MAGNETISM AND MAGNITIC EFFECTS OF ELECTRIC CURRENT

PHYSICS - VOL 1 | **UNIT - 3**

NAME :

STANDARD : 12 SECTION :

SCHOOL :

EXAM NO :

கண்ணுடைய ரென்பவர் கற்றோர் முகத்திரண்டு
புண்ணுடையவர் கல்லா தவர்

கற்றவரே கண்ணுடையவர்கள் ஆனால் கல்லாதவரோ முகத்தில் இரண்டு புண்ணையே உடையவர்

webStrake

victory R. SARAVANAN. M.Sc, M.Phil, B.Ed.,

PG ASST (PHYSICS)

GBHSS, PARANGIPETTAI - 608 502

webStrake Recognized Teacher

PART - II 2 MARK QUESTIONS & ANSWERS

1. Define magnetism. Give its applications.

- The property of attracting iron is called magnetism.
- In olden days, magnets were used as magnetic compass for navigation, magnetic therapy for treatment and magic shows.
- In modern days most of the things we use in daily life contains magnets. For example loud speaker, motors, dynamo, cell phones, pendrive, CD, hard disc in laptop etc

2. Define Giomagnetism or Terrestrial magnetism.

- The branch of physics which deals with the Earth's magnetic field is called Geomagnetism .

3. Define pole strength of the magnet.

- The attracting property of the magnet is concentrated at its poles only and this property is called pole strength (q_m).
- The S.I unit of pole strength is $\boldsymbol{A\ m}$

4. Define magnetic dipole moment.

- Manetic dipole moment ($\boldsymbol{p_m}$) is defined as the product of the pole strength (q_m) and magnetic length ($2\,l$). i.e $\boldsymbol{p_m = q_m\, 2\, l}$
- In vector notation ; $\vec{\boldsymbol{p}}_m = \boldsymbol{q_m}\, \vec{\boldsymbol{d}}$ $\quad [\because |\vec{d}| = 2\,l]$
- Its S.I unit is $A\,\boldsymbol{m^2}$. Its direction is from South pole to North poke.

5. Define magnetic field.

- The magnetic field $\vec{B}$ at a point is defined as a force experienced by the bar magnet of unit pole strength.

$$\vec{\boldsymbol{B}} = \frac{\vec{\boldsymbol{F}}}{\boldsymbol{q_m}}$$

- Its S.I unit is $\boldsymbol{N\, A^{-1} m^{-1}}$

6. What are the types of magnet?

- Magnets are classified in to natural magnets and artificial magnets.
- Iron, cobalt, nickel etc are natural magnets. Strength of natural magnets are very weak and the shape of the magnet are irregular.
- Artificial magnets are made our desired shape and strength. Bar magnets, cylindrical magnets, horse shoe magnets are some examples for artificial magnets.

7. Define magnetic flux. Give its unit.

- the number of magnetic field lines crossing per unit area is called magnetic flux (Φ_B)

$$\boldsymbol{\Phi_B = \vec{B}\,.\vec{A} = B\,A\cos\theta}$$

- The S.I unit of magnetc flux is ***weber (Wb)*** and C.G.S unit is ***maxwell*** (1 Wb = 10^8 maxwell)
- Its dimentional formula is **$[ML^2T^{-2}A^{-1}]$**

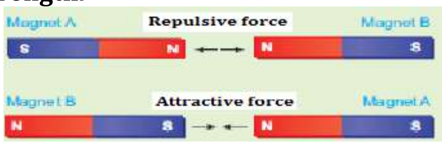
8. Define magnetic flux density.

- The magnetic flux density can be defined as the number of magnetic field lines crossing unit area kept normal to the direction of line of force.
- Its S.I unit is ***tesla*** or $\boldsymbol{Wb\ m^{-2}}$

9. Distinguish between uniform and non-uniform magnetic field.

Uniform magnetic field	Non-uniform magnetic field
1) Magnetic field is said to be uniorm If it has the same magnitude and direction at all the points in a given region.	1) Magnetic field is said to be non-uniform If the magnitude or direction or both varies at all its points.
2) (e.g) Locally Earth's magnetic field is uniform	2) (e.g) Magnetic field of a bar magnet

10. Discuss the types of force between two magnetic pole strength.



- When north pole (N) of magnet A and north pole (N) of magnet B or south pole (S) of magnet A and south pole (S) of magnet B are brought close together, they repels each other.
- On the other hand, when north pole of magnet A and south pole of magnet B or south pole of magnet A and north pole of magnet B are brought close together they attracts each other.
- Thus like poles repels and unlike poles attracts.

11. State Coulomb's inverse square law of magnetism.

- The force of attraction or repulsion between two magnetic poles is directly proportional to the product of their pole strengths and inversely proportional to the square of the distance between them.

12. What happens when a bar magnet is freely suspended in uniform and non-uniform magnetic field?

- Even though Earth has non- uniform magnetic field, it is locally (at particular place) taken as uniform. So bar magnet suspended freely in unifom magnetic field experience only torque (rotational motion)
- When a bar magnet is freely suspended in non-uniform magnetic field, it undergo translator motion due to net force and rotational motion due to torque.

13. Define magnetic dipole moment of current loop.

- The magnetic dipole moment of any current loop is equal to the product of the current and area of the loop. $[\vec{p}_m = I\,\vec{A}]$

14. Define gyro-magnetic ratio.

- The ratio of magnetic moment (μ_L) of the electron to its angular momentum (L) is called gyro-magnetic ratio.

$$\frac{\mu_L}{L} = \frac{e}{2\,m} = 8.78\ X\ 10^{10}\ C\ kg^{-1}$$

15. Define Bohr magneton.

- It is the unit of atomic magnetic moment.
- The minimum value of atomic magnetic moment is called Bohr magneton.

$$\boldsymbol{1\ bohrmagneton = \mu_B = \frac{e\,h}{4\,\pi\,m} = 9.27\ X\ 10^{-24}\ A\ m^2}$$

16. State Ampere's circuital law.

- It state that the line integral of magnetic field over a closed loop is $\boldsymbol{\mu_o}$ times net current enclosed by the loop.

$$\oint \vec{\boldsymbol{B}}\,.\vec{\boldsymbol{dl}} = \boldsymbol{\mu_o\, I_o}$$

17. Define Lorentz force.

- If the charge is moving in the electric field ($\vec{E}$) and magnetic field ($\vec{B}$), the total force experienced by the charge is given by $\vec{\boldsymbol{F}} = \boldsymbol{q}\,[\vec{\boldsymbol{E}} + (\vec{\boldsymbol{v}}\ X\ \vec{\boldsymbol{B}})]$
- It is known as Lorentz forec.

18. Define one tesla.

- The strength of the magnetic field is one tesla if unit charge moving in it with unit velocity experiences unit force.

19. Write a note on fast-neutron cancer therapy.
- When a deuteron is bombarded with a beryllium target, a beam of high energy neutrons are produced.
- These high energy neutrons are sent into the patient's cancerous region to break the bonds in the DNA of the cancer cells.
- This is used in treatment of fast-neutron cancer therapy.

20. State Flemming's left hand rule (FLHR).
- Stretch fore finger, the middle finger and the thrumb of the left hand in mutully perpendicular directions. If,
  - (i) fore finger points the direction of magnetic field,
  - (ii) the middle finger points the direction of the electric current, then
  - (iii) thumb will point the direction of the force experienced by the conductor.

21. Define one ampere.
- One ampere is defined as that current when it is passed through each of the two infinitely long parallel straight conductors kept at a distance of one metre apart in vacuum caused each conductor to experience a force of $2 \; X \; 10^{-7}$ newton per metre length of conductor.

22. Define figure of merit of a galvanometer.
- It is defined as the current which produces a deflection of one scale division in the galvanometer.

23. Define current sensitivity of a galvanometer.
- It is defined as the deflection produced per unit current flowing through it.

$$I_S = \frac{\theta}{I} = \frac{N\,B\,A}{K} = \frac{1}{G}$$

24. How the current sensitivity of galvanometer can be increased?
- By increasing the number of turns N
- By increasing the magnetic induction B
- By increasing the area of the coil A
- By decreasing the couple per unit twist of the suspension wire

25. Why Phosphor - bronze is used as suspension wire?
- Because, for phosphor - bronze wire, the couple per unit twist is very small.

26. Define voltage sensitivity of the galvanometer.
- It is defined as the deflection produced per unit voltage applied across it.

$$I_S = \frac{\theta}{I} = \frac{N\,B\,A}{K} = \frac{1}{G}$$

27. How galvanometer can be converted in to ammeter?
- A galvanometer is converted in to an ammeter by connecting a low resistance (shunt) in parallel with the galvanometer.

28. How galvanometer can be converted in to voltmeter?
- A galvanometer is converted into a voltmeter by connecting high reistance in series with galvanometer.

29. Why ammeter should always connected in series to the circuit?
- The ammeter must offer low resistance such that it will not change the current passing through it. So ammeter is connected in series to measure the circuit current.
- An *ideal ammeter has zero resistance*.

30. Why voltmeter should always connected in parallel to the circuit?
- The voltmeter must offer high resistance so that it will not draw appreciable current. So voltmeter is connected in paralle to measure the potential difference.
- An *ideal voltmeter has infinite resistance*.

PART - III 3 MARK OUESTIONS AND ANSWERS

1. What are the properties of bar magnet?

<u>Properties of magnet</u>:
- (i) A freely suspended bar magnet wil always point along the north - south direction.
- (ii) The attractive property of the magnet is maximum near its end or pole. This is called pole strength.
- (iii) Two poles of a magnet have pole strength equal to one another.
- (iv) When a magnet is broken into pieces, each piece behave like a magnet with poles at its ends.
- (v) The length of the bar magnet is called *geometrical length* and length between two magnetic poles in a bar magnet is called *magnetic length*. The magnetic length is always slightly smaller than geometrical length. (i.e.)

magnetic length : geometrical length = 5 : 6

2. Write a note on pole strength.

<u>Pole strength</u> :
- The attracting property of the magnet is concentrated at its poles only and this property is called pole strength (q_m).
- It is a scalar quantity with dimension $[L\,A]$. Its S.I unit is $\boldsymbol{A\,m}$ (or) $\boldsymbol{N\,T^{-1}}$
- North pole of the magnet experiences a force in the direction of the magnetic field and south pole experiences force opposite to the magnetic field.
- Pole strength depends on the nature of materials of the magnet, area of cross-section and the state of magnetization.
- If a magnet is cut in to two equal halves along the length, then pole strength is reduced to half.
- If the magnet is cut into two equal halves perperdicular to the length, then pole strength remains same.
- If we cut the magnet in to two pieces, we will not separate north and south poles. Instead we get two magnets. (i.e) isolated mono pole does not exist in nature

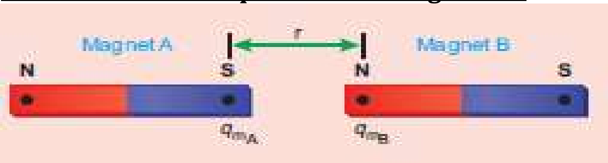
3. Give the properties of magnetic field lines.

<u>Properties of magnetic field lines</u>:
- They are continuous closed lines. Their direction is from North pole to South pole outside the magnet and South pole to North pole inside the magnet.

- The tangent drawn at any point on the magnetic field lines gives the direction of magnetic field at that point.
- They never intersect each other.
- The degree of closeness of the field lines determines the relative strength of the magnetic field. The magnetic field is strong where magnetic field lines crowd and weak where magnetic field lines thin out.

4. Explain Coulomb's inverse square law in magnetism.

<u>Coulomb' inverse square law in magnetism</u> :



- Consider two bar magnets A and B as shown.
- Let , Pole strength of A $= Q_{m_A}$

  Pole strength of B $= Q_{m_B}$

  Distance between A and B $= r$
- Then by Coulomb's law, the force of attraction or repulsion between two mannetic poles is directly proportional to the product of their pole strengths and inversely proportional to the square of the distance between them. Hence

$$\vec{F} \propto \frac{Q_{m_A}\, Q_{m_A}}{r^2}\,\hat{r} \quad (or) \quad \vec{F} = k\,\frac{Q_{m_A}\, Q_{m_A}}{r^2}\,\hat{r}$$

- In magnitude,

$$F = k\,\frac{Q_{m_A}\, Q_{m_A}}{r^2}$$

- where, $k \rightarrow$ proportionality constant.
- In S. I unit, the value of k is

$$k = \frac{\mu_o}{4\,\pi} \cong 10^{-7}\ H\,m^{-1}$$

- Then the force,

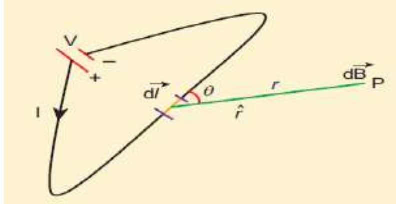
$$\boldsymbol{F = \frac{\mu_o}{4\,\pi}\,\frac{Q_{m_A}\, Q_{m_A}}{r^2}}$$

- where, $\mu_o \rightarrow$ permiability of free space or vacuum

$$[\mu_o = 4\,\pi\ X\ 10^{-7}\ H\,m^{-1}]$$

5. State and explain Biot-Savart law.

<u>Biot - Savart law</u> :



- According to Biot - Savart law, the magnitude of magnetic field $\overrightarrow{dB}$ at a point 'P' at a distance 'r' from the small elemental length 'dl' of the current 'I' carrying conductor varies,
  - (i) $dB \propto I$
  - (ii) $dB \propto dl$
  - (iii) $dB \propto \sin\theta$
  - (iv) $dB \propto \frac{1}{r^2}$
- Hence,

$$dB \propto \frac{I\,dl\sin\theta}{r^2}$$

$$(or) \qquad dB = k\,\frac{I\,dl\sin\theta}{r^2} \qquad ----\ (1)$$

- where, $k \rightarrow$ constant
- In S. I. units, $k = \frac{\mu_o}{4\,\pi}$
- Hence,

$$\boldsymbol{dB = \frac{\mu_o}{4\,\pi}\,\frac{I\,dl\sin\theta}{r^2}} \qquad ----\ (2)$$

- In vector notation,

$$\boldsymbol{\overrightarrow{dB} = \frac{\mu_o}{4\,\pi}\,\frac{I\,\overrightarrow{dl}\ X\ \hat{r}}{r^2}} \qquad -----\ (3)$$

- Here $\boldsymbol{\overrightarrow{dB}}$ is perpendicular to both $\boldsymbol{I\,\overrightarrow{dl}}$ and $\boldsymbol{\hat{r}}$
- From superposition principole the total magnetic field due to entire conductor is,

$$\boldsymbol{\vec{B} = \int \overrightarrow{dB} = \frac{\mu_o\,I}{4\,\pi}\int \frac{\overrightarrow{dl}\ X\ \hat{r}}{r^2}}$$

6. Give the difference between Coulomb's law and Biot-Savart's law.

Coulomb's law	Biot-Savart's law
1) Electric field is calculated	1) Magnetic field is calculated
2) Produced by a scalar source (i.e) charge 'q'	2) Produced be vector source (i.e.) current element '$I\,\overrightarrow{dl}$'
3) It is directed along the position vector joining the source and the point at which the field is calculated.	3) It is directed perpendicular to the position vector and the current element
4) Does not depends on angle	4) Depends on the angle between $I\,\overrightarrow{dl}$ and $\hat{r}$

7. Explain the current loop acts as a magnetic dipole and calculate its dipole moment.

<u>Current loop as a magnetic dipole</u> :

- The magnetic field from the centre of a currnt loop of radius 'R' along the axis

$$\vec{B} = \frac{\mu_o\,I\,R^2}{2\,(R^2 + z^2)^{\frac{3}{2}}}\,\hat{k}$$

- At larger distance, $z \gg R$ and hence $R^2 + z^2 \approx z^2$

$$\vec{B} = \frac{\mu_o\,I\,R^2}{2\,z^3}\,\hat{k} = \frac{\mu_o\,I\,\pi\,R^2}{2\,\pi\,z^3}\,\hat{k}$$

  Here, $\pi R^2 \rightarrow$ area of the loop

$$\vec{B} = \frac{\mu_o\,I\,A}{2\,\pi\,z^3}\,\hat{k} = \frac{\mu_o}{4\,\pi}\,\frac{2\,I\,A}{z^3}\,\hat{k} \qquad ----(1)$$

- We know that, magnetic field at a distance 'z' along the axial line is

$$\vec{B} = \frac{\mu_o}{4\,\pi}\,\frac{2\,\vec{p}_m}{z^3} \qquad ------(2)$$

- Compare equation (1) and (2)

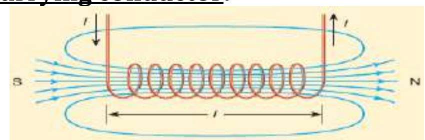
$$\boldsymbol{\vec{p}_m = I\,\vec{A}}$$

$$(or) \qquad \boldsymbol{p_m = I\,A}$$

- This implies that a current carrying circular loop behaves as a magnetic dipole of dipole moment $\boldsymbol{p_m}$
- So the ***magnetic dipole moment of any current loop is equal to the product of the current and area of the loop***.

8. Explain current carrying solenoid behaves like a bar magnet.

<u>Current carrying conductor</u>:



- A solenoid is a long coil of wire closely wound in the form of helix.
- When current flows through the solenoid, magnetic field is produced.
- It is due to the superposition of magnetic fields of each turn of the solenoid.

- Inside the solenoid, the magnetic field is nearly uniform and parallel to its axis. But outside the solenoid, the field is negligibly small.
- Depending on the direction of current, one end of the solenoid behaves like North pole and the other end behaves like South pole.
- The direction of magnetic field is given by ***right hand palm rule.*** (i.e.) if the current carrying solenoid is held in right hand such that the fingers curl in the direction of current, then extended thumb gives the direction of magnetic field.
- Hence magnetic field of a solenoid looks like the magnetic field of a bar magnet.

<u>Uses</u> :

- Solenoid can be used as electromagnets which produces strong magnetic field that can be turned ON or OFF.
- The strength of the magnetic field can be increased by keeping iron bar inside the solenoid.
- They are useful in designing variety of electrical appliences.

9. Write a note in MRI.

<u>MRI</u> :

- MRI is *Magnetic Resonance Imaging* which helps the physicians to diagonise or monitor treatment for a variety of abnormal conditions happening within the head, chest, abdomen and pelvis.
- It is a non invasive medical test.
- The patient is placed in a circular opening and large current is sent through the superconduction wire to produce a strong magnetic field.
- This magnetic field produces radio frequency pulses which are fed to a computer which produce pictures of organs which helps the physicians to examine various parts of the body

10. Define Lorentz force. Give the properties of Lorentz magnetic force.

<u>Lorentz force</u> :

- When an electric charge $'q'$ moves in the magnetic field $\vec{B}$, it experience a force called Lorentz magnetic force.

$$\boldsymbol{F_m = B\, q\, v \sin\theta}$$

- In vector notation,

$$\boldsymbol{\vec{F}_m = q\,(\vec{v}\; X\; \vec{B})}$$

<u>**Properties of Lorentz magnetic force**</u> :

(i) $\vec{F}_m$ is directly proportional to the magnetic field $(\vec{B})$

(ii) $\vec{F}_m$ is directtly proportional to the velocity $(\vec{v})$

(iii) $\vec{F}_m$ is directly proportional to sine of the angle between the velocity and magnetic field.

(iv) $\vec{F}_m$ is directly proportional to the magnitude of the charge

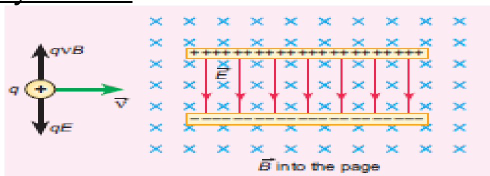
(v) The direction of $\vec{F}_m$ is always perpendicular to $\vec{v}$ and $\vec{B}$

(vi) The direction of $\vec{F}_m$ on negative chanrge is opposite to the direction of $\vec{F}_m$ on positive charge

(vii) If the of the charge is along the manetic field, then $\vec{F}_m$ is zero.

11. Write a note on velocity selector.

<u>**Velocity selector**</u>:



- Let an electric charge 'q' of mass 'm' enters in to a region of uniform magnetic field $\vec{B}$ with velocity $\vec{v}$
- Dut to Lorentz force, the charged particle moves in helical path.
- By applying proper electric field $\vec{E}$, the Lorentz force can be balanced by Coulomb force
- Here Coulomb force acts along the direction of electric field, whereas the Lorentz force is perpendicular to the direction of magnetic field.
- Therefore in order *to balance these forces, both electric and magnetic fields must be perpendicular to each other*.
- Such an arrangement of perpendicular electric and magnetic fields are known as ***cross fields***.
- The force on electric charge due to these fields is,

$$\vec{F} = q\,[\vec{E} + (\vec{v}\; X\; \vec{B})]$$

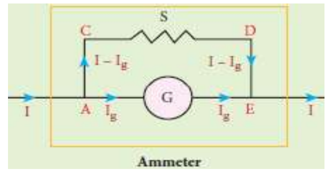
- For a positive charge, the electric force on the charge acts in downward direction whereas the Lorentz force acts upwards.
  When these two forces balance one another, the net force $\vec{F} = 0$. Hence $q\,E = B\,q\,v_o$

$$\therefore \quad \boldsymbol{v_o = \frac{E}{B}}$$

- This means for a given magnitude of electric field $\vec{E}$ and magnetic field $\vec{B}$, the forces act only for the particle moving with particular speed $\boldsymbol{v_o}$.
- This speed is independent of mass and charge,
  (i) If $> v_o$, then charged particle deflects in the direction of Lorentz force.
  (ii) If $v < v_o$, then charged particle deflects in the direction of Coulomb force.
  (iii) If , then no deflection and the charged particle moves in straight line.
- Thus by proper choice of electric and magnetic fields, the particle with particular speed can be selected. Such an arrangement of fields is called a ***velocity selector***.
- This principle is used in Bainbridge mass spectrograph to separate the isotopes.

12. How Galvanometer can be converted in to Ammeter.

<u>**Galvanometer to an Ammeter**</u> :



- Ammeter is an instrument used to measure current.
- A galvanometer is converted into an ammeter by connecting a low resistance called shunt in parallel with the galvanometer.
- The scale is calibrated in amperes.
- Galvanometer resistance $= R_G$
  Shunt resistance $= S$
  Current flows through galvanometer $= I_G$
  Current flows through shunt resistance $= I_S$
  Current to be measured $= I$
  The potential difference across galvanometer is same as the potential difference shunt resistance.
  (i.e.) $V_{Galvanometer} = V_{shunt}$

$$I_G\; R_G = I_S\; S$$

$$I_G\; R_G = (I - I_G)\, S \quad ----(1)$$

$$\boldsymbol{S = \frac{I_G}{I - I_G}\, R_G}$$

- From equation (1),

$$I_G\; R_G = S\, I - \; I_G\, S$$

$$I_G\; (S + R_G) = S\, I$$

$$\boldsymbol{I_G = \frac{S}{S + R_G}\, I}$$

- Let R_a be the resistance of ammeter, then

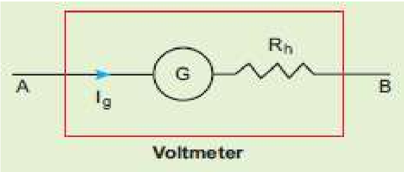
$$\frac{1}{R_a} = \frac{1}{R_G} + \frac{1}{S}$$

$$\Rightarrow \quad \boldsymbol{R_a = \frac{R_G\, S}{R_G + S}}$$

- Here, $R_G > S > R_a$
- Thus an ammeter is a low resistance instrument, and it always connected in series to the circuit.
- An ***ideal ammeter has zero resistance***.

13. How Galvanometer can be converted in to voltmeter?

<u>Galvanometer to a voltmeter</u> :



- A voltmeter is an instrument used to measure potential difference across any two points.
- A galvanometer is converted in to voltmeter by connecting high resistance in series with the galvanometer.
- The scale is calibrated in volts.
- Galvanometer resistance $= R_G$
  High resistanc $= R_h$
  Current flows through galvanometer $= I_G$
  Voltage to be measured $= V$
  Total resistance of this circuit $= R_G + R_h$
- Here the current in the electrical circuit is same as the current passing through the galvanometer. (i.e.)

$$I_G = I$$

$$\boldsymbol{I_G = \frac{V}{R_G + R_h}}$$

$$(or) \qquad R_G + R_h = \frac{V}{I_G}$$

$$\therefore \qquad \boldsymbol{R_h = \frac{V}{I_G} - R_G}$$

- Let R_v be the resistance of voltmeter, then

$$\boldsymbol{R_v = R_G + R_h}$$

- Here, $R_G < R_h < R_v$
- Thus an voltmeter is a highresistance instrument, and it always connected in parallel to the circuit element.
- An ***ideal ammeter has zero resistance***.

14. Differentiate Scalar, Vector and Tensor.

<u>Scalar</u> :
- It has only one component.
- It has no direction (i.e) no unit vector
- Since it has no direction, its rank is zero.

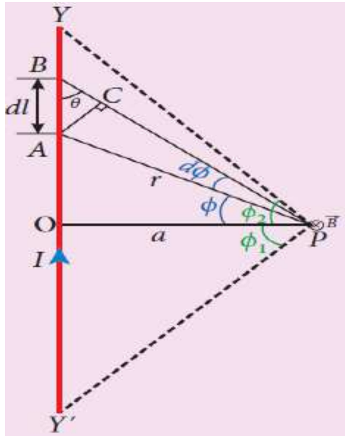
<u>Vector</u> :
- It hals resolved in to components.
- It has only one direction. (i.e.) has one unit vector
- Since each component have one direction, its rank is one

<u>Tensor</u> :
- It has resolved into components.
- It has more than one direction (i.e) has more than one unit vector
- If each component associated with two direction, then its rank is two and if each component associated with three direction, then its rank is three.
- In general, if each component associated with 'n' direction, then it is called tensor of rank 'n'

PART - IV 5 MARK OUESTIONS AND ANSWERS

1. Deduce the relation for magnetic induction at a point due to an infinitely long straight conductor carrying current.

<u>Magnetic field due to long straight current carrying conductor</u> :



- Consider a long straight wire YY' carrying a current I
- Let P be a point at a distance 'a' from 'O'
- Consider an element of length 'dl' of the wire at a distance 'l' from point 'O'
- Let $\vec{r}$ be the vector joining the element 'dl' with the point 'P' and 'θ' be the angle between $\vec{r}$ and $\vec{dl}$
- Then the magnetic field at 'P' due to the element is,

$$\boldsymbol{\vec{dB} = \frac{\mu_o}{4\,\pi}\, \frac{I\, dl \sin\theta}{r^2}\, \hat{n}} \qquad ----(1)$$

- where, $\hat{\boldsymbol{n}} \rightarrow$ points into the page
- In ΔABC, $\sin\theta = \frac{AC}{AB} = \frac{AC}{dl}$

$$AC = dl \sin\theta \qquad -------(2)$$

- In ΔACP

$$AC = r\, d\varphi \qquad --------(3)$$

- From equation (2) and (3)

$$dl \sin\theta = r\, d\varphi \qquad -------(4)$$

- Put this in eqation (1)

$$\vec{dB} = \frac{\mu_0}{4\,\pi}\frac{I\, r\, d\varphi}{r^2}\hat{n} = \frac{\mu_0}{4\,\pi}\frac{I\ d\varphi}{r}\hat{n} \qquad --- (5)$$

- In ΔOAP

$$\cos\varphi = \frac{a}{r} \quad (or) \quad r = \frac{a}{\cos\varphi} \qquad ---(6)$$

- Put this in equation (5)

$$\overrightarrow{dB} = \frac{\mu_0}{4\pi}\frac{I\ d\varphi}{\left(a/\cos\varphi\right)}\ \hat{n} = \frac{\mu_0\ I}{4\pi\ a}\cos\varphi\ \hat{n}$$

- The total magnetic field at 'P' due to conductor YY'

$$\vec{B} = \int_{-\varphi_1}^{\varphi_2} \overrightarrow{dB} = \int_{-\varphi_1}^{\varphi_2} \frac{\mu_0\ I}{4\pi\ a}\cos\varphi\ \hat{n}$$

$$\vec{B} = \frac{\mu_0\ I}{4\pi\ a}\left[\sin\varphi\right]_{-\varphi_1}^{\varphi_2}\ \hat{n}$$

$$\vec{B} = \frac{\mu_0\ I}{4\pi\ a}\left[\sin\varphi_1 + \sin\varphi_2\right]\ \hat{n} \quad ----(7)$$

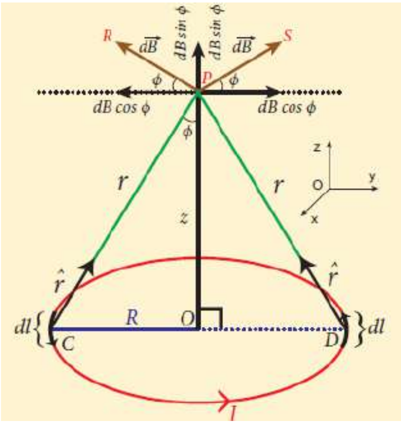
- For infinitely long conductor, $\varphi_1 = \varphi_2 = 90°$

$$\vec{B} = \frac{\mu_0\ I}{4\pi\ a}[\,2\,]\,\hat{n}$$

$$\boldsymbol{\vec{B} = \frac{\mu_0\ I}{2\pi\ a}\ \hat{n}}$$

2. Obtain a relation for the magnetic induction at a point along the axis of a circular coil carrying current.

<u>Magnetic field due to current carrying circular coil</u> :



- Consider a circular coil of radius 'R' carrying a current 'I' in anticlock wise direction.
- Let 'P' be the point on the axis at a distance 'z' from centre 'O'
- Consider two diametrically opposite line elements of the coil of each of length $\vec{dl}$ at C and D.
- Let $\vec{r}$ be the vector joining the current element $(I\ \vec{dl})$ at C to the point 'P'
- From Pythogorous theorem,

$$PC = PD = r = \sqrt{R^2 + z^2}$$

and $\angle COP = \angle DOP = \phi$

- According to Biot - Savart law, the magnetic field at 'P' due to the current elements C and D are,

$$\overrightarrow{dB} = \frac{\mu_o}{4\pi}\frac{I\ \vec{dl}\ X\ \vec{r}}{r^2}$$

- Their magnitudes are same and it is given by,

$$dB = \frac{\mu_o}{4\pi}\frac{I\ dl}{r^2} \qquad [\because \theta = 90°]$$

- Here, $\overrightarrow{dB}$ can be resolved in to two componenets.
  (i) $\overrightarrow{dB}\cos\phi$ – horizontal component (Y - axis)
  (ii) $\overrightarrow{dB}\sin\phi$ – vertical component (Z - axis)
- Here horizontal components of each element cancel each other.
- But vertical components alone contribute to total magnetic field at the point 'P'

$$\bar{B} = \int \overrightarrow{dB} = \int dB\sin\phi\ \hat{k}$$

$$\bar{B} = \frac{\mu_o\ I}{4\pi}\int \frac{dl}{r^2}\sin\phi\ \hat{k} \quad ----- \quad (1)$$

- Also from ΔCOP,

$$\sin\phi = \frac{R}{r} = \frac{R}{(R^2 + z^2)^{\frac{1}{2}}}$$

- But from equation (1)

$$\vec{B} = \frac{\mu_o\ I}{4\pi}\int \frac{dl}{(R^2 + z^2)}\frac{R}{(R^2 + z^2)^{\frac{1}{2}}}\ \hat{k}$$

$$\vec{B} = \frac{\mu_o\ I\ R}{4\pi\ (R^2 + z^2)^{\frac{3}{2}}}\int dl\ \hat{k}$$

- where, $\int dl = 2\pi R \rightarrow$ total length of the coil.

$$\vec{B} = \frac{\mu_o\ I\ R}{4\pi\ (R^2 + z^2)^{\frac{3}{2}}}[2\pi R]\ \hat{k}$$

$$\boldsymbol{\vec{B} = \frac{\mu_o\ I\ R^2}{2\ (R^2 + z^2)^{\frac{3}{2}}}\ \hat{k}}$$

- If the circular coil contains 'N' turns, then

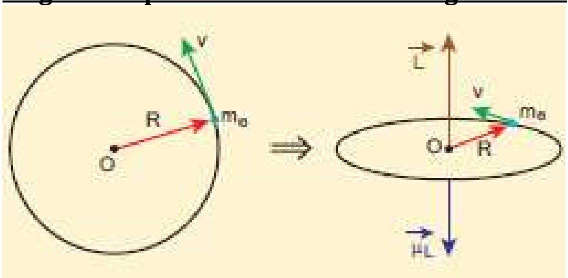
$$\boldsymbol{\vec{B} = \frac{\mu_o\ N\ I\ R^2}{2\ (R^2 + z^2)^{\frac{3}{2}}}\ \hat{k}}$$

- The magnetic field at the centre of the coil is,

$$\boldsymbol{\vec{B} = \frac{\mu_0\ N\ I}{2\ R}\ \hat{k}} \qquad \boldsymbol{(z = 0)}$$

3. Compute the magnetic dipole moment of revolving electron. And hence define bohr magneton.

<u>Magnetic dipole moment of revolving electron</u> :



- Let an electron moves in circular motion around the nucleus. The circulating electron in a loop is like current in a circular loop.
- The magnetic dipole moment due to current carrying circular loop is, $\boldsymbol{\vec{\mu}_L = I\,\vec{A}}$
- In magnitude, $\boldsymbol{\mu_L = I\ A} \quad ------ \quad \mathbf{(1)}$
- If T is thetime period of an electron, the current due to revolving electron is, $I = -\frac{e}{T}$
  where '- e' → charge of an electron.
- If 'R' be the radius and 'v' be the velocity of electron in the circular orbit, then

$$T = \frac{2\pi}{\omega} = \frac{2\pi R}{v}$$

- Then equation (1) becomes,

$$\boldsymbol{\mu_L} = -\frac{e}{T}A = -\frac{e}{\left[\frac{2\pi R}{v}\right]}\pi R^2$$

where, $A = \pi R^2 \rightarrow$ area of the circular orbit

$$\therefore \quad \boldsymbol{\mu_L = -\frac{e\ v\ R}{2}} \quad ---- \quad (2)$$

- By definition, angular momentum of the electron about 'O' is $\vec{L} = \vec{R}\ X\ \vec{p}$
- In magnitude, angular momentum is given by,

$$L = R\ p = m\ v\ R \quad ---- \quad (3)$$

- Dividing equation (2) by (3),

$$\frac{\mu_L}{L} = -\frac{e\ v\ R}{2\ m\ v\ R} = -\frac{e}{2\ m}$$

- In vector notation,

$$\boldsymbol{\vec{\mu}_L = -\frac{e}{2\ m}\vec{L}} \quad ---- \quad (4)$$

- Here negative sign indicates that the magnetic dipole moment and angular momentum are in opposite direction. In magnitude,

$$\frac{\mu_L}{L} = \frac{e}{2\ m} = 8.78\ X\ 10^{10}\ C\ kg^{-1} = constant$$

- This constant is called ***gyro-magnetic ratio***.
- According to Bohr quantization rule, angular momentum of an electron is,

$$L = n\,\hbar = n\frac{h}{2\pi}$$

- where, $h \rightarrow$ Plank's constant $(h = 6.63\ X\ 10^{-34}\ J\ s)$
  $n \rightarrow$ Positive integer $(n = 1, 2, 3, \ldots\ldots)$

$$\therefore \quad \mu_L = \frac{e}{2\ m}L = \frac{e}{2\ m}n\frac{h}{2\pi}$$

$$\boldsymbol{\mu_L = n\frac{e\ h}{4\pi\ m}} \quad ---- \quad \mathbf{(5)}$$

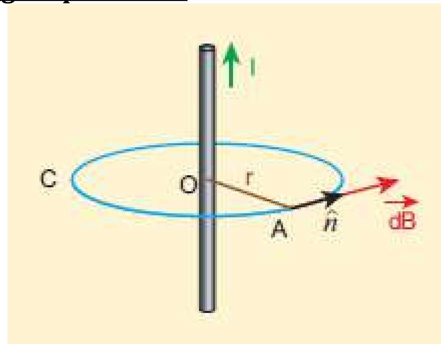
- The minimum magnetic moment can be obtained by substituting $n = 1$

$$(\mu_L)_{min} = \mu_B = \frac{e\,h}{4\,\pi\,m} = 9.27\ X\ 10^{-24}\ A\ m^2$$

- The minimum value of magnetic moment of revolving electron is called ***Bohr magneton*** (μ_B)

4. Using Ampere's law, obtain an expression for magnetic field due to the current carrying wire of infinite length.

<u>**Magnetic field due to current carrying straight wire using Ampere's law**</u> :



- Consider a straight conductor of infinite length carrying current 'I'
- Imagine an Amperian circular loop at a distance 'r' from the centre of the conductor.
- From Ampere's circuital law,

$$\oint \vec{B}\,.\vec{dl} = \mu_o\,I$$

- Here $\vec{dl}$ is the line element along the tangent to the Amperian loop. So the angle between $\vec{B}$ and $\vec{dl}$ is zero $(\theta = 0°)$. Thus,

$$\oint B\,dl = \mu_o\,I$$

- Due to symmetry, the magnitude of the magnetic field is uniform over the Amperian loop and hence,

$$B \oint dl = \mu_o\,I$$

- For circular loop, $\oint dl = 2\,\pi\,r$

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

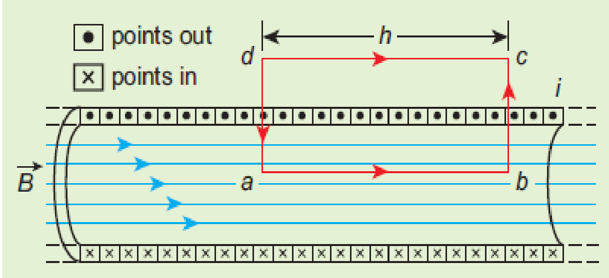
$$\boldsymbol{B} = \frac{\boldsymbol{\mu_o\,I}}{\boldsymbol{2\,\pi\,r}}$$

- In vector notation,

$$\vec{\boldsymbol{B}} = \frac{\boldsymbol{\mu_o\,I}}{\boldsymbol{2\,\pi\,r}}\,\hat{n}$$

5. Obtain an expression for magnetic field due to long current carrying solenoid.

<u>**Mangnetic field due to current carrying solenoid**</u> :



Magnetic field of a solenoid

- Consider a solenoid of length 'L' having 'N' turns.
- To calculate the magnetic field at any point inside the solenoid, consider an Amperian loop 'abcd'
- From Ampere circuital law,

$$\oint \vec{B}\,.\vec{dl} = \mu_o\,I_o \qquad ------ (1)$$

- The LHS of equation (1) can be written as

$$\oint \vec{B}\,.\vec{dl} = \int_a^b \vec{B}\,.\vec{dl} + \int_b^c \vec{B}\,.\vec{dl} + \int_c^d \vec{B}\,.\vec{dl} + \int_d^a \vec{B}\,.\vec{dl}$$

- Here,

$$\int_a^b \vec{B}.\vec{dl} = \int_a^b B\,dl\cos 0° = B\int_a^b dl = B\,\boldsymbol{h}$$

$$\int_b^c \vec{B}.\vec{dl} = \int_b^c B\,dl\cos 90° = 0$$

$$\int_c^d \vec{B}.\vec{dl} = 0 \qquad [\because\ B = 0]$$

$$\int_d^a \vec{B}.\vec{dl} = \int_b^c B\,dl\cos 90° = 0$$

- Here ab = h . If we take large loop such that it is equal to length of the solenoid, we have

$$\oint \vec{B}.\vec{dl} = B\,\boldsymbol{L} \qquad -------- (2)$$

- Let 'I' be the current passing through the solenoid of 'N' turns, then

$$I_0 = N\,I \qquad --------- (3)$$

- Put equation (2) and (3) in (1)

$$B\,L = \mu_0\,N\,I$$

$$B = \mu_0\,\frac{N}{L}\,I \qquad ---- (4)$$

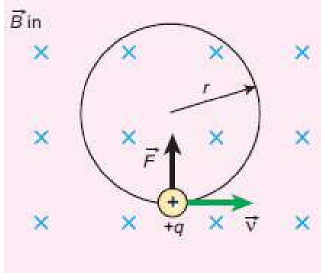
- Let 'n' be the number of turns per unit length, then $\frac{\mathbf{N}}{\boldsymbol{L}} = \boldsymbol{n}$. Hence,

$$\mathbf{B} = \frac{\boldsymbol{\mu_0}\ \mathbf{N\,I}}{\boldsymbol{L}} = \boldsymbol{\mu_0}\,\mathbf{n\,I} \qquad ---- (5)$$

- Since 'n' and μ_0 are constants, for fixed current 'I' the magnetic field 'B' inside the solenoid is also constant.

6. Obtain the expression for force on a moving charge in a magnetic field.

<u>**Force on moving charge in a magnetic field**</u> :



- Consider a charged particle of charge 'q' having mass 'm' enters perpendicular to uniform magnetic field 'B' with velocity $\vec{v}$
- So this charged particle experience Lorentz force which acts perpendicular to both $\vec{B}$ and $\vec{v}$ and it is

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

- Since Lorentz force alone acts on the particle, the magnitude of this force is

$$F = B\,q\,v \qquad [\theta = 90°]$$

- Hence charged particle moves in a circular orbit and the necessary centripetal force is provided by Lorentz force. (i.e.)

$$B\,q\,v = \frac{m\,v^2}{r}$$

- The radius of the circular path is,

$$r = \frac{m\,v}{B\,q} = \frac{p}{B\,q} \qquad ---- (1)$$

where, $m\,v = p \rightarrow$ linear momentum

- Let 'T' be the time period, then

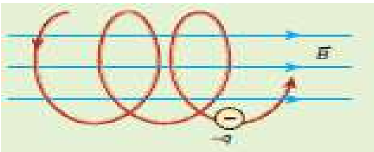
$$T = \frac{2\,\pi\,r}{v} = \frac{2\,\pi\,m\,v}{v\,B\,q}$$

$$\boldsymbol{T} = \frac{\boldsymbol{2\,\pi\,m}}{\boldsymbol{B\,q}} \qquad ---- (2)$$

It is called ***cyclotron time period.***

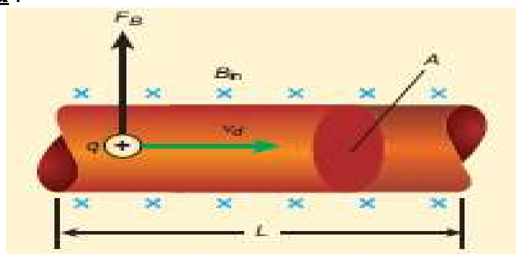
- Let 'f' be the frequency, then
$$f = \frac{1}{T} = \frac{B\,q}{2\,\pi\,m} \qquad ----\ (3)$$
- In terms of angular frequency,
$$\omega = 2\,\pi\,f = \frac{B\,q}{m} \qquad -----\ (4)$$
It is called ***cyclotron frequency*** or ***gyro-frequency***.
- From equantion (2), (3) and (4), we infer that time period (T), frequency (f) and angular frequency (ω) depends only on specific charge, but not velocity or the radius of the circular path.

<u>**Special cases**</u> :
- If a charged particle moves in uniform magnetic field, such that its velocity is not perpendicular to the magnetic field, then its velocity is resolved into two components.
- One component is parallel to the fjeld and the other component is perpendicular to the field.
- Here parallel component remains unchanged and the perpendicular component keeps on changing due to Lorentz force.
- Hence the path of the paricle is not circle, it is helix around the field.



7. Obtain an expression for the force on a current carrying conductor placed in a magnetic field.

<u>**Force on current carrying conductor in magnetic field**</u> :



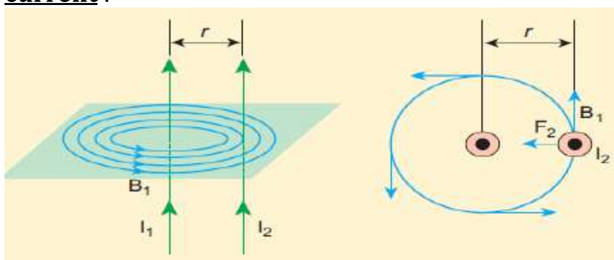
- When a current carrying conductor is placed in a magnetic field, the force experienced by the wire is equal to the sum of Lorentz forces on the individual chage carriers in the wire.
- Let a current 'I' flows through a conductor of lengh 'L' and area of cross-section 'A'
- Consider a small segment of wire of length 'dl'
- The free electorns drift opposite to the direction of current with drift velocity v_d
- The relation between current and drift velocity is,
$$I = n\,A\,e\,v_d \qquad ------\ (1)$$
- If the wire is kept in a magnetic field, then average force experienced by the electron in the wire is
$$\vec{F} = -\,e\,\left(\vec{v}_d\, X\, \vec{B}\right)$$
- Let 'n' be the number of free electrons per unit volume, then the total number of electrons in the small element of volume ($V = A\,dl$) is $N = n\,A\,dl$
- Hence Lorentz force on the small element,
$$\overrightarrow{dF} = -e\,n\,A\,dl\,\left(\vec{v}_d\, X\, \vec{B}\right) \qquad ---\ (1)$$
- Here length dl is along the length of the wire and hence the current element is
$$\mathrm{I}\,\overrightarrow{dl} = -\,n\,A\,e\,\,dl\,\vec{v}_d$$
- Put this in equation (1),
$$\overrightarrow{dF} = I\,\overrightarrow{dl}\,X\,\vec{B} \qquad ---\ (2)$$
- Therefore, the force in a straight current carrying conductor of length '$\boldsymbol{l}$' placed in a uniform magnetic field
$$\vec{\boldsymbol{F}} = \mathbf{I}\,\vec{\boldsymbol{l}}\,\boldsymbol{X}\,\vec{\boldsymbol{B}} \qquad ---\ (3)$$
- In magnitude,
$$\boldsymbol{F} = \boldsymbol{B}\,\mathbf{I}\,\boldsymbol{l}\,\sin\boldsymbol{\theta} \qquad ---\ (4)$$

<u>**Special cases**</u> :

(i) If the current carrying conductor placed along the direction of magnetic field, then $\theta = 0°$
$$\therefore \quad \boldsymbol{F} = \mathbf{0}$$
(ii) If the current carrying conductor is placed perpendicular to the magnetic field, then $\theta = 90°$
$$\therefore \quad \boldsymbol{F} = \boldsymbol{B}\,\mathbf{I}\,\boldsymbol{l} = \boldsymbol{maximum}$$

8. Obtain a force between two long parallel current carrying conductors. Hence define ampere.

<u>**Force between two parallel conductors carrying current**</u> :



- Consider two straight parallel current carrying conductors 'A' and 'B' separated by a distance 'r' kept in air.
- Let I_1 and I_2 be the currents passing through the A and B in same direction (z-direction)
- The net magnetic field due to I_1 at a distance 'r'
$$\vec{B}_1 = \frac{\mu_o\,I_1}{2\,\pi\,r}\,(-\,\hat{\imath}) = -\,\frac{\mu_o\,I_1}{2\,\pi\,r}\,\hat{\imath}$$
- Here $\vec{B}_1$ acts perpendicular to plane of paper and inwards.
- Then Lorentz force acts on the length element dl in conductor 'B' carrying current I_2 due to this magnetic field $\vec{B}_1$
$$\overrightarrow{dF} = I_2\overrightarrow{dl}\,X\,\vec{B}_1 = -\,I_2\,dl\,\hat{k}\,X\,\frac{\mu_o\,I_1}{2\,\pi\,r}\,\hat{\imath}$$
$$\overrightarrow{dF} = -\,\frac{\mu_o\,I_1\,I_2\,dl}{2\,\pi\,r}\,(\hat{k}\,X\,\hat{\imath})$$
$$\overrightarrow{dF} = -\,\frac{\mu_o\,I_1\,I_2\,dl}{2\,\pi\,r}\,\hat{\jmath}$$
- By Flemming's left hand rule, this force acts left wards. The force per unit length of the conductor B
$$\frac{\vec{\boldsymbol{F}}}{\boldsymbol{l}} = -\,\frac{\boldsymbol{\mu_o\,I_1\,I_2}}{\boldsymbol{2\,\pi\,r}}\,\hat{\boldsymbol{\jmath}} \qquad ------\ (\mathbf{1})$$
- Similarly, net magnetic field due to I_2 at a distance 'r' is
$$\vec{B}_2 = \frac{\mu_o\,I_2}{2\,\pi\,r}\,\hat{\imath}$$
- Here $\vec{B}_2$ acts perpendicular to plane of paper and outwards.
- Then Lorentz force acts on the length element dl in conductor 'A' carrying current I_1 due to this magnetic field $\vec{B}_2$
$$\overrightarrow{dF} = I_1\overrightarrow{dl}\,X\,\vec{B}_2 = I_1\,dl\,\hat{k}\,X\,\frac{\mu_o\,I_2}{2\,\pi\,r}\,\hat{\imath}$$
$$\overrightarrow{dF} = \frac{\mu_o\,I_1\,I_2\,dl}{2\,\pi\,r}\,(\hat{k}\,X\,\hat{\imath})$$
$$\overrightarrow{dF} = \frac{\mu_o\,I_1\,I_2\,dl}{2\,\pi\,r}\,\hat{\jmath}$$
- By Flemming's left hand rule, this force acts right wards. The force per unit length of the conductor A
$$\frac{\vec{\boldsymbol{F}}}{\boldsymbol{l}} = \frac{\boldsymbol{\mu_o\,I_1\,I_2}}{\boldsymbol{2\,\pi\,r}}\,\hat{\boldsymbol{\jmath}} \qquad -----\ (2)$$
- Thus the force experienced by two parallel current carrying conductors is attractive if they carry current in same direction.

- On the other hand, the force experienced by two parallel current carrying conductors is repulsive if they carry current in opposite direction.

Definition of ampere :

- One ampere is defined as that current when it is passed through each of two infinitely long parallel conductors kept a a distance of one metre apart in vacuum causes each conductor experience a force of $2 X 10^{-7}$ newton per meter length of conductor.

9. **Describe the principle, construction and working of moving coil galvanometer.**

Moving coil galvanometer :

- It is a device which is used to indicate the flow of current.

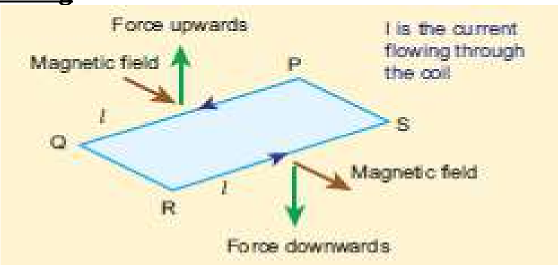
Principle :

- When a current carrying loop is placed in a uniform magnetic field it experiences a torque.

Construction :

- It consists of a rectangular coil PQRS of insulated thin copper wire.
- A cylindrical soft-iron core is placed symmentrically inside the coil.
- This rectangular coil is suspended freely between two pole pieces of a horse-shoe magnet by means of phosphor - bronze wire.
- Lower end of the coil is connected to a hair spring which is also made up of phosphor bronze.
- A small plane mirror is attached on the suspension wire to measure the deflection of the coil with help of lamp and scale arrangement.
- In order to pass electric current through the galvanometer, the suspension strip W and the spring S are connectee to terminals.

Working :



- Consider a single turn of rectangular coil PQRS of length l and breadth b, such that

$$PQ = RS = l \quad ; \quad QR = SP = b$$

- Let 'I' be the electric current flowing through the rectangular coil
- The horse-shoe type magnet has hemi-spherical magnetic poles which produces a ***radial magnetic field***.
- Due to this radial field, the sides QR and SP are always parallel to the magnetic field 'B' and experience no force.
- But the sides PQ and RS are always perpendicular to the magnetic field 'B' and experience force and due to ths ***torque is produced***.
- For single turn, the deflecting couple is,

$$\tau_{def} = F\,b = B\,I\,l\,b = B\,I\,A$$

- For coil with N turns, we get

$$\boldsymbol{\tau_{def} = N\,B\,I\,A} \qquad ---- \ (1)$$

- Due to this deflecting torque, the coil get twisted and restoring torque is developed.
- The magnitude of restoring torque is proportional to amount of twist and it is given by

$$\boldsymbol{\tau_{res} = K\,\theta} \qquad ---- \ (2)$$

where $K \rightarrow$ restoring couple per unit twist (or) torsional constant

- At equilibrium, $\boldsymbol{\tau_{def}} = \boldsymbol{\tau_{res}}$

$$N\,B\,I\,A = K\,\theta$$

$$\boldsymbol{I = \frac{K}{N\,B\,A}\,\theta = G\,\theta} \qquad --- \ (\mathbf{3})$$

where, $G = \frac{K}{N\,B\,A}$ $\rightarrow$ galvanometer constant (or) current reduction factor

PDF Creator :

Mr.R.Saravanan

webStrake Recognized Teacher