CHAPTER 14
ELECTROMAGNETISM

MULTIPLE CHOICE

1. The unit of magnetic flux is

A. weber B. Henry C. coulomb D. tesla

2. The relation between current I and angle of deflection θ in a moving coil galvanometer is

A. $I \propto \frac{1}{\theta}$ B. $I \propto \cos\theta$

C. $I \propto \theta$ D. $I \propto \sin\theta$

3. The field around a moving charge is called:

A. Gravitational field B. Electric field

C. Magnetic field D. None of the above

4. The magnetic force experienced by a charge particle moving in a magnetic field will be maximum if it moves:

A. Parallel to field B. Anti-parallel to field

C. Perpendicular to field D. At an angle of 60°

5. The SI unit of magnetic induction is tesla which is equal to:

A. $\frac{N}{A \cdot M}$ B. $N/A\text{-}m^2$ C. $N/A^2\text{-}m$ D. None

6. A current carrying coil having N turns with area A at an angle 'a' to magnetic induction "B". Then torque in the coil is given by:

A. NIAB cos α B. NIAB sin α C. NIAB D. None

7. A current carrying conductor is surrounded by

A. magnetic field B. electric field

C. gravitational field D. conservative field

8. In order to increase the range of an ammeter the shunt resistance is

A. decreased

B. increased

C. kept constant

D. sometimes increased and sometimes decreased

9. An ammeter is a galvanometer with

A. high resistance B. low resistance

C. zero resistance D. none of these

10. The unit of magnetic flux density is

A. farad B. tesla

C. newton D. none of these

11. The value of shunt resistance R_s to convert galvanometer into ammeter is

A. $R_s =$ [illegible] B. [illegible]

C $R_s = \frac{I_g R_g}{I}$ D $R_s = [illegible]$

12. **To convert a galvanometer into voltmeter, a high resistance Rh can be calculated by relation,**

A $R_h = R_g - \frac{V}{I_g}$ B $R_h = \frac{V}{I - I_g}$

C. $R_h = \frac{V}{I_g} - R_g$ D $R_h = [illegible]$

13. **A charged particle moving in a magnetic field experiences a magnetic force given by,**

A $F_m = q\, v \times B$ B $F_m = q\, v \cdot B$

C $F_m = \frac{v \times B}{q}$ D $F_m = \frac{v \cdot B}{q}$

14. **A moving proton develops in the surrounding space**

A Electric field B magnetic field

C electromotive force D. none of these

15. **The force on a moving charge particle in a magnetic field is**

A. $F_m = q\, B \times v$ B $F_m = q\,(v + B)$

C $F_m = Q\,(v \times B)$ D. $F_m = B\,I\,L$

16. **An electron enters a region where the electric field 'E' is perpendicular to magnetic field 'B' it will suffer no deflection if:**

A E = BeV B B = eE/V C VB = E D. Ve/E

17. **A device which is used for the detection of current is:**

A Galvanometer . B Ohm meter

C. Voltmeter D AVO meter

18. **The galvanometer can be made sensitive if the value of the factor C/BAN is:**

A. Large B Small C Very large D. None

19. **Which one of the following is not electromechanical instrument?**

A Galvanometer B Voltmeter

C Am meter D. Electric motor

20. **Ammeter can only be used in:**

A. Series B Parallel

C. Both arrangement D None

21. **Minimum current required to produce a deflection of one mm on a scale at a distance of 1 meter is:**

A 1 Ampere B 1 Coulomb

C Current sensitivity D None

22. **The magnetic field inside a current carrying long solenoid is**

A. non uniform B. weak C. uniform & steady D. zero

23. **If a current flows from top to bottom through a wire then the direction of lines of force would be**

A. Parallel to wire B. perpendicular to wire

C. clockwise D anticlockwise

24. **A galvanometer whose internal resistance is 50 Ω, and current 50 mA, is converted into ammeter of range 5 A. What is the resistance required:**

A. 0.50 Ω B. 5 Ω C. 1 Ω D. 10 Ω

25. The Lorenz force on a charged particle moving in an electric field E and magnetic field B is given by:

A. $F_E + F_B$ B. $F_E - F_B$ C. $F_E \times F_B$ D. F_E / F_B

26. The grid in CRO:

A. Controls brightness B. Voltage
C. Both A & B D. None

27. Two parallel wires carrying current in the same direction:

A. Repel each other B. Attract
C. No effect D. None

28. One tesla is equal to

A. $1\ N A^{-1} m$ B. $1\ N A^{-1}$
C. $1\ N m^{-1}$ D. $1\ N A^{1} m^{1}$

29. An instrument that gives a pointer deflection proportional to the current through itself is called a

A. Voltmeter B. Galvanometer
C. Wattmeter D. Potentiometer

30. A voltmeter is always connected in

A. Parallel B. Series
C. Perpendicular D. straight line

31. A useful device for the measurement of resistance is:

A. Barometer B. Ohmmeter
C. Galvanometer D. Voltmeter

32. In order to increase the range of ammeter, the shunt resistance is:

A. Increased B. Decreased C. Constant D. None

33. In order to increase the range of voltmeter, the high resistance connected to Galvanometer:

A. Increased B. Decreased
C. Constant D. None

34. The magnetic force is simply a

A. reflecting force B. deflecting force
C. restoring force D. gravitational force

Answers:

1. A	**2. C**	**3. C**	**4. C**	**5. A**	**6. A**	**7. A**
8. A	**9. B**	**10. B**	**11. B**	**12. C**	**13. A**	**14. B**
15. C	**16. C**	**17. A**	**18. B**	**19. D**	**20. A**	**21. C**
22. C	**23. C**	**24. A**	**25. A**	**26. A**	**27. B**	**28. D**
29. B	**30. A**	**31. B**	**32. B**	**33. A**	**34. B**	

SHORT & LONG QUESTIONS

Q1: How magnetic field due to current in a long straight wire is produce?

Ans: Magnetic field due to current in a long straight wire:

Example:

A. 0.50 Ω B. 5 Ω C. 1 Ω D. 10 Ω

25. The Lorenz force on a charged particle moving in an electric field E and magnetic field B is given by:

A. $F_E + F_B$ B. $F_E - F_B$ C. $F_E \times F_B$ D. F_E / F_B

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Answers:

1. A	2. C	3. C	4. C	5. A	6. A	7. A
8. A	9. B	10. B	11. B	12. C	13. A	14. B
15. C	16. C	17. A	18. B	19. D	20. A	21. C
22. C	23. C	24. A	25. A	26. A	27. B	28. D
29. B	30. A	31. B	32. B	33. A	34. B	

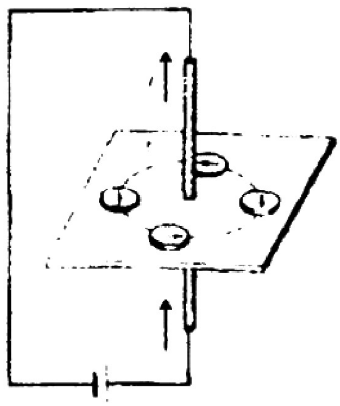
SHORT & LONG QUESTIONS

Q1: How magnetic field due to current in a long straight wire is produce?

Ans: Magnetic field due to current in a long straight wire:

Example:

Take a straight, thick copper wire and pass it vertically through a hole in a horizontal piece of cardboard Place small compass needles on the cardboard along a circle with the centre at the wire All the compass needles will point in the direction of N - S. Now pass a heavy current through the wire It will be seen that the needles will rotate and will set themselves tangential to the circle



On reversing the direction of current, the direction of needles is also reversed. As the current through the wire is stopped, all the needles again point along the N - S direction

Conclusions:

Following conclusions can be drawn from the above mentioned experiment:

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

(ii) The lines of force are circular and their direction depends upon the direction of current

(iii) The magnetic field lasts only as long as the current is flowing through the wire

Q2: Describe right hand rule to find the direction of lines of force?

Ans: Right hand rule:

The direction of the lines of force can be found by a rule which is known as right hand rule and stated as:

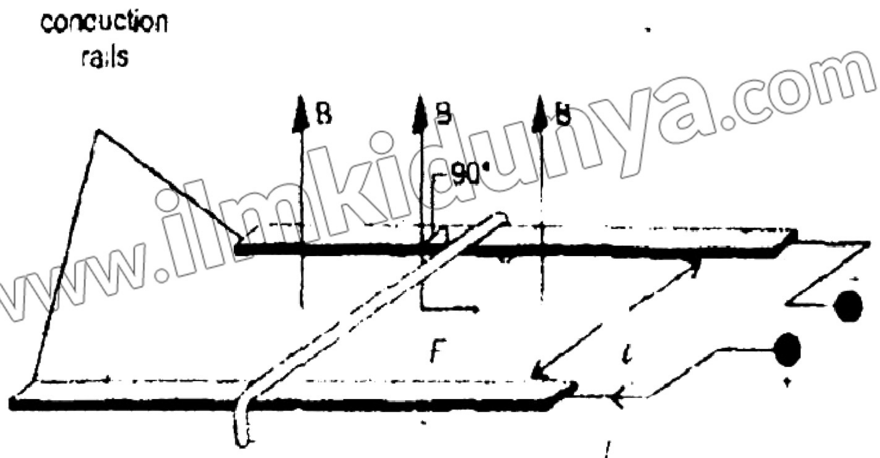
"If the wire is grasped in fist of right hand with the thumb pointing in the direction of the current the fingers of the hand will circle the wire in the direction of the magnetic field."

Q3: Derive a relation for force on a current carrying conductor in a uniform magnetic field?

Ans: Force on a current carrying conductor in a uniform magnetic field:

i. Consider a rod of copper, capable of moving on a pair of copper rails.

ii. The whole arrangement is placed in between the pole pieces of a horseshoe magnet so that the copper rod is subjected to a magnetic field directed vertically upwards.



iii. When a current is passed through the copper rod from a battery, the rod moves on the rails. The relative directions of the current, magnetic field and the motion of the conductor are shown in Fig.

iv. It can be seen that the force on a conductor is always at right angles to the plane which contains the rod and the direction of the magnetic field.

v. **The magnitude of the force depends upon the following factors:**

(i) The force F is directly proportional to $\sin\alpha$ where α is the angle between the conductor and the field. From this, it follows that the force is zero if the rod is placed parallel to the field and is maximum when the conductor is placed at right angles to the field.

$$F \propto \sin\alpha \ldots\ldots (1)$$

(ii) The force F is directly proportional to the current I flowing through the conductor. The more the current, greater is the force.

$$F \propto I \ldots\ldots (2)$$

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

$$F \propto L \ldots\ldots (3)$$

(iv) The force F is directly proportional to the strength of the applied magnetic field. The stronger the field, the greater is the force. If we represent the strength of the field by B, then

$$F \propto B \ldots\ldots (4)$$

Combining all these four factors,

$$F \propto ILB\sin\alpha$$

$$F = k\,I\,L\,B\sin\alpha.$$

Where k is constant of proportionality. If we follow SI units, the value of k is 1. Thus in SI units

$$F = ILB\sin\alpha \qquad (5)$$

Note:

i. Eq.5 provides a definition for the strength of magnetic field. If I = 1 A, L = 1 m and $\alpha = 90°$, then F = B.

ii. It can be seen that the force on a current carrying conductor is given both in magnitude and direction by the following equation:

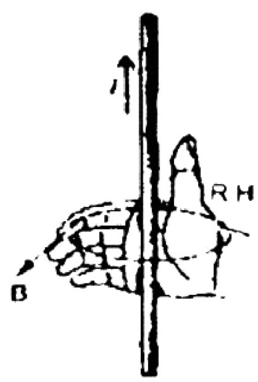
$$F = IL \times B$$

Where the vector L is in the direction of current flow. The magnitude of the vector $IL \times B$ is $ILB\sin\alpha$, where α the angle between the vectors L is and B. This gives the magnitude of the force.

Q4: Define magnetic induction and its unit?

Ans: Magnetic induction (B):

The strength of magnetic field which is also known as magnetic induction is defined as the force acting on one metre length of the conductor placed at right angle to the magnetic field when 1 A current is passing through it.



Unit of magnetic induction:

In SI units the unit of magnetic induction (B) is tesla.

Tesla:

A magnetic field is said to have strength of one tesla if it exerts a force of one Newton on one metre length of the conductor placed at right angles to the field when a current of one ampere passes through the conductor. Thus

$$1\,T = 1NA^{-1}m^{-1}$$

Q5: Describe the rules to determine the direction of magnetic force?

Ans: Direction of magnetic force:

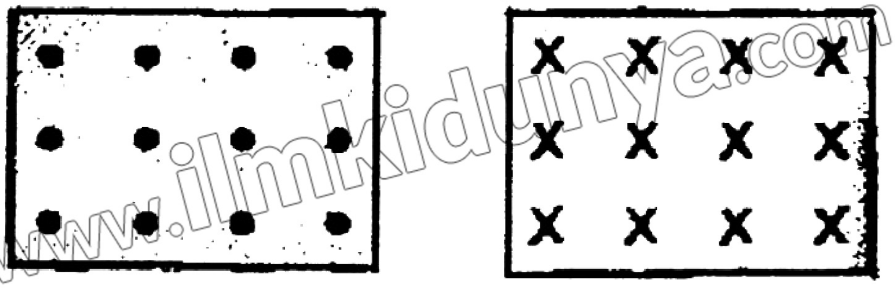
i. Right hand rule:

The direction of the force F is also correctly given by the right hand rule of the cross product of vectors of L and B i.e., rotates L to coincide with B through the smaller angle. Curl the fingers of right hand in the direction of rotation. The thumb points in the direction of force.

ii. By using dot (•) and cross (×):

In some situations the direction of the force is conveniently determined by applying the following rule:

Consider a straight current carrying conductor held at right angle to a magnetic field such that the current flows out of the plane of paper i.e., towards the reader as shown in Fig. It is customary to represent a current flowing towards the reader by a symbol dot (•) and a current flowing away from him by a cross (×).



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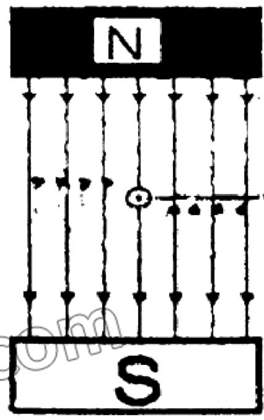
iii. Extension of right hand rule:

In order to find the direction of force, consider the lines of force.

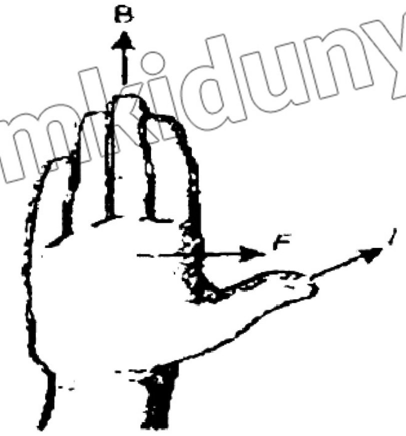


The two fields tend to reinforce each other on left hand side of the conductor and cancel each other on the right side of it. The conductor tends to move towards the weaker part of the field i.e., the force on the conductor will be directed towards right in a direction at right angles to both the conductor and the magnetic field. This rule is often referred as extension of right hand rule. It can be seen that the direction of the force is the same as given by the direction of the vector **L × B**.

Q6: How will you find the direction of magnetic field (B), current (I) and force (F) on the conductor?

Ans: Right hand palm rule:

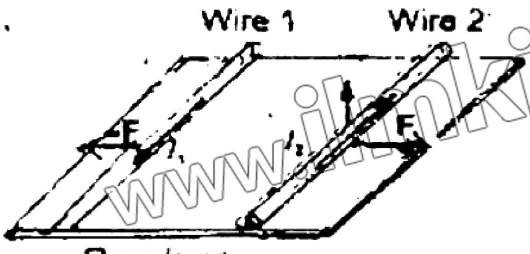
If the middle figure of right hand points in the direction of the magnetic field, the thumb in the direction of current, the force on the conductor will be normal to the palm towards the reader.



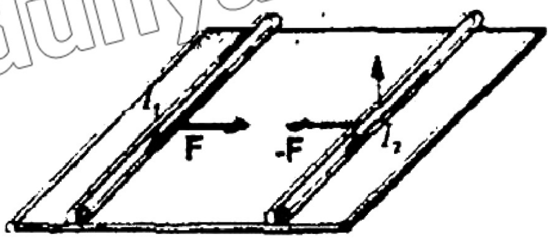
Q7: Indicate the direction of the currents when two parallel wires carrying current moves (a) in opposite direction (b) in same direction?

Ans: (a) Two long parallel wires carrying currents I_1 and I_2 in opposite direction repel each other

(b) The wires attract each other when the currents are in the same direction.



Repulsion

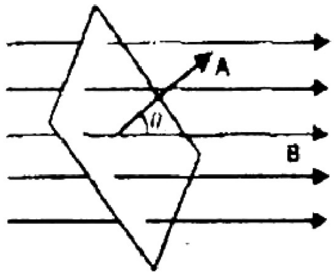


Attraction

Q8: Illustrate magnetic flux and flux density?

Ans: Magnetic flux:

The number of lines of magnetic induction passing through an area placed in the magnetic field known as magnetic flux.

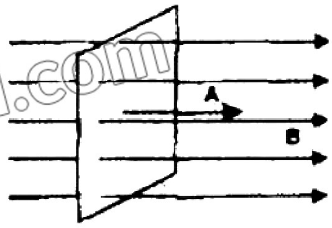


Explanation:

Like electric flux, the magnetic flux $\emptyset_B$ through a plane element of area A in a uniform magnetic field B is given by dot product of B and A.

$$\emptyset_B = B.A$$

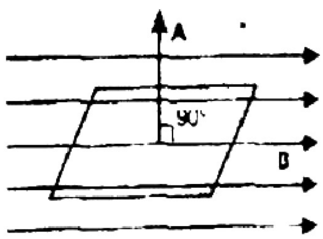
$$\emptyset_B = B A \cos\theta \quad .... \quad (1)$$



Note that A is a vector whose magnitude is the area of the element and whose direction is along the normal to the surface of the element, θ is the angle between the directions of the vectors B and A.

Case 1:

In Fig. the field is directed along the normal to the area so θ is zero and the flux is maximum, equal to BA.



Case 2:

When the field is parallel to the plane of the area, the angle between the field and normal to area is 90° i.e., $\theta = 90°$ so the flux through the area in this position is zero.

Case 3:

In case of a curved surface placed in a non uniform magnetic field, the curved surface is divided into a number of small surface elements, each element being assumed plane and the flux through the whole curved surface is calculated by sum of the contributions from all the elements of the surface.

Unit of magnetic flux:

From the definition of tesla, the unit of magnetic flux is NmA^{-1} which is called weber (Wb).

Flux density:

According to Eq. ($\emptyset_B$ = B A cosθ), the magnetic induction B is the flux per unit area of a surface perpendicular to B, hence it is also called as flux density.

Unit of flux density:

Unit of flux density is, Wbm^{-2}. Therefore, magnetic induction, i.e., the magnetic field strength is measured in terms of Wbm^{-2} or $NA^{-1}m^{-1}$ (tesla).

Q9: Enlist the factor on which magnetic flux depends?

Ans: Since $\emptyset_B = B\,A\cos\theta$

Therefore magnetic flux depends upon:

i. Flux density (B) of the magnetic field.
ii. Surface area A.
iii. Orientation of the surface with respect to the field direction which is indicated by cosθ

Q10: Explain how the magnetic flux density (B) at any point due to a current carrying conductor can be computed by using Ampere Circuital law?

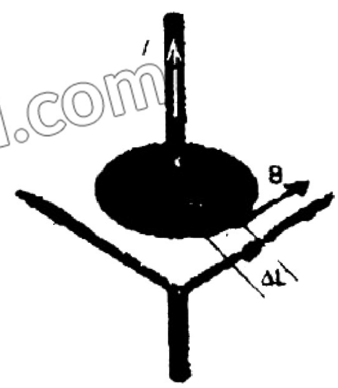
Ans: Ampere's law and determination of flux density (B):

According to ampere's law total flux density or magnetic field, over a closed path due to current is equal to μ_0 times the total current enclosed by the closed path.

Mathematical form of ampere's law:

$$\sum_{r=1}^{N}(B.\Delta L)_r = \mu_0 I$$

Where μ_0 is a constant, known as permeability of free space. In SI units its value is $4\pi \times 10^{-7}\ WbA^{-1}m^{-1}$.



We know that an electric current produces a magnetic field. Ampere, after carrying out a series of experiments, generalized his results into a law known as Ampere circuital law by which the magnetic flux density B at any point due to a current carrying conductor can be easily computed as explained below:

Determination of flux density (B):

i. Consider a closed path in the form a circle of radius r enclosing the current carrying wire.

ii. This closed path is referred as Amperean path. Divide this path into small elements of length like ΔL. Let B be the value of flux density at the site of ΔL. Determine the value of B. ΔL. If θ is the angle between B and ΔL, then

$$B.\ \Delta L = B\,\Delta L\cos\theta$$

B cos θ represents the component of B along the element of length ΔL i.e., Componentof B parallel to ΔL. Thus **B. ΔL** represents the product of the length of the element ΔL and the component of B parallel to ΔL.

iii. Ampere stated that the sum of the quantities **B. ΔL** for all path elements into which the complete loop has been divided equals μ_0 times the total current enclosed by the loop,

iv. Permeability of free space:

Where μ_0 is a constant, known as permeability of free space. In SI units its value is $4\pi \times 10^{-7}$ $WbA^{-1}m^{-1}$. This can be mathematically expressed as

$(B.\Delta L)_1 + (B.\Delta L)_2 + \ldots + (B.\Delta L)_r + \ldots + (B.\Delta L)_N = \mu_0 I$

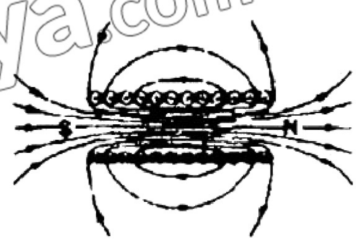
$$\sum_{r=1}^{N}(B.\Delta L)_r = \mu_0 I \quad \ldots\ldots\ldots (1)$$

Where $(B.\Delta L)_r$ is the value of B. ΔL along the r th element and N is the total number of elements into which the loop has been divided. This is known as Ampere's circuital law.

Q11: Derive a relation for a field due to a current carrying solenoid by using ampere's law? OR Describe the application of ampere's law?

Ans: Solenoid:

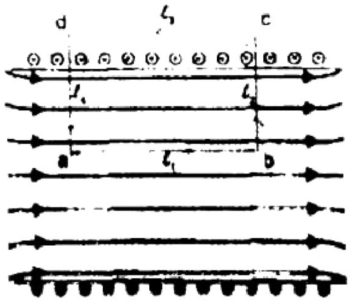
A solenoid is a long, tightly wound, cylindrical coil of wire. When current passes through such a coil, it behaves like a bar magnet.



The field inside a long solenoid is uniform and much strong whereas outside the solenoid, it is so weak that it can be neglected as compared to the field inside.

Field due to a current carrying solenoid:

The value of magnetic filed B can be easily determined by applying Ampere's circuital law. Consider a rectangular loop abcd as shown in Fig.



Divide it into four elements of length

ab $= \ell_1$, bc $= \ell_2$, cd $= \ell_3$, and da $= \ell_4$.

Applying Ampere's law, we have

$\sum_{r=1}^{4}(B.\Delta L)_r = \mu_0 \times$ current enclosed

$(B.\Delta L)_1 + (B.\Delta L)_2 + (B.\Delta L)_3 + (B.\Delta L)_4 = \mu_0 \times$ current enclosed

Calculation of the value of B. ΔL:

Now we will calculate the value of B. ΔL for each of the elements.

Calculation of the value of $(B.\Delta L)_1$:

First we will consider the element ab $= \ell_1$, that lies inside the solenoid. Field inside the solenoid is uniform and is parallel to

$$(B.\Delta L)_1 = \ell_1 B\cos 0° = \ell_1 B$$

Calculation of the value of $(B.\Delta L)_3$:

For the element cd $= \ell_3$, that lies outside the solenoid, the field B is zero, so

$$(B.\Delta L)_3 = 0$$

Calculation of the value of $(B.\Delta L)_2$ and $(B.\Delta L)_4$:

Again B is perpendicular to ℓ_2 and ℓ_4 inside the solenoid and is zero outside, so

$$(B.\Delta L)_2 = (B.\Delta L)_4 = 0$$

Calculation of the value of $\sum_{r=1}^{4}(B.\Delta L)_r$:

$$\sum_{r=1}^{4}(B.\Delta L)_r = B\ell_1 \times \text{current enclosed}$$

Calculation of the value of flux density along a loop:

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

If n is the number of turns per unit length of the solenoid, the rectangular surface will intercept $n\ell_1$, turns, each carrying a current I. So the current enclosed by the loop is $n\ell_1 I$. Thus Ampere's law gives

$$B\ell_1 = \mu_0 \times n\ell_1 I$$

$$B = \mu_0 n I \quad .... \quad (1)$$

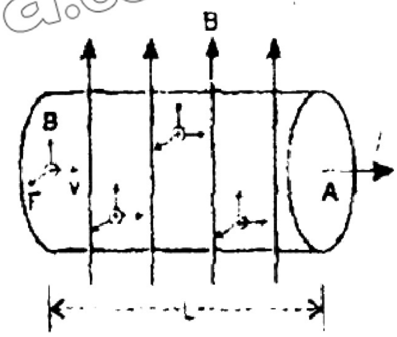
Direction of field B along the axis of solenoid:

The field B is along the axis of the solenoid and its direction is given by right hand grip rule which states "hold the solenoid in the right hand with fingers curling in the direction of the current, the thumb will point in the direction of the field".

Q12: Derive a relation for force on a moving charge in a magnetic field?

Ans: Force on a moving charge in a magnetic field:

i. Consider the situation as shown in Fig. where we see a portion of the wire that is carrying a current I.



ii. Suppose there are n charge carriers per unit volume of the wire, and that each is moving with velocity v as shown. We will now find how long it takes for all the charge carriers originally in the wire segment shown to exit through the end area A.

iii. The volume of the wire segment is AL. Because there are n charge carriers per unit volume, the number of charge carrier in the segment is n AL.

iv. If the charge on a charge carrier is q, each of it, as it crosses the end area, will transport a charge q through it.

v. Assuming the speed of the carriers to be v, the carrier entering the left face of the segment takes a time $\Delta t = L/v$ to reach the right hand face. During this time, all the charge carriers originally in the segment, namely n AL, will exit through the right hand face. As each charge carrier has a charge q, the charge ΔQ that exits through the end area in time $\Delta t = L/v$ is

$$\Delta Q = nALq$$

Then, from the definition of the current, the current I through the conductor is

$$I = \frac{\Delta Q}{\Delta t} = \frac{nALq}{L/v} = nAqv \quad .... \quad (1)$$

vi. The force on the segment L of a conductor, carrying current I is given by

$$F_L = IL \times B$$

Substituting the value of the current I, from Eq. 1 we get,

$$F_L = nAqvL \times B \quad .... \quad (2)$$

vii. In Fig., it can be seen that the direction of the segment L is the same as the direction of the velocity of the charge carriers. If $\hat{L}$ is a unit vector along the direction of the segment L and $\hat{v}$, a unit vector along the velocity vector v, then $\hat{L} = \hat{v}$

$$vL = v\hat{L}L = v\hat{v}L = vL$$

Substituting the value of v L in Eq. 2, we have

$$F_L = nAq\,(vL) \times B = nALqv \times B$$

nAL is the total number of charge carries in the segment L, so the force experienced by a single charge carrier is

$$F = \frac{F_L}{nAL} = qv \times B$$

Thus the force experienced by a single charge carrier moving with velocity v in magnetic field of strength B is

$$F = q\,(v \times B) \quad \ldots\ldots\ldots \quad (3)$$

viii. Projection of electron ion the magnetic field:

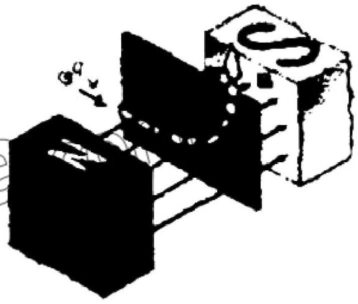
If an electron is projected in a magnetic field with a velocity v, it will experience a force which is given by putting q = - e in Eq. 3 where e is the magnitude of the electronic charge.

$$F = -ev \times B \quad \ldots\ldots\ldots \quad (4)$$

ix. Projection of proton in the magnetic field:

In case of proton, F is obtained by putting q = + e.

$$F = +ev \times B \quad \ldots\ldots\ldots \quad (5)$$



The direction of the force on a moving negative charge will be opposite to that of positive charge. Due to this force, the electron is deflected in the downward direction as it enters into a magnetic field. Whereas protons are positive charge experiences a force in the upward direction.

Maximum force:

It may be noted that the magnitude of the force on a moving charge carrier is qvB sinθ where θ is the angle between the velocity of the carrier and the magnetic field. It is maximum when θ = 90° i.e., when the charged particle is projected at right angles to the field.

Minimum force:

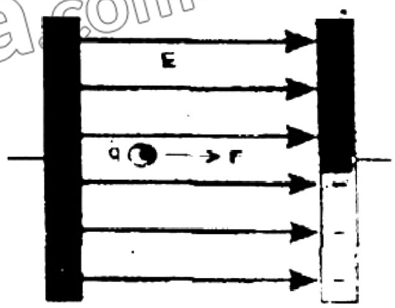
Force is zero when θ = 0° i.e., a charged particle projected in the direction of the field experiences no force.

Q13: Discuss the motion of charged particle in an electric and magnetic field? OR Derive a relation for Lorentz force?

Ans: Motion of charged particle in an electric and magnetic field (Lorentz force):

i. When an electric charge q is placed in an electric field E, It experiences a force F parallel to electric field. It is given by

$$F = qE$$



ii. If the charge is free to move, then it will accelerate according to Newton's second law as

$$a = \frac{F}{m} = \frac{qE}{m} \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

iii. When a charge particle q is moving with velocity v in a region where there is an electric field E and magnetic field B, the total force F is the vector sum of the electric force qE and magnetic force q (v × B) that is,

$$F = F_e + F_b$$
$$F = qE + q\,(v \times B) \quad \ldots\ldots\ldots \quad (2)$$

This force F is known as the **Lorentz force.**

iv. Note:

It is to be pointed out that only the electric force does work, while no work is done by the magnetic force which is simply a deflecting force.

Lorentz force:

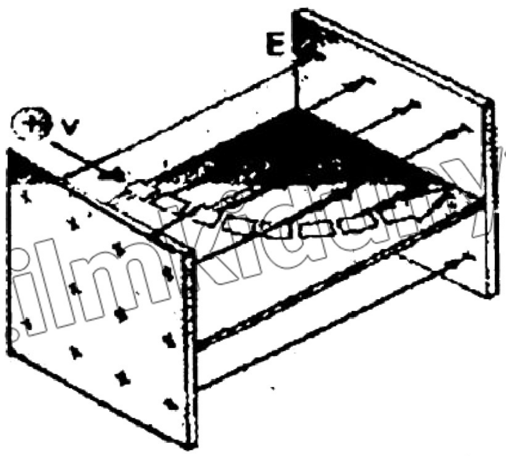
The total force F is the vector sum of the electric force qE and magnetic force q (v × B), this force is known as Lorentz force. That is,

$$F = F_e + F_b$$

$$F = qE + q(v \times B)$$

Q14: What is effect of electric force that acts on a positive charge parallel to electric field?

Ans: The electric force F that acts on a positive charge is parallel to the electric field E and causes the particle's trajectory to bend in a horizontal plane.

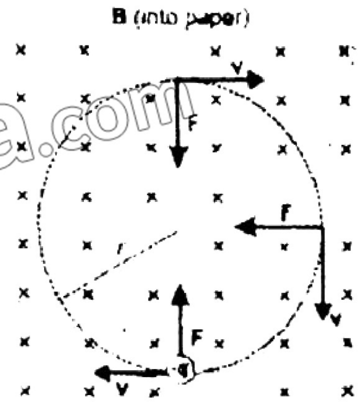


Q15: Explain the method for the determination of e/m of an electron. Also describe the method to measure radius and velocity of electron?

Ans: Determination of e/m of an electron:

i. Let a narrow beam of electrons moving with a constant speed v be projected at right angles to a known uniform magnetic field B directed into plane of paper. The electrons will experience a force

$$F = -ev \times B$$



ii. The direction of the force will be perpendicular to both v and B

iii. As the electron is experiencing a force, the magnitude of the force is qvB sinθ. As θ is 90°, so F= evB. As both v and B do not change, the magnitude of F is constant. Thus the electrons are subjected to a constant force evB at right angle to their direction of motion. Under the action of this force, the electrons will move along a circle as shown in Fig.

iv. The magnetic force F = Bev provides the necessary centripetal force $\frac{mv^2}{r}$ to the electron of mass m to move along r a circular trajectory of radius r Thus we have

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

$$\frac{e}{m} = \frac{v}{Br} \quad \text{.........} \quad (1)$$

If v and r are known, e/m (charge/mass) of the electron is determined.

v. Measurement of a radius with the help of electronic trajectory:

The radius r is measured by making the electronic trajectory visible. This is done by filling a glass tube with a gas such as hydrogen at low pressure. This tube is placed in a region occupied by a uniform magnetic field of known value. As electrons are shot into this tube, they begin to move along a circle under the action of magnetic force. As the electrons move, they collide with atoms of the gas. This excites the atoms due to which they emit light and their path becomes visible as a circular ring of light. The diameter of the ring can be easily measured (radius = diameter/2).

v. Measurement of a velocity of the electrons:

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

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

$$V = \sqrt{\frac{2Ve}{m}}$$

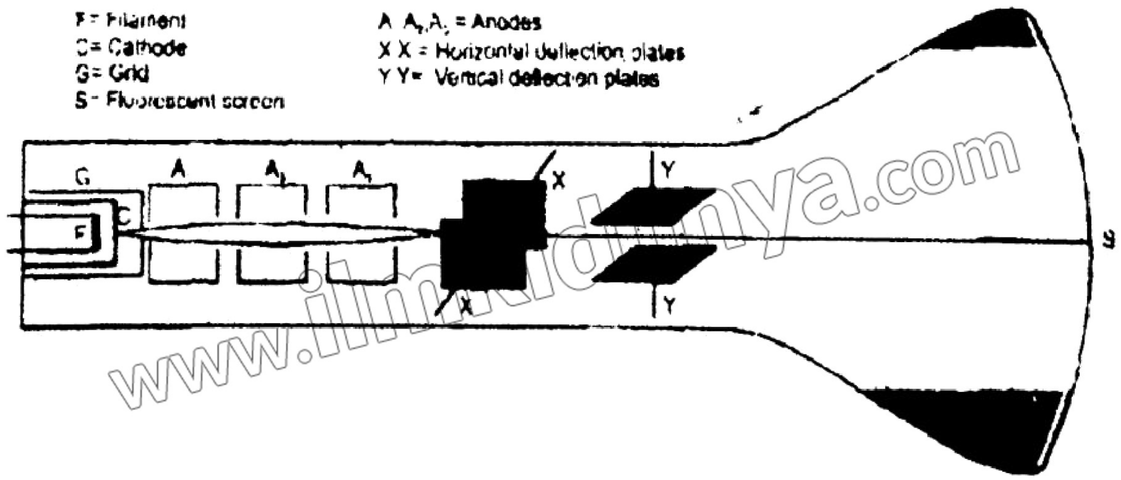
Substituting the value of v in Eq. 1, we have

$$\frac{e}{m} = \frac{2V}{B^2r^2} \quad \text{........} \quad (2)$$

Q16: Describe the construction, working and the use of cathode ray oscilloscope?

Ans: Cathode ray oscilloscope (CRO):

Cathode ray oscilloscope (CRO) is a very versatile electronic instrument which is, in fact, a high speed graph plotting device. It is used for analysis of waveform.



Principle of Cathode ray oscilloscope (CRO):

It works by deflecting beam of electrons as they pass through uniform electric field between the two sets of parallel plates as shown in the Fig

Working of Cathode ray oscilloscope (CRO):

The deflected beam then falls on a fluorescent screen where it makes a visible spot.

It can display graphs of functions which rapidly vary with time.

Why it is called Cathode ray oscilloscope (CRO):

It is called cathode ray oscilloscope because it traces the desired waveform with a beam of electrons which are also called cathode rays.

Construction of Cathode ray oscilloscope (CRO):

Electron gun:

The beam of the electrons is provided by an electron gun which consists of an indirectly heated cathode, a grid and three anodes.

Function of filament:

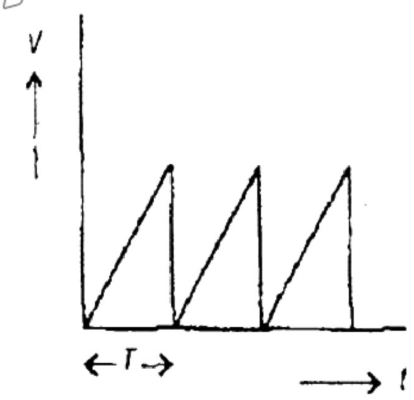
The filament F heats the cathode C which emits electrons. The anodes A_1, A_2, A_3 which are at high positive potential with respect to cathode, accelerate as well as focus the electronic beam to fixed spot on the screen S.

Function of Grid:

The grid G is at a negative potential with respect to cathode. It controls the number of electrons which are accelerated by anodes, and thus it controls the brightness of the spot formed on the screen.

The formation of waveform of various voltages formed in CRO:

i. The two set of deflecting plates, shown in Fig. are usually referred as x and y deflection plates because a voltage applied between the x plates deflects the beam horizontally on the screen i.e., parallel to x-axis.



ii. A voltage applied across the y plates deflects the beam vertically on the screen i.e., along the y-axis.

iii. Sweep or time base generator:

The voltage that is applied across the x plates is usually provided by a circuit that is built in the CRO. It is known as **sweep or time base generator**. Its output waveform is a saw tooth voltage of period T.

iv. The voltage increases linearly with time for a period T and then drops to zero. As this voltage is impressed across the x plates, the spot is deflected linearly with time along the x-axis for a time T. Then the spot returns to its starting point on the screen very quickly because a saw tooth voltage rapidly falls to its initial value at the end of each period. We can actually see the spot moving on the x-axis. If the time period T is very short, we see just a bright line on the screen.

v. Application of sinusoidal voltage:

If a sinusoidal voltage is applied across the y plates when, simultaneously, the time base voltage is impressed across the x plates, the sinusoidal voltage, which itself gives rise to a vertical line, will now spread out and will appear as a sinusoidal trace on the screen. The pattern will appear stationary only if the time T is equal to or is some multiple of the time of one cycle of the voltage on y plates. It is thus necessary to synchronize the frequency of the time base generator with the frequency of the voltage at the y plates. This is possible by adjusting the synchronization controls provided on the front panel of the CRO.

Uses of Cathode ray oscilloscope (CRO):

i. The CRO is used for displaying the waveform of a given voltage. Once the waveform is displayed, we can measure the voltage, its frequency and phase. For example, Fig. shows the waveform of an alternating voltage. As the y-axis is calibrated in volts and the x-axis in time, we can easily find the instantaneous value and peak value of the voltage.

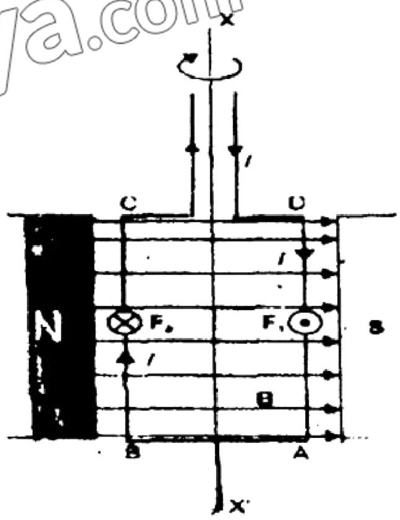
ii. The time period can also be determined by using the time calibration of x-axis.

iii. Information about the phase difference between two voltages can be obtained by simultaneously displaying their waveforms. For example, the waveforms of two voltages are shown in Fig. These waveforms show that when the voltage of **I** is increasing, that of **II** is decreasing and vice versa. Thus the phase difference between these voltages is 180°.

Q17: Derive a relation for torque on a current carrying coil?

Ans: Torque on a current carrying coil:

i. Consider a rectangular coil carrying a current I. The coil is capable of rotation about an axis. Suppose it is placed in uniform magnetic field B with its plane along the field.



ii. We know that a current carrying conductor of length L when placed in a magnetic field experiences a force $F = ILB \sin\theta$ where θ is the angle between conductor and the field.

iii. In case of sides AB and CD of the coil, the angle θ is zero or 180°, so the force on these sides will be zero.

iv. In case of sides DA and BC, the angle θ is 90° and the force on these sides will be

$$F_1 = F_2 = ILB$$

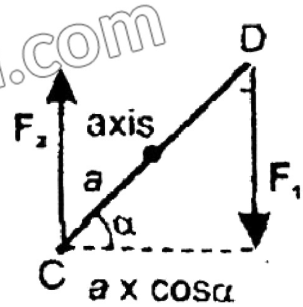
Where L is the length of these sides, F_1, is the force on the side DA and F_2 on BC.

v. The direction of the force is given by the vector $I\,L \times B$. It can be seen that F_1, is directed out of the plane of paper and F_2 into the plane of paper.

Therefore, the forces F_1 and F_2 being equal and opposite form a couple which tends to rotate it about the axis.

vi. The torque of this couple is given by

$$\tau = \text{Force} \times \text{Moment arm} = I\,LB \times a$$



Where 'a' is the moment arm of the couple and is equal to the length of the side AB or CD. La is the area A of the coil,

$$\tau = IBA \quad .... \quad (1)$$

Note that the Eq. 1 gives the value of torque when the field B is in the plane of the coil. However if the field makes an angle α with the plane of the coil, as shown in Fig., the moment arm now becomes a cos α.

So

$$\tau = ILB \times a\cos\alpha = IBA\cos\alpha \quad .... \quad (2)$$

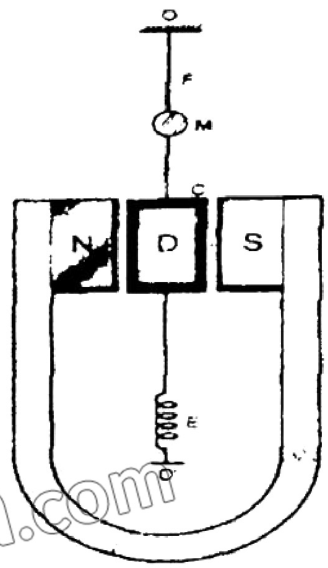
Q18: Describe the principle, construction and working of the galvanometer?

Ans: Galvanometer:

A galvanometer is an electrical instrument used to detect the passage of current.

Principle of galvanometer:

The working of galvanometer depends upon the fact that when a conductor is placed in a magnetic field, it experiences a force as soon as a current passes through it.



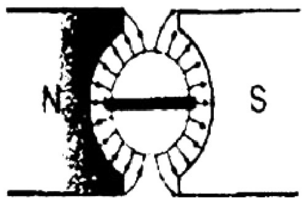
Construction of galvanometer:

The construction of a moving coil galvanometer is shown in Fig.

i. A **rectangular coil** C is suspended between the concave shaped poles N and S of a **U-shaped magnet** with the help of a fine metallic suspension wire.

ii. The rectangular coil is made of enameled copper wire. It is wound on a frame of nonmagnetic material. The **suspension wire** F is also used as one current lead to the coil. The other terminal of the coil is connected to a loosely **wound spiral** E which serves as the second current lead.

iii. A **soft iron cylinder** D is placed inside the coil to make the field radial and stronger near the coil as shown in Fig.



Working of galvanometer:

i. Production of torque:

Due to this force, a torque τ acts upon the conductor if it is in the form of a coil or loop

$$\tau = N I BA \cos\alpha$$

where N is the number of turns in the coil, A is its area, I is current passing through it, B is the magnetic field in which the coil is placed such that its plane makes an angle a with the direction of B. Due to action of the torque, the coil rotates and thus it detects the current.

iv. Deflecting couple:

When a current is passed through the coil, it is acted upon by a couple which tends to rotate the coil. This couple is known as deflecting couple and is given by N I B A cos α. As the coil is placed in a radial magnetic field in which the plane of the coil is always parallel to the field, so α is always zero. This makes cos α = 1 and thus,

Deflecting couple = N I B A

v. Torsional couple:

As the coil turns under the action of deflecting couple, the suspension wires is twisted which gives rise to a torsional couple

Restoring couple:

It tends to untwist the suspension and restore the coil to its original position. This couple is known as restoring couple. The restoring couple of the suspension wire is proportional to the angle of deflection θ as long as the suspension wire obeys Hooke's law. Thus

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

Where the constant c of the suspension wire is known as torsional couple and is defined as couple for unit twist.

Calculation of current (I):

Under the effect of these two couples, coil comes to rest when

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

$$I = \frac{c}{BAN}\theta \quad \text{............ (1)}$$

Thus $\quad I \propto \theta \quad$ since $\quad \frac{c}{BAN} = \text{constant}$

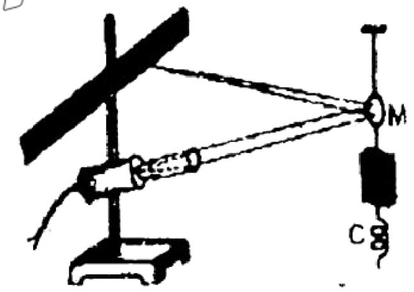
Thus the current passing through the coil is directly proportional to the angle of deflection.

Q19: Describe the methods which are used for observing the angle of deflection of the coil?

Ans: Methods for observing the angle of deflection:

There are two methods commonly used for observing the angle of deflection of the coil.

i. Lamp and scale method:

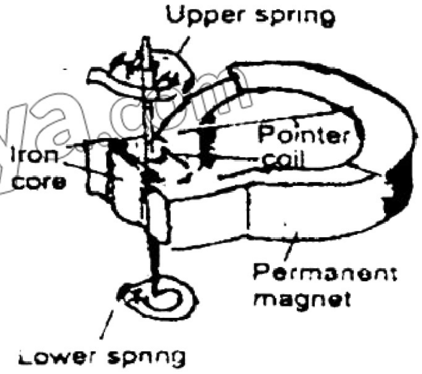


In sensitive galvanometers the angle of deflection is observed by means of small mirror attached to the coil along with a lamp and scale arrangement.

A beam of light from the lamp is directed towards the mirror of the galvanometer. After reflection from the mirror it produces a spot on a translucent scale placed at a distance of one metre from the galvanometer. When the coil rotates, the mirror attached to coil also rotates and spot of light moves along the scale. The displacement of the spot of light on the scale is proportional to the angle of deflection (provided the angle of deflection is small).

Q20: Which type of galvanometer is used in schools and college laboratories?

Ans: Pivoted type galvanometer:



The galvanometer used in school and college laboratories is a pivoted type galvanometer. In this type of galvanometer, the coil is pivoted between two jewelled bearings. The restoring torque is provided by two hair springs which also serve as current leads. A light aluminum pointer is attached to the coil which moves over a scale. It gives the angle of deflection of the coil.

Q21: How a galvanometer can be made more sensitive? OR Write a note on the sensitivity of a galvanometer?

Ans: Sensitivity of a galvanometer:

Since $\quad I = \frac{c}{BAN}\theta$

Thus $\quad I \propto \theta \quad$ since $\frac{c}{BAN}$ = constant

i. It is obvious from above Eqs. that a galvanometer can be made more sensitive (to give large deflection for a given current) if c/BAN is made small. Thus, to increase sensitivity of a galvanometer, c may be decreased or B, A and N may be increased

Method to decrease couple c:

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

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

iii. Method to compensate for the loss of sensitivity:

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

Current sensitivity of a galvanometer:

We define current sensitivity of a galvanometer as the current, in microamperes, required to produce one millimetre deflection on a scale placed one metre away from the mirror of the galvanometer.

Q22: Explain what is meant buy stable or dead beat galvanometer?

Ans: Stable or dead beat galvanometer:

i. When the current passing through the galvanometer is discontinued, the coil will not come to rest as soon as the current flowing through the coil is stopped. It keeps on oscillating about its mean position before coming to rest.

ii. In the same way if the current is established suddenly in a galvanometer, the coil will shoot beyond its final equilibrium position and will oscillate several times before coming to rest at its equilibrium position.

iii. As it is annoying and time consuming to wait for the coil to come to rest, artificial ways are employed to make the coil come to rest quickly. Such galvanometer, in which the coil comes to rest quickly after the current passed through it or the current is stopped from flowing through it, is called **stable or a dead beat galvanometer**.

Q23: What is an ammeter? Explain how a galvanometer can be converted into ammeter?

Ans: Ammeter:

An ammeter is an electrical instrument which is used to measure current in amperes. This is basically a galvanometer.

Placement of ammeter in circuit:

Ammeter is always connected in series with the circuit through which the current is passing.

Meter-movement:

The portion of the galvanometer whose motion causes the needle of the device to move across the scale is usually known as meter-movement. Most meter movements are very sensitive and full scale deflection is obtained with a current of few milliamperes only. So an ordinary galvanometer cannot be used for measuring large currents without proper modification.

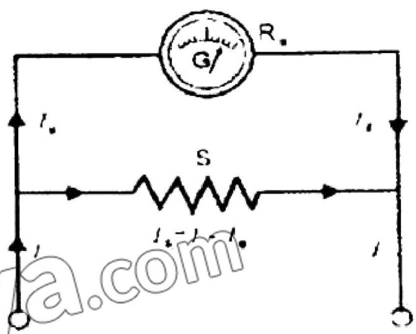
Suppose we have a galvanometer whose meter - movement (coil) has a resistance R_g and which gives full scale deflection when current I_g is passed through it. From Ohm's law we know that the potential difference V_g which causes a current I_g to pass through the galvanometer is given by

$$V_g = I_g R_g$$

Conversion of a galvanometer into ammeter:

Use of Shunt:

If we want to convert this galvanometer into an ammeter which can measure a maximum current I, it is necessary to connect a low value bypass resistor called shunt. The shunt resistance is of such a value so that the current I_g for full scale deflection of the galvanometer passes through the galvanometer and the remaining current $(I - I_g)$ passes through the shunt in this situation.



Calculation of Shunt resistance (R_s):

The shunt resistance R_s can be calculated from the fact that as the meter - movement and the shunt are connected in parallel with each other, the potential difference across the meter - movement is equal to the potential difference across the shunt.

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

$$R_s = \frac{I_g}{I - I_g} R_g \quad \text{..........} \quad (1)$$

Shunt resistance (R_s) should be very small:

The resistance of the shunt is usually so small that a piece of copper wire serves the purpose. The resistance of the ammeter is the combined resistance of the galvanometer's meter-movement and the shunt. Usually it is very small. An ammeter must have a very low resistance so that it does not disturb the circuit in which it is connected in series in order to measure the current.

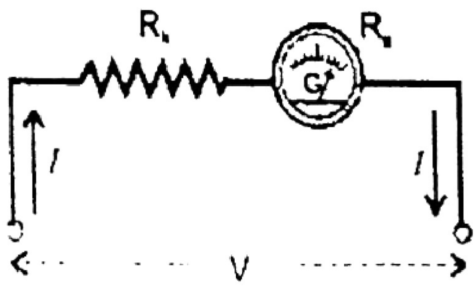
Q24: What is a voltmeter? Explain how a galvanometer can be converted into voltmeter?

Ans: Voltmeter:

A voltmeter is an electrical device which measures the potential difference in volts between two points. This, too, is made by modifying a galvanometer.

Placement of voltmeter in circuit:

Since a voltmeter is always connected in parallel, it must have a very high resistance so that it will not short the circuit across which the voltage is to be measured. This is achieved by connecting a very high resistance R_h placed in series with the meter-movement.



Conversion of a galvanometer into ammeter:

Conversion of a galvanometer into voltmeter:

Suppose we have a meter-movement whose resistance is R_g and which deflects full scale with a current I_g In order to make a voltmeter from it which has a range of V volts, the value of the high resistance R_h should be such that full scale deflection will be obtained when it is connected across V volt. Under this condition the current through the meter - movement is I_g. Applying Ohm's law we have

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

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

$$R_h = \frac{V}{I_g} - R_g \quad .... \quad (1)$$

Conditions for connecting voltmeter:

i. It may be noted that a voltmeter is always connected across the two points between which potential difference is to be measured.

ii. Before connecting a voltmeter, it should be assured that its resistance is very high in comparison with the resistance of the circuit across which it is connected otherwise it will load the circuit and will alter the potential difference which is required to be measured.

Q25: What is an ohmmeter? Describe its construction and working?

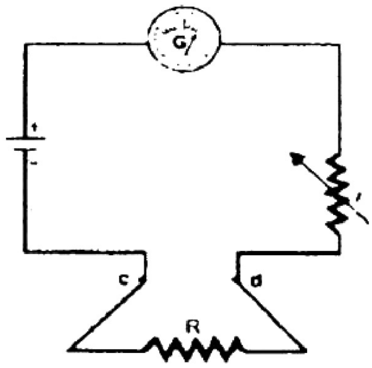
Ans: Ohmmeter:

It is a useful device for rapid measurement of unknown resistance.

Placement of ohmmeter in circuit:

It consists of a voltmeter, a variable resistance of known value and a battery connected in series with one another.

Construction of ohmmeter:

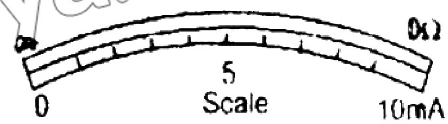


It consists of a galvanometer, and adjustable resistance r_s and a cell connected in series.

Working of ohmmeter:

i. The series resistance r_s is so adjusted that when terminals c and d are short circuited, i.e., when R = 0, the galvanometer gives full scale deflection. So the extreme graduation of the usual scale of the galvanometer is marked 0 for resistance measurement.

ii. When terminals c and d are not joined, no current passes through the galvanometer and its deflection is zero. Thus zero of the scale is marked as infinity.



iii. Now a known resistance R is connected across the terminals c and d. The galvanometer deflects to some intermediate point. This point is calibrated as R. In this way the whole scale is calibrated into resistance.

iv. The resistance to be measured is connected across the terminals c and d. The deflection on the calibrated scale reads the value of the resistance directly.

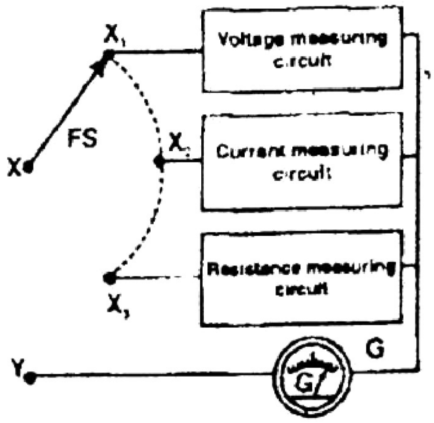
Q26: Discuss how AVO meter (Multimeter) is used to measure voltage, current and resistance?

Ans: AVO meter (Multimeter):

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

Construction of AVO meter (Multimeter):

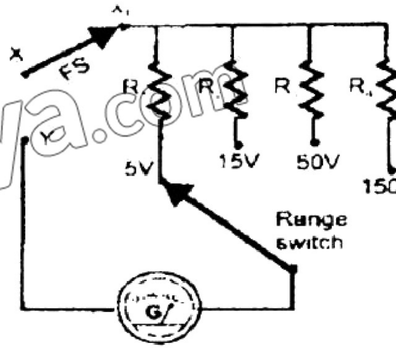
It basically consists of a sensitive moving coil galvanometer which is converted into a multirange ammeter, voltmeter or ohmmeter accordingly as a current measuring circuit or a voltage measuring circuit or a resistance measuring circuit is connected with the galvanometer with the help of a switch known as **function switch**.



Here X, Y are the main terminals of the AVO meter which are connected with the circuit in which measurement is required. FS is the function selector switch which connects the galvanometer with relevant measuring circuit.

Voltage measuring part of AVO meter:

The voltage measuring part of the AVO meter is actually a multirange voltmeter. It consists of a number of resistances each of which can be connected in series with the moving coil galvanometer with the help of a switch called the range switch.



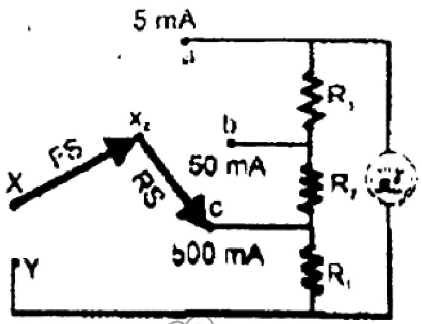
The value of each resistance depends upon the range of the voltmeter which it controls.

Alternating voltages are also measured by AVO meter. AC voltage is first converted into DC voltage by using diode as rectifier and then measured as usual.

Current measuring part of the AVO meter:

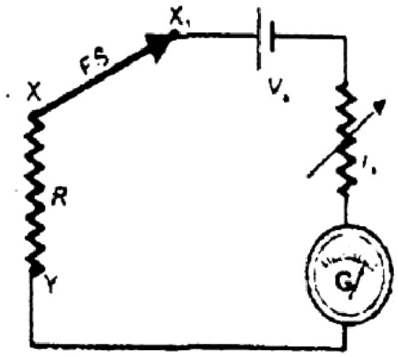
The current measuring part of the AVO meter is actually a multirange ammeter. It consists of a number of low resistances connected in parallel with the galvanometer. The values of these resistances depend upon the range of the ammeter.

The circuit also has a range selection switch RS which is used to select a particular range of the current.



Resistance measuring part of the AVO meter:

The resistance measuring part of AVO meter is, in fact, a multirange ohmmeter. Circuit for each range of this meter consists of a battery of emf V_o and a variable resistance r, connected in series with galvanometer of resistance R_g. When the function switch is switched to position X_3, this circuit is connected with the terminals X, Y of the AVO meter.



Before measuring an unknown resistance by an ohmmeter it is first zeroed which means that we short circuit the terminals X, Y and adjust r_o, to produce full scale deflection.

Q27: Write a short note on Digital Multimeter (DMM)?

Ans: Digital Multimeter (DMM):

Another useful device to measure resistance, current and voltage is an electronic instrument called digital multimeter.

It is a digital version of an AVO meter. It has become a very popular testing device because the digital values are displayed automatically with decimal point, polarity and the unit for V, A or Ω. These meters are generally easier to use because they eliminate the human error that often occurs in reading the dial of an ordinary AVO meter

SUMMARY

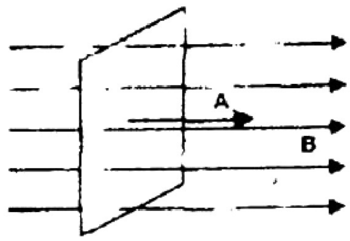
1. A magnetic field is set up in the region surrounding a current carrying conductor.
2. The right hand rule states, "If the wire is grasped in the fist of right hand with the thumb pointing in the direction of current, the fingers of the hand will circle the wire in the direction of the magnetic field".
3. The strength of the magnetic field or magnetic induction is the force acting on one metre length of the conductor placed at right angle to the magnetic field when 1A current is passing through it.
4. A magnetic field is said to have strength of one tesla if it exerts a force of one Newton on one metre length of the conductor placed at right angle to the field when a current of one ampere passes through the conductor.
5. The magnetic flux ϕ_B through plane element of area A in a uniform magnetic field B is given by dot product of B and A.
6. Ampere circuital law states the sum of the quantities $B \cdot \Delta L$ for all path elements into which the complete loop has been divided equals μ_0 times the total current enclosed by the loop.
7. The force experienced by a single charge carrier moving with velocity v in magnetic field of strength B is $F = q\,(v \times B)$.
8. **Cathode ray oscilloscope (CRO) is a high speed graph plotting device. It works by deflecting beam of electrons as they pass through uniform electric field between the two sets of parallel plates.**
9. **A torque may act on a current carrying coil placed in a magnetic field.** $\tau = IAB\cos\alpha$
10. A galvanometer is an electric device which detects the flow of current. It usually consists of a coil placed in a magnetic field. As the current passes through the coil, the coil rotates, thus indicating the flow of current.
11. A galvanometer is converted into an ammeter by properly shunting it.
12. A galvanometer is converted into a voltmeter by connecting a high resistance in series.

SOLUTION OF EXERCISE

14.1. A plane conducting loop is located in a uniform magnetic field that is directed along the x-axis. For what orientation of the loop is the flux maximum and for what orientation is the flux a minimum?

Ans: The flux will be the maximum when the plane of the loop will be perpendicular to the magnetic field (perpendicular to x-axis) The flux will be the minimum when the plane of the loop will be parallel to the magnetic field (parallel to x-axis)

Since $\Phi_B = BA\cos\theta$



Case 1:

In Fig. the field is directed along the normal to the area, so θ is zero and the flux is maximum, equal to BA.

Case 2:

When the field is parallel to the plane of the area, the angle between the field and normal to area is 90° i.e., $\theta = 90°$, so the flux through the area in this position is zero

14.2. A current in a conductor produces a magnetic field, which can be calculated using Ampere's law. Since current is defined as the rate of flow of charge, what can you conclude about the magnetic field due to stationary charges? What about moving charges?

Ans: Stationary charges will not produce any magnetic field as it requires the movement of charges. Moving charges, however, will give rise to a magnetic field which will be in a plane perpendicular to their velocities and can be calculated using ampere's law.

14.3. Describe the change in the magnetic field inside a solenoid carrying a steady current I, if (a) the length of the solenoid is doubled but the number of turns remains the same and (b) the number turns is doubled but the length remains the same.

Ans: Magnetic field inside a solenoid is

$$B = \frac{\mu_0 N I}{L} \Rightarrow B \propto \frac{1}{L} \quad \text{and} \quad B \propto N$$

Therefore, it is clear that

(a) By doubling length L the magnetic field will be halved.

$$B \propto \frac{1}{L}$$

(b) By doubling number of turns N, the magnetic field will be doubled

$$B \propto N$$

14.4. At a given instant, a proton moves in the positive x direction in a region where there is a magnetic field in the negative z direction. What is the direction of the magnetic force? Will the proton continue to move in the x direction? Explain.

Ans: i. **Direction of the magnetic force:**

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

The direction of magnetic field, according to right hand rule, is along +y-axis. The proton will be deflected by the magnetic force and will start circulating and will not move in the x-direction any more.

ii. Movement of proton:

No, the proton will move in xy-plane.

14.5. Two charged particles are projected into a region where there is a magnetic field perpendicular to their velocities. If the charges are deflected in opposite directions, what can you say about them?

Ans: The magnetic force on a moving charged particle is $\vec{F} = \pm q\,(\vec{v} \times \vec{B})$. Clearly, if the charges are deflected in the opposite directions, the forces must be opposite, which is only possible when the charges have opposite nature i.e. one is positive (proton) and other is negative (electron).

14.6. Suppose that a charge q is moving in a uniform magnetic field with a velocity v. Why is there no work done by the magnetic force that acts on the charged, q?

Ans: Since magnetic field is a conservative field and work done in a conservative field in a closed path is always zero. As the charged particle follows a circular path in a magnetic field so the work done by the magnetic force is zero.

As magnetic force always acts at right angle to velocity therefore work done is given by

$$W = Fd\cos 90^0 = 0$$

14.7. If a charged particle moves in a straight line in a certain region of space, can you say that the magnetic field in the region is zero?

Ans: Since according to Ampere's law.

$B = \mu_0 n I \quad \Rightarrow \quad B \propto I$

When a charged particle moves in a straight line in a certain region of space it will produce current hence there will be a magnetic field around the current carrying conductor. Therefore magnetic field in the region is not zero.

14.8. Why does the picture on a TV screen become distorted when a magnet is brought near the screen?

Ans: Picture on TV screen is formed by a beam of fast moving electrons by electron gun when electrons strike the TV screen. Due to the presence of external magnetic field due to magnet the beam must be deflected which causes distortion in the picture.

14.9. Is it possible to orient a current loop in a uniform magnetic field such that the loop will not tend to rotate?

Ans: Yes, it is possible when we place it in the magnetic field such that the plane of the loop is perpendicular to the magnetic field. We know that $\tau = BNIA\cos\alpha$ in this case, $\alpha = 90°$ and $\cos 90° = 0$, hence torque on the loop will be zero and loop will not rotate.

14.10. How can a current carrying loop be used to determine the presence of a magnetic field in a given region of space?

Ans: A torque is produce due to current in a loop of wire when place in a magnetic field. If the loop of wire is deflected when current carrying loop is taken in the region and should be rotated. The loop must experience a torque if any magnetic field is present. But if the loop does not experience any torque, there is no magnetic field present there.

14.11. How can you use a magnetic field to separate isotopes of a chemical element?

Ans: $r = \frac{mv}{qB}$ $\Rightarrow$ $r \propto m$

If isotopes in the ions form are projected into the field, they will be deflected due to the magnetic field in circular paths whose radii will depend on their masses (radii being directly proportional to the masses). Hence, they will be separated easily.

14.12. What should be the orientation of a current carrying coil in a magnetic field so that torque acting on it is (a) maximum (b) minimum?

Ans: Since torque is τ = NIAB $\cos\theta$. Where α is the angle between the plane of the loop and the magnetic field. Clearly,

(a) Parallel loop and magnetic field will cause maximum torque because $\theta = 0^0$ and $\cos 0^0 = 1$ which is maximum.

(b) Perpendicular loop and magnetic field will cause minimum torque because $\theta = 90^0$ and $\cos 90^0 = 0$ which is minimum.

14.13. A loop of wire is suspended between the poles of a magnet with its plane parallel to the pole faces. What happens if a direct current is put through the coil? What happens if an alternating current is used instead?

Ans: Since torque is τ = NIAB $\cos\theta$. Where α is the angle between the plane of the loop and the magnetic field.

(a) When direct current is passed through the suspended coil then parallel loop and magnetic field will cause maximum torque because $\theta = 0^0$ and $\cos 0^0 = 1$ which is maximum.

(b) When alternating current passed through the coil direction of torque reverses periodically therefore coil will oscillates in the magnetic field instead of repeating.

14.14. Why the resistance of an ammeter should be very low?

Ans: Since ammeter is always connected in series with the circuit to measure current therefore high resistance will reduce the current through the circuit and affect working of ammeter therefore, the resistance of ammeter should be very low, so that it does not affect the current through the circuit which is to be measured.

14.15. Why the voltmeter should have a very high resistance?

Ans: Since voltmeter is always connected in parallel with the circuit to measure potential difference therefore high resistance will reduce the current through the circuit and affect working of voltmeter therefore the resistance of voltmeter should be very high otherwise it will load the circuit and change the potential difference which is to be measured.

Therefore the resistance of the voltmeter should be very high as compared to the resistance of the circuit. An ideal voltmeter would have infinite resistance.

SOLUTION OF EXAMPLES

Example 14.1: **A 20.0 cm wire carrying a current of 10.0 A is placed in a uniform magnetic field of 0.30 T. If the wire makes an angle of 40^0 with the direction of magnetic field, find the magnitude of the force acting on the wire.**

Solution:

Length of the wire = L = 20.0cm = 0.20 m

Current = I = 10.0 A

Strength of magnetic field = B = 0.30 T

Angle = α = 40°

Force acting on wire = F =?

By using the formula

$$F = IBL \sin\alpha$$

F = 10.0 × 0.30 × 0.20 × sin 40°

F = 10.0 × 0.30 × 0.20 × 0.642

F = 0.386 = 0.39 N

Example 14.2: **The magnetic field in a certain region is given by $B = (40\,\hat{i} - 18\hat{j})$ Wb m^{-2}. How much flux passes through a 5.0 cm^2 area loop in this region if the loop lies flat in the xy-plane?**

Solution:

Magnetic induction = $\vec{B}$ = $40\,\hat{i} - 18\,\hat{k}$

Area of the loop = $\vec{A}$ = $5.0\,\hat{k}\ cm^2 = 5.0 \times 10^{-4}\,\hat{k}\ m^2$

Magnetic Flux = ϕ_B = ?

Since $\phi_B = \vec{B}\cdot\vec{A}$

$\phi_B = (40\hat{i} - 18\hat{k}).(5.0\times10^{-4}\,m^2\hat{k})$

$= 200\times10^{-4}\hat{i}.\hat{k} - 90\times10^{-4}\,m^2\,\hat{k}.\hat{k}$

$\phi_B = -90\times10^{-4}$ $(\because \hat{i}.\hat{k} = 0 \text{ and } \hat{k}.\hat{k} = 1)$

$\phi_B = 90\times10^{-4}$ Wb

Note:

Negative sign simply shows that the flux is going out of the surface

Example 14.3: **A solenoid 15.0 cm long has 300 turns of wire. A current of 5.0 A flows through it. What is the magnitude of magnetic field inside the solenoid?**

Solution:

Length of the solenoid = L = 15.0 cm = 0.15 m $(\because 1cm = \frac{1}{100} m)$

Number of turns of wire = N = 300

Current = I = 5.0 A

Permeability of free space = $\mu_0 = 4\pi\times10^{-7}$ Wb $A^{-1}m^{-1}$

Number of turns per unit length = $n = \frac{N}{L} = \frac{300}{0.15} = 2000\ m^{-1}$

Magnetic field = B = ?

By using the formula

$$B = \mu_0 nI$$

$B = 4 \times 3.14 \times 10^{-7} \times 2000 \times 5.0\ Wb\,m^{-2}$

$B = 1.3 \times 10^{-2}\ Wbm^{-2}$

Example 14.4: **Find the radius of an orbit of an electron moving at a rate of $2.0 \times 10^{7}\ ms^{-1}$ in a uniform magnetic field of 1.20×10^{3} T.**

Solution:

Speed of the electron	=	v	=	$2.0 \times 10^{7}\ m\,s^{-1}$
Strength of magnetic field	=	B	=	1.2×10^{3} T
Mass of the electron	=	m	=	9.11×10^{-31}
Charge on electron	=	e	=	1.61×10^{-19} C
Radius of the orbit	=	r	=	?

Radius of orbit is given by

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

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

$$r = \frac{9.11 \times 10^{-31} \times 2.0 \times 10^{7}}{1.61 \times 10^{-19} \times 1.20 \times 10^{-3}} = 9.43 \times 10^{2}\ m$$

Example 14.5: **Alpha particles ranging in speed from $1000\ ms^{-1}$ to $2000\ ms^{-1}$ enter into a velocity selector where the electric intensity is $300\ Vm^{-1}$ and the magnetic induction 0.20 T. Which particle will move undeviated through the field?**

Solution:

Electric intensity = E = $300\ Vm^{-1}$ = $300\ NC^{-1}$ $(\because Vm^{-1} = NC^{-1})$

Magnetic induction = B = 0.20 T

Selected speed of particle = v = ?

Since electric force eE acting on the particle balances the magnetic force BeV on the particles. Now using the relation

$$F_m = F_e$$

$$qvB = qE$$

$$v = \frac{E}{B}$$

$$v = \frac{300}{0.20} = 1500\ ms^{-1}$$

Thus, alpha particle having a speed of $1500\ ms^{-1}$ will move undeviated (in straight line) through the field

Example 14.6: **What shunt resistance must be connected across a galvanometer of 50.0 Ω resistance which gives full scale deflection with 2.0 mA current, so as to convert it into an ammeter of range 10.0 A?**

Solution:

Resistance of galvanometer	=	R_g	=	50.0Ω
Current for full scale deflection	=	I_g	=	2.0 mA = 2.0×10^{-3}A
Current to be measured	=	I	=	10.0 A
Shunt resistance	=	R_s	=	?

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

$$R_s = \frac{2.0 \times 10^{-3}}{10.0 - 2.0 \times 10^{-3}} \times 500 = 0.01\Omega$$

SOLUTION OF PROBLEMS

14.1 **Find the value of the magnetic field that will cause a maximum force of 7.0×10^{-3} N on a 20.0cm straight wire carrying a current of 10.0 A.**

Solution:

$F = 7.0 \times 10^{-3} N$

$L = 20 \text{ cm} = 20 \times 10^{-2} m$

$I = 10 A$

$B = ?$

Since $F = I L B$

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

$$B = \frac{7\times10^{-3}}{10\times20\times10^{-2}} = 3.5 \times 10^{-3} T$$

14.2 **How fast must a proton move in a magnetic field of 2.50×10^{-3} T such that the magnetic force is equal to its weight?**

Solution:

$B = 2.50 \times 10^{-3} T$

$e = 1.6 \times 10^{-19} C$

$g = 9.8 ms^{-2}$

$v = ?$

Given that the magnetic force and weight are equal in magnitude, so we can write

weight = magnetic force

$mg = q v B$

$$v = \frac{mg}{qB}$$

$$v = \frac{1.67\times10^{-27}\times9.8}{1.6\times10^{-19}\times2.5\times10^{-3}} = 4.09 \times 10^{-5} ms^{-1}$$

14.3 **A velocity selector has magnetic field of 0.30 T. If a perpendicular electric field of 10,000 Vm^{-1} is applied, what will be the speed of the particle that will pass through the selector?**

Solution:

$B = 0.30T$

$E = 10\,000 \; Vm^{-1}$

$\theta = 90^\circ$

$V = ?$

Since the magnitude of electric and magnetic force on the particle become equal in magnitude so we can write

$qE = qvB \sin\theta$

$E = vB \sin\theta$

$$v = \frac{E}{B\sin\theta}$$

$$v = \frac{10000}{0.30\times\sin 90^\circ} = 3.3 \times 10^{4} ms^{-1}$$

14.4 **A coil of 0.1 m × 0.1 m and of 200 turns carrying a current of 1.0 mA is placed in a uniform magnetic field of 0.1 T. Calculate the maximum torque that acts on the coil.**

Solution: $A = 0.1m \times 0.1m = 0.01 \; m^2$

N = 200 turns
I = 1 mA = 1×10^{-3} A
B = 0.1 T
τ_{max} = ?

$$\tau_{max} = BIAN\cos\alpha$$

For maximum torque $\alpha = 0^0$

$\tau_{max} = 0.1 \times 1 \times 10^{-3} \times 0.01 \times 200 \times \cos 0^0$

$\tau_{max} = 2 \times 10^{-4}$ Nm

14.5 A power line 10.0 m high carries a current 200 A. Find the magnetic field of the wire at the ground.

Solution: r = 10 m
I = 200 A
B = ?

According to Ampere's law

$$B = \frac{\mu_0 I}{2\pi r}$$

$B = \frac{4\pi \times 10^{-7} \times 200}{2\pi \times 10} = 4 \times 10^{-6}$ T

14.6 You are asked to design a solenoid that will give a magnetic field of 0.10T, yet the current must not exceed 10.0 A. Find the number of turns per unit length that the solenoid should have.

Solution: B = 0.10 T
I = 10 A

Permeability of free space = $\mu_0 = 4\pi \times 10^{-7}$ Wb $A^{-1}m^{-1}$

n = ?

Since $B = \mu_0 n I$

$$n = \frac{B}{\mu_0 I}$$

$n = \frac{0.10}{4\pi \times 10^{-7} \times 10} = 7.9567 \times 10^3$ turns/meter

14.7 What current should pass through a solenoid that is 0.5 m long with 10,000 turns of copper wire so that is will have a magnetic field of 0.4 T?

Solution: L = 0.50 m
N = 10,000 turns

$n = \frac{N}{L} = \frac{10000}{0.5} = 20000$ turns/meter

Permeability of free space = $\mu_0 = 4\pi \times 10^{-7}$ Wb $A^{-1}m^{-1}$

B = 0.4 T
I = ?

Since $B = \mu_0 n I$

$$I = \frac{B}{\mu_0 n}$$

$I = \frac{0.4}{4\pi \times 10^{-7} \times 20000} = 15.9150$ A

I = 16A

14.8 A galvanometer having an internal resistance $R_g = 15.0\ \Omega$ gives full scale deflection with current Ig = 20.0 mA. It is to be converted into an ammeter of range 10.0 A. Find the value of shunt resistance R_s.

Solution:

$R_g = 15\ \Omega$

$I_g = 20\text{ mA} = 20 \times 10^{-3}\text{ A}$

$I = 10\text{ A}$

$R_s = ?$

The formula for shunt resistance is,

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

$$R_s = \frac{20 \times 10^{-3} \times 15}{10 - 0.020} = 0.03\ \Omega$$

14.9 The resistance of a galvanometer is 50.0Ω and reads full scale deflection with a current of 2.0 mA. Show by a diagram, how to covert this galvanometer into voltmeter reading 200 V full scale.

Solution:

$R_g = 50\ \Omega$

$I_g = 2\text{mA} = 2 \times 10^{-3}\text{A}$

$V = 200\text{ volts}$

$R_h = ?$

The formula for the value of high resistance in case of voltmeter is,

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

$$R_h = \frac{200}{0.002} - 50 = 99950\ \Omega$$

14.10 The resistance of a galvanometer coil is 10.0 Ω and reads full scale with a current of 1.0mA. What should be the values of resistance R_1, R_2 and R_3 to convert this galvanometer into a multirange ammeter of 100, 10.0 and 1.0A as shown in the fig. 14.10?

Solution:

$R_g = 10\Omega$

$I_g = 1\text{mA} = 1 \times 10^{-3}$

$A = 0.001\text{ A}$

$I_1 = 100\text{ A}$

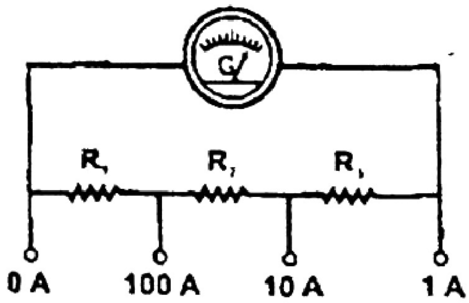
$I_2 = 10\text{ A}$

$I_3 = 1\text{A}$

$R_1 = ?$

$R_2 = ?$

$R_3 = ?$



The formula for shunt resistance is,

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

Since $R_1 = \frac{I_g R_g}{I_1 - I_g}$

$$R_1 = \frac{0.001 \times 10}{100 - 0.001} = 0.0001\ \Omega$$

Since $R_2 = \frac{I_g R_g}{I_2 - I_g}$

$$R_2 = \frac{0.001 \times 10}{10 - 0.001} = 0.001\ \Omega$$

Since $R_3 = \frac{I_g R_g}{I_3 - I_g}$

$$R_3 = \frac{0.001 \times 10}{1 - 0.001} = 0.01\ \Omega$$