CHAPTER 13

ELECTROMAGNETISM

Q1: Explain the concept of magnetic induction field. How are its direction and magnitude defined?

Answer: Magnetic Field:

Definition: "The region or space around a magnet in which the effect of that magnet can be felt is known as magnetic field."

Explanation:

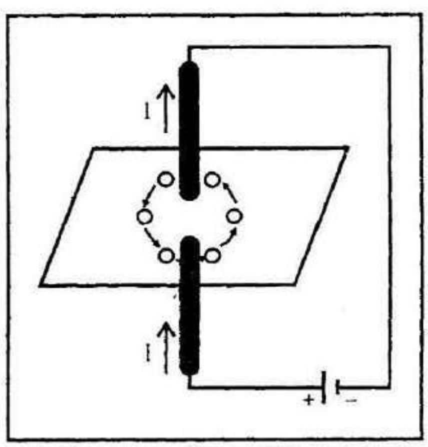
The magnetic field is a vector field. It is represented by magnetic field lines or magnetic lines of forces. At any point, the magnetic field is specified by a vector "$\vec{B}$" which is known as magnetic induction.

The magnitude and direction of $\vec{B}$ at any field point can be determined by magnetic force which is exerted by the field on a test magnet placed at that point.

Q2: How would you demonstrate that a current produces magnetic field around itself? Hence deduce the fact that moving charges have magnetic interaction? (ETEA 2009)

Answer:

It has been found experimentally that moving charges can produce magnetic field around them. This fact can be explained with the help of following experiment.



Experiment:

Consider a straight wire conductor which is fitted vertically in a piece of card board as shown in the figure.

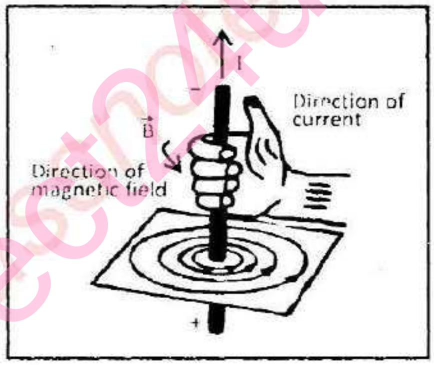
Let the ends of the wire are connected to the terminal of a battery by means of a switch. When the switch is turn-ON, then current passes through the conducting wire.

Now if we keep some iron fillings on the card board, we will see that these fillings arrange themselves in the form of concentric circles around the conductor [wire], as shown in the figure. This shows that current [moving charges] gives rise to magnetic field with circular lines of forces.

Q3: State and explain the right hand rule?

Answer:

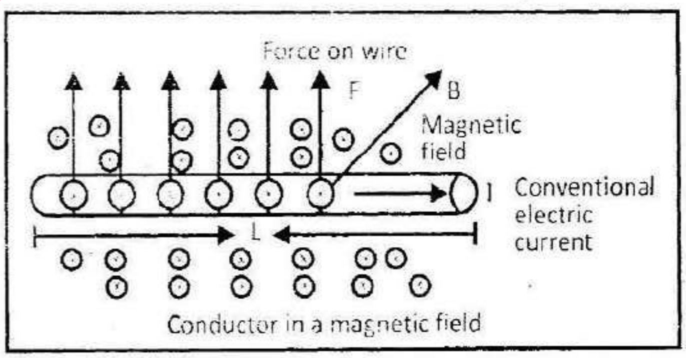
The right hand rule can be used for the specification of direction of magnetic field. According to right hand rule, if the current carrying wire is grasped by the right hand with the thumb in the direction of current, then the fingers around the wire gives the direction of magnetic field.



Q4: Discuss the magnetic force on a current carrying conductor.

Answer:

Consider a straight wire conductor of length "L" place at right angle to a uniform magnetic field "B" as shown in the figure. Here the magnetic field of the wire and external uniform field interact and as a result a certain magnetic force "F" acts on the wire. The magnitude of this force depends on the following factors:



1. The force "F" is directly proportional to the length of wire inside the magnetic field i.e.

$$F \propto L \quad \text{------} \quad (1)$$

2. The force "F" is directly proportional to the current "I" flowing through the conductor i.e.

$F \propto I$ _______________ (2)

3. The force "F" is directly proportional to the strength of magnetic field "B" i.e.

$F \propto B$ _______________ (3)

4. The force "F" is directly proportional to the value of $\sin\theta$ between L and B i.e.

$F \propto \sin\theta$ _______________ (4)

Combining relations (1), (2), (3) and (4), we get,

$F \propto LIB \sin\theta$

$\Rightarrow F = KLIB \sin\theta$ _______________ (5)

In equation (5), "K" is constant of proportionality. In SI units, its value is equal to "1", so equation (5) becomes,

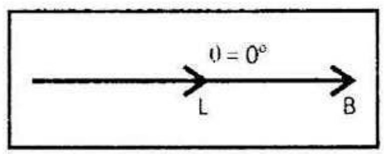
$\boxed{F = BIL \sin\theta}$ _______________ (6)

Equation (6) represents the magnitude of magnetic force acting on a current carrying conductor. In vector form, equation (6) can be written as,

$\boxed{\vec{F} = I(\vec{L} \times \vec{B})}$ _______________ (7)

Special Cases:

For given values of B, L and I, the magnitude of force depends upon "θ". For example,

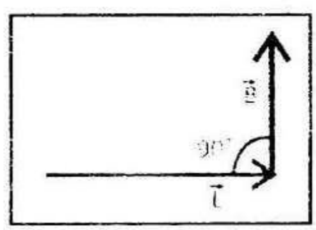


1. If $\theta = 0°$ i.e. if $\vec{L}$ and $\vec{B}$ are parallel, then equation (6) becomes

$F = BIL \sin 0°$ $\quad [\sin 0° = 0]$

$\Rightarrow \boxed{F = 0}$

This shows that the resultant force on the conductor will be zero if $\vec{B}$ and $\vec{L}$ are parallel.



2. If $\theta = 90°$, i.e. $\vec{L}$ and $\vec{B}$ are perpendicular to each other, then equation (6) becomes.

$F = BIL \sin 90°$ $\quad [\sin 90° = 1]$

$\Rightarrow \boxed{F_{max} = BIL}$

This shows that the result force on the conductor will be maximum if $\theta = 90^\circ$ i.e. when $\vec{L}$ and $\vec{B}$ are at right angle to each other.

Unit of $\vec{B}$: (ETEA 2014)

As $\quad F = BIL \sin\theta$

$$\Rightarrow \quad B = \frac{F}{IL\sin\theta} \quad \_\_\_\_\_\_\_\_\_\_\_\_ (a)$$

Now if $F = 1N$, $I = 1$ amp; $L = 1m$; $\sin\theta = \sin 90^\circ = 1$ then equation (a) becomes,

$$B = \frac{1N}{1amp \times 1m} = 1 \text{ tesla}$$

So the unit of "$\vec{B}$" is tesla, which is defined as, "the magnetic induction is said to be one tesla, if a force of 1N acts on one meter length of a conductor placed at 90° to the field when a current of 1 ampere is flowing through the conductor".

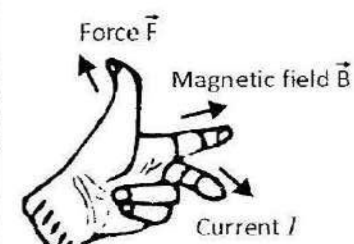
Another unit of "B" is Gauss which is given by,

$$\boxed{1G = 10^{-4}T}$$

Q5: Explain Fleming's left hand rule.

Answer: **Fleming's Left Hand Rule:**

Using Fleming's left hand rule, we can determine the direction of magnetic force "$\vec{F}$". Fleming's left hand rule is shown in the figure.



Fleming's left hand rule

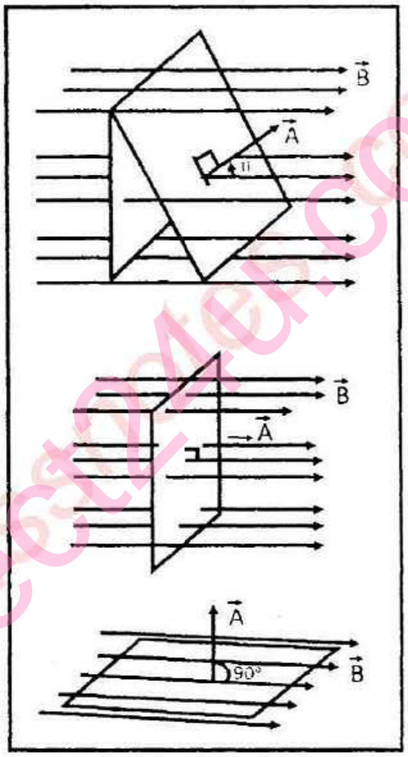
The thumb and first two fingers of the left hand are set at right angles to each other. The first finger indicates the direction of magnetic field, the 2^{nd} finger indicates the direction of current while the thumb indicates the direction of magnetic force.

Q6: (a) Explain the concept of magnetic flux with the help of necessary diagrams and mathematical expressions. What is its unit? (b) What is magnetic flux density? What is its unit?

Answer: a) **Magnetic Flux:**

Definition: "The number of magnetic field lines passing through a certain area of the surface is known as magnetic flux." (OR)

"The dot product of magnetic induction "$\vec{B}$" and vector "$\Delta\vec{A}$" is known as magnetic flux." i.e. $\Delta\phi = \vec{B}\cdot\Delta\vec{A}$



Explanation:

Let "$\Delta\vec{A}$" represents the vector area of a certain surface and "$\vec{B}$" represents the magnetic induction, then the magnetic flux is given by,

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

$$\Rightarrow \boxed{\Delta\phi = B\Delta A\cos\theta} \quad \text{\_\_\_\_\_\_\_\_(1)}$$

Special Cases:

Equation (1) shows that for given values of "ΔA" and "B", the flux depends on the value of "θ" between "ΔA" and "B".

For example,

1. If the normal to the surface is parallel to B, then we put $\theta = 0°$, so equation (1) becomes,

$$\Delta\phi = B\Delta A\cos 0° \qquad [\cos 0° = 1]$$

$$\Rightarrow \boxed{\Delta\phi_{max} = B\Delta A} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_(2)}$$

Equation (2) represents the maximum value of magnetic flux.

2. If the normal to the surface is perpendicular to B, then we put $\theta = 90°$, so equation (1) becomes,

$$\Delta\phi = B\Delta A\cos 90° \qquad [\cos 90° = 1]$$

$$\Rightarrow \boxed{\Delta\phi = 0} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_(3)}$$

Equation (3) represents the minimum value of flux.

Unit of Magnetic Flux: (ETEA 2011)

As $\Delta\phi = B\Delta A$

$$\Rightarrow \Delta\phi = N\cdot A^{-1}\cdot m^{-1}\cdot m^2$$

$$\Rightarrow \Delta\phi = N\cdot A^{-1}\cdot m = N\cdot m\cdot A^{-1}$$

$$\Rightarrow \boxed{\Delta\phi = N\cdot m\cdot A^{-1} = wb}$$

B = Tesla = $NA^{-1}m^{-1}$

$\Delta A = m^2$

Weber = W_b

So the unit of magnetic flux is $N \cdot m \cdot A^{-1}$ or weber.

b) *Magnetic Flux Density:*

Magnetic induction "B" is also known as magnetic flux density.

As $\quad \Delta\phi = B \cdot \Delta A \Rightarrow B = \dfrac{\Delta\phi}{\Delta A}$ ________________ (1)

Equation (1) shows that magnetic flux per unit area is known as magnetic flux density.

As $\quad B = \dfrac{\Delta\phi}{\Delta A} = \dfrac{Weber}{m^2}$

So the unit of magnetic flux density is weber/m^2 and tesla.

$$\boxed{1\ Tesla = 1 weber / m^2}$$

Q7: State ampere's circuital law. Find an expression for magnetic flux density "B" at radial distance "r" from a straight current carrying wire.

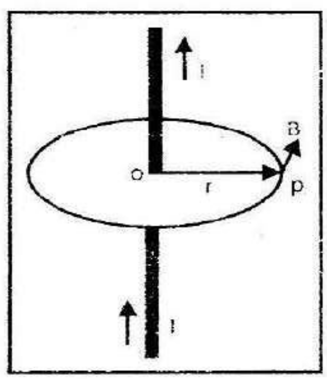
Answer: ***Ampere's Circuital Law:***

Statement: This law states that, "the dot product of magnetic induction "$\vec{B}$" and length "$\vec{l}$" around any closed path is always equal to product of permeability "μ_o" and total current "I" enclosed by that path".

i.e. $\quad \boxed{\vec{B} \cdot \vec{l} = \mu_o I}$

Explanation:

Consider a conductor having current "I" in a uniform magnetic field "$\vec{B}$" as shown in the figure.



Let there is a point "P" at a distance "r" from the conductor. Then the magnetic field "B" at point "P" depends on the following factors:

1. "B" is directly proportional to the current "I" flowing through the conductor. i.e.

   $B \propto I$ ________________ (1)

2. "B" is inversely proportional to the distance "r" from the conductor i.e.

$$B \propto \frac{I}{r} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_(2)}$$

Combining relations (1), (2), we get,

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

$$\Rightarrow B = \text{constant}\ \frac{I}{r} \Rightarrow B = \frac{\mu_o}{2\pi}\frac{I}{r} \quad \text{\_\_\_\_\_\_\_\_\_\_(3)}$$

In equation (3), $\frac{\mu_o}{2\pi}$ represents ampere's constant. μ_o = permeability of free space

$$\Rightarrow \mu_o = 4\pi \times 10^{-7}\ web \cdot A^{-1} \cdot m^{-1}$$

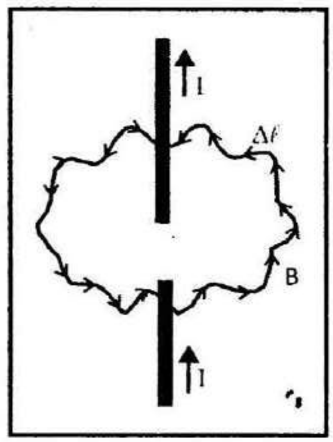
Equation (3) $\Rightarrow$

$$B(2\pi r) = \mu_o I \quad \text{\_\_\_\_\_\_\_\_ (4)}$$

Here $2\pi r$ = length of the path around the conductor = ℓ, so equation (4) becomes,

$$B(\ell) = \mu_o I \Rightarrow \boxed{\vec{B} \cdot \vec{\ell} = \mu_o \cdot I} \quad \text{\_\_\_\_\_\_\_\_\_\_(5)}$$

Equation (5) represents the mathematical form of ampere's law. Now if the magnetic lines of forces are not circular, then we divide the whole path into large number of length elements each of length "$\Delta\ell$", as shown in the figure. We find the value of $\vec{B} \cdot \Delta\vec{\ell}$ for each element and finally take their sum. So we get,



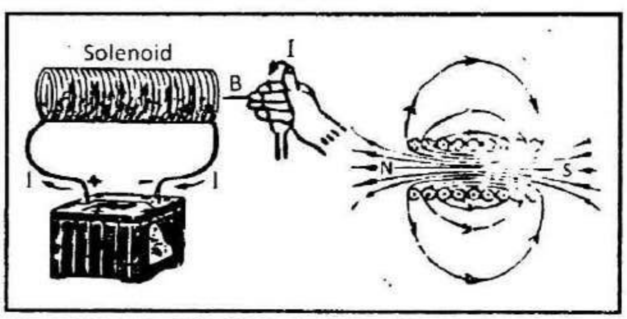
$$\boxed{\sum_{i=1}^{n} (\vec{B} \cdot \Delta\vec{\ell}_i) = \mu_o I}$$

Q8: Discuss the application of ampere's law.

Answer: <u>Magnetic Field due to Current in Solenoid:</u>

(ETEA: 2006-2008, 11)

A solenoid is a conductor which is wound to form a spring shape as shown in the figure.



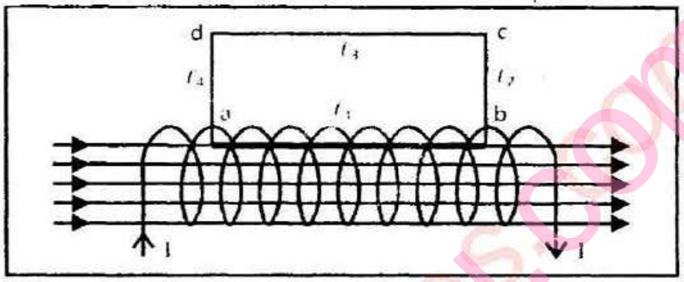
When current "I" passes through it, a magnetic field is produced in it. To find the value of this magnetic field, we consider rectangular path "abcda" on the solenoid, as shown in the figure.

Now for path "ab" we have,

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

$\Rightarrow \vec{B} \cdot \vec{l}_1 = Bl_1 \cos 0^\circ$

$\Rightarrow \vec{B} \cdot \vec{l}_1 = Bl_1$ ______(1)



For path "bc", we have,

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

$\Rightarrow \vec{B} \cdot \vec{l}_2 = Bl_2 \cos 90^\circ$

$\Rightarrow \vec{B} \cdot \vec{l}_2 = 0$ ____________(2)

For path "cd", we have,

$\vec{B} \cdot \vec{l}_3 = Bl_3 \cos \theta_3$

$\Rightarrow \vec{B} \cdot \vec{l}_3 = 0 \times l_3 \cos 0_3$

$\Rightarrow \vec{B} \cdot \vec{l}_3 = 0$ ______________(3)

For path "da", we have,

$\vec{B} \cdot \vec{l}_4 = Bl_4 \cos \theta_4 = Bl_4 \cos 90^\circ$

$\Rightarrow \vec{B} \cdot \vec{l}_4 = 0$ ______________(4)

- B is parallel to l_1 so put $\theta_1 = 0^\circ$
- B is perpendicular to l_2 so put $\theta_2 = 90^\circ$
- As l_3 lies outside the field, so $B = 0$ for l_3
- B is perpendicular to l_4. So $\theta_4 = 90^\circ$

Now according to ampere's law, we have,

$\sum \vec{B} \cdot \Delta \vec{l} = \mu_o \times$ current enclosed __________(5)

$\Rightarrow \vec{B} \cdot \vec{l}_1 + \vec{B} \cdot \vec{l}_2 + \vec{B} \cdot \vec{l}_3 + \vec{B} \cdot \vec{l}_4 = \mu_o \times$ current enclosed

$\Rightarrow Bl_1 + 0 + 0 + 0 = \mu_o \times$ current enclosed

$\Rightarrow Bl_1 = \mu_o \times$ current enclosed ______________(6)

Now if "n" represents the number of turns per unit length, then the number of turns over "l_1" will be "nl_1".

Now if "I" represents the current in each turn, then the current in "nl_1" turns will be equal to "$nl_1 I$". i.e.

Current enclosed $= nl_1 I$ ______________(7)

Putting equation (7) in equation (6), we get,

$Bl_1 = \mu_o n l_1 I$

$\boxed{B = \mu_o n I}$ ______________(8)

Equation (8) represents the magnetic field due to current in solenoid.

Q9: Discuss the applications of magnetic field.

Answer:

The magnetic strength of an electromagnet depends on:

1. The number of turns of wire around the electromagnet's core.
2. The current through the wire and
3. The size of the iron core.

By increasing these factors, we can introduce an electromagnet which will be more larger and stronger than a natural magnet. These strong electromagnets can be used for various purposes. Some important uses are given below:

1) Cranes:

The strong electromagnets are used in cranes to move large pieces of iron or steel.

2) Electromagnetic Lock:

An electromagnetic lock can be used to lock a door by creating a strong field in an electromagnet that is in contact with a magnetic plate. The door remains closed and locked as long as there is current through the electromagnet.

Another type of electromagnetic lock uses an electromagnet to extend a plunger between the doors. It makes the door impossible to open until the electromagnet releases the plunger.

3) Doorbell Ringer:

The electromagnet is used in doorbell due to which it can turned "ON" and "OFF" rapidly to pull a clangor against a bell.

Q10: Discuss the magnetic force on a moving charge "q" in a uniform magnetic field. (OR) Show that $F = qVB\sin\theta$ (OR) $\vec{F} = q(\vec{V}\times\vec{B})$

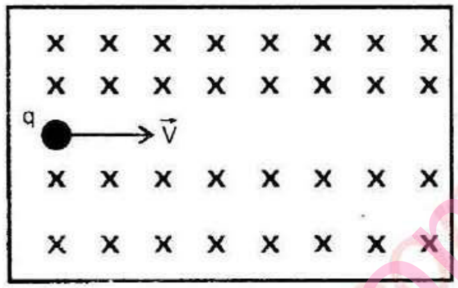
Answer: **(ETEA 2012-13)**

Consider a charge "q" moving with velocity "V" in a uniform magnetic field of strength "B" as shown in the figure.

This charge will experience a certain magnetic force "F" whose magnitude depends on the following factors:

1. The force is directly proportional to the magnitude of the charge. i.e.

$$F \propto q \quad \text{\_\_\_\_\_\_\_\_\_\_ (1)}$$



2. The force is directly proportional to the velocity of the charge. i.e.

$$F \propto V \quad \text{\_\_\_\_\_\_\_\_\_\_ (2)}$$

3. The force is directly proportional to the value of $\sin\theta$ between $\vec{V}$ and $\vec{B}$. i.e.

$$F \propto \sin\theta \quad \text{\_\_\_\_\_\_\_\_\_\_ (3)}$$

4. The force is directly proportional to the magnitude of magnitude of magnetic induction. i.e.

$$F \propto B \quad \text{\_\_\_\_\_\_\_\_\_\_ (4)}$$

Combining relations (1), (2), (3) and (4), we get,

$$F \propto qVB\sin\theta$$

$$\Rightarrow F = \text{constant } qVB \sin\theta \qquad \text{[Put constant = 1}$$

$$\Rightarrow \boxed{F = qVB \sin\theta} \quad \text{\_\_\_\_\_\_\_\_\_\_ (5)}$$

Equation (5) represents the magnitude of magnetic force on charge "q" inside magnetic field.

In vector form, equation (5) can be written as,

$$\boxed{\vec{F} = q(\vec{V} \times \vec{B})} \quad \text{\_\_\_\_\_\_\_\_\_\_ (6)}$$

Special Cases:

For given values of q, V and B, the magnitude of force depends up-on the value of "θ" between $\vec{V}$ and $\vec{B}$. For example,

1. If $\theta = 0^\circ$ i.e. $\vec{V}$ is parallel to $\vec{B}$, then equation (5)

$$F = qVB \sin 0^\circ \qquad [\sin 0^\circ = 0]$$

$$\Rightarrow \boxed{F = 0} \quad \text{\_\_\_\_\_\_\_\_\_\_ (7)}$$

Equation (7) shows that the resulting force on the charge will be zero if $\vec{V}$ is parallel to $\vec{B}$.

2. If $\theta = 90^\circ$ i.e. $\vec{V}$ is perpendicular to $\vec{B}$, then equation (5)

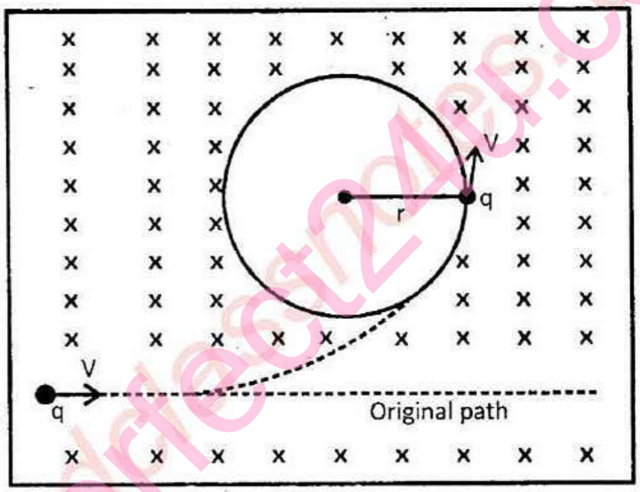
$$F = qVB\sin 90^\circ \qquad [\sin 90^\circ = 1]$$

$$\Rightarrow \boxed{F_{max} = qVB} \quad \text{\_\_\_\_\_\_\_\_\_\_ (8)}$$

Equation (8) shows that force on the charge will be maximum if $\vec{V}$ is perpendicular to $\vec{B}$.

Q11: (a) Show that the trajectory of a charged particle projected perpendicular to a uniform magnetic field is a circle. (b) Find the momentum of charged particle. (c) Find the time period and cyclotron frequency of the charged particle inside magnetic field.

Answer:



a) Consider a charged particle having charge "q" and mass "m" moving with certain velocity "v" as shown in the figure. When the particle enters the uniform magnetic field "B", it experiences certain magnetic force, which is given by,

$$F = qVB \quad \text{\_\_\_\_\_\_(1)}$$

Now due to this maximum force, [illegible]d particle deviates from its original path and follow a circular path of radius "r" as shown in the figure. Thus this force acts as centripetal force, so we have,

$$F = \frac{mv^2}{r} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_(2)}$$

Comparing equations (1), (2), we get,

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

$$\Rightarrow \frac{mv}{r} = qB \Rightarrow \frac{r}{mv} = \frac{1}{qB}$$

$$\Rightarrow \boxed{r = \frac{mv}{qB}} \quad \text{\_\_\_\_\_\_\_\_\_\_(3)}$$

Equation (3) represents the radius of circular path followed by the charged particle inside the uniform magnetic field "B". Thus the trajectory of charged particle inside the uniform magnetic field represents a circle.

b) Momentum of Charge Particle:

As we have,

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

$$\Rightarrow r = \frac{P}{qB} \qquad [mv = P]$$

$$\Rightarrow \boxed{P = rqB} \quad \_\_\_\_\_\_\_\_(4)$$

Equation (4) represents the expression for momentum of charged particle inside magnetic field.

c) Time Period and Cyclotron Frequency:

The time taken by the charged particle to complete one round trip is known as its time period. We know that,

$$T = \frac{2\pi}{\omega} \quad \_\_\_\_\_\_\_\_(5)$$

We also know that,

$$v = r\omega$$

$$\Rightarrow \omega = \frac{v}{r} \quad \_\_\_\_\_\_\_\_(6)$$

Putting equation (3) in equation (6), we get,

$$\omega = \frac{qBV}{mv}$$

$$\Rightarrow$$

$$\omega = \frac{qB}{m} \quad \_\_\_\_\_\_\_\_(7)$$

Putting equation (7) in equation (5), we get,

$$\boxed{T = \frac{2\pi m}{qB}} \quad \_\_\_\_\_\_\_\_(8)$$

Equation (8) represents the time period of charged particle inside magnetic field.

Cyclotron Frequency:

The number of complete round trips in one second is known as cyclotron frequency of circulating charged particle.

As $\quad f = \frac{1}{T} \quad \_\_\_\_\_\_\_\_(9)$

Putting equation (8) in equation (9), we get,

$$\boxed{f = \frac{qB}{2\pi m}} \quad \_\_\_\_\_\_\_\_(10)$$

Equation (10) represents the cyclotron frequency of charged particle.

Q12: How $\frac{e}{m}$ ratio for electron is determined using magnetic field?

Answer: e/m for Electron:

We know that the trajectory of charged particle inside a uniform magnetic field is given by,

$$r = \frac{mV}{qB} \Rightarrow \frac{m}{q} = \frac{rB}{V}$$

$$\Rightarrow \frac{q}{m} = \frac{V}{rB}$$

$$\Rightarrow \frac{e}{m} = \frac{V}{rB} \quad \text{------------ (1)}$$

For electron, we replace "q" by "e" i.e. put q = e

Now if "V" is the potential difference, then work done on electron before entering into the magnetic field is given by,

$$Work = Ve \quad \text{------------ (2)}$$

This work is equal to the K.E of electron, so equation (2)

$$K.E = Ve$$

$$\left[K.E = \frac{1}{2}mv^2\right.$$

$$\Rightarrow \frac{1}{2}mv^2 = Ve$$

$$\Rightarrow V = \sqrt{2Ve/m} \quad \text{------------ (3)}$$

Putting equation (3) in equation (1), we get,

$$\frac{e}{m} = \frac{\sqrt{\frac{2Ve}{m}}}{Br} \quad \text{------------ (4)}$$

Squaring both sides of equation (4), we get,

$$\frac{e^2}{m^2} = \frac{\left(\frac{2Ve}{m}\right)}{B^2r^2}$$

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

$$\Rightarrow \boxed{\frac{e}{m} = \frac{2V}{B^2r^2}} \quad \text{------------ (5)}$$

Equation (5) represents $\frac{e}{m}$ for electron using magnetic field.

Quiz 1: Why wheat flour is usually passed near a magnet before being packed?

Ans. Wheat flour is usually passed near a magnet before being packed. It is because the flour may be contaminated by iron or steel pieces and before it is put in a bag they get rid of such pieces by putting it closed to the magnet.

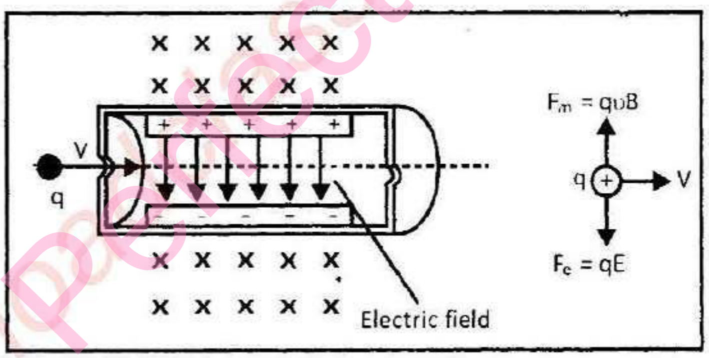
Quiz 2: Why a steel ship becomes magnetized as it is constructed?

Ans. A steel is a ferromagnetic substance. It has magnetic dipoles which tends to acquire magnetic behaviour once being passed through electric current. Hence when huge amount of current is passed through steel plates for information of ships, it becomes magnetized.

Q13: Determine "$\frac{e}{m}$" for electron by using velocity selector method.

__Answer:__

In this method, a charged particle is allowed to pass through a region where both electric and magnetic fields are acting such that the electric and magnetic forces balance each other and as a result, the charged particle will come out undeflected. Under such conditions, we have,



$$F_e = F_m$$

$$\Rightarrow qE = qVB \Rightarrow E = VB$$

$$\Rightarrow V = \frac{E}{B} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_(1)}$$

$$\boxed{\begin{aligned} F_e &= qE \\ F_{mag} &= qVB \end{aligned}}$$

We also know that,

$$\frac{e}{m} = \frac{V}{Br} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_(2)}$$

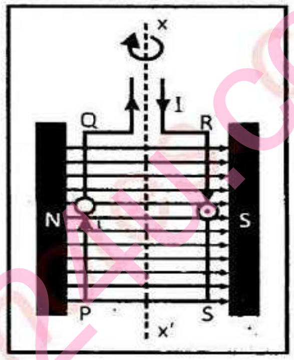
Putting equation (1) in equation (2), we get,

$$\boxed{\frac{e}{m} = \frac{E}{B^2 r}} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_(3)}$$

Equation (3) represents the $\frac{e}{m}$ ratio for electron by using velocity selector method.

Q14: A current carrying loop is placed in a uniform magnetic field. Derive an expression for the torque acting on it.

Answer:



Consider a current carrying rectangular coil "PQRS" placed in a uniform magnetic field "$\vec{B}$" as shown in the figure.

Let "L" represents the length of the coil and "b" represents the breadth as shown in the figure.

The sides "PQ" and "RS" of the coil are perpendicular to the magnetic field, so these sides experience certain magnetic force which is given by,

$$F = BIL \quad \text{\_\_\_\_\_\_\_\_\_\_}(1)$$

Due to this force, the coil rotate about an axis "xx'" and thus torque is produced which is given by,

$$\tau = F \times b \quad \text{\_\_\_\_\_\_\_\_\_\_}(2)$$

Putting equation (1) in equation (2), we get,

$$\tau = BIL\, b \quad \text{\_\_\_\_\_\_\_\_\_\_}(3)$$

In equation (3) Lb = area of coil = A

So equation (3) $\Rightarrow$

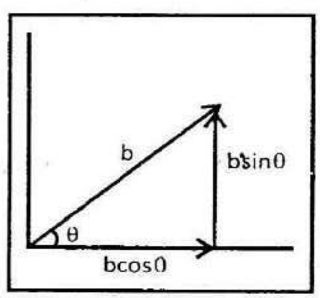
$$\boxed{\tau = BIA} \quad \text{\_\_\_\_\_\_\_\_\_\_}(4)$$

Equation (4) represents the torque on a coil having a single turn. If the coil consists of N-turns, then equation (4) can be written as,

$$\boxed{\tau = NBIA} \quad \text{\_\_\_\_\_\_\_\_\_\_}(5)$$

Equation (5) represents the torque on a coil having N-number of turns.

Special Cases:



If the plane of the coil makes certain angle "θ" with the field, then we resolve "b" into horizontal and vertical components i.e. "$b\cos\theta$" and "$b\sin\theta$". Under such conditions, the component "$b\cos\theta$" is responsible for rotation. So we replace "b" by "$b\cos\theta$" in equation (3), we get,

$$\tau = BIL\, b\cos\theta$$

$$\Rightarrow \boxed{\tau = BIA\cos\theta} \qquad \_\_\_\_\_\_\_\_(6) \qquad [Lb = Area = A]$$

If the coil consists of N-turns, then equation (6)$\Rightarrow$

$$\boxed{\tau = NBIA\cos\theta} \qquad \_\_\_\_\_\_\_\_(7)$$

The torque will be maximum if $\theta = 0^\circ$ i.e. when the plane of the coil is parallel to the magnetic field.

The torque will be zero when the plane of the coil is perpendicular to the magnetic field.

Q15: What is MRI? Discuss its principle of working and uses.

Answer: MRI:

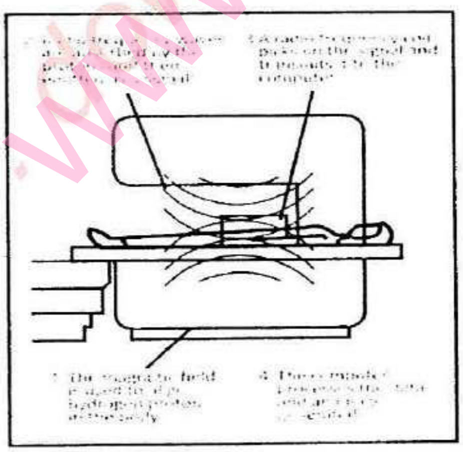
MRI stands for Magnetic Resonance Imaging system which uses the combination of strong magnetic field and radio waves to produce detailed high resolution images of the inside of the body.

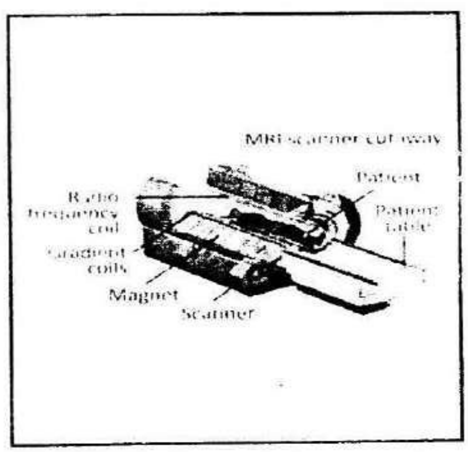
Principle and Working:

The MRI system is used to produce high quality diagnostic images through the use of magnetic field and radio waves.

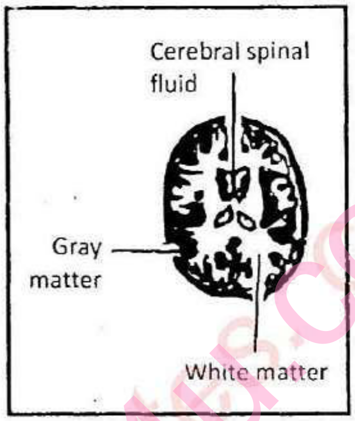
The human body is composed primarily of fat and water which is mostly made up of hydrogen atoms.

When short radio frequency (RF) pulses are applied to a specific anatomical slice, then the protons in the slice absorb energy at this resonant frequency. As a result, the protons perform spin motion perpendicular to the magnetic field.





The RF coil receives signal when the protons relax back into alignment with the magnetic field. This signal acts as an antenna and is processed by a computer to produce diagnostic images of areas of the body.



Example of an MRI Image:

The image of the brain is the example of MRI image. The brain consists of two distinct regions which are known as white matter and gray matter.

The white matter is composed of myelinated nerve fibres while the gray matter is composed of nerve cell bodies. These two regions interact to perform critical information processing and damage to either region cause brain disfunction. The damage to white matter is seen as bright areas due to light colour of myelin insulation covering the nerve fibres.

Uses of MRI:

MRI machine is used in various fields of health for diagnostic purposes. It is most superior to ultrasound, x-rays and CT scan etc. It does not involve use of ionization radiation which are dangerous to health. It gives high intrinsic contrast and has no known biological hazard.

MRI techniques are used to study the defects like brain tumour, spinal cord tumour, brain atrophy, brain hemorrhage, brain tuberculosis, lung cancer, lung degenerative diseases, liver cyst, liver cancer, kidney diseases, bone diseases and many other diseases.

Q16: Discuss the purpose, principle, construction and working of moving coil galvanometer.

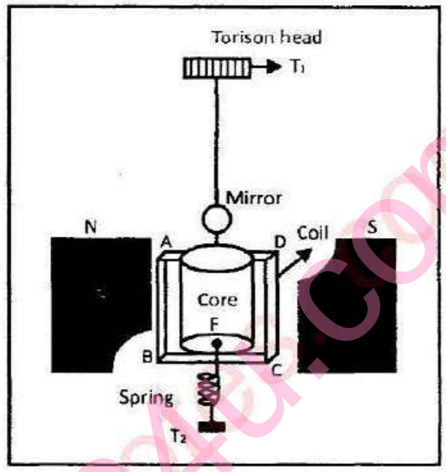
Answer: **Purpose of Galvanometer:**

The galvanometer is an electrical instrument which is used for the detection and measurement of small current in electric circuit.

Principle:

It is based on the principle that whenever a current carrying coil is placed in a magnetic field, it experiences a torque which tends to rotate it.

Construction:



It consists of a rectangular coil ABCD of fine wire wrapped around an aluminum frame and is suspended by conducting ribbons as shown in the figure. A soft iron core "F" is fixed between the poles of a permanent magnet.

The upper terminal of the coil is connected to a suspension wire "T_1" which acts as first current lead. The lower terminal of the coil is connected to a loosely spiral wire "T_2" which acts as 2^{nd} current lead.

A cylinder of soft iron is placed at the centre of the coil which intensifies the magnetic field. The high intensified radial magnetic field gives more inertia to the coil due to its high permeability.

Working:

When a current "I" flows though the coil, a magnetic field is set up which interacts with the magnetic field of the permanent magnet. As a result, the coil faces strong magnetic force due to which it tends to rotate. In this way, torque is produced which is given by,

$$\tau = NBIA\cos\theta \quad \text{\_\_\_\_\_\_\_\_\_\_} (1)$$

In equation (1), "N" represents the number of turns in the coil, "B" represents the strength of radial magnetic field, "I" represents the current in the coil, "A" the area per turn of the coil and "θ" represents the angle between plane of coil and direction of "$\vec{B}$".

Now the torque will be maximum, if the plane of the coil is parallel to the magnetic field i.e. $\theta = 0°$, so equation (1) $\Rightarrow$

$$\boxed{\tau_{max} = NBIA} \quad \text{\_\_\_\_\_\_\_\_\_\_} (2)$$

Now when the coil rotate, the suspension wire is twisted. In reaction, the suspension wire exert an opposing torque to restore its original position. Such torque is known as restoring torque. The restoring torque is proportional to the deflection angle "θ" through which the wire is twisted. So we have,

$$\tau \propto \theta \Rightarrow \tau = C\theta \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_}(3)$$

In equation (3), "C" is constant and is known as torsional constant. Now comparing equations (2), (3), we get,

$$NBIA = C\theta$$

$$\Rightarrow I = \left(\frac{C}{NBA}\right)\theta \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_}(4)$$

Put $\frac{C}{NBA}$ = constant, then equation (4)

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

This shows that the current in the coil is directly proportional to the deflection angle "θ". i.e. greater the current in the coil, larger will be the deflection and vice versa.

Measurement of Angle of Deflection:

The angle of deflection can be determine by the following methods:

1) Lamp Scale Method:

In this method, the angle of deflection can be measured with the help of a mirror which is attached to the coil. There is a lamp and scale arrangement placed at a distance of one meter from galvanometer.

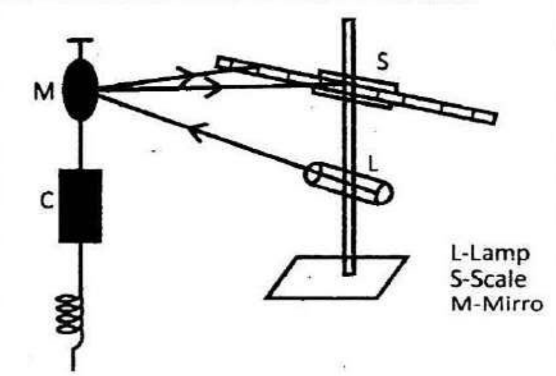


Figure: Lamp and scale arrangement for measuring the angle of deflection.

A beam of light falls on the mirror "M" and then produces a spot on the scale after reflection from the mirror.

Now when the coil rotates, the mirror also rotates due to which the position of spot produced on the screen also changes. The change in position of spot on the scale gives us the value of deflection angle.

2) Pivoted Coil Galvanometer:

In this case, the angle of deflection "θ" is observed by using pivoted coil galvanometer.

In case of pivoted coil galvanometer, the coil is pivoted between two jeweled bearings. The restoring torque is pivoted by two hair springs which also serves as current lead.

A light aluminum pointer is attached to the coil which moves over the scale and thus giving us the angle of deflection of the coil.

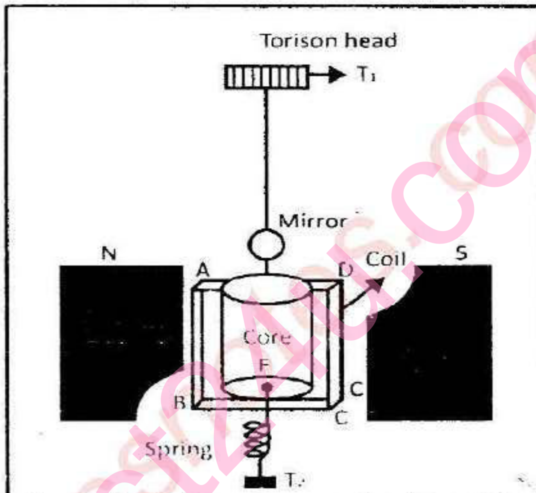


Figure: Pivoted type moving coil galvanometer

Q17: What is ammeter? How galvanometer is converted into ammeter?

Answer: **Ammeter:**

It is a device which is used for the measurement of large current in a circuit.

Explanation:

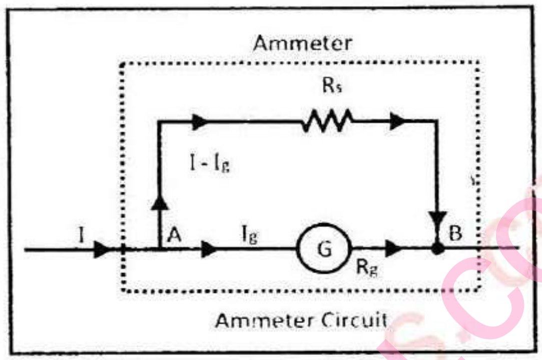
A sensitive galvanometer can measure the current of few milli ampere only. Thus in case of large current, we cannot use such sensitive galvanometer.

For measuring large current, we use the galvanometer with some proper modifications. Such modified galvanometer is known as ammeter.

Conversion of Galvanometer into Ammeter:

For converting the galvanometer into ammeter, a low resistance [called shunt resistance] is connected in parallel with galvanometer "G" in the circuit, as shown in the figure.

Now when large current flows in the circuit, it divides at point "A". Some current is allowed to pass through galvanometer "G" due to which the galvanometer shows full scale deflection. While the remaining current passes through the shunt resistance "R_s".



Ammeter Circuit

If "I_g" is the current flowing through the galvanometer then the current through shunt resistance will be equal to "$I - I_g$" i.e.

$$\boxed{I_s = I - I_g}$$

Expression for Shunt Resistance:

As the galvanometer and shunt resistance are connected in parallel, so the potential difference across them will be the same. i.e.

$$V_s = V_g$$

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

$$\Rightarrow \boxed{R_s = \frac{I_gR_g}{(I - I_g)}} \quad \text{\_\_\_\_\_\_\_\_\_\_(1)}$$

$$\boxed{\begin{aligned} &V = IR \\ &\Rightarrow V_s = I_sR_s \\ &I_s = I - I_g \end{aligned}}$$

Equation (1) represents the expression for shunt resistance.

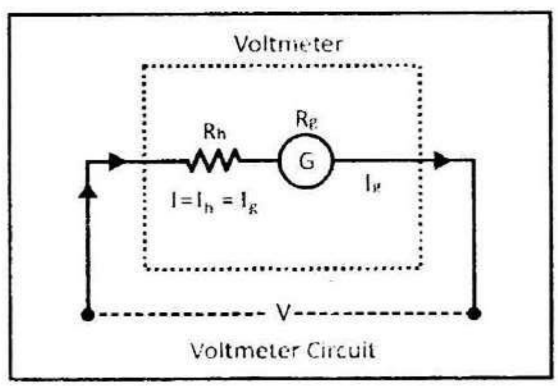
Q18: What is voltmeter? How galvanometer is converted into voltmeter?

Answer: Voltmeter:

A voltage measuring instrument is known as voltmeter.

Conversion of Galvanometer to Voltmeter:

In order to convert the galvanometer to voltmeter, a high resistance "R_h" is connected in series with galvanometer as shown in the figure.



Voltmeter Circuit

If "R_g" is the resistance of galvanometer, then the voltage across "R_g" is given by,

$$V_g = I_gR_g \quad \text{\_\_\_\_\_\_\_\_\_\_(1)}$$

Similarly, the voltage across "R_h" is given by,

$$V_h = I_h R_h$$

$$\Rightarrow V_h = I_g R_h \quad \text{\_\_\_\_\_\_\_\_\_\_(2)} \qquad [I = I_h = I_g$$

Now the voltage across the circuit is given by,

$$V = V_g + V_h$$

$$\Rightarrow V = I_g R_g + I_h R_h \Rightarrow V = I_g R_g + I_g R_h$$

$$\Rightarrow I_g R_h = V - I_g R_g$$

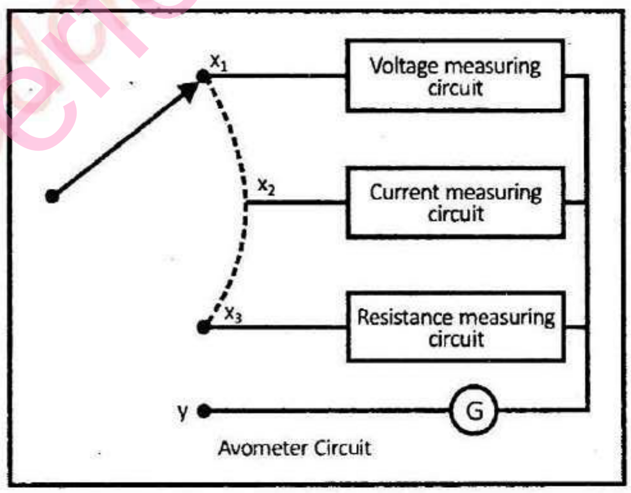
$$\Rightarrow \boxed{R_h = \frac{V}{I_g} - R_g} \quad \text{\_\_\_\_\_\_\_\_\_\_(3)}$$

Equation (3) represents the expression for high resistance connected in series with galvanometer. The above combination of galvanometer and high resistance acts as voltmeter with range from a volt to certain value V-volts.

Q19: What is avometer? Discuss in detail.

Answer: Avometer:

It is an instrument which is used to measure current, voltage and resistance. It is also known as multimeter. It can measure the direct as well as alternating current and voltage. It is a galvanometer having a series of combination of resistors which are 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. The quantity to be measured and its range can be selected by a selector switch which connects the particular electrical circuit to the galvanometer.

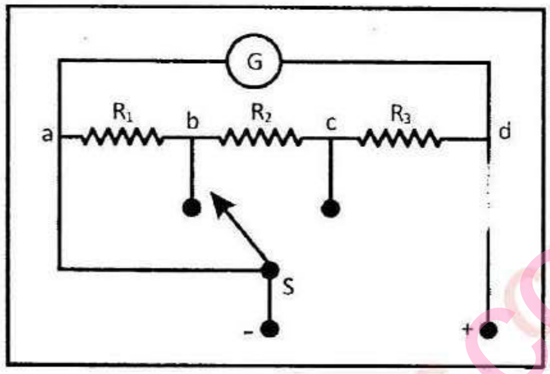


Avometer Circuit

Current Measurement:

For the measurement of current, the selector switch is turned to

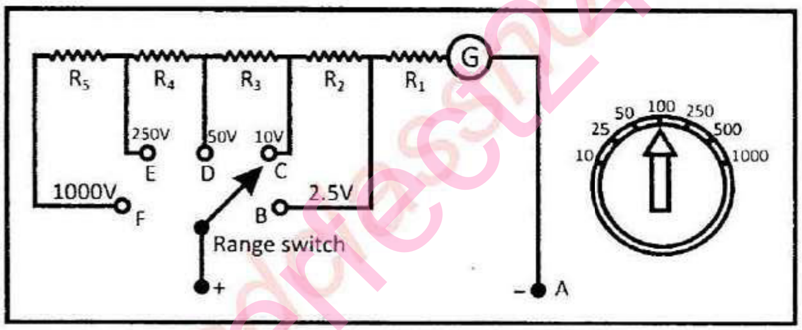
"x_1". The proper scale is selected. This circuit is a series combination of R_1, R_2 and R_3 which is known as universal shunt.



Any one of the shunts can be used for measurement of current in different ranges. This circuit provides a safe method of switching between current ranges without any danger of excessive current through the meter.

Voltage Measurement:

For measuring the voltage, several resistors are connected in series with galvanometer "G" as shown in the figure.

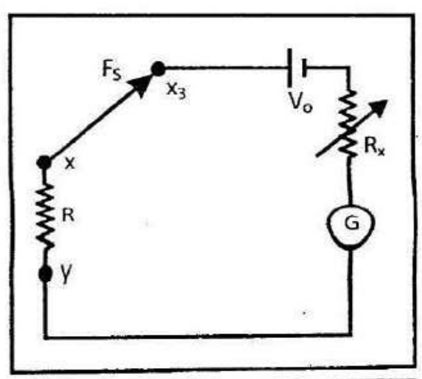


Now the voltage across the resistor can be measure by connecting it with function switch as shown in the figure. The added high resistance converts the galvanometer to a voltmeter of specific range.

For example, connections at "A" and "C" selected by the multiple switch arrangement gives a range of 10 volts. Similarly, the connections at "A" and at "B", D, E and "F" gives the ranges 2.5V, 250VC, 250V and 1000V respectively.

Resistance Measurement:

For measuring resistance, a battery of emf "V_o" and variable resistor "R_x" is connected in series with galvanometer "G" as shown in the figure.



Now for finding the value of "R", the function switch "FS" is connected to x_3. Check the galvanometer for full scale deflection by changing "R_x" gradually. The deflection on the ohms scale directly indicates the magnitude of the resistance.

Q20: Write a note on digital multimeter.

Answer: **Digital Multimeter:**

The modern multimeter are available in digital form which gives us more accurate result as compared to ordinary multimeter.

In a digital multimeter, the signal under test is converted to a voltage and an amplifier with electronically controlled gain preconditions the signal. A digital multimeter displays the measured quantity as a number which eliminates the parallax errors.

SOLUTIONS OF EXAMPLES & ASSIGNMENTS

EXAMPLE 13.1:
A wire carrying 2A current and has length of 10cm between the poles of a magnet is kept at an angle of 30° to the uniform field of 0.6T. Find the force acting on the wire

Solution:

Given Data:

Current through the wire = $I = 2A$

Length of wire = $L = 10cm = 0.1m$

Magnetic induction = $B = 0.6T$, $\theta = 30°$

Required:

Force acting on the wire = $F = ?$

Calculation:

We know that,

$$F = BIL \sin\theta \quad \text{\_\_\_\_\_\_\_\_\_\_}(1)$$

Putting the values in equation (1), we get.

$$F = (0.6 \times 2 \times 0.1 \times \sin 30°)N$$

$$\Rightarrow F = (0.6 \times 2 \times 0.1 \times 0.5)N \qquad \boxed{F = 0.06N}$$

EXAMPLE 13·2:

Two long parallel wires 6cm apart carry current of 8 A and 2A. What is magnitude of magnetic field midway between them.

Solution:

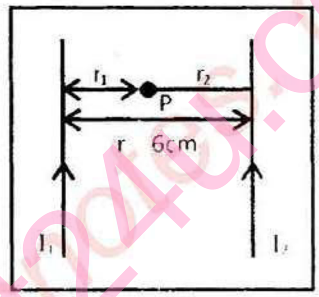
Given Data:

Distance between the two wires = r = 6cm = 0·06m

Distance between each wire and midpoint =

$$r_1 = r_2 = \frac{r}{2} = \frac{0\cdot06}{2}$$

$$\therefore \quad r_1 = r_2 = 0\cdot03m$$



Current through 1st wire = I_1 = 2A

Current through 2nd wire = I_2 = 2A

Permeability of magnetic field

$$= \mu_o = 4\pi \times 10^{-7}\ web \cdot A^{-1} \cdot m^{-1}$$

Required:

Magnitude of magnetic field at midpoint "P" = B = ?

Calculation:

The net magnetic field at point "P" is given by,

$$B_{net} = B_1 + (-B_2)$$

$$\Rightarrow \quad B_{net} = \frac{\mu_o I_2}{2\pi r_1} - \frac{\mu_o I_2}{2\pi r_2} = \frac{\mu_o}{2\pi}\left[\frac{I_1}{r_1} - \frac{I_2}{r_2}\right]$$

$$\therefore \quad B_{net} = \frac{4\pi \times 10^{-7}}{2\pi}\left[\frac{8}{0\cdot03} - \frac{2}{0\cdot03}\right]$$

$$= 2 \times 10^{-7}\left[\frac{8-2}{0\cdot03}\right]$$

$$\therefore \quad B_{net} = \left[\frac{2 \times 10^{-7} \times 6}{0\cdot03}\right] Tesla$$

$$= \left[\frac{12 \times 10^{-7}}{0\cdot03}\right] Tesla$$

$$B_{net} = 400 \times 10^{-7}\ Tesla = 4\cdot0 \times 10^{-5}\ Tesla$$

$$\boxed{B_{net} = 4\cdot0 \times 10^{-5}\ Tesla}$$

The negative sign shows that at midpoint the field are opposite in direction.

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

Ampere's law

ASSIGNMENT 13·1.

A long straight wire carries a current of 1A. Find the magnitude of the magnetic field at a distance 1m from it.

Solution:

Given Data:

Current through the wire = I = 1A

Distance from the wire = r = 1m

Permeability = $\mu_o = 4\pi \times 10^{-7}$ web $A^{-1}\cdot m^{-1}$

Required:

Magnitude of magnetic field = B = ?

Calculation:

According to ampere's law, we have,

$$B = \frac{\mu_o I}{2\pi r} \quad \text{———} (1)$$

Putting the values in equation (1), we get,

$$B = \frac{4\pi \times 10^{-7} \times 1}{2\pi \times 1} = 2 \times 10^{-7} \text{ Tesla}$$

$$\Rightarrow \boxed{B = 2 \times 10^{-7} \text{ Tesla}}$$

EXAMPLE 13.3:

A solenoid is 10cm long and is wound with two layers of wire. The inner layer has 50 turns and the outer layer has 40 turns. A current of 3A flows in both layers in the same direction. What is the magnitude of magnetic flux density along the axis of solenoid?

Solution: **Given Data:**

Length of solenoid = L = 10cm = 0.1m

Number of turns in inner layer = N_1 = 50 turns

Number of turns in outer layer = N_2 = 40 turns

Current in inner layer = I_1 = 3A

Current in outer layer = I_2 = 3A

Required:

Magnitude of magnetic flex density of solenoid = B = ?

Calculation:

As the solenoid consists of two layers of wire, so the magnitude of "B" in such a case is given by,

$$B = B_1 + B_2 = \mu_o n_1 I_1 + \mu_o n_2 I_2$$

$$\Rightarrow B = \mu_o [n_1 I_1 + n_2 I_2] = \mu_o \left[\frac{N_1}{L} I_1 + \frac{N_2}{L} I_2\right]$$

For solenoid we have
$B = \mu_o n I$

$$\Rightarrow \quad B = 4\pi \times 10^{-7}\left[\frac{50}{0\cdot 1} \times 3 + \frac{40}{0\cdot 1} \times 3\right] Tesla$$

$$B = 4\pi \times 10^{-7}\left[1500 + 1200\right]$$

$$\Rightarrow \quad B = 4\pi \times 10^{-7}\left[2700\right] T$$

$$\Rightarrow \quad B = 10800\pi \times 10^{-7} T$$

$$\Rightarrow \quad B = 10800 \times 3\cdot 14 \times 10^{-7} T$$

$$\Rightarrow \quad B = 33912\cdot 0 \times 10^{-7} T$$

$$\Rightarrow \quad B = 3\cdot 39 \times 10^{-3} T$$

$$\Rightarrow \quad \boxed{B = 3\cdot 4 \times 10^{-3} T}$$

$$\boxed{n = \frac{N}{L}}$$

ASSIGNMENT 13·2:
You are asked to design a solenoid that will give a magnetic field or 0·10T, yet the current must not exceed 10·0A· Find the number of turns per unit length that the solenoid should have·

Solution:

Given Data:

Magnetic field of solenoid = $B = 0\cdot 10T$

Current = $I = 10A$

Required:

Number of turns per unit length = $n = ?$

Calculation:

We know that,

$$B = \mu_o nI \Rightarrow n = \frac{B}{\mu_o I} \quad \text{———} (1)$$

Putting the values in equation (1), we get,

$$n = \left(\frac{0\cdot 10}{4\pi \times 10^{-7} \times 10}\right)\frac{turns}{meter} \qquad \left[\mu_o = 4\pi \times 10^{-7} Web\cdot A^{-1}\cdot m^{-1}\right]$$

$$\Rightarrow \quad n = \left(\frac{0\cdot 10}{4 \times 3\cdot 14 \times 10^{-7} \times 10}\right)\frac{turns}{meter}$$

$$\Rightarrow \quad n = \left(0\cdot 000796 \times 10^{7}\right)\frac{turns}{meter}$$

$$\Rightarrow \quad \boxed{n = 7\cdot 96 \times 10^{3}\,\frac{turns}{meter}}$$

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 1cm. Calculate the period of its orbit.

<u>Solution:</u>

<u>Given Data:</u>

Magnetic field density = [illegible] T

Radius of the circle = r = [illegible] = 0.01m

<u>Required:</u>

Period of circular orbit = T = ?

Mass of $\bar{e}$ = 9.1×10^{-31} kg

Charge on $\bar{e}$ = q = 1.6×10^{-19} C

<u>Calculation</u>

We know that.

$$T = \frac{2\pi m}{qB} = \left[\frac{2 \times 3.14 \times 9.1 \times 10^{-31}}{1.6 \times 10^{[illegible]} \times 1 \times 10^{-2}}\right] \text{sec}$$

$$\Rightarrow T = (35.7 \times 10^{[illegible]}) \text{sec} = 35.7 \times 10^{-10} \text{ sec}$$

$$\Rightarrow \boxed{T = 3.57 \times 10^{[illegible]} \text{ sec}} \text{ or } \boxed{T = 3.57\text{ns}} \qquad [10^{-9} = \text{nano}]$$

ASSIGNMENT 13.3:

A velocity selector in a mass spectrometer uses a 0.100T magnetic field (a) What electric field strength is needed to select a speed of $4.00 \times 10^{[illegible]}$ m/s?

<u>Solution:</u>

<u>Given Data:</u>

Magnetic [illegible]

Speed [illegible]

<u>Required:</u>

Electric field [illegible]

<u>Calculation:</u>

In case of [illegible] we have,

[illegible]

$\Rightarrow$ [illegible] $= vB$ [illegible]

Putting the values in equation (1), we get.

[illegible] N

$$\Rightarrow \quad E = 0.4 \times 10^6 \frac{N}{C} = 4.00 \times 10^5 \frac{N}{C}$$

$$\Rightarrow \quad \boxed{E = 4.00 \times 10^5 \frac{N}{C}}$$

EXAMPLE 13.5:
A square loop of wire of side 4.0cm carries 3.0A of current. A uniform magnetic field of magnitude 0.67T makes an angle of 30° 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?

Solution:

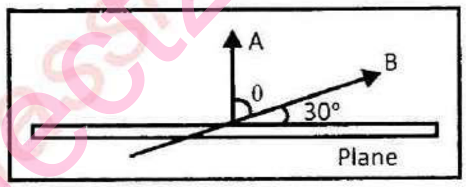
Given Data:

For single square loop number of turns = $N = 1$

Magnetic field "B" = 0.6T

Area "A" = ab = 4.0cm x 4.0cm

= $16cm^2 = 0.0016m^2$



Current "I" = 3.0A

Angle with plane of loop "ϕ" = 30°

Now the angle "θ" between vector area "A" and magnetic field "B" is:

$$\theta = 90^\circ - \phi = 90^\circ - 30^\circ = 60^\circ$$

Required:

(a) Magnitude of torque = τ = ?

(b) What is the net magnetic force on the loop = $\vec{F}_{net}$ = ?

Calculation:

The torque on current carrying coil is given by,

$$\tau = NBIA \sin\theta$$

$$\Rightarrow \tau = 1 \times 0.6 \times 3 \times 0.0016 \times \sin 60^\circ$$

$$= (0.6 \times 3 \times 0.0016 \times 0.866) N \cdot m$$

$$\Rightarrow \boxed{\tau = 2.5 \times 10^{-3} Nm}$$

b) The net force acting on the loop is equal to the sum of following forces:

$$\vec{F}_{net} = \vec{F}_{top} + \vec{F}_{bottom} + \vec{F}_{right} + \vec{F}_{left} \_\_\_\_ (1)$$

Force at top and bottom are equal and opposite. While the force on right and left are opposite equal. So we have,

$$\boxed{\vec{F}_{bottom} = -\vec{F}_{top}}$$

And $\boxed{\vec{F}_{left} = -\vec{F}_{right}}$

So eq. (1) becomes

$$\vec{F}_{net} = \vec{F}_{top} - \vec{F}_{top} + \vec{F}_{right} - \vec{F}_{right}$$

$$\Rightarrow \boxed{\vec{F}_{net} = 0\,N}$$

EXAMPLE 13·6:

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

Solution:

Given Data:

Resistance of galvanometer = $R_g = 100\Omega$

Current through galvanometer = $I_g = 1mA = 1 \times 10^{-3}A$

Ammeter current = $I = 10A$

Voltmeter voltage = $V = 10V$

Required:

a) Shunt resistance = $R_S = ?$

b) High resistance = $R_h = ?$

Calculation:

a) The galvanometer can be converted into ammeter, if the shunt resistance is given by,

$$R_S = \frac{I_g R_g}{I - I_g} \Rightarrow R_S = \frac{1 \times 10^{-3} \times 100}{(10 - 1 \times 10^{-3})}$$

$$\Rightarrow R_S = \left(\frac{10^{-3} \times 10^2}{10 - 0.001}\right)\Omega = \frac{10^{-1}}{9.999}\Omega$$

$$\Rightarrow R_S = \left(\frac{1}{9.999 \times 10^1}\right)\Omega = \frac{1}{99.99}\Omega = 0.010\,\Omega$$

$$\Rightarrow \boxed{R_S = 0.010\,\Omega}$$

Part b): The galvanometer can be converted into voltmeter of the high resistance is given by,

$$R_h = \frac{V}{I_g} - R_g \Rightarrow R_h = \frac{10}{1 \times 10^{-3}} - 100$$

$$\Rightarrow R_h = (10 \times 10^3 - 100)\Omega$$

$$\Rightarrow R_h = (10000 - 100)\Omega = 9900\Omega$$

$$\Rightarrow \boxed{R_h = 9900\,\Omega}$$

Exercise

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

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) Nm^2/A

   c) NA/m d) Nm/A✓

Solution:

$$\phi = B \cdot A = \text{weber} \quad \text{\_\_\_\_\_\_\_\_} (1)$$

Also $F = BIL \Rightarrow B = \frac{F}{IL}$ ________ (2)

Putting equation (2) in equation (1), we get,

$$\phi = \frac{F}{IL} \cdot A$$

$$\phi = \frac{N \cdot m^2}{A \cdot m}$$

$$\phi = \frac{N \cdot m}{A} \quad \text{\_\_\_\_\_\_\_\_} (3)$$

Comparing equation (1), (2), we get,

$$\boxed{\text{one weber} = \frac{N \cdot m}{A}}$$

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

   a) 0°✓ b) 60°

   c) 90° d) 180°

Solution:

$$\phi = BA \cos\theta$$

Put $\theta = 0^\circ$

$$\phi = BA\cos 0^\circ$$

$$\Rightarrow \boxed{\phi_{max} = BA}$$

5. The 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 in the length of the solenoid, its self induction will be:

a) Four times **b) Doubled✓**
c) Halved d) One fourth

<u>Solution:</u>

We know that, $L = \frac{N\phi}{I}$ ____________(1)

When number of turns doubles then equation (1) becomes,

$$L' = \frac{2N\phi}{I} = 2\left(\frac{N\phi}{I}\right) = 2L \Rightarrow \boxed{L' = 2L}$$

So option "b" is correct.

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

a) qVB b) $qVB\cos\theta$
c) $qVB\sin\theta$ **d) Zero✓**

<u>Solution:</u>

$$F = qVB\sin\theta \quad \text{\_\_\_\_\_\_\_\_\_\_(1)}$$

When charge is at rest, then $V = 0$, so equation (1) becomes,

$$F = q \times 0 \times B\sin\theta \Rightarrow \boxed{F = 0}$$

So option "d" is correct.

8. Workdone on a charge particle moving in a uniform magnetic field is:

a) Maximum b) Minimum
c) Zero✓ d) Infinite

<u>Solution:</u> Magnetic field does not work on circulating charges.

9. The earth's northern magnetic pole acts like:

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

<u>Solution:</u>

The earth's northern magnetic pole always attracts north pole. As opposite poles attract each other, so the earth northern magnetic pole must be a south pole.

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 galvanometer, the resulting circuit behaves as:

a) Voltmeter b) Ammeter✓
c) Velocity selector d) Avometer

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 above✓

<u>Solution:</u>

$\tau = NBIA$

CONCEPTUAL QUESTIONS

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

Answer: A compass needle is deflected when a charged plastic rod is held near it.

<u>Reason and Explanation:</u>

In the absence of electric and magnetic field, the compass needle remains neutral. When a charge rod [suppose positively charged] is brought near the compass needle, then according to the phenomenon of electrostatic induction, negative charges are accumulated on that side of the compass needle which are closer to the charged rod. In this way electrostatic force of attraction exist between the positively charged road and negatively charged compass needle, due to which the compass needle tends to deflect. The electrostatic induction phenomena is the origin which produce the electrostatic force and then this force causes the deflection.

Q2. What is the difference between permeability and permittivity?

Answer:

The difference between permittivity and permeability is given below:

Permittivity	Permeability
1. The permittivity is related to the formation of electric field.	1. The permeability is related to the formation of magnetic field.
2. The permittivity measures the obstruction produces by the material in the formation of the electric field.	2. The permeability represents the ability of a material to allow magnetic lines to conduct through it.
3. The permittivity is represented by ε_o or ε.	3. The permeability is represented by μ_o or μ.
4. The value "ε_o" is 8.85×10^{-12} $C^2/N \cdot m^2$.	4. The value of "μ_o" is $4\pi \times 10^{-7}$ web/A·m
5. The permittivity is because of polarization.	5. The permeability is because of magnetization.
6. The high permittivity develops in capacitors.	6. The high permeability develops in inductors.
7. The unit of "ε_o" in $C^2 \cdot N^{-1} \cdot m^{-2}$	7. The unit of "μ_o" is web$\cdot A^{-1} \cdot m^{-1}$

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

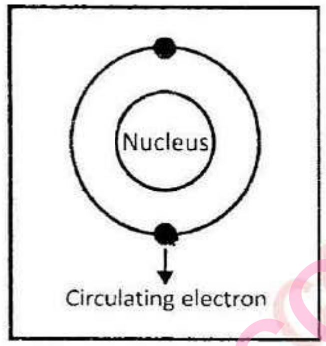
Answer:

Yes an object in rotational motion can create a magnetic field.

Reason and Explanation:

The moving electric charges can generate a magnetic field.

EXAMPLE: Electron is fundamental particle of atom. It is a negatively charged particle. When these electrons circulates around the atom, it create magnetic field around each atom. These magnetic fields have a specific orientation which is called atomic magnetic moment. Now there are two possibilities:



1. If the magnetic moments are in random direction, then they will cancel the effect of each other. As a result the net magnetization will be zero and there will be no magnetic field around the object.

2. If the magnetic moment are align in the same direction, then the net magnetization will exist and as a result the object will create a magnetic field around itself.

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

Answer:

For same velocity, the electron will be deflected more as compare to proton inside magnetic field.

Reason and Explanation:

The deflection of a charged particle by a magnetic field is directly proportional to its electric charges and velocities. i.e. if greater charge and greater velocity of the charge, its deflection inside the field will be greater and vice versa.

While the deflection of the charge particle is inversely depends on the mass of the particle. i.e. massive particle will face less de-

The radius of circular path is given by,

$$\boxed{r = \frac{mV}{qB}} \quad \text{———————} \quad (1)$$

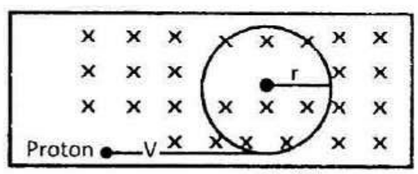


Fig (a)

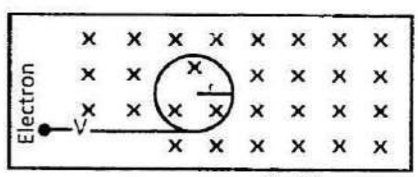


Fig (b)

According to equation (1) proton will follow a path of greater radius due to its heavier mass and less deflection while the electron will flow a path of smaller radius due to less mass and more deflection.

flection and lighter particle will face more deflection.

Now we know that an electron is 1836 times lighter particle than proton, so for same velocity and charge, the electron will be deflected more due to its lighter mass as compare to proton.

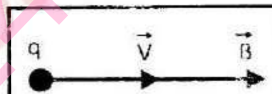
> Q5: A charged particle moves in a straight line through a particular region of space. Could there a non-zero magnetic field in this region? Explain.

Answer:

Yes, a particle can passes straight without deflection in the presence of magnetic field under the following circumstances:

<u>Reason and Explanation:</u>

<u>CASE 1:</u> We know that magnetic force on a charged particle is given by,



Velocity is parallel to magnetic field so $\theta = 0°$

$$F = qVB\sin\theta \qquad (1)$$

If the particle is moving parallel to magnetic field, then we have, $\theta = 0°$ so equation (1) becomes,

$$F_m = qVB\sin 0° = qVB \times 0 \qquad \boxed{\sin 0° = 0}$$

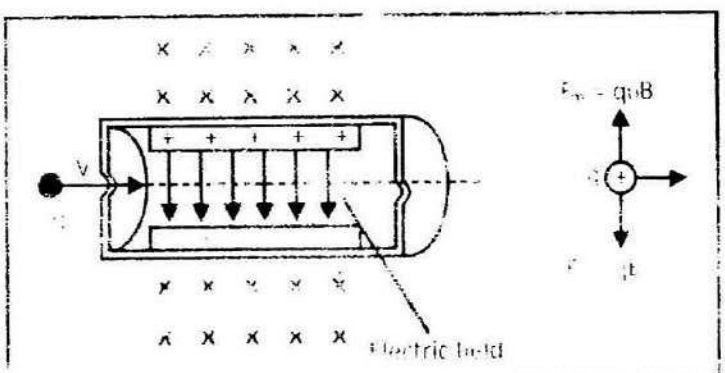
$$\therefore \boxed{F_{mag} = 0}$$

Thus if the particle is moving parallel to the magnetic field, then it will experience no magnetic force and will pass undeflected i.e. straight.

<u>CASE 2:</u> In case of velocity selector method, the electric field and magnetic field are applied in such a way that they cancel the effect of each other. So we have,

$$\boxed{F_{electric} = F_{...}}$$

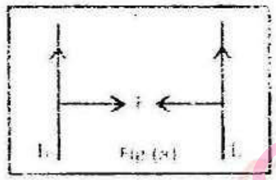
Under such ... deflected ... straight ...



Q6: If a current is passed through a unstretched spring, will the spring contract or expand? Explain.

Answer:

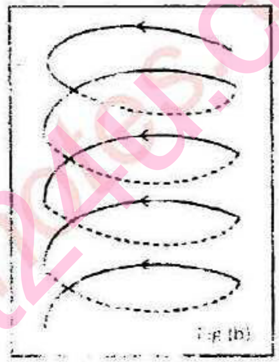
When a current is passed through an unstretched spring, then the spring spring will contract.



Reason and Explanation:

We know that when current passes in the same direction through two parallel conductors, they attract each other as shown in figure (a).

Similarly when current is passed through an unstretched spring, then the current will flow through each turn in same direction as shown in figure (b). Thus force of attraction will exists between the adjacent turns. As a result of this force attractive force, the spring will contract.



Q7: How can neutrons be accelerated [illegible] cyclotron? [illegible]

Answer:

A neutron cannot be accelerated in a cyclotron.

Reason and Explanation:

Cyclotron is a type of particle accelerator in which a charged particle is accelerated towards a target under the application of electric and magnetic fields.

As the neutron is chargeless particle, so there is no effect of electric and magnetic fields on neutron. So we cannot accelerate the neutron inside a 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.

Answer:

A current carrying loop will be in a state of equ[illegible] its plane is perpendicular to the magnetic field.

Reason and Explanation

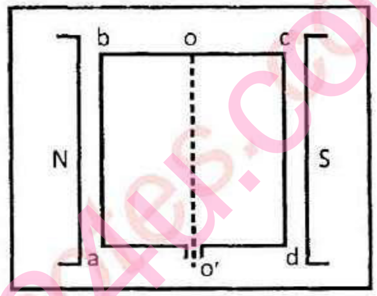
We [illegible]

side the magnetic field which is given by,

$$\tau = NBIA \cos\theta \quad \_\_\_\_\_\_\_\_ (1)$$

Now the loop will be in state of equilibrium, if the torque acting on it is zero. Now for getting zero torque, we should put $\theta = 90^\circ$ in equation (1), we get,

$$\boxed{\tau = 0}$$



For $\theta = 90^\circ$, the plane of the loop should be perpendicular to the magnetic field.

Thus a current-carrying loop will be in a state of equilibrium if its plane is perpendicular to the magnetic field.

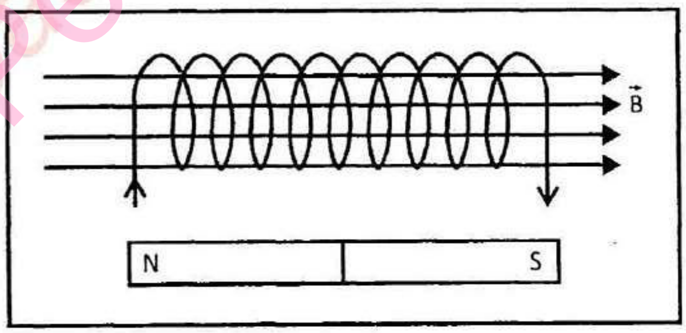
Q9: How does a current carrying coil behaves like a bar magnet?

<u>Answer:</u>

A current carrying coil behaves like a bar magnet.

<u>Reason and Explanation:</u>

Consider a coil as shown in the figure. When current passes through the coil, a uniform magnetic field is produced inside the turns of the coil. The magnetic field lines originate from one side and ends at the other side.



Now if we suspend the coil freely, it will rotate and will settle down along North-South direction. As the earth's magnetic field exists along North-South direction, so the current carrying coil behaves like a bar magnet. Its one end behaves like a North-pole and the other end behaves like a South-pole.

NUMERICAL QUESTIONS

Q1: At what distance from a long straight wire carrying a current of 10A is the magnetic field is equal to the earth's magnetic field of 5×10^{-5}T? (Ans: 0·04m)

Solution:

Given Data:

Current in the wire = I = 10A

Magnetic field = $B = 5 \times 10^{-5}T$

Permeability = $\mu_o = 4\pi \times 10^{-7}$ web/A·m

Required:

Distance from wire = r = ?

Calculation:

According to ampere's law, we have,

$$B = \frac{\mu_o I}{2\pi r} \Rightarrow r = \frac{\mu_o I}{2\pi B} = \frac{4\pi \times 10^{-7} \times 10}{2\pi \times 5 \times 10^{-5}}$$

$$\Rightarrow r = 4 \times 10^{-2}m = 0{\cdot}04m$$

$$\Rightarrow \boxed{r = 0{\cdot}04m}$$

Q2: A long solenoid having 1000 turns uniformly distributed over a length of 0·5m produces a magnetic field of $2{\cdot}5 \times 10^{-3}T$ at the center. Find the current in the solenoid. (Ans: 1A)

Solution:

Given Data:

Number of turns = N = 1000

Length of solenoid = L = 0·5m

Magnetic field = $B = 2{\cdot}5 \times 10^{-3}T$

Permeability = $\mu_o = 4\pi \times 10^{-7}$web/A·m

Required:

Current in the solenoid = I = ?

Calculation:

We know that magnetic field due to solenoid is given by,

$$B = \mu_o nI = \frac{\mu_o N}{L} I \qquad \boxed{n = \frac{N}{L}}$$

$$\Rightarrow B = \frac{\mu_o NI}{L} \Rightarrow I = \frac{BL}{\mu_o N} \quad \text{———— (1)}$$

Putting values in equation (1), we get,

$$I = \left(\frac{2.5 \times 10^{-3} \times 0.5}{4\pi \times 10^{-7} \times 1000}\right) A = \left(\frac{2.5 \times 0.5 \times 10^{-3}}{4 \times 3.14 \times 10^{-7} \times 10^{3}}\right) A$$

$$\Rightarrow I = 0.0995 \times 10^{1} A = 0.995 A \Rightarrow \boxed{I = 1A}$$

Q3: A proton moving at right angles to a magnetic field of 0.1T experiences a force of 2×10^{-12} N. What is the speed of the proton? (Ans: 1.3×10^{8} m/sec)

Solution:

Given Data:

Magnetic field $= B = 0.1T$

Charge on proton $= q_p = 1.6 \times 10^{-19} C$

Angle between "$\vec{V}$" and "$\vec{B}$" $= \theta = 90°$

Required:

Speed of proton $= V = ?$

Calculation:

We know that,

$$F = qVB \sin\theta$$

$$\Rightarrow 2 \times 10^{-12} = 1.6 \times 10^{-19} \times V \times 0.1 \times \sin 90°$$

$$\Rightarrow 2 \times 10^{-12} = 1.6 \times 10^{-19} \times V \times 0.1 \times 1 = 0.16 \times 10^{-19} V$$

$$\Rightarrow V = \left(\frac{2 \times 10^{-12}}{0.16 \times 10^{-19}}\right) m/sec = 12.5 \times 10^{-12+19} = 12.5 \times 10^{7} m/sec$$

$$\Rightarrow V = 1.25 \times 10^{8} m/sec \Rightarrow \boxed{V = 1.3 \times 10^{8} m/sec}$$

Q4: An 8MeV proton enters perpendicularly into a uniform magnetic field of 2.5T. Find (a) the force on the proton (b) What will be the radius of the path of proton?

Ans: (a) 1.5×10^{-11} N (b) 0.16m

Solution:

Given Data:

$$K.E = 8 MeV = 8 \times 10^{6} eV$$ $\boxed{Mega = 10^{6}}$

$$\therefore K.E = 8 \times 10^{6} \times 1.6 \times 10^{-19} J = 12.8 \times 10^{-13} J$$ $\boxed{1eV = 1.6 \times 10^{-19} J}$

$$K.E = 12.8 \times 10^{-13} J \Rightarrow \frac{1}{2} mV^2 = 12.8 \times 10^{-13}$$

$$\Rightarrow V^2 = \frac{2 \times 12.8 \times 10^{-13}}{m} = \frac{2 \times 12.8 \times 10^{-13}}{1.67 \times 10^{-27}}$$

$\Rightarrow V^2 = 15.31 \times 10^{14} \Rightarrow V = \sqrt{15.31 \times 10^{14}}$

$\Rightarrow V = 3.91 \times 10^7 \, m/sec$

Magnetic field = $2.5T$, $\theta = 90^\circ$

<u>Required</u>:

a) Force on proton = F_m = ?

b) Radius of path = r = ?

<u>Calculation</u>:

a) We know that,

$$F = qVB \sin\theta$$

$$\Rightarrow F = 1.6 \times 10^{-19} \times 3.91 \times 10^7 \times 2.5 \times \sin 90^\circ$$

$$\Rightarrow F = 15.64 \times 10^{-12} N \Rightarrow F = 1.564 \times 10^{-11} N$$

$$\Rightarrow \boxed{F = 1.6 \times 10^{-11} N}$$

b) We know that the radius of circular path followed by a charged particle inside magnetic field is given by,

$$r = \frac{mV}{qB} = \frac{1.672 \times 10^{-27} \times 3.91 \times 10^7}{(1.6 \times 10^{-19} \times 2.5)}$$

$$\Rightarrow r = 1.6 \times 10^{-1} m \Rightarrow \boxed{r = 0.16m}$$

Q5: What is the time period of an electron projected into a uniform magnetic field of 10mT and moves in a circle of radius 6cm?

<u>Solution</u>:

<u>Given Data</u>:

Magnetic field = $10mT = 10 \times 10^{-3} T$

Radius of circle = $r = 6cm = 0.06m$

Charge on electron = $q = 1.6 \times 10^{-19} C$

Mass of electron = $m = 9.1 \times 10^{-31} kg$

<u>Required</u>:

Time period of electron = T = ?

<u>Calculation</u>:

We know that the time period of circulating charges is given by,

$$T = \frac{2\pi m}{qB} \Rightarrow T = \left(\frac{2 \times 3.14 \times 9.1 \times 10^{-31}}{1.6 \times 10^{-19} \times 10 \times 10^{-3}}\right) sec$$

$$\Rightarrow T = 3.57 \times 10^{-31+19+3} sec = 3.6 \times 10^{-9} sec$$

$$\Rightarrow \boxed{T = 3.6 \text{ nano sec}}$$

$\boxed{10^{-9} = nano}$

Q6: A rectangular coil with 250 turns is 6·0cm long and 4·0cm wide. When the coil is placed in a magnetic field of 0·25T, its maximum torque is 0·20Nm. What is the current in the coil?

Solution:

Given Data:

Number of turns = N = 250 turns

Length of rectangular coil = L = 6cm = 0·06m

Width of rectangular coil = W = 4cm = 0·04m

Magnetic field = B = 0·25T

Maximum torque = τ_{max} = 0·20N·m

Required:

Current in the coil = I = ?

Calculation:

We know that the maximum torque on a current carrying coil is given by,

$$\tau_{max} = NBIA \qquad \boxed{A = L \times W}$$

$$\Rightarrow \tau_{max} = NBILW$$

$$\Rightarrow I = \frac{\tau_{max}}{NBLW} = \left(\frac{0\cdot20}{250 \times 0\cdot25 \times 0\cdot06 \times 0\cdot04}\right) A$$

$$\Rightarrow \boxed{I = 1\cdot3A}$$

Q7: Crossed electric and magnetic fields are established over a certain region. The magnetic field is 0·105T and the electric field is $2\cdot00 \times 10^5$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? (Ans: $1\cdot9 \times 10^6$m/sec)

Solution: Given Data:

Magnetic field = B = 0·105T

Electric field = E = 2×10^5V/m

Required:

Speed of electron = V = ?

$$\boxed{\begin{aligned} F_e &= qE \\ F_m &= qVB \end{aligned}}$$

Calculation:

When net force on the charge is zero, then we have, Electric force = Magnetic force

$$\Rightarrow F_e = F_m \Rightarrow qE = qVB \Rightarrow E = VB$$

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

$$\Rightarrow V = \left(\frac{2 \times 10^5}{0.105}\right) m/sec = 19.05 \times 10^5 \ m/sec = 1.905 \times 10^6 \ m/sec$$

$$\Rightarrow \boxed{V = 1.905 \times 10^6 \, m/sec} \text{ or } \boxed{V = 1.9 \times 10^6 \, m/sec}$$

Q8: The full scale deflection for a galvanometer is 10mA. Its resistance is 100 ohms. How can it be converted into an ammeter of range 100A?

Solution:

Given Data:

Galvanometer current = I_g = 10mA = 10×10^{-3}A

Galvanometer resistance = R_g = 100Ω

Ammeter current = I = 100A

Required:

Shunt resistance = R_S = ?

Calculation:

We know that the galvanometer can be converted into ammeter, if

$$R_S = \frac{I_g R_g}{(I - I_g)} = \frac{10 \times 10^{-3} \times 100}{(100 - 10 \times 10^{-3})} = \left(\frac{1000 \times 10^{-3}}{100 - 0.010}\right) = \left(\frac{10^3 \times 10^{-3}}{90}\right)$$

$$\Rightarrow R_S = \frac{10^{3-3}}{90} = \frac{1}{90} = \frac{1}{90}$$

$$\Rightarrow \boxed{R_S = 0.10 \, \Omega}$$

Q9: How a 5mA, 100 ohms galvanometer is converted into 20V voltmeter? Ans: 3900Ω

Solution:

Given Data:

Resistance of galvanometer = R_g = 100Ω

Current = I_g = 5mA = 5×10^{-3}A = 0.005A

Voltage = V = 20V

Required:

Value of high resistance = R_h = ?

Calculation:

We know that a galvanometer can be converted into voltmeter if

$$R_h = \frac{V}{I} - R_g \Rightarrow R_h = \frac{20}{0.005} - 100$$

$$\Rightarrow R_h = (4000 - 100)\Omega \Rightarrow \boxed{R_h = 3900\,\Omega}$$

Q10: Two parallel wire 10cm apart carry currents in opposite directions of 8A. What is the magnetic field halfway between them? Ans: $6.4 \times 10^{-5}\,T$

Solution:

Given Data:

$$I_1 = i_2 = 8A$$

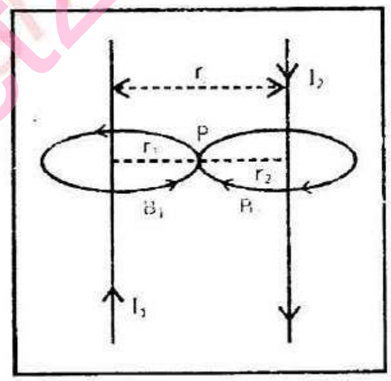
Distance between wires = 10cm

$$\Rightarrow r = 10cm = 0.1 \Rightarrow r = 0.1m$$

Required:

Magnetic field in the middle = B = ?

Calculation:



Let "P" be the point situated at middle of the two wires. Now the distance of 1^{st} wire from point "P" is given by,

$$r_1 = \frac{r}{2} = \frac{0.1}{2}$$

$$\Rightarrow r_1 = 0.05m$$

Similarly, $r_2 = \frac{0.1}{2}$

$$\Rightarrow r_2 = 0.05m$$

Now in the middle i.e. at point "P" both fields "B_1" and "B_2" are parallel, so the resultant field is given by,

Amperes Law:

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

$$B = B_1 + B_2 \Rightarrow B = \frac{\mu_o I_1}{2\pi r_1} + \frac{\mu_o I_2}{2\pi r_2}$$

$$= \frac{4\pi \times 10^{-7} \times 8}{2\pi \times 0.05} + \frac{4\pi \times 10^{-7} \times 8}{2\pi \times 0.05}$$

$$\Rightarrow B = 320 \times 10^{-7} + 320 \times 10^{-7} = (320 + 320) \times 10^{-7}\,T$$

$$\Rightarrow B = 640 \times 10^{-7}\,T$$

$$\Rightarrow \boxed{B = 6.4 \times 10^{-5}\,T}$$