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Second Year Physics

Chapter No 14 Electromagnetism

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Questions from Chapter

QUESTIONS AND ANSWERS FROM THE BOOK

Q.No.1: Define electromagnetism?

Ans: When current passes through a conductor, it produces a magnetic field arround it. This process is called electromagnetism.

Q.No.2: Write down the conclusions which are drawn when a magnetic field is produced due to a current in a long straight wire?

Ans: Following conclusions can be drawn from this experiment:

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

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

(iii) The magnetic field remains only as long as the current flowing through the wire.

Q.No.3: How the direction of magnetic field lines can be found produced due to current in a straight wire?

Ans: The direction of lines of force can be found by <u>right hand rule</u> mentioned below:

" If the wire is grasped in first of right hand with the thumb pointing in the direction of the current, the <u>fingers of the hand</u> will circle the wire in the <u>direction of magnetic field</u>"

Q.No.4: Upon what factors the force on a current carrying conductor in a uniform magnetic field depends?

Ans: The formula of force is given as $F = ILB\ sin\alpha$

The force depends upon

(i) Current flowing the circuit "I"

(ii) Length of the conductor "L"

(iii) Strength of the applied magnetic field "B"

(iv) $sin\alpha$ (where α is the angle between conductor and field)

Q.No.5: Define magnetic induction?

Ans:

Definition: Magnetic induction is defined as the force acting on one meter length of the conductor placed at right angle to the magnetic field when 1A current is passing through it.

Units: SI units of magnetic induction **B** are tesla.

Q.No.6: How you can locate the direction of magnetic force by right hand rule?

Ans: Formula for magnetic force is given as $\vec{F} = I\vec{L} \times \vec{B}$

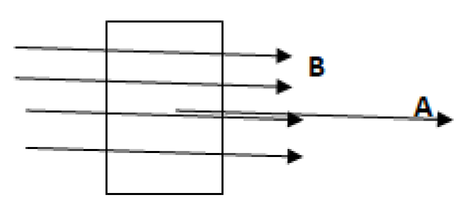
The direction of force **F** can locate correctly by the right hand rule of the cross product of vectors of **L** and **B** i-e. Rotate **L** to meet with **B** such that the curl of fingers of right hands in the direction of rotation. The thumb points the direction of force.

Q.No.7: Define magnetic flux? How you can get its maximum and minimum values?

Ans:

Definition: The magnetic flux is defined as the <u>number of magnetic field lines</u> passing through a <u>certain area.</u>

Formula: It is given by this formula as $\phi = \boldsymbol{B}.\boldsymbol{A} = BA\ cos\theta$

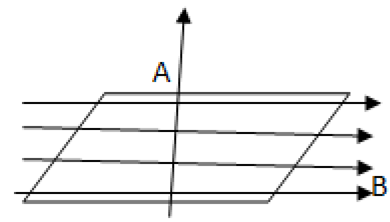


Maximum Flux:

When the <u>plane of the coil is perpendicular</u> to the magnetic field then angle between **B** and **A** becomes zero (θ=0°). Then value of flux will be <u>maximum.</u>

Mathematically

The magnetic flux is given as
$\phi = \boldsymbol{B}.\boldsymbol{A} = BA\, cos\theta$
$\phi = \boldsymbol{B}.\boldsymbol{A} = BA\, cos0^o$
$\phi = BA$
Minimum Flux:
When the plane of the coil is parallel to the magnetic field then angle between **B** and A becomes 90°. Then value of flux will be minimum.
Mathematically
The magnetic flux is given as
$\phi = \boldsymbol{B}.\boldsymbol{A} = BA\, cos\theta$
$\phi = \boldsymbol{B}.\boldsymbol{A} = BA\, cos90^o$
$\phi = 0$



Q.No.8: Define magnetic flux density?
Ans:
Definition: Magnetic flux per unit area is called flux density or magnetic induction **B**.
Formula: It is denoted as $B = \frac{\phi}{A}$
Units: its units are Wb/m^2
Q.No.9: State Ampere's Law?
Ans:
Statement: Ampere law states that sum of quantities B.ΔL for path elements of a loop is equal to the μ_o times the total current enclosed by that loop.
Formula: Mathematically this law can be represented as $\sum_{r=1}^{N}(B.\Delta L)_r = \mu_o I$
Q.No.10: Calculate the maximum as well as minimum force on a moving charge in a magnetic field?
Ans: The force on a moving charge in a magnetic field is given as $F = qvB\, sin\theta$ Where θ is the angle between charge and the field.
Maximum force: When charge is projected at right angle to magnetic field
Thus $\theta = 90^o$
So $F = qvB\, sin90^o = qvB$
which is maximum value of force.
Minimum force: When charge is projected in the direction of magnetic field thus $\theta = 0^o$ So $F = qvB\, sin0^o = 0$ which is minimum value of force.
Q.No.11: What do you know about Lorentz force?
Ans:
Definition: When a charge particle q moving with velocity **v** in an electric field **E** and a magnetic field **B** then the total force acing on it is the sum of electric force and magnetic force. Formula: Mathematically it is denoted as $\boldsymbol{F} = \boldsymbol{F_e} + \boldsymbol{F_b}$
This implies that $\boldsymbol{F} = q\boldsymbol{E} + q\,\boldsymbol{v} \times \boldsymbol{B}$
This force is known as Lorentz force.
Q.No.12: Differentiate between electric force and magnetic force?
Ans: There are some differences between electric and magnetic forces as mentioned below:

Electric force	Magnetic force
It is produced due to the presence of electric field	It is produced due to the presence of magnetic field.
It does work	It does not work. It is simple deflecting force
The electric force is denoted as **F**=q**E**	Magnetic force is denoted as **F**=q(**v**×**B**)

Q.No.13: Define CRO? Also write down it uses?

Ans:

Definition of CRO: It is an electronic instrument which is in fact a high speed graph plotting device.

Uses of CRO: The uses of CRO are following:

(i) CRO is used for displaying the waveform of a given voltage.

(ii) It is also used for measuring the voltage of displaying waveform as y-axis is calibrated in volts

(iii) It is also used for measuring the time period of displaying waveform as x-axis is calibrated in time

(iv) As by knowing the value of time period, the frequency of waveform can be calculated.

(v) The phase difference between two waveforms can also be find out by using CRO.

Q.No.14: Define sweep or time base generator? What is its role in CRO?

Ans:

Definition: The voltage in CRO is applied across the x-plates is usually provided by a circuit that is built in CRO. It is known as sweep or time base generator.

Role of Sweep/Time base generator:

Sweep or time base generator is basically used to draw the saw tooth wave on screen of CRO.

Q.No.15: Define Galvanometer? How many methods are commonly used for observing the angle of deflection of the coil?

Ans:

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

Methods for observing angle of deflection:

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

Q.No.16 What is principle for the working of galvanometer?

Ans: Its working depends upon the fact that when a conductor is placed in a magnetic field. It experience a force as soon as current passes through it. Due to this torque acts on the conductor as given $\tau = NIAB$

Q.No.17: Differentiate between deflecting and restoring torque?

Ans:

Deflecting torque	**Restoring torque:**
When a current passed through a coil, then a torque/couple is acted upon it which tends to rotate the coil. This is known as deflecting torque/couple.	As the coil turns under the action the deflecting couple the suspended wire is twisted then a restoring torque is applied to untwist the wire. This is called restoring torque
$deflecting\ couple = NIAB$	$restoring\ torque = c\theta$

Q.No.18: How the sensitivity of the galvanometer can be increased?

Ans: The sensitivity of the galvanometer can be increased by decreasing C or increasing B, A and N as describe in the given mentioned formula

$$\theta \propto \frac{NAB}{C}$$

Q.No.19: What do you know about stable or dead beat galvanometer?

Ans: Such a galvanometer in which coil comes to rest quickly after the current passing through it or the current is stopped from flowing through it is called stable or dead beat galvanometer.

Q.No.20: Define the following: Ammeter, Voltmeter, Ohmmeter?

Ans:

Ammeter: Ammeter is an electrical instrument which is used to measure the current in amperes. It is always connected in series of circuit.

Voltmeter: Voltmeter is an electrical instrument which is used to measure the potential difference in volts between two points. It is always connected parallel to the circuit

Ohm meter: Ohm-meter is an electrical instrument which is used to measure the resistance in ohms.

Q.No.21: What is term " meter-movement"?

Ans: The portion of the galvanometer whose motion causes the needle of the device to move across the scale is known as meter-movement.

AVO meter: It is

Q.No.22: What is AVO meter? Give its possible measuring parts?

Ans:

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

Measuring circuits: It has following three measuring circuits:

(i) voltage measuring part
(ii) current measuring part
(iii) resistance measuring part

Q.No.23: Explain digital multimeter?

Ans:

A device which is used to measure resistance, current and voltage is called digital multimeter. It a digital version of an AVO meter. It eliminates human errors and display values in decimals with great accuracy.

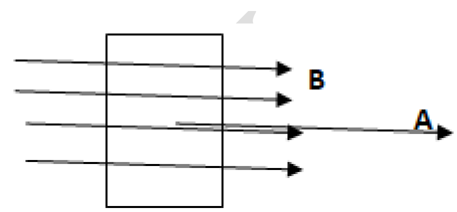
Exercise Questions

Q.No.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 a maximum? For what orientation is the flux a minimum?

Ans:

Definition: The magnetic flux is defined as the number of magnetic field lines passing through a certain area.

Formula: It is given by this formula as $\phi = \boldsymbol{B}.\boldsymbol{A} = BA\ cos\theta$



Maximum Flux:

When the plane of the coil is perpendicular to the magnetic field then angle between **B** and **A** becomes zero ($\theta=0^o$). Then value of flux will be maximum.

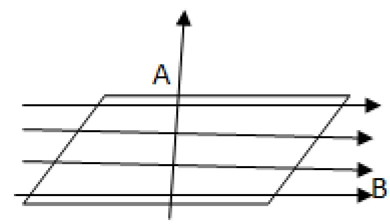
Mathematically

The magnetic flux is given as

$\phi = \boldsymbol{B}.\boldsymbol{A} = BA\ cos\theta$

$\phi = \boldsymbol{B}.\boldsymbol{A} = BA\ cos0^o$

$\phi = BA$



Minimum Flux:

When the plane of the coil is parallel to the magnetic field then angle between **B** and A becomes 90^o. Then value of flux will be minimum.

Mathematically

The magnetic flux is given as

$\phi = \boldsymbol{B}.\boldsymbol{A} = BA\ cos\theta$

$\phi = \boldsymbol{B}.\boldsymbol{A} = BA\ cos90^o$

$\phi = 0$

Q.No. 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 charges, what can you conclude about the magnetic field due to stationary charges? What about moving charges?

Ans:

Stationary Charges:

When charges are at rest then there is no flow of current so there is no magnetic field. Stationary charges can only produce electric field.

Moving Charges:

When charges are in motion then there is flow of current so magnetic field is produced by moving charges

Q.No. 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 (b) the number of turns is doubled, but the length remains the same.

Ans: Formula of magnetic field in a solenoid is given as

$B=\mu_o nI$

Where $n=N/L$

So $B=\mu_o NI/L$---------------(i)

(a) From equation (i) it is concluded that by doubling the length, magnetic field becomes half. Mathematically put L=2L

$B' = \mu_o NI/2L$

$B' = 1/2(\mu_o NI/L)$

$B' = B/2$

(b) From equation (i) it is concluded that by doubling the number of turns, magnetic field will also be doubled. Mathematically put N=2N

$B' = \mu_o 2NI/L$

$B' = 2(\mu_o NI/L)$

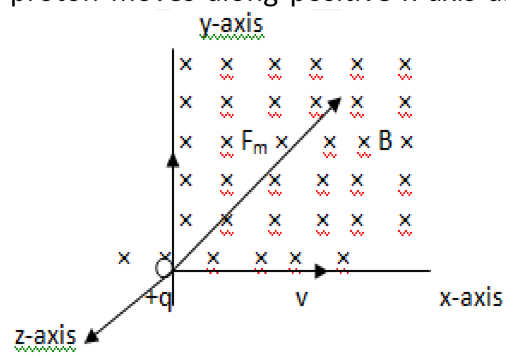
$B' = 2B$

Q.No.14.4: At a given instant, a proton moves in the positive x direction in a region where there is a magnetic files in the negative z direction. What is the direction of the magnetic force? Will the proton continue to move in the positive direction x direction? Explain

Ans: According to right hand rule, magnetic force is directed along y-axis. As the magnetic field is directed into the plane of paper (along negative z-axis) and proton moves along positive x-axis as shown in figure. The formula of magnetic force on the proton is given as **F**=q (**v**×**B**)

Thus magnetic force is directed along y-axis.

No the proton will not continue to move in the positive x-axis. As the magnetic force is at right angle to the motion of proton, therefore it will move along circular path in xy-plane



Q.No. 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 charges are opposite. Means one is positive charge and other is negative.

The magnetic force on the charges is given as $\boldsymbol{F} = q(\boldsymbol{v} \times \boldsymbol{B})$

According to right hand rule, the magnetic forces on the charges will only be opposite if they are opposite charges.

Q.No. 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 charge q?

Ans: There is no work done by the magnetic force because magnetic force and displacement covered by the particle will always perpendicular to each other

Mathematically explanation:

Magnetic force is given as $\boldsymbol{F} = q(\boldsymbol{v} \times \boldsymbol{B})$--------------------(i)

And the formula of work done is given as $W = \boldsymbol{F_m}.\boldsymbol{d}$ --------------------(ii)

According to equation (i) velocity is always perpendicular to the magnetic force and velocity and displacement are in same direction. Hence magnetic force and displacement are also perpendicular and that's why work done by magnetic force is always zero according to equation (ii).

Q.No. 14.7: If the charged particle moves in a straight line through some region of space, can you say that magnetic field in the region is zero?

Ans: If the charged particle moves in straight line through some region of space then it is not necessary that magnetic field is zero. But magnetic force should be zero as described below.

Magnetic force is given as $\boldsymbol{F} = q(\boldsymbol{v} \times \boldsymbol{B}) = qvB\ sin\theta$

Mathematical description: If the charged particle moves in a straight line $\theta = 0^o$ or $\theta = 180^o$

So $F = qvB\ sin0^o = 0$

Q.No. 14.8: Why does the picture on the TV screen become distorted when a magnet is brought near the screen?

Ans: Picture on the T.V screen becomes distorted due to the magnetic force applied by magnet. Picture on the T.V screen is due to motion of electrons. As a magnet is brought close to the T.V screen, the path of electrons is disturbed by magnetic force on them. So the picture on the T.V screen is distorted

Q.No. 14.9: Is it possible to orient a current loop in a uniform magnetic field such that the loop will not tend to rotate? Explain

Ans: If the coil is oriented in such a way that angle between plane of coil and magnetic field becomes 90^o then torque will be zero and loop will not tend to rotate.

Mathematically $\tau = NIAB\ cos\alpha$

As $\alpha = 90^o$

Then $\tau = NIAB\ cos 90^o = 0$

Q.No. 14.10: How can a current loop be used to determine the presence of a magnetic field in a given region of space?

Ans: When a current carrying conductor is placed in a uniform magnetic field then torque is produced in a loop due to current. If loop is deflected then it confirms the presence of magnetic field otherwise not.

Q.No. 14.11: How can you use a magnetic field to separate isotopes of chemical element?

Ans: e/m of ion is given as

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

This relation described that $m \propto r$

So ions of different masses will have different radii. Hence they can be separated by using magnetic field

Q.No. 14.12: What should be the orientation of a current carrying coil in a magnetic field so that torque acting on the coil is a (a) maximum (b) minimum?

Ans:

(a) Maximum torque:

If the plane of coil is parallel to the magnetic field then angle will be zero and torque will be maximum.

Mathematically $\tau = NIAB\ cos\alpha$

As $\alpha=0^o$ then $\tau = NIAB\ cos 0^o$

$\tau = NIAB$

(b) Minimum torque:

If the plane of coil is perpendicular to the magnetic field then angle will be 90^o and torque will be minimum.

Mathematically $\tau = NIAB\ cos\alpha$

As $\alpha=90^o$ then $\tau = NIAB\ cos 90^o$

$\tau = 0$

Q.No. 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 the direct current is put through the coil? What happens if an alternating current is used instead?

Ans:

If the loop of wire is suspended between the poles of a magnet with its plane parallel to the pole faces then there will be no affect of magnetic field and no torque will produced by direct current or alternating current.

But if there will be magnetic force on coil then following affects will occur:

Direct Current:

If the direct current is put through the coil then a torque will produce and it rotates the coil.

Alternating Current:

If an alternating current is put through the coil then it reversed the direction after each half cycle. Hence it oscillates the coil.

Q.No. 14.14: Why resistance of an ammeter should be very low?

Ans: An ammeter is always connected in series of the circuit to measure the current. All the current should pass through it. That's why resistance of ammeter is kept low so that it may not disturb the circuit current.

Q.No. 14.15: Why the voltmeter should have a very high resistance?

Ans: Voltmeter is always connected parallel to the circuit to measure voltage. Its resistance is kept high because little current should pass through it so that current of circuit will remain constant

Long Questions

14.4 AMPERE'S LAW AND MAGNETIC FIELD DUE TO CURRENT CARRYING SOLENOID:

AMPERE'S LAW:

This law states that "Sum of quantities $\boldsymbol{B}.\Delta\boldsymbol{L}$ for all path elements into which complete loop has been divided equals μ_o times the total current enclosed by the loop"

FORMULA:

It is mathematically expressed as

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

FIELD DUE TO CURRENT CARRYING SOLENOID:

Solenoid:

A long, tightly wound cylindrical coil of wire which behaves like bar magnet when current passes through it is called solenoid.

The magnetic field inside the solenoid is uniform and stronger whereas magnetic field is so weak outside the solenoid. So outside field can be neglected as compared to the field inside.

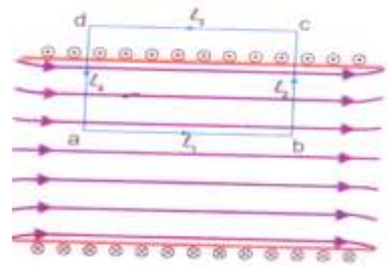
Determination of magnetic field:

The value of magnetic field can easily be determined by applying Ampere's circuital law. For that purpose, consider a rectangular loop abcd as shown in the figure. Divide it into four elements of length $ab = l_1$, $bc = l_2$, $cd = l_3$ and $da = l_4$.

By using Ampere's law, we have

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

$$(\boldsymbol{B}.\Delta\boldsymbol{L})_1 + (\boldsymbol{B}.\Delta\boldsymbol{L})_2 + (\boldsymbol{B}.\Delta\boldsymbol{L})_3 + (\boldsymbol{B}.\Delta\boldsymbol{L})_4 = \mu_o \times current\ enclosed \quad ----(i)$$



Calculation of values $\boldsymbol{B}.\Delta\boldsymbol{L}$:

Now we will calculate the value of $\boldsymbol{B}.\Delta\boldsymbol{L}$ for each of the element.

For element ab:

First we consider the element $ab = l_1$ that lies inside the solenoid. Field inside the solenoid is uniform and parallel to l_1 as shown in figure. So angle will be zero.

$$(\boldsymbol{B}.\Delta\boldsymbol{L})_1 = l_1 B\ cos0^o$$
$$(\boldsymbol{B}.\Delta\boldsymbol{L})_1 = l_1 B$$

For element cd:

The element $cd = l_3$ that lies outside the solenoid. Field outside the solenoid is zero.

$$(\boldsymbol{B}.\Delta\boldsymbol{L})_3 = l_3(0)\ cos\boldsymbol{\theta}$$
$$(\boldsymbol{B}.\Delta\boldsymbol{L})_3 = 0$$

For elements bc and ad:

The elements $bc = l_2$ and $da = l_4$ that lies inside the solenoid. But field inside the solenoid is perpendicular to l_2 and l_4 as shown in figure. So angle will be 90^o.

$$(\boldsymbol{B}.\Delta\boldsymbol{L})_2 = l_2 B\ cos90^o$$
$$(\boldsymbol{B}.\Delta\boldsymbol{L})_2 = 0$$

And

$$(\boldsymbol{B}.\Delta\boldsymbol{L})_4 = l_4 B\ cos90^o$$
$$(\boldsymbol{B}.\Delta\boldsymbol{L})_4 = 0$$

By putting all these values in equation (i) we get

$$l_1 B + 0 + 0 + 0 = \mu_o \times current\ enclosed$$
$$l_1 B = \mu_o \times current\ enclosed - - - - - (ii)$$

Determination of current:

If N is the number of turns of the solenoid then the total enclosed current will be NI. So equation (ii) can be written as

$$l_1 B = \mu_o NI$$

By rearranging

$$B = \mu_o \frac{N}{l_1} I$$

If n is the number of turns per unit length then $n = \frac{N}{l_1}$

So

$$B = \mu_o n\, I$$

Direction of magnetic field:

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

14.5 FORCE ON A MOVING CHARGE IN MAGNETIC FIELD :

INTRODUCTION:

We know that a current carrying conductor, when placed in a magnetic field, experiences a force. The current in the conductor is due to flow of charges. Actually the magnetic field exerts force on these moving charges. We are interested in calculating the force exerted on the moving charges

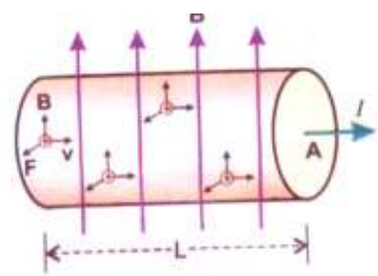
FORMULA:

It is mathematically expressed as

$$\boldsymbol{F} = q\, \boldsymbol{v} \times \boldsymbol{B}$$

CALCULATION:

Consider a segment of wire of length **L** and cross sectional area **A** as shown in the figure. Suppose there are n charge carriers per unit volume of the wire and that each is moving with velocity **v**.



Time taken by charge carrier:

We know that $S = vt$

So $t = \frac{S}{v}$

Assuming the speed of carriers to be v, so the time taken by the carrier form left to right face of wire will be

$$\Delta t = \frac{L}{v}$$

Net charge on the segment:

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

As each charge carrier has a charge q, the charge ΔQ that exits through the end area is

$$\Delta Q = n\, ALq$$

Current though segment:

Then from the definition of current we get

$$I = \frac{\Delta Q}{\Delta t} = \frac{n\, ALq}{L/v}$$

So

$$I = n\,Aqv$$

Magnetic force:

Force on a current carrying conductor is given as

$$\boldsymbol{F_L} = I\,\boldsymbol{L} \times \boldsymbol{B}$$

By putting the value of current we get

$$\boldsymbol{F_L} = n\,Aqv\,\boldsymbol{L} \times \boldsymbol{B} - - - -(i)$$

It can be seen that direction of segment **L** is same as the direction of velocity of charge carriers. So unit vectors of both **L** and **v** will be same then $\hat{L} = \hat{v}$

$$v\,\boldsymbol{L} = v\,\hat{L}\,L = v\,\hat{v}\,L = \boldsymbol{v}\,L$$

By putting in equation (i) we get

$$\boldsymbol{F_L} = n\,Aq\,(\boldsymbol{v}\,L) \times \boldsymbol{B}$$
$$\boldsymbol{F_L} = n\,AqL\,\boldsymbol{v} \times \boldsymbol{B}$$

$n\,AL$ is the total number of charge carriers in the segment L, so the force experienced by a single charge carrier is

$$F = \frac{F_L}{n\,AL}$$

So

$$\boldsymbol{F} = \frac{n\,AqL\,\boldsymbol{v} \times \boldsymbol{B}}{n\,AL} = q\,\boldsymbol{v} \times \boldsymbol{B}$$

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

$\boldsymbol{F} = q\,\boldsymbol{v} \times \boldsymbol{B}$

For electron:

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.

$$\boldsymbol{F} = -e\,\boldsymbol{v} \times \boldsymbol{B}$$

For proton:

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

$$\boldsymbol{F} = +e\,\boldsymbol{v} \times \boldsymbol{B}$$

DIRECTION OF FORCE:

In the case of proton or positive charge the direction of force is given by direction of vector $\boldsymbol{v} \times \boldsymbol{B}$. Rotate v to coincide with B through the smaller angle of rotation and curl the fingers of right hand in the direction of rotation. Thumb will point in the direction of force.

According to below mentioned figure, if a proton enters in to magnetic field along the direction of dotted line. It experiences a force in the upward direction according to right hand rule. The direction of force on a moving negative charge will be opposite to that of positive charge

CONCLUSION:

It is concluded that if charge particles are projected perpendicular to the direction of magnetic field then magnetic force will be maximum and given as $F = qvB\,sin90^o = qvB$. And if the charge particles are projected parallel or ant parallel to the direction of magnetic field then magnetic force will be minimum and given as $F = qvB\,sin0^o = 0$

14.7 DETERMINATION OF e/m OF AN ELECTRON:

INTRODUCTION:

J.J Thomson was the first scientist who measured charge to mass ratio (e/m) of an electron.

PRINCIPLE:

When a narrow beam of charge particles are projected at constant speed v across a magnetic field in a direction perpendicular to the field, the beam of particles experiences a force, which makes them move in a circular path

APPARATUS:

It consists of

(i) A glass tube
(ii) Electrodes
(iii) Tungsten filament

EXPLANATION:

Force on an electron:

This law considers a narrow beam of electrons moving with a constant speed v. A uniform magnetic field $\vec{B}$ is applied across the beam of electrons directed into the plane of paper. We know that the electron will experience a force

$$F = -e\,\vec{v} \times \vec{B} \qquad (1)$$

The direction of force will be perpendicular to both $\vec{v}$ and $\vec{B}$. This force will change the direction of the velocity. The magnitude of velocity will remain unchanged.

Magnitude of force:

The magnitude of force is

$$F = evB\sin\theta$$

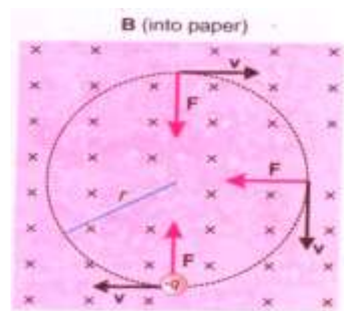
As $\theta = 90^o$

So $$F = evB \qquad (2)$$

Due to this magnetic force, electrons will move in a circle as shown in fig.

Magnetic force as a centripetal force:

This magnetic force provides the centripetal force which is represented as



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

As the magnetic force acts as a centripetal force so

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

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

$$\frac{e}{m} = \frac{v}{Br} \qquad (3)$$

if v and r are known, $\frac{e}{m}$ of the electron can be calculated.

Determination of 'r':

The radius r is measured by making the beam of electrons 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 of a uniform magnetic field of known value.

As the electrons begin to move in a circle under the action of magnetic force as shown in fig, the electrons will collide with the gas molecules and as a result, light will be emitted due to de-excitation of atoms. This will produce visible ring. The diameter of the ring can be measured and thus we can get r.

Suppose the electron is accelerated through a potential difference 'V' then energy gained by the electron is represented as

$$K.E = eV \quad (4)$$

This energy is equal to the K.E. of the electron.

$$\frac{1}{2}mv^2 = eV \quad (5)$$

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

By squaring equation number (3) we get

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

By putting the value v^2 in above mentioned equation we get

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

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

So in order to measure the velocity v of electrons, we should know the potential difference through which the electrons are accelerated before entering into the magnetic field.

So by knowing the values of magnetic filed **B**, applied potential V and radius r we can measure the e/m of electron.

Numerical value of e/m:

After substituting the values in above mentioned equation we get

$$e/m = 1.75888 \times 10^{11}\, C/kg$$

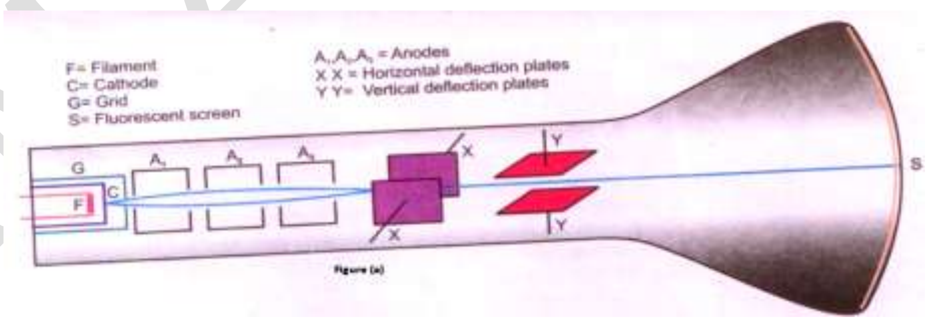
14.8 CATHODE RAYS OSCILLOSCOPE:

INTRODUCTION:

CRO is a high speed graph potting device. It is very versatile electronic instrument. It is very accurate but expensive device.

PRINCIPLE:

It works by deflecting beam of electrons as they pass through uniform electric field between the sets of parallel plates as shown in the figure (a).



APPARATUS:

It consists of

- (i) Filament
- (ii) Grid
- (iii) Cathode
- (iv) Anodes
- (v) Fluorescent screen
- (vi) Horizontal deflecting plates
- (vii) Vertical deflecting plates

EXPLANATION:

It can display graphs of functions which vary with time rapidly. It is called cathode rays oscilloscope because it traces the desired waveform with a beam of electrons which are also called cathode rays.

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

Role of filament and Grid:

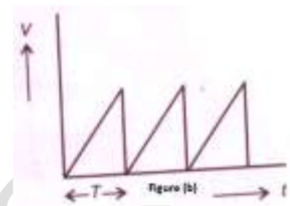
The filament F heats the cathode C which emits electrons. The grid is at negative potential with respect to cathode. It controls the number of electrons which are accelerated by anodes, and thus it controls the brightness of the spot formed on the screen.

Role of Anodes:

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

WAVEFORM OF VARIOUS VOLTAGES:

Now we would explain how the waveform of various voltages is formed in CRO. The two set of deflecting plates shown in the fig (b) which are usually referred as x and y deflecting plates.



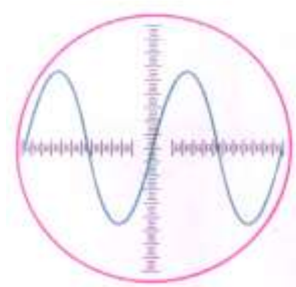
Sweep or time base generator:

The voltage that is applied across the x plates is usually provided by a circuit. This is called sweep or time base generator. Its output form is tooth wave form as shown in figure. The voltage increases linearly and then drops to zero.

Saw tooth wave:

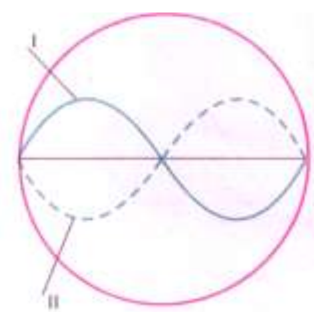
As the voltage is applied across x plates then spot on screen deflected linearly with time and then returns quickly to its initial value and there will be a saw tooth wave in the result.

Sine wave:



If a sinusoidal voltage is applied across the y plates at the same time as the time base voltage is applied across x plates. So due to both voltages across x plates and y plates the point on the screen will deflect horizontally as well vertically. Then a sine wave will be produced on the screen. But it is necessary to synchronize the frequency of the time base generator with the frequency of voltage across y plates. This is possible by adjusting the synchronization controls provided on the front panel of the CRO.

USES OF CRO:



The CRO is used

i. For displaying the waveform of a given voltage
ii. To measure the voltage of waveform. Y axis is calibrated in volt
iii. To measure the frequency of waveform
iv. To measure the time period of wave form. X axis is calibrated in time
v. To measure instantaneous and peak values of voltage
vi. To find out the phase difference between two voltages.
The phase difference between two voltages is 180^{o} as shown in the figure

14.9 TORQUE ON CURRENT CARRYING COIL:

INTRODUCTION:

When a current carrying conductor is placed in a uniform magnetic field then it experiences a force as well torque on the coil which rotates the coil. Let us calculate the value of that torque.

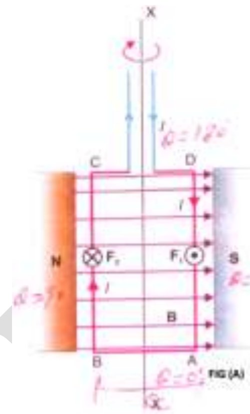
EXPLANATION:

Consider a rectangular coil carrying current I. The coil can rotate about an axis. Suppose it is placed in a uniform magnetic field **B** as shown in the figure (a).

Magnetic force:

We know that when a current carrying conductor placed in a uniform magnetic field experiences a force which is described as

$$F = ILB\ sin\theta$$



Where θ is the angle between conductor and magnetic field.

The rectangular coil consists of four sides AB, BC, CD and DA. Let us calculate the magnetic force on each side.

Force of sides AB and CD:

In case of sides AB and CD of the coil, the angle is zero or 180^o. So the force on these sides will be zero as described below.

$$F = ILB\ sin0^o = ILB\ sin180^o = 0$$

Force of sides DA and BC:

In case of sides DA and BC, the angle is 90^o and force on these sides is will be maximum which is described as

$$F_1 = F_2 = ILB\ sin90^o = ILB$$

Where L is the length of these sides. $\mathbf{F_1}$ is the force on the side DA and $\mathbf{F_2}$ on BC.

Direction of force:

The direction of force is determined is the applying the right hand rule using the formula $I\boldsymbol{L} \times \boldsymbol{B}$**.** It can be seen that $\mathbf{F_1}$ is directed out of the plane of paper and $\mathbf{F_2}$ into the plane of paper as shown in the figure (a)

Couple:

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

When field is parallel to plane:

The torque of this couple is given by

$$\tau = Force \times Moment\ arm$$

$$\tau = ILB \times a$$

Where a is the moment arm of the couple and is equal to the length of the side AB or CD

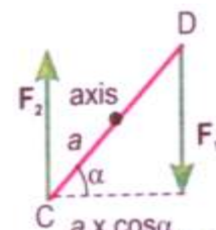
By rearranging above mentioned equation we get

$$\tau = IB(La)$$

Where La is equal to area A. So final torque will be

$$\tau = IBA$$

When field is at some angle to plane:



FIG(B)

If the field makes an angle α with the plane of coil as shown in figure (b) then moment arm now becomes a cosα.

So

$$\tau = ILB \times a\ cos\alpha$$

$$\tau = IB(La)\ cos\alpha$$

Bt substituting the value of area we get

$$\tau = IBA\ cos\alpha$$

APPLICATIONS :

Due to the action of this torque mentioned above, the coil rotates and this phenomenon leads to the working of galvanometer and motor.

14.10 GALVANOMETER:

DEFINITION:

An electrical device which is used to measure and detect the passage of the current is called galvanometer.

PRINCIPLE:

Its working depends upon the fact that when a conductor is placed in a magnetic field, it experiences a force as soon as current passing through it. Due to this force a torque τ acts upon the conductor if it is in form of a coil or loop.

$$\tau = NIBA\ cos\alpha$$

Where N is the number of turns in the coil, A is the area and $I$is the current passing through it, B is the magnetic field in which coil is placed.

CONSTRUCTION:

The construction of moving coil galvanometer is shown in Fig. A rectangular coil C is suspended between north and south poles of U- shaped magnetic. The rectangular coil is made of copper wire. The suspension wire is also used so serve the current. A soft iron is placed inside the coil is real and stronger.

EXPLANATION:

Deflecting couple:

When current is passed through the coil, a couple is produced which tend to rotate the coil. This couple is known as deflecting couple and represented as

$$\tau = NIAB\ cos\alpha$$

As the plane of the coil is placed parallel to the magnetic field so α is zero. So the deflecting couple will be maximum as given below

$$\tau = NIAB$$

Restoring torque:

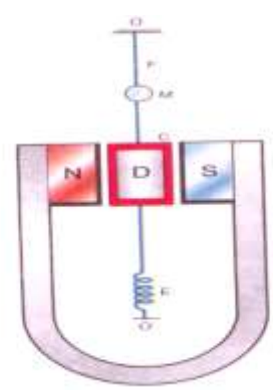
As the coil turns under the action of deflecting couple, the suspended wire is twisted which give rise to tensional couple. It tends to untwist and restore the coil in its original position. So this couple is known as restoring couple.

The restoring couple of the wire is directly proportional to the angle of deflection $\boldsymbol{\theta}$ as long as the suspension wire obeys Hook's law.

Thus $$Restoring\ torque = c\theta$$

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

Effects of two couples:



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

$$Deflecting\ couple = Restoring\ couple$$

$$NIAB = c\theta$$

Or

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

Since $\frac{c}{BAN}$ is the constant value thus

$$I \propto \theta$$

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

Methods for observing angle of deflection:

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

i. In sensitive galvanometer the angle of deflection is observed by means of small mirror attached to the coil along with a lamp and scale arrangement
ii. Other is pivoted type galvanometer in which coil is pivoted between two bearings. This type of galvanometer is mostly used in school and college laboratories.

Sensitivity of galvanometer:

Sensitivity of galvanometer means to give large deflection for a given current. So the galvanometer can be made more sensitive if $c/_{BAN}$ is made small. Thus to increase the sensitivity of galvanometer, c may be decreased or B, A and N may be increased.

But there is limitation in decreasing c or increasing A and N. It is more convenient to increase the magnetic field.

Stable or dead beat galvanometer:

Such a galvanometer in which the coil comes to rest quickly after the current passed through it or the current stopped flowing through it, is called stable or dead beat galvanometer. This type of galvanometer prevents from time consuming which is used for the coil come to rest.

APPLICATIONS:

A galvanometer is electromechanical instrument for detecting and measuring the electric current. The most common use of galvanometer is as analog measuring instruments called ammeter, voltammeter and ohmmeter.

NUMERICALS

Numerical 14.1: Find the value of magnetic field that will cause a maximum force of $7.0 \times 10^{-3}\ N$ On 20 cm straight wire carrying a current of 10.0A .

Solution:

$\mathrm{F} = 7.0 \times 10^{-3}\ \mathrm{N}$ $\quad \mathrm{L} = 20\ \mathrm{cm} = \frac{20}{100}\mathrm{m} = 0.2\ \mathrm{m}$

$\mathrm{I} = 10.0\ \mathrm{A}$ $\quad B = ?$

Maximum magnetic force is given as

$$F = ILB$$

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

$$B = \frac{7.0 \times 10^{-3}}{(10.0)(0.2)} T$$

$$\boxed{B = 3.5 \times 10^{-3}\ \mathrm{T}}$$

Numerical 14.2: How fast must a proton move in magnetic field of $2.50 \times 10^{-3}\ T$ such that magnetic force is equal to its weight?

Solution:

$\mathrm{B} = 2.50 \times 10^{-3}\ \mathrm{T}$ $\quad \mathrm{m} = 1.67 \times 10^{-27}\mathrm{kg}$

$\mathrm{q} = 1.6 \times 10^{-19}\ \mathrm{C}$ $\quad v = ?$

As magnetic force equals the weight so

$$F_m = F_g$$

$$qvB = mg$$

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

$$v = \frac{(1.67 \times 10^{-27})(9.8)}{(1.6 \times 10^{-19})(2.50 \times 10^{-3})} m/s$$

$$v = \frac{(1.64 \times 10^{-26})}{(4 \times 10^{-22})} m/s$$

$$\boxed{B = 4.09 \times 10^{-5}\ \mathrm{m/s}}$$

Numerical 14.3: A velocity selector has a magnetic field of 0.30 T. If a perpendicular electric field of 10000 V/m is applied, what will be the speed if the particle that will pass througxvh the selector?

Solution:

$\mathrm{B} = 0.30\ \mathrm{T}$ $\quad E = 10000\ V/m$

$v = ?$

As magnetic force equals the electric force so

$$F_m = F_e$$

$$qvB = qE$$

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

$$v = \frac{10000}{0.30} m/s$$

$$\boxed{v = 3.3 \times 10^4\ \mathrm{m/s}}$$

Numerical 14.4: A coil of $0.1m \times 0.1m$ 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:

$\mathrm{A} = 0.1m \times 0.1m = 0.01\mathrm{m}^2$

$\mathrm{I} = 1.0\ \mathrm{mA} = 1.0 \times 10^{-3}\mathrm{A}$ $\quad N = 200$

$B = 0.1\ T$ $\quad \tau = ?$

Maximum torque is given as

$$\tau = (200)(1.0 \times 10^{-3})(0.01)(0.1)Nm$$

$$\boxed{\tau = 2.0 \times 10^{-4}\ \mathrm{Nm}}$$

Numerical 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:

$\mathrm{r} = 10.0\ \mathrm{m}$ $\quad \mu_o = 4\pi \times 10^{-7}\ WbA^{-1}m^{-1}$

$\mathrm{I} = 200\ \mathrm{A}$ $\quad B = ?$

Formula for magnetic field is given as

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

$$B = \frac{(4\pi \times 10^{-7})(200)}{2\pi(10.0)} T$$

$$\boxed{B = 4.0 \times 10^{-6}\ \mathrm{T}}$$

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

Solution:

$\mathrm{I} = 10.0\ \mathrm{A}$ $\quad B = 0.10\ T$

$n = ?$ $\quad \mu_o = 4\pi \times 10^{-7}\ WbA^{-1}m^{-1}$

Formula for magnetic field in solenoid is given as

$$B = \mu_o nI$$

$$0.10 = (4\pi \times 10^{-7})n(10.0)$$

$$n = \frac{0.10}{(4\pi \times 10^{-7})(10.0)}$$

$$\boxed{n = 7.96 \times 10^3}$$

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

Solution:

$I = ?$ $B = 0.4\,T$

$N = 10000$ $L = 0.5\,m$

$\mu_o = 4\pi \times 10^{-7}\,WbA^{-1}m^{-1}$

Formula for magnetic field in solenoid is given as

$$B = \mu_o nI$$

Where

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

So

$$B = \mu_o \frac{N}{L} I$$

$$I = \frac{BL}{\mu_o N}$$

$$I = \frac{(0.4)(0.5)}{(4\pi \times 10^{-7})(10000)} A$$

$$\boxed{I = 16.0\,A}$$

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

Solution:

$R_g = 15.0\,\Omega$ $I_g = 20.0\,mA = 20.0 \times 10^{-3}\,A$

$I = 10.0\,A$ $R_s = ?$

Formula for shunt resistance is given as

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

$$R_s = \frac{(20.0 \times 10^{-3})(15.0)}{10.0 - 20.0 \times 10^{-3}} \Omega$$

$$\boxed{R_s = 0.30\Omega}$$

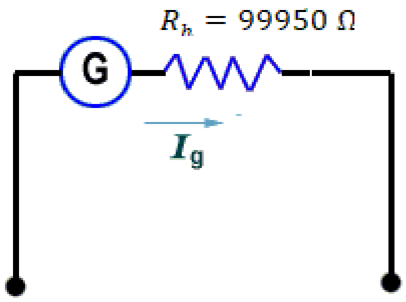
Numerical 14.9: The resistance of galvanometer is 50.0 Ω and reads full scale deflection with a current of 2.0 mA. Show by a diagram how to convert this galvanometer into voltmeter reading 200 V full scale.

Solution:

$R_g = 50.0\,\Omega$ $I_g = 2\,mA = 2 \times 10^{-3}\,A$

$V = 200\,V$ $R_h = ?$

Formula for shunt resistance is given as



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

$$R_h = \frac{200}{2 \times 10^{-3}} - 50.0\,\Omega$$

$$\boxed{R_h = 99950\,\Omega}$$