  This appears as the kinetic energy of the electrons

Kinetic energy gained by electrons
= Energy supplied by battery

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

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

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

substituting 'v' in eq. (i)

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

Squaring both sides gives $\frac{e^2}{m^2} = \frac{\frac{2eV}{m}}{B^2r^2}$

$$\frac{e^2}{m^2} = \frac{2eV}{mB^2r^2}$$

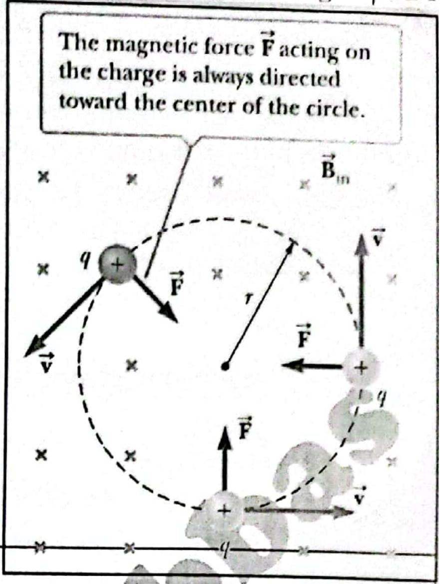
$$\boxed{\frac{e}{m} = \frac{2V}{B^2r^2}}$$

Knowing the value of potential difference 'V', Magnetic field 'B' and radius 'r' charge to mass ratio of electron can be calculated. **The accurately known value of e/m for electron is 1.7588 x 10^{+11} C kg^{-1}**

compiled by hassan a

Important Question:

Show that work done by magnetic force is zero.



Ans- Let a charged particle is shot perpendicularly in the magnetic field, it will follow the circular path.
Centripetal force for this purpose will be provided by Magnetic force (F_B)

$$F_B = F_C$$

As velocity of moving particle and magnetic force are always perpendicular to each other **(θ=90⁰)** so, Displacement and force are also perpendicular.

W.D = Fdcosθ

W.D = Fdcos90⁰

W.D = Fd (0)

W.D = 0

So, W.D by magnetic force is Zero it is just a deflecting force(That force which only change direction)

Remember!
We cannot bring a charge into motion with the help of magnetic force, because work done by magnetic force is zero, that is why it is also called a **deflecting force.**

Important Question:

What is the effect on speed (K.E) of moving particle when it enters perpendicularly in magnetic field?

Ans- There will be no effect on the speed of moving particle **(v=constant)** when it enters perpendicularly in the magnetic field (B).

Reason:

On entering magnetic field, charge will follow circular path. The centripetal force or F_B is always directed towards Centre of circle. As we know work done by magnetic force (F_B) on charge particle is **Zero.**
So, according to

Work Energy principle:

$$\Delta K.E = W.D$$

$$\Delta K.E = 0 \quad \because W.D \text{ by magnetic force } = 0$$

$$K.E_f - K.E_i = 0 \quad \because \Delta K.E = K.E_f - K.E_i$$

$$K.E_f = K.E_i$$

$$\frac{1}{2}mv_f^2 = \frac{1}{2}mv_i^2$$

$$v_f^2 = v_i^2$$

$$v_f = v_i$$

$$\boxed{\textit{No effect on speed of moving particle when it enters perpendicularly in magnetic field.}}$$

Due to magnetic field, velocity of particle remains constant.
1) Magnitude of velocity remains same. 2) Only direction of velocity changes throughout the motion.

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Applications Involving Charged Particles Moving in a Magnetic Field (Imp)

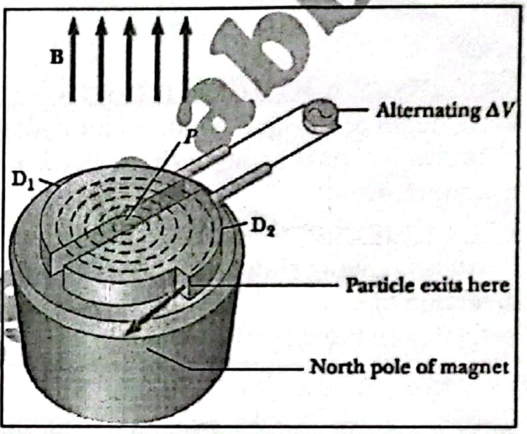
A charge moving with a velocity 'v' in the presence of **both an electric field 'E' and a magnetic field 'B'** experience both an electric force **'qE'** and a magnetic force **'qvB'**. The total force called the **Lorentz force** acting on the charge is

$$\vec{F} = \vec{F}_E + \vec{F}_B$$

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

Following are the applications involving charged particles moving in a magnetic field.
1) The cyclotron
2) The Mass Spectrometer (in last chapter)
3) Velocity Selector (will discuss this only)

Cyclotron



"A cyclotron is a device that can accelerate charged particles to very high speeds"

Principle

The cyclotron uses **both electric and magnetic fields** in combination to increase the energy of charged particles. As both **fields are perpendicular to each other they are called crossed fields.**

Uses

The energetic particles produced are used to **bombard atomic nuclei and thereby produce nuclear reactions.**
It is used in hospitals to **produce radioactive substances which can be used in diagnosis and treatment.**

(E)VELOCITY SELECTOR (Imp) (For short

Introduction:

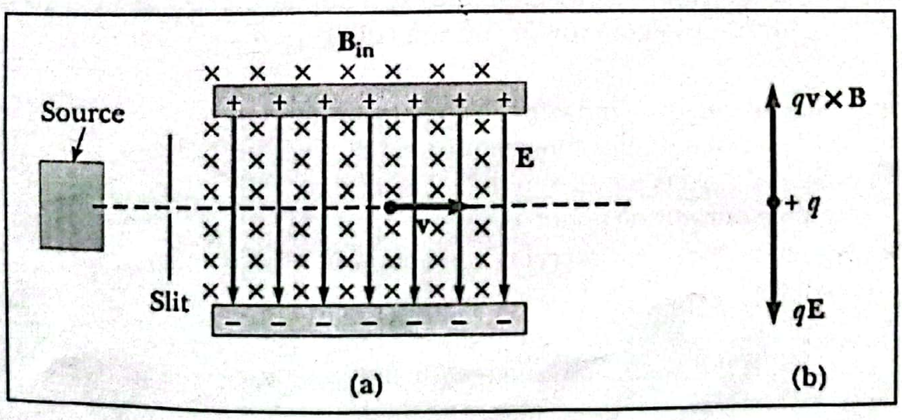
In many experiments involving moving charged particles, it is important to select charged particles of a particular velocity out of a beam containing charges moving with different speeds, this can be **achieved by ~~applying a crossed combination of an electric field and a magnetic field~~.** velocity selector

Definition:

"The arrangement of the electric field and the magnetic field is used to select a charged particle of a certain velocity out of a beam containing charges moving with different velocities"

Arrangement of velocity selector

The arrangement of such method consists of **crossed combination of an electric field and a magnetic field** i.e. both are perpendicular to each other.
A uniform electric field is directed vertically downward and a uniform magnetic field is applied into the page.



Working:

When a beam of positive charges moving with different velocities enters into the velocity selector to the right, then **magnetic force 'qvB' acting on the charge particles is upward** and the **electric force 'qE' acting on the charge particles is downward i.e. both forces are in opposite direction.**

For undeflected charged particles:

Some particles go undeflected through the velocity selector, these are those particles for which the magnitude of electric force is equal to magnetic force but opposite in direction.

For undeflected positive charge particles

$$F_{electric} = F_{magnetic}$$
$$qE = qvB$$
$$E = vB$$
$$\boxed{v = \frac{E}{B}}$$

Velocity of undeflected particles:

If the beam of charged particles moving with different velocities pass through velocity selector only those particles will pass straight through the device **which have velocities equal to the ratio of electric to the magnetic field.**

For other charged particles:

Particles moving slower than this speed will experience less magnetic force and will be deflected in the direction of electric force and those having greater speed will experience more magnetic force and will be deflected in the direction of magnetic force.

Lottery Question

Alpha particles ranging in speed from 1000 ms^{-1} to 2000 ms^{-1} enter into a velocity selector where the electric intensity is 300 Vm^{-1} and the magnetic induction 0.20 T. Which particle will move undeviated through the field?

$V = E/B$
$= 300/0.2$
$= 1500$

Assignment 13.3

A velocity selector in a mass spectrometer uses a 0.100 T magnetic field. What electric field strength is needed to select a speed of 4.00 x 10^6 ms^{-1} ?

($E = 4 \times 10^5$ N/C)

13.7 TORQUE ON A CURRENT CARRYING COIL/LOOP PLACED IN A MAGNETIC FIELD

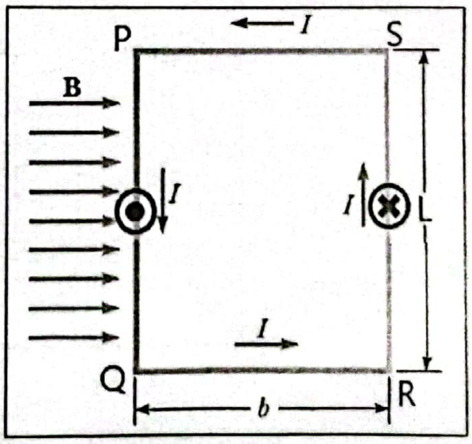
4 times (imp)

Introduction:

We know that magnetic force is exerted on a current carrying conductor when the conductor is placed in an external magnetic field.

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

Explanation:



- Consider a rectangular coil of length '*l*' and width '*b*' having 'N' turns carrying a current *I* placed in uniform magnetic field 'B' such that the direction of magnetic field is parallel to the plane of the loop. Also, the coil is capable of rotation about an axis.
- In order to calculate torque on a current carrying coil/loop we have to calculate force on each of its side. Force on each side is given by,

$F = ILB\sin\theta$ where θ is the angle between length and Magnetic field.

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Force on sides PS and QR:

As, the sides PQ and RS are parallel or antiparallel to the magnetic field so $\theta = 0^0$ or 180^0

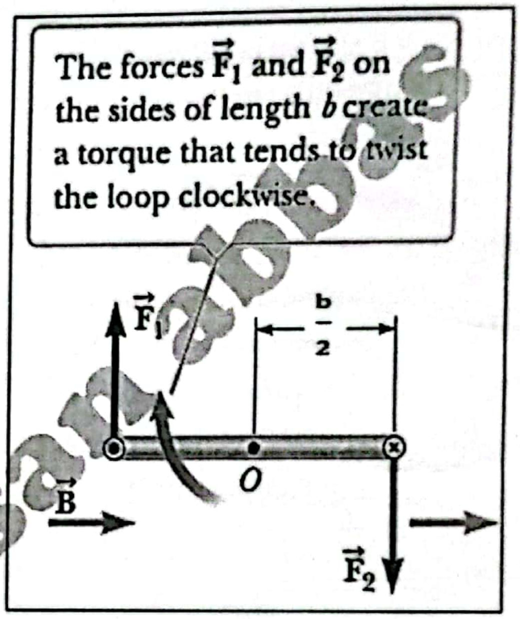
Hence force on sides PS and QR,

$$F_{PS} = F_{QR} = ILB\sin\theta = 0 \qquad \because \sin 0^0 = 0 \;\&\; \sin 180^0 = 0$$

Force on sides PQ and SR:

As, the side PQ and SR are perpendicular to the magnetic field so $\theta = 90^0$

$$F_{PQ} = F_{SR} = ILB\sin\theta = ILB \qquad \because \sin 90^0 = 1$$



The direction of $F_{PQ} = F_1$, the force on the left side of the loop, is out of the page and that of $F_{SR} = F_2$, the force on the right side of the loop, is **into the page.**

If we view the loop from the side QR, the forces are directed as shown.

If we assume the loop is pivoted so that it can rotate about point O, we see that these two forces produce a couple(torque) about O that rotates the loop clockwise. The magnitude of this torque, τ_{max}, is

$$\tau_{max} = \text{torque due to force } F_1 + \text{torque due to force } F_2$$

$$\tau_{max} = (F_1 \times \text{moment arm}) + (F_2 \times \text{moment arm})$$

$$\tau_{max} = \left(F_1 \times \frac{b}{2}\right) + \left(F_2 \times \frac{b}{2}\right)$$

where the moment arm about O is $\frac{b}{2}$ *for both forces*

Subsituting $F_1 = F_2 = ILB$

$$\tau_{max} = \left(ILB \times \frac{b}{2}\right) + \left(ILB \times \frac{b}{2}\right)$$

$$\tau_{max} = \frac{ILbB}{2} + \frac{ILbB}{2} = \frac{2(ILbB)}{2}$$

$$\tau_{max} = ILbB$$

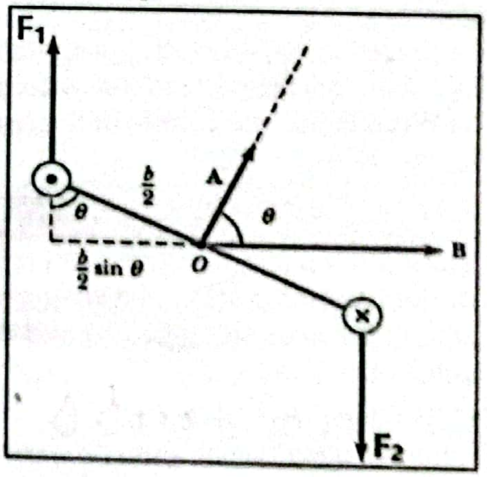
Moment Arm:
The shortest perpendicular distance between a force's line of action and an axis of rotation (e.g. a pivot)

where 'Lb' is the area 'A' of the loop. So, above equation becomes

$$\boxed{\tau_{max} = IAB}$$

This is the maximum torque produced by a current carrying coil and this result is valid only when the magnetic field is parallel to the plane of the loop.

When magnetic field makes an angle θ < 90⁰ with the plane of loop



- Now consider the case **when the plane of the loop is not parallel/not aligned with the magnetic field** but makes an angle $\theta < 90^\circ$ with it.
- We take the angle between the field and the normal to the coil to be angle θ. In this case, the magnetic forces F_3 and F_4 exerted on sides PS and QR cancel each other and produce no torque because they pass through a common origin.
- However, the magnetic forces F_1 and F_2 acting on sides PQ and SR produce a couple(torque) about any point.

$$\tau = \text{torque due to force } F_1 + \text{torque due to force } F_2$$

$$\tau = F_1 \times \text{moment arm} + F_2 \times \text{moment arm}$$

$$\tau = F_1 \times \left(\frac{b}{2}\sin\theta\right) + F_2 \times \left(\frac{b}{2}\sin\theta\right)$$ the moment arm about O is $\frac{b}{2}$ *for both forces*

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Subsituting $F_1 = F_2 = ILB$

$$\tau = ILB\left(\frac{b}{2}\sin\theta\right) + ILB\left(\frac{b}{2}\sin\theta\right)$$

$$\tau = \frac{ILbB\sin\theta}{2} + \frac{ILbB\sin\theta}{2} = \frac{2(ILbB\sin\theta)}{2} = ILbB\sin\theta$$

where 'Lb' is the area of the loop. So, above equation becomes

$$\boxed{\tau = IAB\sin\theta} \text{ or } \boxed{\vec{\tau} = I\vec{A}\times\vec{B}}$$

where θ is the angle between $\vec{A}$ & $\vec{B}$ i.e. between normal of the loop and magnetic field.

The torque on a coil with N turns is

$$\boxed{\tau = NIAB\sin\theta}$$

Maximum Torque:

Equation $\tau = IAB\sin\theta$ shows that the torque has the maximum value when normal of the plane is perpendicular to the field ($\theta = 90^0$)

$\tau = IAB\sin\theta$

When $\theta = 90^0$ then $\tau = \tau_{max}$

$\tau_{max} = IAB\sin 90^0$

$\boxed{\tau_{max} = IAB}$

Minimum (zero) Torque:

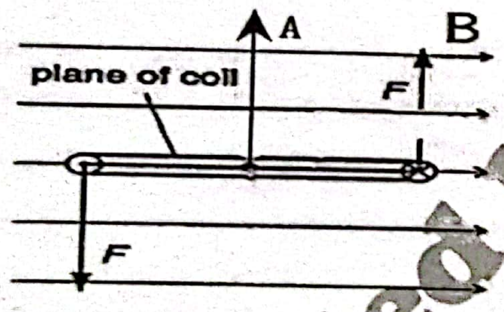
Equation $\tau = IAB\sin\theta$ shows that the torque has the minimum value *'zero'* when normal of the plane is parallel to the field ($\theta = 0^0$)

$\tau = IAB\sin\theta$

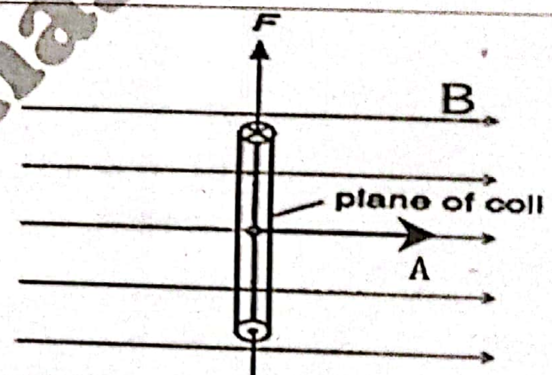
When $\theta = 0^0$ then $\tau = \tau_{min}$

$\tau_{min} = IAB\sin 0^0$

$\boxed{\tau_{min} = 0}$



Maximum Torque



Minimum Torque

Example 13.5

A square loop of wire of side 4.0 cm carries 3.0 A of current. A uniform magnetic field of magnitude 0.67 T makes an angle of 30⁰ with the plane of the loop.

(a) What is the magnitude of the torque on the loop? (b) What is the net magnetic force on the loop?

($\tau = 2.5 \times 10^{-3}$ Nm, $F_{net} = 0$)

MAGNETIC RESONANCE IMAGING(MRI) mcq/short

Magnetic Resonance Imaging (MRI) is one of the most advance diagnostic tools available. **MRI uses a combination of a strong magnetic field up to 20,000 gauss (common refrigerator magnets are around 10 gauss) and radio waves to produce detailed high-resolution images of the inside of the body.**

Principle (For shorts Q:- Describe Principle of MRI?

The human body is composed primarily of fat and water, which are made up mostly of hydrogen atoms(we are concerned with the protons of the nuclei). All these protons have magnetic field in random directions due to which net magnetic field is zero.

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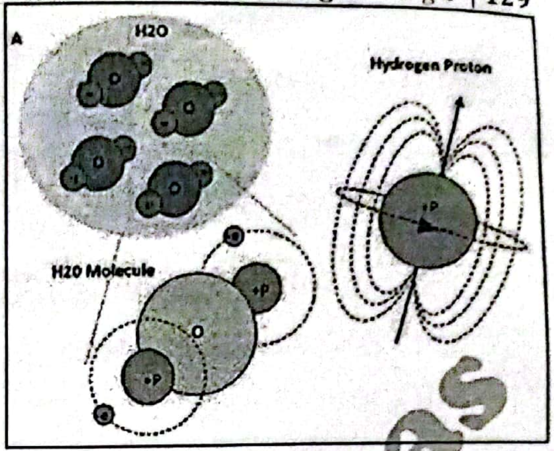
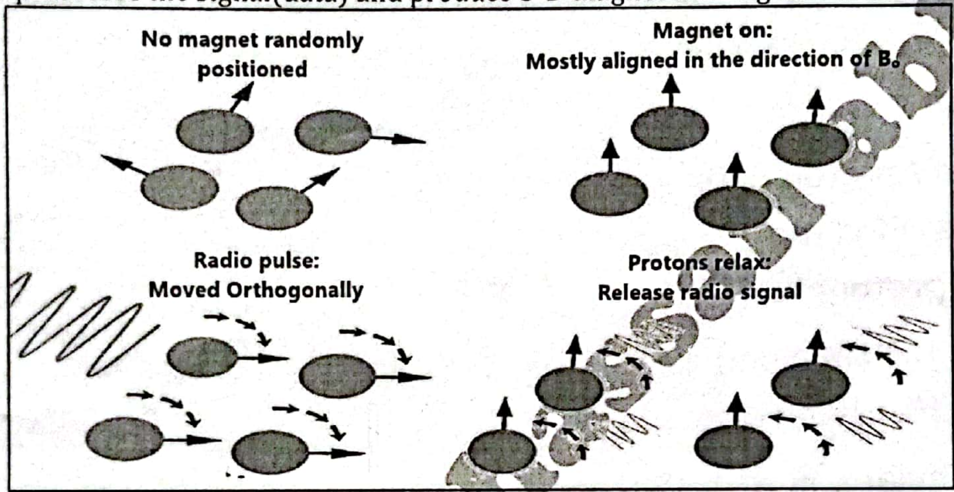


1. The Strong magnetic field is used to align hydrogen protons in the body.
2. Radio frequency coil ~~(acting as transmitting antenna)~~ transmits Radio frequency pulses (RF) ~~which are applied to specific anatomical slice (selected by gradient coils)~~, if the precession frequency of protons is equal to the frequency of RF pulses, then resonance occurs and protons in that slice absorb maximum amount of energy, causing them to spin perpendicular to the magnetic field.
3. As the protons relax back into the alignment with the magnetic field. energy is released in the form of signal and this signal is received by Radio frequency coils(acting as receiving antenna) and then transmits it to the computer.
4. The computer processes the signal(data) and produce 3-D diagnostic images of areas of the body.



Role of MRI

- MRI is used widely to study brain function, where damage to white matter is seen as bright areas.
- MRI is also capable of imaging such as the movement of the wall of the heart and the injection of fluid(contrasting agent) into a blood vessel in order to reach an organ or tissues.
- MRI is able to create detailed images to assist in the diagnosis of cancer, heart disease.

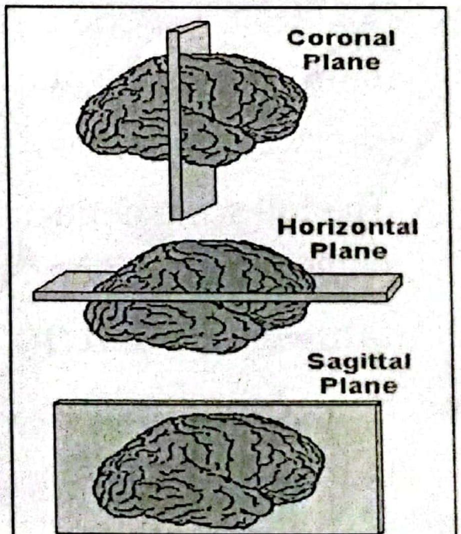
Pros and Cons of MRI

advantages

- MRI scanning is painless and does not involve any type of radiations as compared to other imaging techniques.
- MRI can easily create hundreds of images from almost any direction and in any orientation.
- MRIs are the perfect machines for checking brain and spinal tumours. They clearly show where the tumour is and helps the doctors make better decisions regarding the treatment of such tumours.

Disadvantages

- The MRI unit is an extremely strong magnet, so patients should avoid wearing jewelry and other accessories because they could interfere with the machine's magnetic field.
- If there is any doubt about the presence of metal(artificial heart valves, implanted electronic devices, artificial limbs, pacemaker or metallic joint prostheses) in the patient's body, an x-ray should be taken.
- Among many other radiology machines, MRIs are among the most expensive alternatives.



Anatomical slice selection

Those who have a cardiac pacemaker, defibrillator, or ear implant absolutely cannot be scanned and should take caution to not enter the MRI exam room because the strength of the magnet could cause serious problems.

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NUMERICAL PROBLEMS (KPK TEXT BOOK)

1. At what distance from a long straight wire carrying a current of 10 A is the magnetic field is equal to the earth's magnetic field of 5×10^{-5} T?

   (Answer: 0.04 m)

2. A long solenoid having 1000 turns uniformly distributed over a length of 0.5 m produces a magnetic field of 2.5×10^{-3} T at the center. Find the current in the solenoid?

   (Answer: 1 A)

3. A proton moving at right angles to a magnetic field of 0.1 T experiences a force of 2×10^{-12} N. What is the speed of the proton?

   (Answer: 1.3×10^{8} m/s)

4. An 8 MeV proton enters perpendicularly into a uniform magnetic field of 2.5 T. (a) Find the force on the ~~electron~~ proton? (b) What will be the radius of the path of proton?

   (Answer: 1.6×10^{-11} N, 0.17 m)

5. What is the time period of an electron projected into a uniform magnetic field of 10 mT and moves in a circle of radius 6 cm?

   (Answer: 3.6 ns)

6. A rectangular coil with 250 turns is 6.0 cm long and 4.0 cm wide. When the coil is placed in a magnetic field of 0.25 T, its maximum torque is 0.20 N m. What is the current in the coil?

   (Answer: 1.5 A)

7. Crossed electric and magnetic fields are established over a certain region. The magnetic field is 0.105 T and the electric field is 2.00 × 105 V/m. An electron, experiences zero net force from these fields and so continues moving in a straight line. What is the electron's speed?

   (Answer: 1.9×10^{6} m/s)

8. The full scale deflection for a galvanometer is 10 mA. Its resistance is 100 ohms. How can it be converted into an ammeter of range 100 A?

   (Answer: $R_s = 0.01\ \Omega$)

9. How a 5 mA, 100 Ω galvanometer is converted into 20 V voltmeter?

   (Answer: R_H = ~~1~~3900 Ω)

10. Two parallel wire 10 cm apart carry currents in opposite directions of 8 A. What is the magnetic field halfway between them?

    (Answer: 6.4×10^{-5} T)

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Q:- Define radial magnetic field & How it can be achieved in a galvanometer. (For short)

13.8 GALVANOMETER

"A galvanometer is a sensitive electrical instrument used for detection and measurement of small electric currents"

→Most modern galvanometers are of the **moving-coil type** and are called **D'Arsonval or Weston type or Pivoted coil galvanometer.**

Principle:

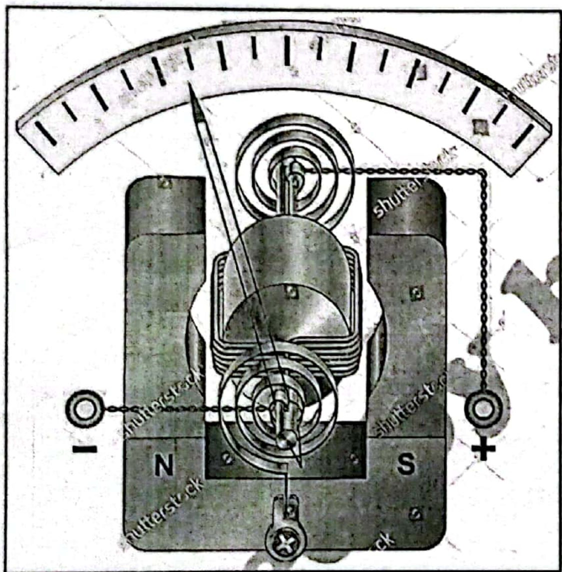
The basic operation of the galvanometer uses the fact that a **torque acts on a current carrying loop/coil placed in the magnetic field.**

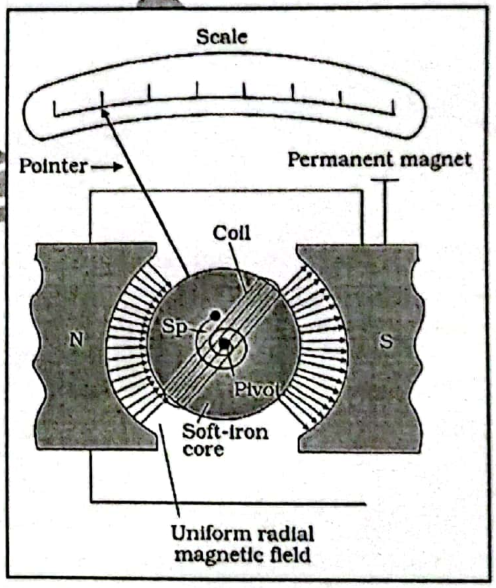
$$\tau = NIAB\ sin\theta$$

The torque experienced by the coil is proportional to the current in it i.e. the larger the current, the greater will be the torque experience by current carrying coil.

Construction:

- Moving coil galvanometer mainly consists of ~~pivoted~~ fixed coil wrapped around soft iron core, placed between the concave shaped poles N and S of a permanent magnet.
- A soft iron cylinder is placed inside the coil which intensifies the magnetic field (due to high permeability) and also make the field radial near the coil by concentrating the magnetic field due to its high permeability and also gives more inertia to the coil. (for short) Reason of using





- A loosely wound spiral(spring) is attached to the lower end of the coil which produces a restoring torque, bringing the coil to initial state when current stops.
- The springs at the upper end and lower end also acts as current leads.
- A light **aluminium pointer** is fixed to the coil which moves over a well **calibrated** circular scale with equal divisions which measure the deflection(in divisions) or current directly.

Working:

When a current *I* flow through the coil. a magnetic field 'B' is set up which interacts with that of the permanent magnet producing a torque 'τ' also called **deflecting torque.**

$$\text{Deflecting torque} = NIAB\ sin\theta$$

In this expression,

$N = number\ of\ turns\ in\ the\ coil,\quad A = Area\ per\ turn\ of\ the\ coil$

$B = Magnetic\ induction\ of\ the\ radial\ magnetic\ field$

$\theta = Angle\ between\ Area\ Vector\ and\ the\ direction\ of\ \vec{B}$

- (As the coil is placed in a radial magnetic field ~~in which plane of the coil is always parallel to the magnetic field i.e.~~ it's area vector is always perpendicular to magnetic field so θ is always 90⁰. This makes sin 90⁰ = 1 so deflecting torque becomes

$$\text{Deflecting torque} = NIABsin90^0\ )$$

1- Magnetic → concave shaped magnet.
2- Coil → Inside: coil is ...

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

- As the coil turns under the action of deflecting torque, the spring compresses and stores energy.

As a result, a restoring torque comes into play trying to restore the coil back to its original position. The restoring torque of the spring is proportional to the angle of deflection/twist θ,

$$\text{Restoring torque} \propto \theta \text{ (angle of deflection)}$$

$$\text{Restoring torque} = c\theta$$

where the constant 'c' of the suspension wire called **"torsion constant"** and it is defined as "It is the restoring torque per unit twist".

- Let the deflecting torque which is due to current be counter clockwise (taken +ive) while the restoring torque due to spring be clockwise (taken -ive) (always opposite to deflecting torque)

$$\vec{\tau}_{net} = \vec{\tau}_{deflecting} + (-\vec{\tau}_{restoring}) \text{---(i)}$$

- When the coil is in equilibrium then net torque acting on the coil is zero, so eq(i) becomes

$$0 = \vec{\tau}_{deflecting} + (-\vec{\tau}_{restoring})$$

$$\vec{\tau}_{deflecting} = \vec{\tau}_{restoring}$$

$$NIAB = c\theta \text{ ----(i)}$$

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

$$\text{(angle of deflection) } \theta = (constant)\, I \qquad \because \frac{NIAB}{c} = \text{constant}$$

$$\therefore \boxed{\theta \propto I}$$

The angle of deflection/angular displacement θ produced being proportional to the current I passing through the coil and this angular deflection is used to detect and measure small currents.

Sensitivity of Galvanometer:

⇒ Sensitivity of a galvanometer can be increased by making C/NAB
a) large (b) small c) None

Rearranging equation (i) gives

$$\boxed{\frac{\theta}{I} = \frac{NAB}{c}}$$

→ The factor $\frac{\theta}{I}$ is called "sensitivity of galvanometer".

→ A sensitive galvanometer is the one which produces large deflection for small value of current.

→ A Galvanometer can be made more sensitive by making deflecting angle θ large for a certain small value of current I.

How sensitivity of galvanometer can be increased?

Galvanometer can be made more sensitive (to give large deflection for a given current) if c/BAN is made small. Thus, to increase sensitivity of a galvanometer

(i) 'c' may be decreased.

The couple 'c' for unit twist of the suspension wire can be decreased by increasing its length and by decreasing its diameter. This process, however, cannot be taken too far, as the suspension must be strong enough to support the coil.

(ii) B, A or N may be increased.

Another method to increase the sensitivity of galvanometer is to increase **N**, the number of turns of the coil. In case of suspended coil type galvanometer, the number of turns cannot be increased beyond a limit because it will make the coil heavy.

To compensate for the loss of sensitivity, in case fewer turns are used in the coil, we increase the value of the magnetic field employed.

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escribe the

(A) CONVERSION OF GALVANOMETER INTO AMMETER?

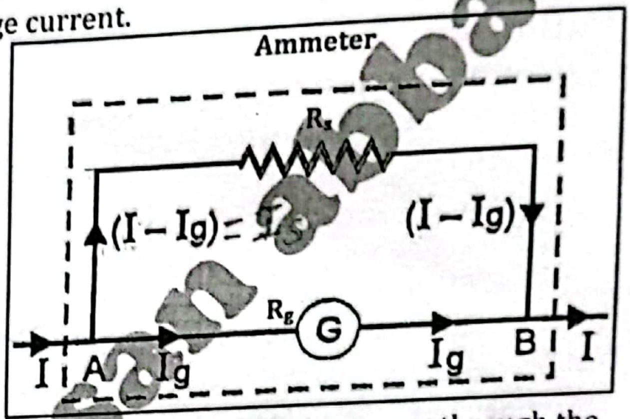
Introduction:

Galvanometer is very sensitive instrument; a large current cannot be passed through it because it gives a full-scale deflection for currents on the order of 1 mA or less. Consequently, such a galvanometer cannot be used directly to measure currents greater than this value or if large current is passed through galvanometer it may damage the coil, so a device which can measure large current without damaging itself called 'Ammeter'.

Definition:

"An ammeter is a measuring instrument used to measure the electric current in a circuit". (mA or A)

→Ammeter is modified form of galvanometer to measure large current.



Conversion:

- The conversion of galvanometer into an ammeter is done by connecting a low resistance called shunt resistance in parallel with galvanometer.
- As a result, when large current flows in a circuit, large portion of the current passes through the low resistance and only a small portion of the current passes through the galvanometer.
- The scale is marked in ampere.

Value of Shunt Resistance:

The value of shunt resistance depends on the fraction of the total current required to be passes through the galvanometer. If small fraction of current is required to pass through galvanometer then value of shunt resistance is kept small so that large fraction of current passes through shunt resistance and vice versa.

Expression for calculation of Shunt Resistance:

- Let R_s represent the shunt resistance.
  R_g represent the resistance of galvanometer.
  I represent current flowing in circuit.
  I_g represent current which produces full scale deflection in the galvanometer.
  I_s represent current passing through shunt resistance.
- Since the shunt resistance is connected in parallel to the galvanometer, so the potential difference across both of them is same i.e.

Potential difference across galvanometer = Potential difference across shunt

$$V_g = V_s$$

$$I_gR_g = I_sR_s \text{ ----(i)}$$

As, we know that $I = I_s + I_g \rightarrow I_s = I - I_g$

Substituting $I_s = I - I_g$ in equation (i)

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

$$\frac{I_gR_g}{(I - I_g)} = R_s$$

$$\boxed{R_s = \frac{I_gR_g}{(I - I_g)}}$$

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:- Why the

Resistance of Ammeter: is kept very small?

The resistance of the ammeter is the combined resistance of the galvanometer and the shunt. Usually it is very small (small piece of copper wire serves the purpose).

An **ammeter must have a very low resistance** so that it does not disturb the circuit in which **it is connected in series** in order to measure the current.

An ideal ammeter has zero resistance so that the current being measured is not altered.

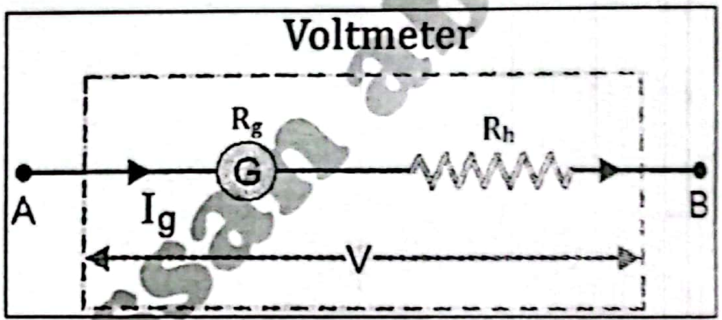
Ammeter is always connected in series with the circuit.

(B) CONVERSION OF GALVANOMETER INTO VOLTMETER

Definition:

" A voltmeter is an electrical device which measures the potential difference in volts between two points in the circuit"

Conversion:



- A Galvanometer can be converted into voltmeter by connecting a high resistance called multiplier in series with a galvanometer.
- The scale is calibrated in volts.

Value of High Resistance:

The value of this resistance depends upon the range of voltmeter.

Expression for calculation of High Resistance:

- Let R_h represent the high resistance(multiplier).
  R_g represent the resistance of galvanometer.
  I_g represent current flowing through galvanometer.
  V_g represent the potential drop across galvanometer.
  V_h represent the potential drop across galvanometer.
  V represent the desired voltage which has to be measure or range of voltmeter.
- As galvanometer and high resistance are in series so same current passes through them.

$$I_g = I_h$$

- As, galvanometer and high resistance are in series,
  Voltage supplied = Voltage drop across galvanometer + Voltage drop across high resistance

$$V = V_g + V_h$$

$$V = I_g R_g + I_h R_h = I_g R_g + I_h R_h \qquad \because I_g = I_h$$

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

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

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

$$\boxed{R_h = \frac{V}{I_g} - R_g}$$

This works as a voltmeter of range 0

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Q1-Why the

Resistance of Voltmeter: is kept very large?/High?

Since the value of R_h is high, the effective resistance $(R_g + R_h)$ of voltmeter also has a higher value.

As **voltmeter is always connected in parallel** across the two points between which potential difference is to be measured. Resistance of voltmeter should be very high in comparison with the resistance of the circuit across which it is connected because it should not draw current from the circuit otherwise it will alter the potential difference which is required to be measured. Good voltmeter (R↑)

It is necessary to observe the polarity of the instrument. The positive terminal of the voltmeter must be connected to the end of the resistor that is at the higher potential, and the negative terminal to the end of the resistor at the lower potential.

An ideal voltmeter has infinite resistance so that no current draw by it when connected across the circuit.

Voltmeter is always connected in parallel with the circuit.

Example 13.6

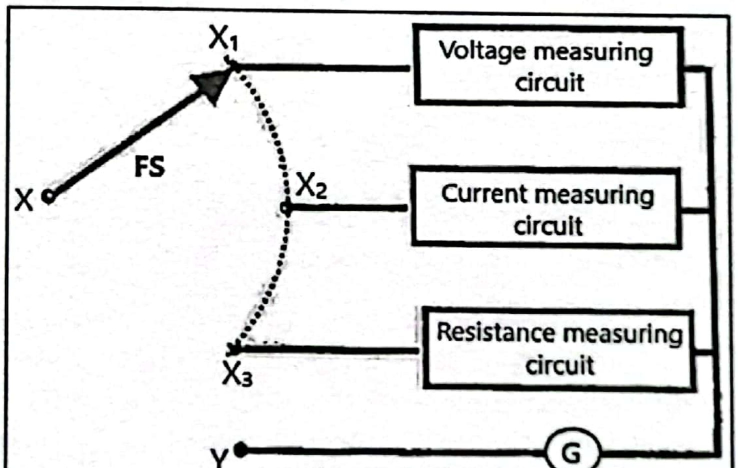
A galvanometer has a resistance of 100 ohms and gives full scale deflection on 1 mA current. How it can be converted into (a) an ammeter of range 10 A. (b) voltmeter of range 10 V ?

$(R_s) = ?$ $(R_h) = ?$ **($R_s = 0.010\ \Omega$, $R_h = 9900\ \Omega$)**

13.9 AVO METER/MULTI-METER

"It is an instrument which can measure current in amperes, potential difference in volts and resistance in ohms".

- 'A' stands for amperes, 'V' stands for volts and 'O' stands for ohm.
- It can measure direct as well as Alternating current and voltage.
- It basically consists of a sensitive moving coil galvanometer which is converted into a multirange ammeter, voltmeter or ohmmeter accordingly as current measuring circuit or voltage measuring circuit or resistance measuring circuit is connected with the galvanometer with the help of a switch known as **Function switch.**
- A single galvanometer is added in a circuitry in such a way that all the three quantities can be measured.
- Here **X, Y** are the main terminals (leads) of AVO meter which are connected with the circuit in which measurement is required.
- The quantity to be measured can be selected by a function selector switch **FS** which connects the particular electrical circuit to the galvanometer.
- It is a galvanometer having of combination of resistors, all enclosed in a box.
- It has different scales graduated in such a manner that all the three quantities can be measured.
- It has its own battery for its function and for operating the electrical circuits.



AVO meter circuit block diagram

(A)VOLTAGE MEASUREMENT (for short) diagram

- For the measurement of voltage, the function selector switch is turned to X_1.
- The voltage measuring part of the AVO meter is actually a multirange voltmeter. It consists of a number of resistances each of which can be connected in series with the moving coil galvanometer with the help of switch called **range switch.**

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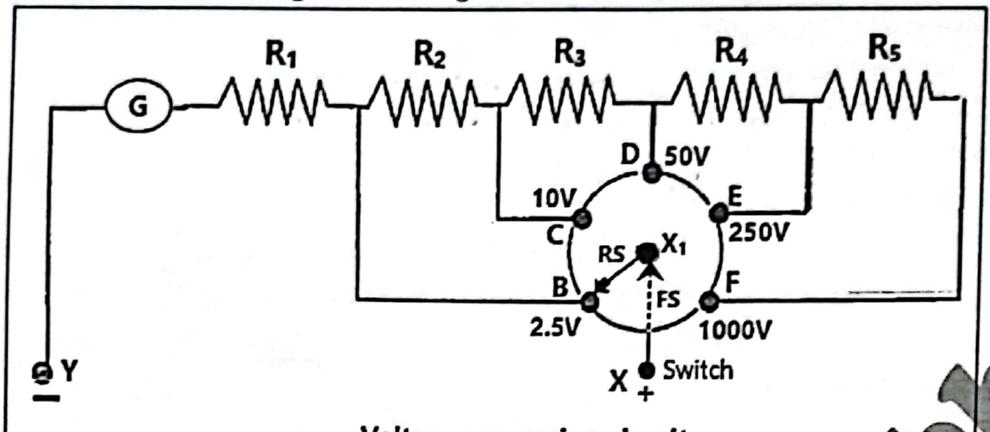
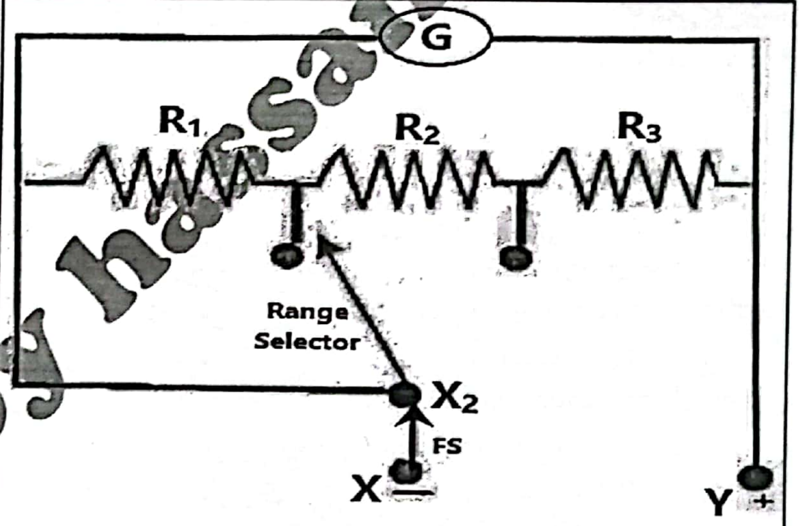
- The added high resistance converts the galvanometer to a voltmeter of specific range.
  For example, connections at Y and C, selected by range switch X gives range of 10V. Similarly, connections at Y and at B, D, E or F gives the ranges of 2.5V, 50V, 250V, 1000V



Voltage measuring circuit

(B) CURRENT MEASUREMENT (for short) diagram

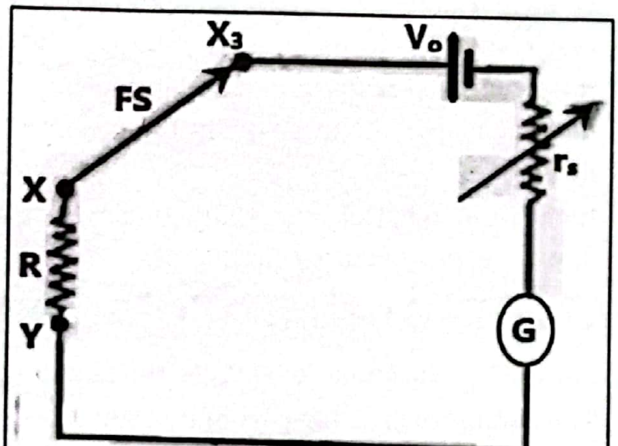
- For the measurement of current the function selector switch is turned to X_2.
- The current measuring part of the AVO meter is actually a multirange ammeter.
- Current measuring circuit is a series combination of shunt resistances R_1, R_2 and R_3 called universal shunt.
- These low resistances are connected in parallel with the galvanometer. The values of these resistances depend upon the range of the ammeter.
- This circuit provides a safe method of switching between current ranges without any danger of excessive current through the galvanometer.



Current Measuring Circuit

(c) RESISTANCE MEASUREMENT (for short) dargram

- For the measurement of resistance, the function selector switch is turned to X_3.
- The resistance measuring part of AVO meter is, in fact, a multirange ohmmeter.
- Circuit for each range of this AVO meter consists of a battery of V_o and a variable resistance r_s connected in series with galvanometer of resistance R_g
- The ohmmeter reads up resistance regardless of the polarity of the leads because the polarity of the internal battery determines the direction of the current through the galvanometer.
- Commercial AVO meters provide resistance measurements from less than one ohm up to many megaohms.



Resistance measuring circuit

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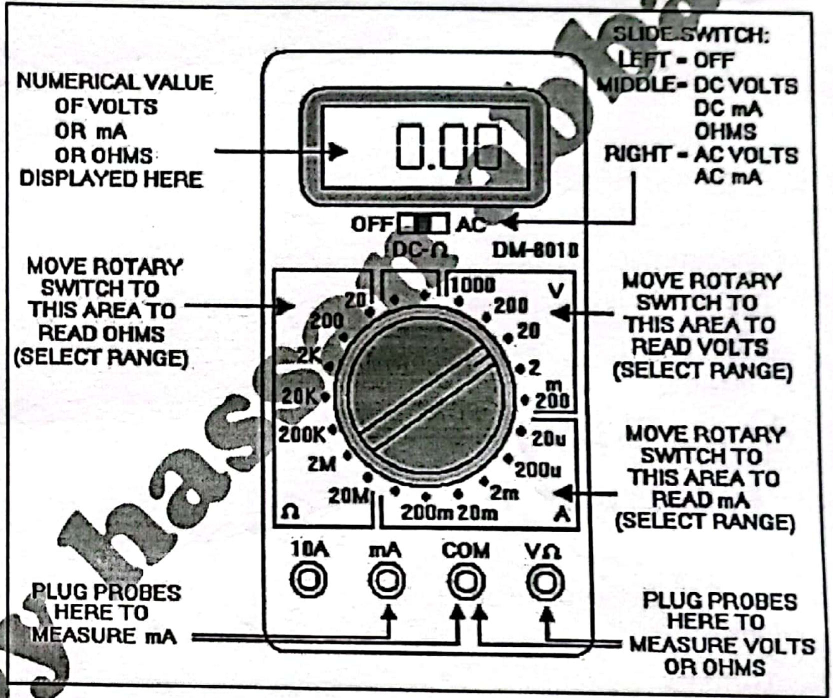
Calibration of Ohm-meter:

- The leads(X & Y) are connected across the known resistance.
- The ohmmeter battery supplies current to the galvanometer for deflecting its coil. Since the amount of deflection depends upon the amount of current and the amount of current through the galvanometer depends upon the external resistance, we can calibrate the scale in ohms.
- The amount of deflection on the ohms scale indicates directly the magnitude of the resistance.

(D) DIGITAL MULTIMETERS (Avo meter

Digital multimeters are measuring instruments that can measure quantities such as voltage, current, and resistance. Measured values are shown on a digital display(which eliminates **parallax error** - human error that often occurs in reading the dial of an ordinary analog AVO meter) allowing them to be read easily and directly, even by first-time users.



- It is a digital version of AVO meter.
- Some digital multimeters select the measurement range automatically, eliminating the need to choose it manually and values are displayed automatically in decimal with proper units.
- DMM have made analog multimeters obsolete as they are cheaper, more precise, and more physically robust than analog multimeters.
- DMM can be used to measure DC voltage and current, AC voltage and current, frequencies, capacitance, resistance or temperature.
- Modern digital multimeters have an embedded computer, which provides a variety of convenience features.

COMPREHENSIVE QUESTIONS

Q1- Derive an expression for the force acting on a current carrying conductor in a uniform magnetic field.

Q2- A current carrying loop is placed in a uniform magnetic field. Derive an equation for the torque acting on it.

Q3- Does a moving charge experience a force in magnetic field? Explain

Q4- How charge to mass ratio for electron is determined using magnetic field?

Q5- Define and explain magnetic flux?

Q6- State Ampere's law and use it to derive an expression for the magnetic field of a solenoid.

Q7- What is galvanometer? how it is converted into an ammeter and a voltmeter?

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Exercise (KPK TEXTBOOK)

Choose the best possible answer.

1. A current is flowing North in a magnetic field that points West. It experiences

   A. a force down. B. a force up.
   C. a force west. D. no force.

Reasoning:

2. Two long, straight wires have currents flowing in them in the same direction, the force between the wires is

   A. attractive. B. repulsive C. zero D. Infinite

3. One weber is equal to

   A. NA^2/m B. $N\ m^2/A$ C. $N\ A/m$ D. $N\ m/A$

Reasoning:

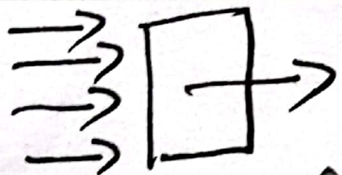
$\phi_B = BA\cos\theta$

weber $= N m A^{-1}$

4. Magnetic flux will be maximum if the angle between magnetic field strength and vector area is

   A. 0° B. 45^0 C. 60° D. 90°

Reasoning:



$\theta = 0$

$\phi = max$

5. Ampere's law is applied over any

   A. surface B. closed surface C. path D. closed path

6. When the number of turns in a solenoid is doubled without any change the length of the solenoid its self-induction will be

   A. Four times B. Doubled C. Halved D. One forth

Reasoning:

7. If the charge is at rest in magnetic field, then force on charge is

   A. qvB B. qvB cos θ C. qvB sin θ D. zero

Reasoning:

$v_{(rest)} = 0\ ms^{-1}$

$F_B = q v B \sin\theta$

$F_B = q(0) B \sin\theta$

$F_B = 0$

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8. Work done on a charge particle moving in a uniform magnetic field is
   A. maximum B. minimum C. zero D. Infinite

Reasoning:

•

9. The Earth's northern magnetic pole acts like:
   (in simple words, the magnetic pole which is created on the north of the earth is like a)
   A. the north pole of a magnet B. the south pole of a magnet
   C. it has a positive charge D it has a negative charge
10. The pole pieces of the magnet in galvanometer are made concave to make the field
    A. Radial B. Stronger C. Weaker D. Both A&B
11. When a small resistance is connected parallel to a galvanometer, the resulting circuit behaves as,
    A. Voltmeter B. Ammeter C. Velocity Selector D. AVO meter
12. To measure the voltage the voltmeter is connected with the circuit in
    A. series B. Parallel C. Perpendicular D. Straight Line
13. The resistance of ideal voltmeter is
    A. Small B. Large C. Zero D. Infinite
14. The Torque in the coil can be increased by increasing
    A. Number of turns B. Current and Magnetic field
    C. Area of coil D. All of these

Reasoning:

$\vec{\tau} = N\uparrow I\uparrow A\uparrow B\uparrow \sin\theta$

Exercise (KPK TEXTBOOK)

1. A maximum force that acts on a current carrying conductor placed in a magnetic field, when angle between the field and length of the conductor is
   (a) 0^0 (b) 45^0 (c) 90^0 (d) 180^0
2. Tesla in terms of base units is equal to
   (a) $kg\ m^{-1}A^{-1}$ (b) kg mA (c) $kg\ s^{-1}A^{-1}$ (d) $kg\ s^{-2}A^{-1}$
3. One Gauss is equal to
   (a) 1T (b) 10^2T (c) $10^{-4}T$ (d) 10^4T
4. The unit of magnetic flux is
   (a) Tesla (b) Weber (c) Gauss (d) Henry
5. The magnetic flux is maximum when angle between magnetic field and vector area is
   (a) 0^0 (b) 30^0 (c) 60^0 (d) 90^0
6. Magnetic flux density is defined in terms of
   (a) Tesla (b) $wb\ m^{-2}$ (c) $NA^{-1}m^{-1}$ (d) All of them
7. A charged particle is moving along X-axis in a magnetic field along the Y-axis. The direction of magnetic force acting on it is

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

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(a) along x-axis (b) along y-axis (c) along z-axis (d) in xy-plane

8. Ampere's Law gives us the relationship between
(a) Force and velocity of charge (b) Force and magnitude field
(c) Current and force (d) Current and magnetic field

9. The value of permeability of free space is
(a) $10^{-7} T.m.A^{-1}$ (b) $2\pi\times10^{-7} T.m.A^{-1}$
(c) $4\pi\times10^{-7} T.m.A^{-1}$ (d) $4\pi\times10^{7} T.m.A^{-1}$

10. The magnetic field due to a current-carrying solenoid which has 'n' number of turns per unit length is
(a) $B=\mu_o n I$ (b) $B=\mu_o n^2 I$ (c) $B=\frac{\mu_o n I}{\ell}$ (d) $B=\frac{\mu_o n^2 I}{\ell}$

11. The magnetic field inside the solenoid is independent of one of the following quantities
(a) Permeability (b) Position vector
(c) Number of turns (d) Flow of current

12. What is the magnetic force on a stationery charged particle in a uniform magnetic field?
(a) Zero (b) $F=q(v\times B)$ (c) $F=qvB$ (d) $F=ILB\sin\theta$

13. An electron is moving horizontally towards east. If it enters in magnetic field directed upward then the electron will be deflected in the direction of
(a) East (b) West (c) North (d) South

14. When the direction of motion of a charged particle is perpendicular to the direction of magnetic field, then the particle follows the path of a
(a) Straight line (b) helix (c) ellipse (d) circle

15. The torque due to a current carrying rectangular coil placed in a uniform magnetic field is
(a) $\tau=IBA\sin\theta$ (b) $\tau=IAN\sin\theta$ (c) $\tau=IBN\sin\theta$ (d) $\tau=NAIB\sin\theta$

16. The working principle of a galvanometer is based upon
(a) Momentum (b) Torque (c) Force (d) Impulse

17. The current passing through the coil of a galvanometer is directly proportional to the
(a) Resistance (b) Conductance (c) Reactance (d) Angle of deflection

18. A shunted galvanometer is called
(a) Voltmeter (b) Ammeter (c) Ohmmeter (d) Potentiometer

19. A galvanometer can be converted into voltmeter by connecting it with
(a) Low resistance in parallel (b) Low resistance in series
(c) High resistance in parallel (d) High resistance in series

20. Which one of the following quantity is not measured by Avometer
(a) Charge (b) Current (c) Resistance (d) Potential difference

CONCEPTUAL QUESTIONS

Q1- A compass needle is deflected when a charged plastic rod is held near it. What is the origin of the force that produces the deflection?

A compass needle that is suspended in air can indeed easily be deflected by a nearby charged object. The compass needle is metallic, which means that it is conductor. If we bring a charged plastic rod close to the needle, we see that the end of the compass needle which is closest to the plastic rod will induce opposite charges due to electrostatic force of attraction (polarization) and will repel like charges to the opposite end of the needle. As a result, electrostatic force of attraction develops between charged plastic rod and oppositely charged end of compass and this closer end swings even closer to the charged plastic rod.
This a totally electrostatic demonstration with absolutely NO relation to magnetism.

Q2- What is the difference between permeability and permittivity?

Permeability	Permittivity
It is the ability of a material to magnetize in the response of magnetic field.	It is the ability of a material to polarize in response to an electric field.
High permeability materials are used in the core of	High permittivity materials are used as dielectric

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transformer & in motors.	materials in the capacitors.
It measures the ability of the material to allow the magnetic lines of force to pass through it.	It measures the opposition offered by the material against the formation of electric field.
Its unit is Henry/meter.	Its unit is Faraday/meter.
The permeability of free space is $\mu_o = 4\pi \times 10^{-7}$ H/m.	The permittivity of free space is $\varepsilon_o = 8.85 \times 10^{-12}$ F/m.

Q3- Can the objects in rotational motion create a magnetic field? Provide an example.

imp

Q4- Electron and proton are projected with the same velocity normal to the magnetic field. Which one will suffer greater deflection? Why?

As electron and proton are projected normal($\theta = 90^0$) to the magnetic field, both performs circular motion as they enters in magnetic field and their radius of curvature is

$$r = \frac{mv}{qB} \quad --- (i)$$

A particle will make large radius of curvature if it is deflected less and will make smaller radius of curvature if deflected more, so inverse relation between radius of curvature and deflection.

equation (i) *can be written as* $\frac{1}{r} = \frac{qB}{mv}$

As deflection $\propto \frac{1}{r}$ *so,* $Deflection \propto \frac{qB}{mv}$

The deflection of a charged particle by a magnetic field is directly proportional to its electric charge and inversely proportional to velocity and mass. As proton and electron going at the same velocity in a magnetic field and having equal(but opposite charges) electric charge, so their deflection only depends upon the mass of charged particle.

As mass of electron of 1836 times less than that of proton so they deflect more as compared to proton.

Q5- A charged particle moves in a straight line through a particular region of space. Could there be a non-zero magnetic field in this region?

It is not necessary that the magnetic field is zero when a charged particle experiences no magnetic force and moves in a straight line. This may be proved by following cases.

As the magnetic force on moving ~~electron~~ charge in B is

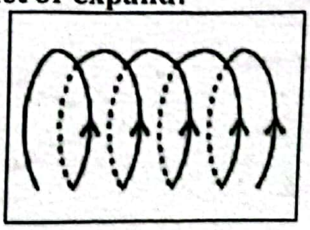
$$F = evB\sin\theta$$

The force can also be zero when,

- The ~~electron~~ charge is moving parallel or anti parallel to the magnetic field ($\theta = 0^0$ or 180^0)
- The ~~electron~~ charge is moving perpendicularly into a region where electric and magnetic fields are also perpendicular such that that $F_e = F_B$, so net force on charge is zero and it will pass un-deflected.

Q6- If a current is passed through an unstretched spring, will the spring contract or expand?

Ans. If a current is passed through an unstretched spring, it will contract the spring.



Reasoning:

As we know, when current is passed through a spring then the current flows parallel in the adjacent turns. We also know when two wires are placed parallel to each other in which current flows is in the same direction, then the wires will attract each other. Similarly, when the current flows in the spring then each coil

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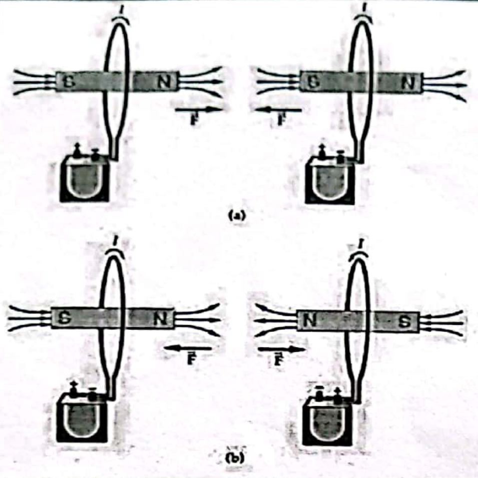
get current flow in the same direction. So, they are attracted to one another which in turn results in compression of spring.



If the currents are in the same direction the two loops attract each other

If the currents are in opposite directions the two loops repel

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Q7- How can neutrons be accelerated in a cyclotron?

Ans. A cyclotron is a device that can accelerate charged particles to very high speeds. No neutrons cannot be accelerated in a cyclotron, because neutron is not a charged particle (neutral particle).

$$F = qvB\sin\theta$$

$$F = (0)vB\sin\theta$$

$$F = 0$$

→For the particle to accelerate in cyclotron, the charge on the particle is required

→Since neutron is a neutral particle, it is not affected by electric and magnetic field. Therefore, it will not be accelerated or deflected in the cyclotron.

Q8- A current carrying loop free to turn, is placed in a uniform magnetic field B. What will be its orientation relative to B, in the equilibrium state?

Ans. When plane of loop is perpendicular to magnetic field or area vector of loop is parallel to magnetic field ($\theta = 0^0$)

In equilibrium state,

$$F_{net} = 0$$

$$\tau_{net} = 0$$

As we know that torque on a current carrying loop is mathematically given as

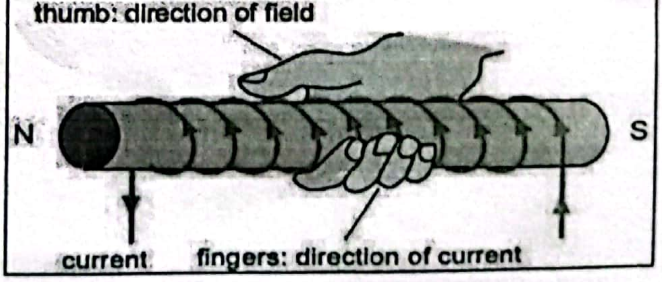
$$\tau = NIAB\sin\theta$$

where θ is the angle between the Area vector of loop and magnetic field 'B'.

The torque will be zero then, as $\sin 0^0 = 0$. In such a position the plane of the loop is perpendicular to B. At this position, no force would be acting on the loop, no torque would produce and the loop would be in equilibrium.

Q9- How does a current carrying coil behave like a bar magnet?

Ans. Current carrying coil(solenoid) will behave like a bar magnet due to passage of current in the coil due to which one end of coil will become north pole and other will become south pole.



Inside the coil the magnetic field is strong and parallel to the axis of coil. Its direction can be found by the Right-hand grip rule. The straight magnetic field inside the coil consists of magnetic lines of force like the magnetic lines of force due to a bar magnet.

Direction of B outside the solenoid = North→South

Direction of B inside the solenoid = South → North

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