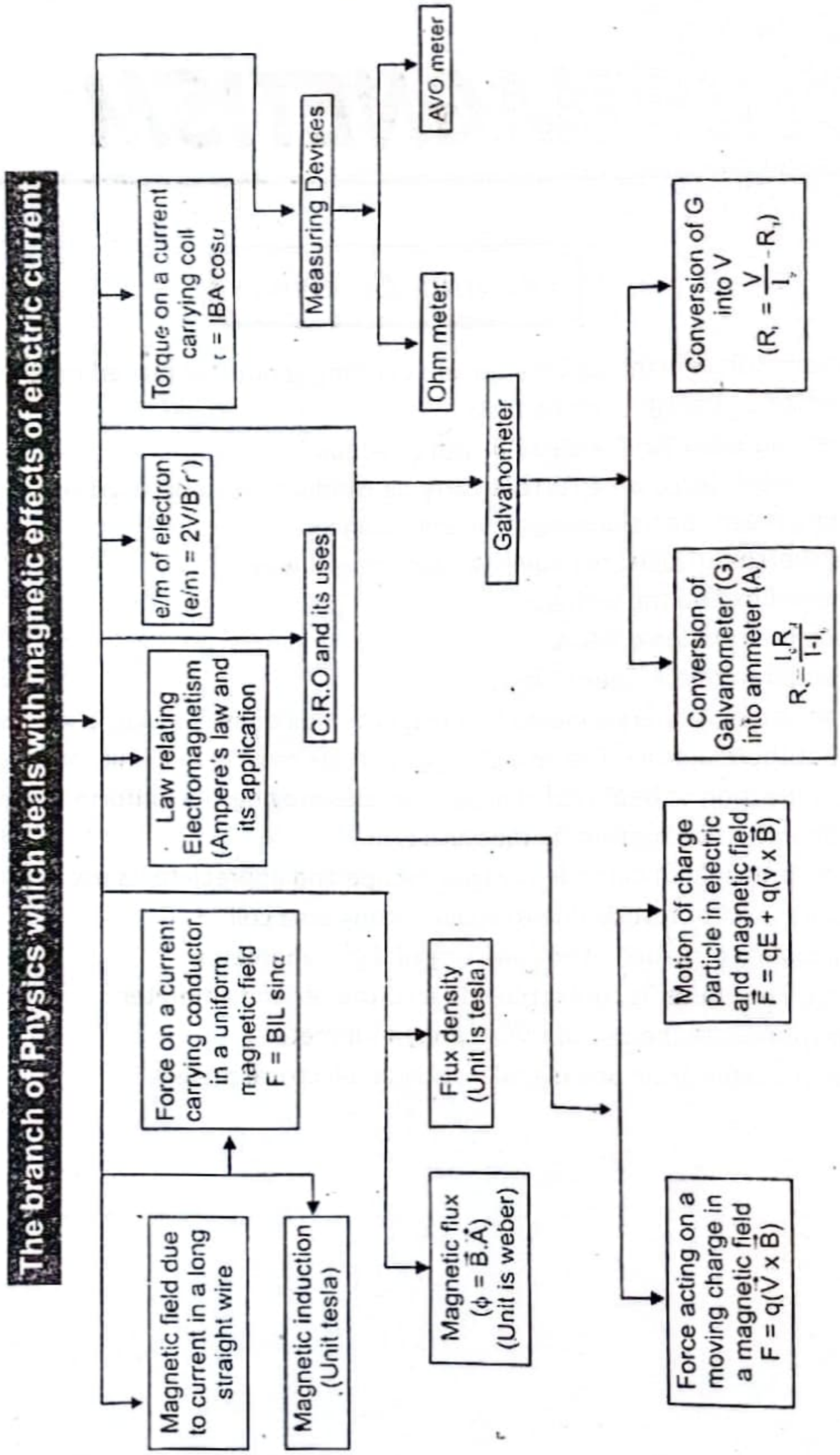
CHAPTER 14

ELECTROMAGNETISM

Learning Objectives

- Appreciate that a force might act on a current carrying conductor placed magnetic filed.
- Define magnetic flux density and the tesla.
- Derive and use the equation F = BIL sinθ with direction.
- Understand how the force on a current carrying conductor can be used to measure the magnetic flux density of a magnetic field using a current balance.
- Describe and sketch flux patterns due to a long straight wire.
- Define magnetic flux and the weber.
- Derive and use the relation $\phi = \mathbf{B.A}$.
- Understand and describe Ampere's law.
- Appreciate the use of Ampere's law to find magnetic flux density inside a solenoid.
- Appreciate that there acts a force on a charged particle moving in a uniform magnetic field.
- Describe the deflection of beams of charged particles moving in a uniform magnetic field.
- Understand and describe method to measure e/m.
- Know the basic principle of cathode ray oscilloscope and appreciate its use.
- Derive the expression of torque due to couple acting on a coil.
- Know the principle, construction and working of a galvanometer.
- Know how a galvanometer is converted into a voltmeter and ammeter.
- Describe and appreciate the use of AVO meter/multimeter.
- Read through analogue scale and digital display on electrical meters.

CONCEPT MAP

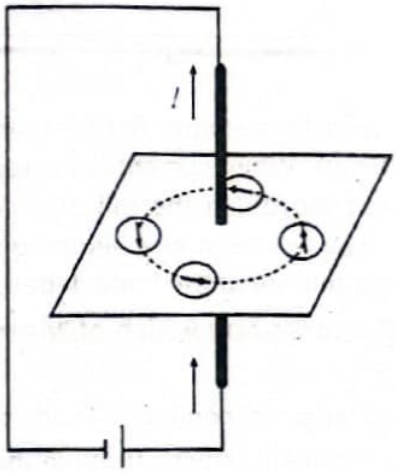


EIECTROMAGNETISM
The branch of Physics which deals with magnetic effects of electric current
Magnetic field due to current in a long straight wire
Magnetic induction (Unit tesla)
Force on a current carrying conductor in a uniform magnetic field F = BIL sinα
Magnetic flux (ϕ = B.A) (Unit is weber)
Flux density (Unit is tesla)
Law relating Electromagnetism (Ampere's law and its application
e/m of electron (e/m = 2V/B²r²)
C.R.O and its uses
Torque on a current carrying coil τ = IBA cosα
Measuring Devices
AVO meter
Ohm meter
Galvanometer
Conversion of G into V
Conversion of Galvanometer (G) into ammeter (A)
Motion of charge particle in electric and magnetic field F = qE + q(v x B)
Force acting on a moving charge in a magnetic field F = q(V x B)

An electric current through a conductor, produces the magnetic field around it. The magnetic effect of current is called electromagnetism. In the same way, when the magnetic field changes, it produces the electric current. ***Electromagnetism is the branch of physics which inter-relates electricity and magnetism.***

Q.1 How can we describe the Magnetic Field Due to Current Carrying Conductor?

Ans.

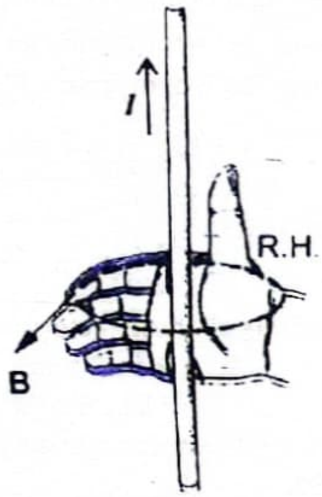


MAGNETIC FIELD DUE TO CURRENT IN A LONG STRAIGHT WIRE

Prof. Hans Oersted firstly described the magnetic field due to current in a wire in 1820.

Experiment

- Take a copper wire that passes vertically through a horizontal piece of card board.
- Place small magnetic compass needles on the card board along a circle with centre at the wire.
- All the compass needles point in the direction of north-south. When a heavy current passes through wire, the compass needles set themselves along the tangent to the circle.
- Reverse the direction of current, the direction of needles is also reversed.
- When the current though the wire is stopped, all the needles again point in the north south direction



Conclusions

i) A magnetic field is set up around current carrying conductor.

ii) The lines of forces 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 it.

Direction of Magnetic Field

The direction of magnetic field can be determined by right hand rule.

Right hand rule

If the wire is grasped in the fist of right hand with the thumb pointing in the direction of current, then the curled fingers indicate the direction of magnetic field.

Q.2 Determine the Expression for the Force on a Current Carrying Conductor in Uniform Magnetic Field. Also Define Magnetic Induction. **Lhr 2015 Rwp 2015 D.G.Khan 2009**

Ans. L.Q

FORCE ON CURRENT CARRYING CONDUCTOR IN A UNIFORM MAGNETIC FIELD

A current carrying conductor has its own magnetic field but when it is placed in an external magnetic field. Then as a result of interaction between these two magnetic fields, a force may be experienced by the conductor.

Explanation

Consider a copper rod capable to move along a pair of copper rails. The whole arrangement is placed between the pole pieces of horse-shoe magnet. So the uniform magnetic field acts on the rod in vertical upward direction.

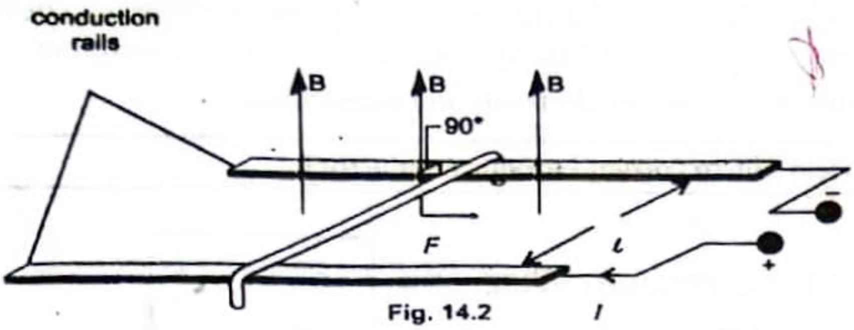


Fig. 14.2

Consider a copper rod that can move on a pair of copper rails as shown in figure. When current is passed through the copper rod by a battery, the rod moves on the rail. *It is found that the direction of force is at right angle to the plane containing the rod and direction of magnetic field.* The magnitude of the force depends upon the following factors.

Factors upon which of Magnitude of Force Depends

If

L= length of conductor inside the magnetic field.

I = current flowing through the conductor.

B = strength of magnetic field applied

α = angle between conductor and the field

F = magnitude of magnetic force acting on the conductor

Then,

$F \propto \sin\alpha$ ________ (i)

$F \propto I$ ________ (ii)

$F \propto L$ ________ (ii)

$F \propto B$ ________ (iv)

Combining all these factors, we get.

$F \propto I\,L\,B\sin\alpha$

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

Where k is the proportionality constant and in SI system its value is equal to 1. So,

$$\boxed{F = I\,L\,B\sin\alpha} \quad \text{\_\_\_\_\_\_\_\_ (1)}$$

Vector Form

In vector form, the force acting on a current carrying conductor is given by

$$\vec{F} = I\,L\,B\sin\alpha\,\hat{n}$$

OR

$$\boxed{\vec{F} = I(\vec{L}\times\vec{B})} \quad \text{\_\_\_\_\_\_\_\_ (2)}$$

Special cases

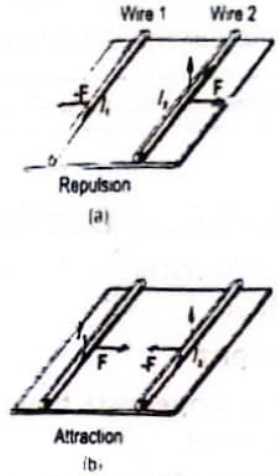
1. If $\alpha = 0°$ i.e. the rod is parallel to the field, Then

$F = I\,L\,B\sin 0°$

$F = I\,L\,B\,(0)$

$F = 0$ [zero]

Do You Know?



(a) Two long parallel wires carrying currents I_1 and I_2 in opposite direction repeal each other. (b) The wires attract each other when the currents are in the same direction

Warning

Many electromagnetic devices are very sensitive to magnetic fields. You can easily ruin your television screen, scramble your credit card or erase your hard drive by bringing a magnet too close to it. Keep all magnets far away from anything with a screen or a memory.

Use of Electromagnets

Electromagnets are primarily used to **move things** and to **store information**. They are used to move things because a magnetic field will physically repel iron and certain other materials, Magnets are used to store information because many materials will absorb and store a magnetic field. The field can then be read back by a magnetic reader when the information is needed again. Many mediums--from audiotapes to memory sticks--use magnets in this way.

2. If $\alpha = 90^\circ$ i.e. the rod is **right angle** to the field then

$$F = I L B \sin 90^\circ$$
$$F = I L B (1)$$
$$F = I L B \quad \text{[maximum]}$$

Direction of magnetic force

The direction of force can also be determined by right hand rule as follows,

Right Hand Rule

Join the tails of vectors $\vec{L}$ and $\vec{B}$. Rotate the vector $\vec{L}$ towards $\vec{B}$ through the smaller angle.

Curl the fingers of right hand in the direction of rotation. The erect thumb indicates the direction of force.

Extension of Right Hand Rule

This rule is often referred as extension of right hand rule.

Physical view to develop the magnetic force

Consider a straight current carrying wire placed at right angle to the magnetic field. Let the current is flowing out of the paper. The two fields tend to reinforce each other on left hand side of the conductor and cancel each other on the right side. So the conductors tend 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.

Magnetic Induction

(Magnetic Field Strength, magnetic flux density)

As we know,

$$F = ILB \sin\alpha$$

By putting, $I = 1A$, $L = 1\,m$ and $\alpha = 90^\circ$

$$F = B(1)(1)\sin 90^\circ$$

OR $F = B$

Definition

Magnetic field strength can be defined as,

The magnetic force on one meter length of a conductor, carrying one ampere current placed at right angle to the magnetic field.

Unit

The SI unit of magnetic induction is tesla.

tesla

The magnetic induction is said to be one tesla if it exerts one newton force on conductor of length one meter placed at right angle to the field, when one ampere current passes through it. SQ

$$1\ \text{tesla} = \frac{1\ \text{newton}}{1\ \text{ampere} \times 1\ \text{meter}}$$

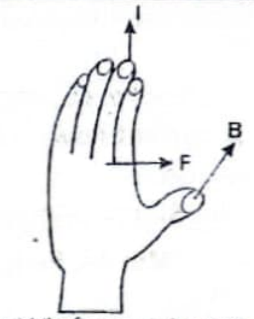
OR $$\boxed{1T = 1\,NA^{-1}m^{-1}}$$

Note

The smaller unit of magnetic induction is **Gauss**.

$$1\text{tesla} = 10^4\ \text{Gauss}$$

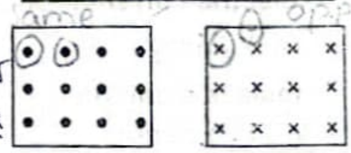
Do You Know?



If the middle finger of the 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

For Your Information

for same opposite



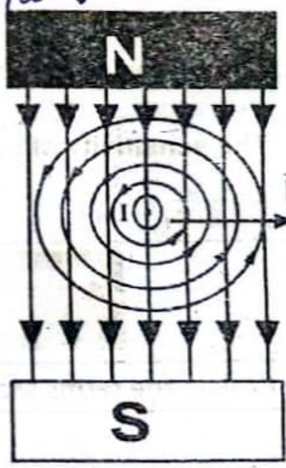
weak
strong

Out of page Into page

attraction weak

Convention to represent direction

strong b/w center



The magnetic force on the current carrying conductor placed at right angle to a magnetic field.

Electromagnets

Electromagnets are particularly useful for doing electromechanical work such as lifting, pulling, rotating or holding.

MCQ's From Past Board Papers

1. **Two parallel straight wires carrying current in same direction will:** **(Mirpur 2014, Swl 2015, Bwp 2014, Fed 2014)**
(A) repel each other (B) attract each other (C) no effect (D) may repel or attract

2. **A current flowing towards the reader be denoted by:** **(D.G.Khan 2014 Mtn 2015 G – I)**
(A) Cross (B) A bracket (C) A dot (D) Positive sign

3. **The SI unit of magnetic induction tesla is equal to:** **(Mtn 14, Federal 12, Lhr 14 G I , 15 G – I Mtn 15 G – II, D. G. Khan 15 G – II, Grw 15, Fsd 2016)**
(A) $NA^{-1}m^{-1}$ (B) Nam^{-1} (C) $NA^{-1}m$ (D) $NA^{-2}m^{-1}$

4. **One henry is equal to:** **(Lhr 2011 G – II)**
(A) $Vs^{-1}A$ (B) NmA^{-1} (C) $V^{-1}sA$ (D) VsA^{-1}

5. **If fingers of right show the direction of magnetic field and palm shows the direction of force then thumb points for:** **(Grw 2013 G I))**
(A) Torque (B) voltage (C) current (D) inducted emf

6. **Electric current produces magnetic field was suggested by:** **(Rwp 2015 Grw 2013 G I)**
(A) Faraday (B) Oersted (C) Henry (D) Lenz

7. **tesla is a unit of:** **(Rwp 2014, Mir-II-13/1)**
(A) Flux density (B) Magnetic flux (C) Self inductance (D) Mutual inductance

8. **Two parallel wires carrying current in the same direction:** **(Grw 2016)**
(A) attract each other (B) repel each other (C) cancel their fields (D) no effect on each other

9. **_____ is correct relation.** **(Mtn 2016 Group I)**
(A) $1T = 10^4 G$ (B) $1T = 10^{-4} G$ (C) $1T = 10^{-2} G$ (D) $1T = 10^2 G$

10. **The SI unit of magnetic induction is:-** **(Mtn 2016 Group II)**
(A) Weber (B) Tesla (C) Gauss (D) Newton

11. **The sensitivity of galvanometer is given by** **(Swl 2016)**
(A) $\frac{C}{BAN}$ (B) $\frac{BAN}{C}$ (C) $\frac{CAN}{B}$ (D) $\frac{B}{CAN}$

Answer Keys												
	1.	B	2.	C	3.	A	4.	D	5.	C	6.	B
	7.	A	8.	A	9.	A	10.	B	11.	B		

Q.3 Explain the terms Magnetic Flux and Magnetic Flux Density.

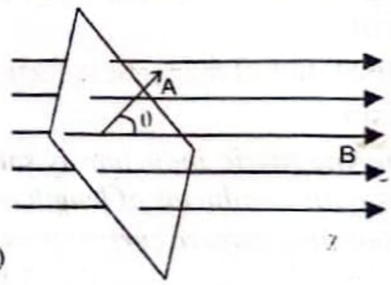
Ans.

MAGNETIC FLUX

The number of magnetic lines of force passing through certain element of area is called magnetic flux.

OR

Magnetic flux through a plane area is defined as *the scalar product of uniform magnetic field and vector area.*

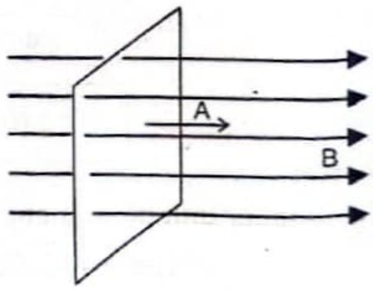


(a)

Mathematically,

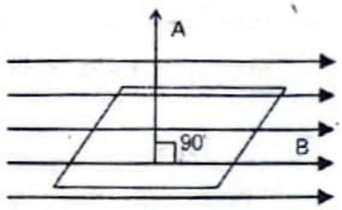
$$\boxed{\Phi_B = \vec{B} \cdot \vec{A}}$$

OR $\Phi_B = BA\cos\theta$



(b)

Where $\vec{A}$ is the vector area, whose magnitude is equal to the area of



(c)

surface and direction is along the normal to the surface of the element. θ is the angle between the direction of the vector $\vec{B}$ and $\vec{A}$.

Special Cases

(i) Maximum flux

If the area is held **perpendicular** the magnetic field lines perpendicular to area and parallel to A ?

i.e. $\theta = 0^\circ$

Then $\Phi_B = B\,A\cos 0^\circ$

$\Phi_B = B\,A\,(1)$

$\Phi_B = B\,A$

(ii) Minimum flux

If the area is held **parallel** to the magnetic field lines are parallel to area and perpendicular to A?

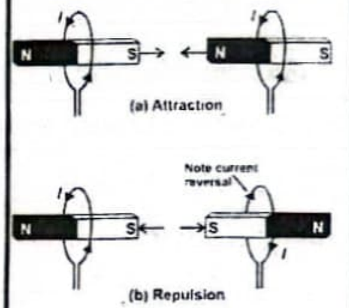
i.e. $\theta = 90^\circ$

Then $\Phi_B = B\,A\cos 90^\circ$

$\Phi_B = B\,A\,(0)$

$\Phi_B = 0$

For Your Information



The "Phantom" magnet included for each loop helps to explain the attraction and Repulsion between the loops.

(iii) Flux through a curved surface

When a curved surface is placed in non-uniform magnetic field. Then, we divide the curved surface into a number of small elements. The net magnetic flux can be found by adding the value of magnetic flux through each element.

Thus $\Phi_B = \sum \vec{B}.\Delta\vec{A}$ $\Phi_B = \frac{N}{Am} \times m$ (Tesla) $\Rightarrow NA^{-1}m$

Unit

The SI unit of magnetic flux is **weber or Nm /A.**

Magnetic flux Density (Magnetic Induction)   Diff b/w M.flux and density

The magnetic flux per unit area of a surface perpendicular to magnetic field is called magnetic flux density.

Thus, magnetic flux density,

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

NA^{-1} weber

Unit

SI unit is magnetic flux density is **$Wb\,m^{-2}$ or $NA^{-1}m^{-1}$** or **tesla**.

MCQ's From Past Board Papers

1. The unit of magnetic flux is **(Mtn 2015 G – I Federal 2011, 2013)**
(A) tesla (B) weber (C) weber m^{-2} (D) tesla m^2

2. If 0.5 T field over an area of $2m^3$ which lies at an angle of 60° with field. Then the resultant flux will be BACosθ **(Rwp 2011, 2014 Sgd 2015 G – II, Lhr 2015 Mirpur 14, 15)**
(A) 0.50 T (B) 0.50 Wb (C) 0.25 Wb (D) 0.25 T

3. The S.I unit of magnetic flux is given by: **(Lhr 2015 G – II Bwp 2015)**
(A) NmA^{-1} (B) $NA^{-1}m^{-1}$ (C) Nm^2A^{-1} (D) $Nm^{-1}A$

4. One weber is equal to: **(Grw 2014 Lhr 2013, 14)**
(A) NA^{-1} (B) $Nm^{-1}A$ (C) NmA^{-1} (D) $Nm^{-1}A^{-1}$

5. The unit of magnetic flux is: **(Swl 2015 Grw 2014, Bwp 2010, 13)**
(A) Curie (B) Weber (C) Newton (D) Farad

6. **Magnetic field $\vec{B} = (4\hat{i} + 18\hat{k})$ Wbm^{-2} passes through $(5\hat{k})$m^2 area. Net flux through the area is:** **(Grw 11)**
(A) 20 Wb (B) 90×10^{-4} Wb (C) 90 Wb (D) zero

7. **The SI unit of electric flux is:** **(Grw 2016)**
(A) N mc^{-2} (B) N m^{2}C^{-1} (C) N c m^{-2} (D) N m c^2

8. **The magnetic flux ϕ_B is equal to** **(D.G.Khan 2016 Group II)**
(A) $\bar{B} \cdot \bar{A}$ (B) $\bar{B} \times \bar{A}$ (C) $\frac{B}{A}$ (D) BA Sin θ

9. **Total Flux through a closed surface depends on:** **(Bwp 2015)**
(A) Shape of Surface (B) Charge enclosed only (C) Medium Only (D) charge and Medium

Answer Keys	1.	C	2.	B	3.	C	4.	C	5.	B	6.	C	7.	B	8.	A	9.	D

Q.4 State and Explain the Ampere's Law.

Ans.

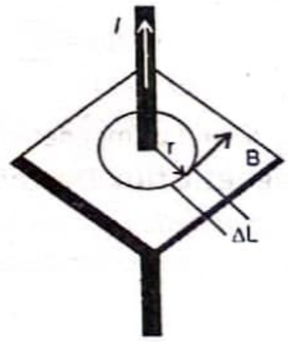
AMPERE'S LAW

Statement
S.Q

The sum of quantities $\vec{B}.\Delta\vec{L}$ for all path elements into which the complete loop has been divided equals μ_o times the total current enclosed by the loop.

Mathematically

$$\boxed{\sum_{r=1}^{N}\left(\vec{B}.\Delta\vec{L}\right)_r = \mu_o I}$$



Ampere's law to find the magnetic field in the vicinity of this long, straight. Current - carrying wire.

Explanation

Consider a current carrying straight conductor and circular loop of wire of radius r. Such a closed path is called **Amperean path**. Divide this path into N small elements each of length $\Delta\vec{L}$. Let B be the value of magnetic flux density at the site of $\Delta\vec{L}$. If θ is the angle between $\vec{B}$ and $\Delta\vec{L}$ then product of length element ΔL and the component of B parallel to ΔL is

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

Where

Bcosθ = component of $\vec{B}$ along element of length $\Delta\vec{L}$

According to Ampere's Law the sum of all the quantities $\vec{B}.\Delta\vec{L}$ for all path elements is μ_o times the current enclosed by the loop. So

For Your Information
Ampere's law is the magnetic equivalent of Gauss's law.

$$(\vec{B}.\Delta\vec{L})_1 + (\vec{B}.\Delta\vec{L})_2 + \text{-----} + (\vec{B}.\Delta\vec{L})_N = \mu_o I$$

OR $$\sum_{r=1}^{N}\left(\vec{B}.\Delta\vec{L}\right)_r = \mu_o I$$

Where μ_o is a constant known as **permeability of free space**, whose value is **$4\pi \times 10^{-7}$ Wb / A-m**. This is known as Ampere's circuital law.

Q.5 Calculate the Magnetic Field due to Current Carrying Solenoid using Ampere's Law.

Mtn 2014, D.G.Khan 15 G II, GRW 15, LHR 14 G I, 16 G II, RWP 14, 15

Ans.

FIELD INSIDE A CURRENT CARRYING SOLENOID

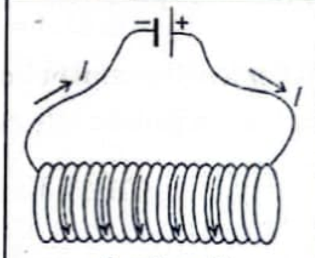
Solenoid

The solenoid is a long tightly wound cylindrical coil of wire. When the current passes the solenoid, then it behaves like a bar magnet. The magnetic field due to solenoid is shown in figure.

Field due to solenoid

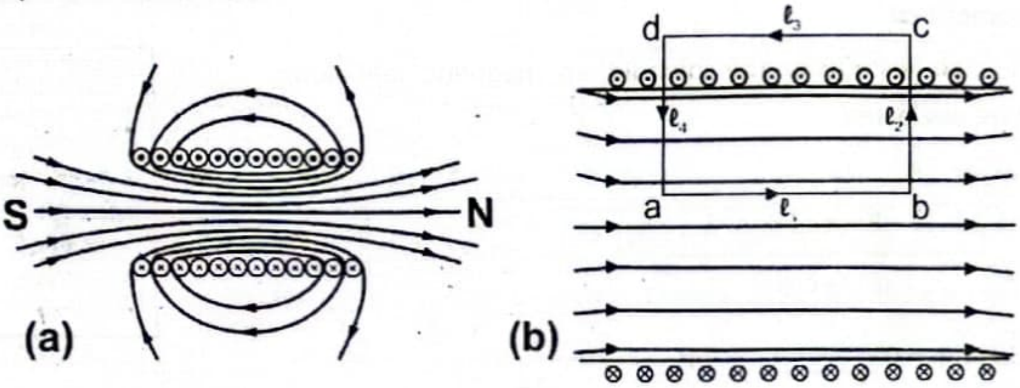
The field inside the solenoid is strong and uniform as compare to outside. The field outside of the solenoid is so weak that it can be neglected as compare to inside field.

For Your Information



A solenoid

S ⊙ N



Determination of $\vec{B}$

Amperean loop

We consider a rectangular loop abcd. Divide the loop into four elements of lengths as

ab = ℓ_1, bc = ℓ_2, cd = ℓ_3 and da = ℓ_4

Current enclosed

If

Number of turns per unit length of the solenoid= n $= \frac{N}{L}$

Number of turns in length ℓ_1 of the solenoid = $n\ell_1$

Current enclosed by the loop = I

Current enclosed by the $n\ell_1$loops = $n\ell_1 I$________ (1)

Ampere's law

Applying Ampere's Law, we get

$$\sum_{r=1}^{4}\left(\vec{B}.\Delta\vec{L}\right)_r = \mu \text{ (Current enclosed)}$$

$(\vec{B}.\Delta\vec{L})_1 + (\vec{B}.\Delta\vec{L})_2 + (\vec{B}.\Delta\vec{L})_3 + (\vec{B}.\Delta\vec{L})_4 = \mu_o \times$ current enclosed ______ (1)

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

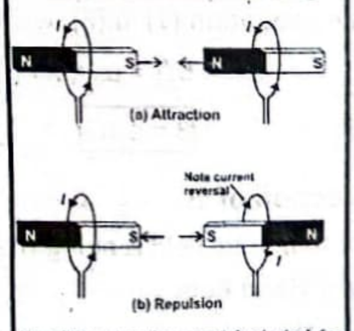
(i) For length element ab

For the element ab = ℓ_1, field inside the solenoid is uniform and parallel to ℓ_1, so

Do You Know

The current loop can be imagined to be a phantom bar magnet with a north pole and a south pole.

For Your Information



The "Phantom" magnet included for each loop helps to explain the attraction and Repulsion between the loops.

$$(\vec{B}\,\Delta\vec{L})_1 = B\ell_1 \cos\theta$$
$$= B\ell_1 \cos 0^\circ \quad [\because \theta = 0^\circ]$$
$$= B\ell_1 (1)$$
$$(\vec{B}.\Delta\vec{L})_1 = B\ell_1 \text{ \_\_\_\_\_\_\_\_ } (2)$$

(ii) For length element bc

For the element bc = ℓ_2, field is perpendicular to ℓ_2, so

$$(\vec{B}.\Delta\vec{L})_2 = B\ell_2 \cos 90^\circ \qquad [\because \theta = 90^\circ]$$
$$= B\ell_2 (0)$$
$$(\vec{B}.\Delta\vec{L})_2 = 0 \text{ \_\_\_\_\_\_\_\_ } (3)$$

(iii) For length element cd

As the element ℓ_2 = cd lies outside the solenoid. So, magnetic field along this element can be neglected.

So B = 0

$$(\vec{B}.\Delta\vec{L})_3 = B\ell_3 \cos\theta$$
$$= (0)\, \ell_3 \cos\theta$$
$$(\vec{B}.\Delta\vec{L})_3 = 0 \text{ \_\_\_\_\_\_\_\_ } (4)$$

(iv) For length element da

For the element da = ℓ_4, Here field is perpendicular to ℓ_4, so

$$(\vec{B}.\Delta\vec{L}_4) = B\ell_4 \cos 90^\circ$$
$$= B\ell_4 (0)$$
$$(\vec{B}.\Delta\vec{L}_4) = 0 \text{ \_\_\_\_\_\_\_\_ } (5)$$

Using equations (2), (3), (4) and (5) in equation (1), we have

$$B\ell_1 + 0 + 0 + 0 = \mu_o \text{ (current enclosed)}$$
$$B\ell_1 = \mu_o \text{ (current enclosed)} \text{ \_\_\_\_\_\_\_\_ } (6)$$

Using equation (1) in (6), we get

$$B\cancel{\ell_1} = \mu_o \times n\cancel{\ell_1} I$$

OR $$\boxed{B = \mu_o n I} \text{ \_\_\_\_\_\_\_\_ } (7)$$

Do You Know?

An ideal solenoid is infinitely long and has tightly packed turns.

Application of solenoid

It is often used to produce a uniform magnetic field. In door bells and loud speakers it produces a magnetic field that accelerates the magnetic material.

For Your Information

The solenoid magnetic field is the vector sum of the fields produced by the individual turns

Direction of $\vec{B}$

The magnetic field is along the axis of solenoid. Its direction can be determined by right hand rule.

Right Hand Rule

Hold the solenoid in right hand with fingers curling in the direction of current, the thumb will point in the direction north pole.

MCQ's From Past Board Papers

1. **If the number of turns become double but length remain same, then magnetic field in the solenoid become:** **(Rwp 2014, 15 Lhr 2015 G – II)**
   (A) Half (B) Double (C) Remain same (D) Zero
2. **The magnetic field produced by a carrying conductor at distance r is:**
   (A) $\frac{\mu_0 I}{2\pi r}$ (B) $\frac{2\pi r}{\mu_0 I}$ (C) $\frac{2\pi\mu_0}{Ir}$ (D) $\frac{I}{2\pi\mu_0 r}$
3. **The mathematical expression $\sum_{i=1}^{n}(B.\Delta l)_i=\mu_o I$ is known as:** **(Lhr 10, 11, 12, 14, 15, Mtn 13 Grw 15)**
   (A) Lenz's law (B) Ampere's law (C) Gauss's law (D) Faraday's law
4. **The unit for permeability of free space is:** **(Sgd 2014 Bwp 2014)**
   (A) $WbA^{-1}m^{-1}$ (B) WbAm (C) $WbA^{-1}m^{2}$ (D) $TA^{-1}m^{-1}$
5. **The value of permeability of free space μ_o is given by** **(D.G.Khan 2016 Group I, Fsd 2014, 15 Mtn 2014)**
   (A) 4×10^{-7} Wb $A^{-1}m^{-1}$ (B) 4×10^{7} Wb $A^{-1}m^{-1}$ (C) 4×10^{-7} Wb Am (D) 4×10^{-9} Wb $A^{-1}m^{-1}$
6. **Energy stored per unit volume inside a solenoid is called as;** **(Mirpur 2016)**
   (A) Energy density (B) Electric flux (C) Work (D) volume charge density

Answer Keys	1.	B	2.	A	3.	B	4.	A	5.	A	6.	A

Q.6 Derive the Expression for Force on moving electric Charge in a Uniform Magnetic Field. Also Determine its Direction. **Lhr 2014 Rwp 2015 Grw 2008**

Ans.

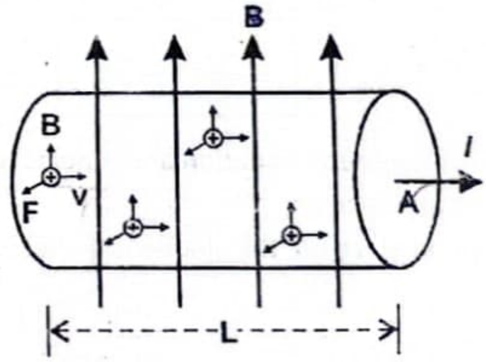
Imp L.Q

FORCE ON A MOVING CHARGE IN MAGNETIC FIELD

A force is experienced by a current carrying conductor placed in uniform magnetic field. Actually the magnetic field exerts the force on the charged particles moving in the conductor.

Mathematically, this force is given as

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



Proof

Consider a segment of wire of length L and area of cross section A placed in a magnetic field $\vec{B}$. Let I be the current flowing through the wire. Then the magnetic force acting on the conductor is

$$\vec{F}_L = I(\vec{L}\times\vec{B}) \quad \text{(1)}$$

Let

area of cross-section of wire = A

Length of the conductor = L

Volume of the wire segment = AL

Number of charge carrier per unit volume = n

Total number of charge carriers in the wire segment = nAL

Velocity of each charge = $\vec{v}$

Charge on a charge carrier = q

Total charge on nAL charge carriers = $\Delta Q = nALq$

As current is defined as

$$I = \frac{\Delta Q}{\Delta t}$$

OR $$I = \frac{nALq}{L/v} \qquad [\text{As } \Delta t = \frac{L}{v}]$$

OR $$I = nAqv \text{ \_\_\_\_\_\_\_\_ (2)}$$

Using this value of current in equation (1), we get

$$\vec{F}_L = nAqv\,(\vec{L} \times \vec{B}) \text{ \_\_\_\_\_\_\_ (3)}$$

As, the direction of segment $\vec{L}$ is similar to $\vec{v}$. So we can write

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

So, $$\vec{L} = L\hat{L} = L\hat{v}$$

Thus equation (3) becomes

$$\vec{F}_L = nAqv\,(L\hat{v} \times \vec{B})$$

OR $$\vec{F}_L = nAqL\,(v\hat{v} \times \vec{B})$$

OR $$\vec{F}_L = nAqL\,(\vec{v} \times \vec{B}) \qquad [\because v\hat{v} = \vec{v}]$$

This is the force exerted on nAL charges. Now, the force experienced by a single charge is,

$$\vec{F} = \frac{\vec{F}_L}{nAL}$$

$$\vec{F} = \frac{nAqL(\vec{v} \times \vec{B})}{nAL}$$

$$\boxed{\vec{F} = q\,(\vec{v} \times \vec{B})} \text{ \_\_\_\_\_\_\_\_ (4)}$$

This is general equation and it holds for any charge carrier moving in a magnetic field.

For an Electron

For an electron, the charge is q = -e. So

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

For a Proton

For a proton, the charge is q = +e. So

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

Direction of Force

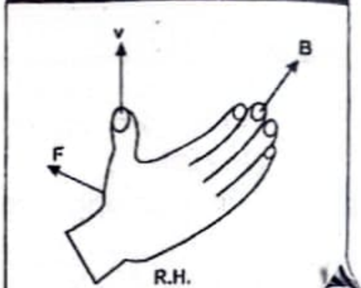
For a positive charge, the direction of force is given by the direction of vector $(\vec{v} \times \vec{B})$

It can be determined by right hand rule

Right Hand Rule

- Rotate the first vector $\vec{v}$ towards the second vector $\vec{B}$ through the smaller angle θ

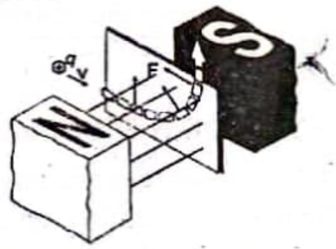
For your Information



The moving charge experiences a magnetic force because of magnetic field

For Your Information

Motion of a charged particle in a magnetic field alone is always motion with constant speed.



Magnetic force F is perpendicular to both the magnetic field B and the velocity v and causes the particle's trajectory to bent in a vertical plane

Do You Know?

When a charged particle moves at right angle to the magnetic field, its kinetic energy remains constant.

- Curl the fingers of right hand in the direction of rotation.
- The erect thumb points the direction of force.

Special Cases

1) When $\vec{v}$ and $\vec{B}$ are at right angle to each other (i.e. $\theta = 90^\circ$)

$$F = qvB\sin\theta$$
$$F = qvB\sin 90^\circ$$
$$F = qvB \quad \text{[maximum]}$$

When the charged particle moves at an angle of **90°** to the field, then the particle moves in a **circle**.

> **For Your Information**
> The ratio (F_m/F_e) of magnetic force and the electric force acting on a charged particle moving undeflected through the fields is one.

2) When $\vec{v}$ and $\vec{B}$ are parallel. (i.e. $\theta = 0^\circ$)

$$F = qvB\sin\theta$$
$$F = qvB\sin 0^\circ$$
$$F = qvB\,(0)$$
$$F = 0$$

3) When $\vec{v}$ and $\vec{B}$ are anti-parallel (i.e. $\theta = 180^\circ$)

$$F = qvB\sin\theta$$
$$F = qvB\sin\theta$$
$$F = qvB\,(0)$$
$$F = 0$$

4) When the charged particle is at rest (i.e. $v = 0$)

$$F = qvB\sin\theta$$
$$F = q(0)\,B\sin\theta$$
$$F = 0$$

> **For Your Information**
> If the charge particle enters n a magnetic field so that the angle between $\vec{v}$ and $\vec{B}$ is other than 0°, 90°, 180° and 270° than it will move along the helical path.

Q.7 Determine the Magnitude of Force on a Charged Particle in an Electric and Magnetic Field?

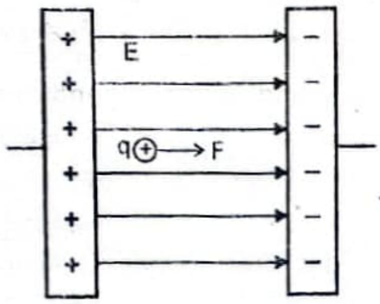
Ans. S.Q

MOTION OF A CHARGED PARTICLE IN AN ELECTRIC & MAGNETIC FIELD

Consider an electric charge q placed in an electric field, it experiences a force F parallel to the field, given by

$$\vec{F}_e = q\vec{E} \quad \text{\_\_\_\_\_\_\_\_ (1)}$$

If charge is free to move then it will accelerate. The acceleration of the charge can be determined by Newton's second law as



$$\vec{F}_e = m\vec{a}$$

OR
$$\vec{a} = \frac{\vec{F}_e}{m} = \frac{q\vec{E}}{m}$$

For uniform electric field, the acceleration of charged particle is also uniform. So by using the equations of uniformly accelerated motion, the position of a particle can be determined at any instant.

When the charge is moving in uniform magnetic field $\vec{B}$ with velocity $\vec{v}$, then the force acting on the charged particle is

$$\vec{F} = q(\vec{v} \times \vec{B}) \quad \text{\_\_\_\_\_\_\_\_ (2)}$$

S.Q and role of e.f and magn.f

Lorentz force

Electric force is ⊥ to magnetic

When the charge particle q is moving with velocity $\vec{v}$ in a region where there is an electric and magnetic field, then the total force $\vec{F}$ is the vector sum of electric and magnetic force. i.e.

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

OR

$$\boxed{\vec{F} = q\vec{E} + q(\vec{v} \times \vec{B})} \quad \text{(3)}$$

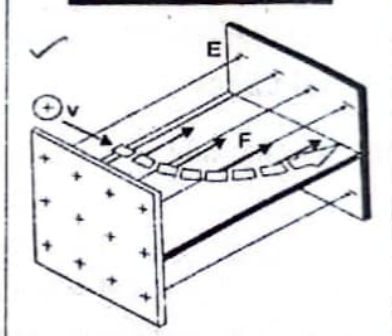
This force is known as **Lorentz force.**

Note

Does magnetic force do any work on the charge particle? S.Q

Electrical force does work only, while the magnetic force just **deflects** the charged particle. It performs **no work.**

Do You Know?



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

Q.8 Describe, how can we determine the e/m Ratio of an Electron. *FEDERAL – 2008, GRW – 2010*

Ans. L.Q

DETERMINATION OF e/m OF AN ELECTRON

J.J Thomson firstly determines the charge to mass ratio of an electron.

Principle

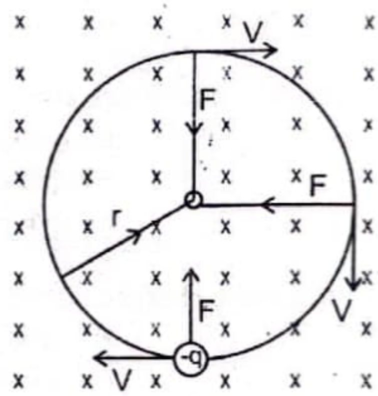
When a beam of charged particles passes through a magnetic field, it is deflected.

Explanation

Consider a narrow beam of electrons moving with uniform velocity $\vec{v}$ at right angle to a known uniform magnetic field $\vec{B}$ directed into the plane of paper. Then the force acting on the electron is

So,

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



An electron is moving perpendicular to a constant magnetic field. The magnetic force F causes the particle to move on a circular path.

Where the direction of force is perpendicular to $\vec{v}$ and $\vec{B}$. So the direction of electron beam changes continuously, while the magnitude of velocity remains unchanged. Magnitude of force acting on an electron is given by

$$F_B = e\,vB\sin\theta$$

As $\vec{v}$ and $\vec{B}$ are perpendicular to each other, so $\theta = 90^\circ$

Hence,

$$F_B = e\,vB\sin 90^\circ$$

$$F_B = e\,vB\,(1)$$

$$F_B = e\,v\,B \quad \text{(1)}$$

As this force provides the necessary centripetal force

So,

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

Equating equations (1) and (2), we get

$$F_B = F_c$$

So,

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

Significance of e/m

In some experiments, the charge-to-mass ratio is the only quantity that can be measured directly. Often, the charge can be inferred from theoretical considerations, so that the charge-to-mass ratio provides a way to calculate the mass of a particle.

$V = \frac{E}{B}$ the ratio of magnetic and electric field has the same unit ... ve

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

If v and r are known, e/m of the electron can be determined.

Measurement of radius

To measure the radius, we make the path of the electrons visible by filling the glass tube with 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. Thus the atoms become excited. When the excited atoms return to their ground state, they emit light and their path becomes visible as a circular ring of light. The diameter of the ring can be easily measured.

Measurement of Velocity

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 the electrons, so

$$K.E. = Ve$$

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

or $$v = \sqrt{\frac{2Ve}{m}}$$

Substituting the value of v in equation (3), we get

$$\frac{e}{m} = \frac{1}{Br}\sqrt{\frac{2Ve}{m}}$$

Squaring both sides, we get

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

$$\boxed{\frac{e}{m} = \frac{2V}{B^2r^2}} \qquad (4)$$

Knowing all the values, e/m can be calculated.

Use of e/m

- Once we have determined e/m, we can use Millikan's value for electron charge to calculate electron's mass.
- Alpha particles are He-nuclei on the basis of their e/m.

MCQ's From Past Board Papers

1. **When a charge is projected perpendicular to a uniform magnetic field, its path is:** **(Swl 2015, Lhr 2015 Swl 2015)**
   (A) Spiral (B) Helix (C) Ellipse (D) Circular
2. **The sum of electric and magnetic force is called.** **(Rwp 2015 Sgd 2015 G – I)**
   (A) Maxwell force (B) Lorentz force (C) Newton's force (D) Centripetal force
3. **Force on a charged particle is zero when projected at angle with the magnetic field:** **(Mtn 2015 G – II)**
   (A) 0° (B) 90° (C) 60° (D) 270°
4. **When a particle of charge q and mass m enters a region of constant magnetic induction B, traveling with the velocity v perpendicular to the direction of the field, it describes a circular orbit of radius:** **(D.G.Khan 15 Federal 2014)**

(A) r = mq/vB (B) r = mqv/B (C) r = mv/Bq (D) r = Bq/mv

5. Charge to mass ratio (e/m) of an electron is given by **(Lhr 2015 Grw 2014, 15, Mirpur 13, 15)**

(A) $\frac{2V}{Br^2}$ (B) $\frac{2V}{B^2r}$ (C) $\frac{2V}{B^2r^2}$ (D) $\frac{V}{2B^2r^2}$

6. If a charge particle moves in a straight line through some region of space, then: **(Fsd 2014 Mir-II-13/1)**

(A) No Magnetic field in that region
(B) Magnetic field is parallel or anti parallel to motion of charge particle
(C) Both (A) and (B) (D) Magnetic field is ⊥ to the motion of particle

7. A charge 'q' is placed stationary in a region where both the electric and magnetic fields are present. The charge will experience ________. **(Sgd 2014 Fed 2014)**

(A) Both electric and magnetic forces (B) Electric force
(C) Magnetic force (D) No force at all

8. Magnetic force on a moving charged particle is perpendicular to the______. **(Sgd 15 Lhr –12 Grw 12, 15)**

(A) magnetic field (B) electric filed.
(C) velocity of the particle (D) magnetic field and velocity of the particle

9. The unit of $\vec{E}$ is NC^{-1} and that of B is $NA^{-1}\ m^{-1}$ then the unit of $\frac{E}{B}$ is: $I = \frac{q}{t}$ $C = AS$

$\frac{N/AS}{NA^{-1}m^{-1}} \Rightarrow m s^{-1}$

(Bwp 2015, Sgd 2015 Fsd 2014)

(A) ms^{-2} (B) ms (C) $m^{-1}\ s^{-1}$ (D) ms^{-1}

10. Work done on a charged particle moving in uniform magnetic field is: **(Mtn 2014, 15 Swl 2014)**

(A) Maximum (B) Zero (C) Minimum (D) Negative

11. A magnetic field acts on a charged particle so as to change its **(Lhr 2014, 15 Grw 2010, 2014)**

(A) speed (B) energy (C) direction of motion (D) all of these

12. The e/m of a neutron is: **(Grw 2015)**

(A) less than electron (B) greater than electron (C) zero (D) the same as electron

13. Lorentz force is given by: **(Rwp 2015)**

(A) $q(\bar{E} - \bar{V} \times \bar{B})$ (B) $q(\bar{E} + \bar{V} \times \bar{B})$ (C) $q\left[\bar{E} \times \left(\bar{V} + \bar{B}\right)\right]$ (D) $q\left(\bar{V} + \bar{E} \times \bar{B}\right)$

14. The charges moving perpendicular to magnetic field experience force **(Fsd 2015)**

(A) Maximum (B) Minimum (C) Zero (D) Infinite

15. Force on a charged particle is zero when projected at angle with the magnetic field: **(Mtn 2015 Group II)**

(A) 0° (B) 90° (C) 180° (D) 270°

16. An electron enters the magnetic field at right angle from left, B is into paper. The electron will be deflected:- **(Mtn 2016 Group I)**

(A) Upward (B) Towards right (C) Downward (D) Towards left

17. The value of $\frac{e}{m}$ is smallest for:- **(Mtn 2016 Group II)**

(A) Proton (B) Electron (C) B-Particle (D) Positron

18. Brightness of screen of CRO controlled by **(Sgd 2016 Group I)**

(A) Anode (B) Filament (C) Cathode (D) Grid

19. If a charge is at rest in a magnetic field then force on charge is: **(Fsd 2016)**

(A) Zero (B) $q(\bar{V} \times \bar{B})$ (C) q VB sin θ (D) q VB cos θ

20. The magnetic force is simply a: **(Mirpur 14, D.G.Khan 2016 Group I, Lhr 2016 Group I)**

	(A) Reflecting force	(B) Deflecting force	(C) Restoring force	(D) Gravitational force
21.	**A charged particle enters in a strong magnetic field, its K.E. :**			**(Lhr 2016 Group II)**
	(A) Remains constant	(B) Increases	(C) Decreases	(D) Increases then decreases

Answer Keys	1.	D	2.	B	3.	C	4.	C	5.	C	6.	C	7.	B
	8.	D	9.	D	10.	B	11.	C	12.	C	13.	B	14.	A
	15.	A	16.	C	17.	A	18.	D	19.	A	20.	B	21.	A

Q.9 What is cathode ray oscilloscope? Discuss the Principle, Construction and Working of a Cathode Ray Oscilloscope. Mention its uses.

Ans.

CATHODE RAY OSCILLOSCOPE S.Q

It is very **versatile** electronic device. It is in fact a high speed **graph plotting** device.It displays the **shape or size** of an electrical signal on the screen.It is provides **visual images** of varying electrical quantities. Also, it provides accurate **time and amplitude** measurements of voltage signals over a wide range of frequencies.

Principle

When a charged particle moves in an electric field, a force acts on it.

Construction

Ist list parts of CRO

A cathode ray oscilloscope consists of;

i) Electron gun ii) Deflection system iii) Display system

i) Electron Gun

The electron gun produces a beam of electrons. It consists of;

1) Filament

When current is passed through the filament, it glows and heat from it heats up the cathode

2) Cathode

When cathode is heated, it emits electrons by thermionic emission.

3) Grid S.Q

It is at negative potential relative to cathode. It controls the number of electrons reaching the screen and thus controls the brightness of spot on the screen.

4) Focusing Anode

It is at positive potential relative to cathode. The electrons that pass through this anode are focused into a fine beam.

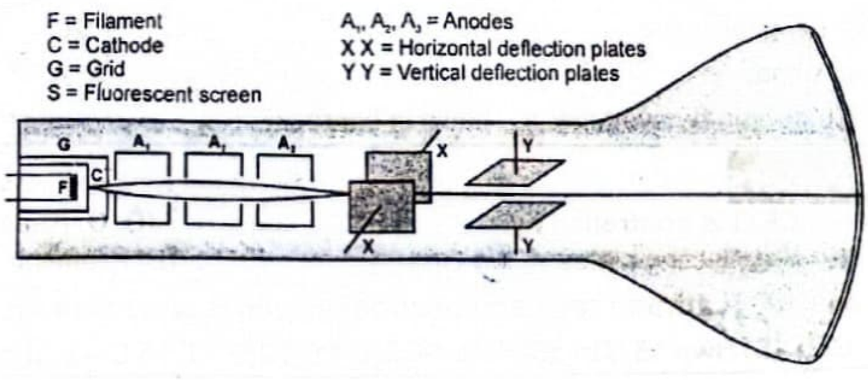
5) Accelerating anode

It is at zero potential. Its main function is to accelerate the electrons.

For Your Information

In CRO,
Potential at cathode is **-1000V**
Potential at grid is **-1050V**
Potential at focusing anode is **-600V.**
Potential at accelerating anode is **0V.**

Saw tooth voltage waveform



ii) Deflection system

The beam of electrons from anodes firstly passes through a pair of horizontal deflecting plates called X-plates which deflect the beam horizontally on the screen i.e., parallel to x-axis and then between two vertical plates called Y- plates which deflect the beam vertically on the screen i.e., along the y-axis.

Do You Know?

There is a graphite coating inside the CRO tube which ends close to the screen. This is at zero potential and provides a return path to the electron which strikes the screen.

iii) Display System

The screen of CRO is coated with a fluorescent material (zinc sulphide). The zinc sulphide gives a glow of light when electrons collide with it.

Working of CRO

voltage across x-plates

The voltage that is applied across the x-plates is usually provided by a circuit that is built in CRO (known as time base generator).

Time base generator S-Q Sweep voltage

Its output wave form is saw-tooth. The voltage increases linearly with time for period T and then drop to zero. As this voltage is applied across x-plates, the spot moves along x-axis for a time T. As after time T, the saw tooth voltage becomes zero, So the spot rapidly reaches to its initial position at the end of each period T. If the time period is very small, the spot moves so quickly that we see just a bright line on the screen.

Three dimensional view of CRO.

Voltage across Y-plates

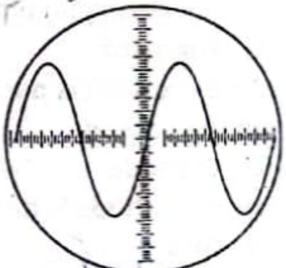
If a sinusoidal voltage is applied across y-plates with time base generator off, the spot moves vertically up and down at the frequency of applied AC voltage. This produces a vertical straight line on the screen whose length represents the peak to peak value of applied voltage.

If a sinusoidal voltage is applied across y-plates time with base generator ON, the vertical straight line now spread out and appears as 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.

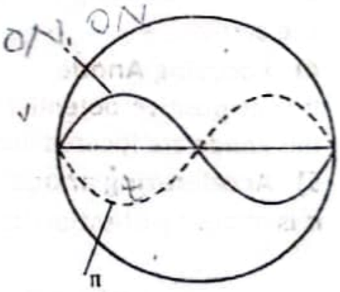
OFF ON



Sinosodial

(a)

ON, ON



(b)

Stationary Fig. 14.14

Uses of CRO S-Q

CRO is used to

a) display the waveform of a given voltage.
b) measure the voltage, frequency and phase of the input signal.
c) measure the instantaneous value, peak value.
d) measure the time period of AC signals
e) measure the phase difference between two voltages as shown in figure.

MCQ's From Past Board Papers

1. **The number of electrons in CRO is controlled by:** **(D. G. Khan 2015 G – I)**
   (A) X-deflecting plates (B) Y-deflecting plates (C) Grid (D) Filament
2. **The brightness of spot on CRO (cathode ray oscilloscope) screen is controlled by:**
   (Mirpur 16, Fsd 15, Grw 16, Bwp 15 Mtn 15, Rwp 14, Lhr 11, 12 G – II 15 G – I, Lhr 16 Group I)

(A) Anodes (B) Cathodes (C) Grid (D) Plates

3. **The grid in CRO ———.** **(Rwp 2014, 15 Bwp 2015, Fed 2013)**
(A) Controls the number of electrons accelerated by anodes
(B) Controls the brightness of the spot fall on the screen
(C) Both a and b
(D) Deflects the beam of electrons

4. **In CRO, the time base generator circuit is connected to the** **(Rwp 2015, Fed 2012)**
(A) X-Plate (B) Y-Plate
(c) Electron Gun (D) Accelerating Electrodes

5. **Cathode ray oscilloscope works by deflecting a beam of : (Mtn 2015 D.G.Khan 2014 Lhr 2014 G I)**
(A) Neutrons (b) Protons (C) Electrons (D) Positrons

6. **Grid in cathode ray oscilloscope controls:** **(Grw 2014 Lhr 2014 G II)**
(A) Number of electrons (B) Temperature of filament
(C) Frequency of electrons (D) Energy of electrons

7. **Out put wave form of sweep or time base generator is:** **(Sgd 2013, Lhr 2015 Swl 2014)**
(A) Saw tooth wave (b) Digital wave (C) Sinusoidal wave (D) Square wave

8. **The anode in the cathode ray oscilloscope:** **(Lhr 11, 12 G – I, Fsd 15, Swl 14 Grw 13 G I,2014)**
(A) Control number of waves (B) Control the brightness of spot formed
(C) Accelerates and focus beam (D) At negative potential with respect to cathode

9. **The brightness of spot on CRO screen is controlled by:**
(A) Anodes (B) Cathodes (C) Grid (D) Plates

10. **The CRO is used for** **(Sgd 2016 Group II)**
(A) Displaying the wave form of frequency (B) displaying the wave form of given vibration
(C) Displaying wave form of given voltage (D) Converting A.C into D.C

Answer Keys	1.	C	2.	C	3.	C	4.	A	5.	C
	6.	A	7.	A	8.	C	9.	C	10.	C

Q.10 Derive the expression for torque on the current carrying coil in uniform magnetic field.

FEDERAL – 2010, FSD – 2009, MIRPUR - 2011

Ans.

TORQUE ON CURRENT CARRYING COIL

L.Q

Consider a current carrying rectangular coil, which is capable of rotating about an axis. Suppose it is placed in uniform magnetic field $\vec{B}$ with its plane along the field. As the force acting on a conductor of length $\vec{L}$ in uniform magnetic filed is,

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

OR $F = I L B \sin\theta$ [magnitude]

Where θ is the angle between length $\vec{L}$ and magnetic field $\vec{B}$.
Divide the length of rectangular coil into four segments AB, BC, CD and DA.
Now forces acting on the sides of the coil can be calculated as

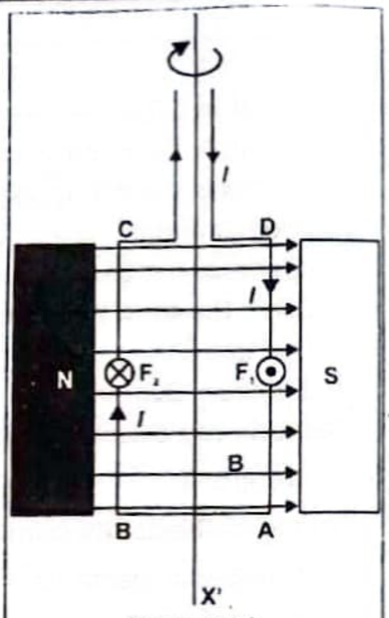


Fig 14.15(a)

Force on segment AB

As AB is anti-parallel to magnetic field So, $\theta = 180^\circ$

$$F_{EF} = I\,(EF)B \sin 180^\circ = I\,(EF)B\,(0) = 0$$

Force on segment BC

As BC is perpendicular to magnetic field So, $\theta = 90^\circ$

$$F_{FG} = F_2 = I\,(FG)B \sin 90^\circ = I\,(FG)B\,(1) = I\,LB$$

By right hand rule, its direction is into the paper (x).

Force on segment CD

As CD is parallel to magnetic field So, $\theta = 0^\circ$

$$F_{GH} = I\,(GH)B \sin 0^\circ = I\,(GH)B\,(0) = 0$$

Force on segment DA

As DA is perpendicular to magnetic field, so, $\theta = 90^\circ$

$$F_{HE} = F_1 = I\,(HE)B \sin 90^\circ = I\,(HE)B\,(1) = I\,LB$$

From right hand rule its direction is out of the paper (.).

As F_1 and F_2 are being equal and opposite. So they form a couple, which tends to rotate the coil about its axis.

Now,

Torque due to couple = (magnitude of either force) (couple arm) ________ (1)

Thus, $\tau = ILB \times a$

OR $\tau = I\,B(La)$

Where a is the perpendicular distance between two forces called **couple arm** and is equal to AB or CD and La is the area of the coil. (i.e., La = A) So

$$\tau = I\,BA$$

Which is the value of torque when field is in the plane of coil. But if the field makes an angle α with the plane of coil then the couple arm become $a\cos\alpha$. So, equation (1) becomes

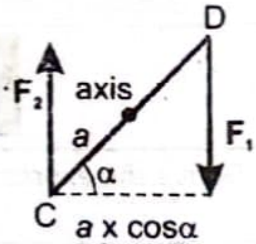
$$\tau = I\,LB \times a \cos\alpha$$

$$\tau = I\,B(La) \cos\alpha$$

or $\tau = I\,BA \cos\alpha$

If there are N number of turns of on coil, then

$$\boxed{\tau = N\,IB\,A \cos\alpha}$$



Where α is angle between magnetic field and plane of coil.

(Top view of coil)

Special Case

The torque acting on current carrying coil will be maximum when the plane of coil is parallel to the magnetic field.(i.e. when $\alpha = 0^\circ$).So,

$$\tau_{max} = N\,IB\,A \cos 0^\circ = N\,IB\,A$$

Q.11 Discuss the Principle, Construction and Working of a Galvanometer?

Ans. ***FSD 2015, 16, LHR 2016 G I, G II, GRW 2016***

GALVANOMETER

Galvanometer is an electrical device which is used to **detect** the passage of current through a circuit.

Principle

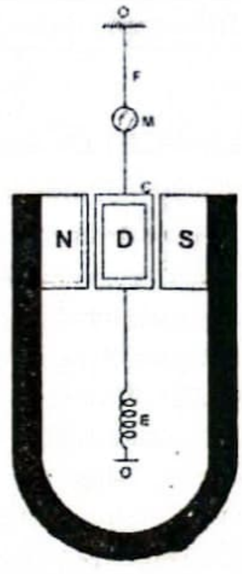
Torque acts on a current carrying coil when placed in uniform magnetic field.

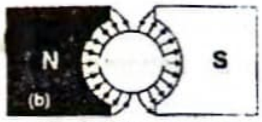
$$\tau = NIBA \cos\alpha$$

Construction

Galvanometer consists of:

1) A **U-shaped magnet** with concave shaped north and south poles
2) A **rectangular coil** C made up of enameled copper wire suspended between poles of U-shaped magnet.
3) A non-magnetic (aluminium) frame over which the wire is wound
4) A **suspension wire** F (connected to one terminal of coil) acting as one current lead
5) A loosely wound **spiral** E (connected to the other terminal of the coil) acting as second current lead.
6) An **iron cylinder** D placed inside the coil to concentrate the field through it.





(a) Moving Coil galvanometer
(b) Concave pole piece and soft iron cylinder ma the field radial and stronger

Working

When the current is passed through the coil, a couple (*two equal and opposite forces acting on two different points on a body*) act on the coil and the coil tends to rotate. Such couple is known as deflecting couple.

Deflecting torque

If N is the number of turns of the coil and A is the area then the torque due to the deflecting couple is given by

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

Since the pole pieces of magnet are made concave to make the field radial, therefore the plane of the coil is always parallel to field, so $\alpha = 0^\circ$

$$\tau = NIBA \cos 0^\circ$$
$$\tau = NIBA\,(1)$$
$$\tau = NIBA \quad \text{\_\_\_\_\_\_\_\_} \quad (1)$$

Restoring torque

As the coil turns under the action of deflecting torque, the suspension wire is twisted which gives rise to torsional couple which tends to untwist the suspension wire and restore the original position. This couple is known as **restoring couple.**

The torque due to restoring couple is proportional to the angle of deflection θ as long as the suspension wire obeys Hook's law,

Thus $\quad$ Restoring torque $\propto \theta$

Restoring torque $= C\theta$ ________ (2)

Where C is the constant of proportionality called **twisting or torsional constant** and it depends upon the nature of suspension wire.

Equilibrium State

When the deflecting couple balances the restoring couple then coil will come to rest. So, in equilibrium.

Deflection Torque = Restoring Torque

$$NIAB = C\,\theta$$

OR

$$I = \frac{C\theta}{NBA}$$

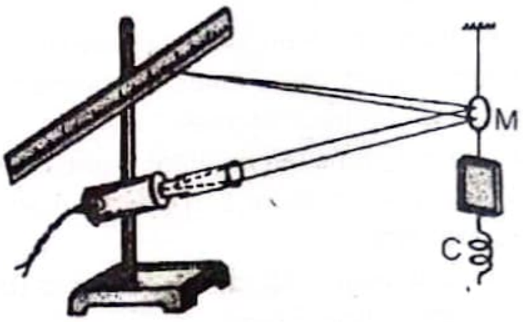
$$I \propto \theta \qquad [\because \text{Since } \frac{C}{BAN} = \text{constant}]$$

So the current passing through the coil is directly proportional to deflection θ.

Q.12 Discuss the methods to measure the angle of deflection of moving coil galvanometer.

Ans.

MEASUREMENT OF ANGLE OF DEFLECTION

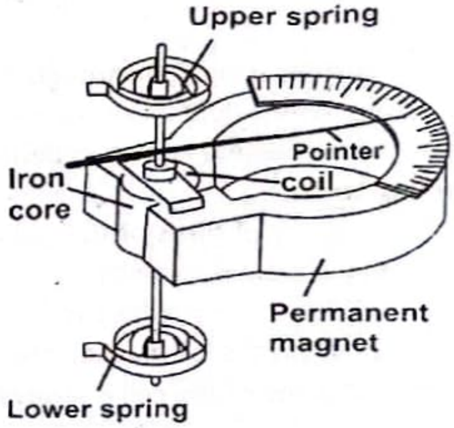


There are two methods to determine the angle of deflection of coil.

i) Lamp & Scale Arrangement

In a sensitive galvanometer, the angle of deflection is observed by means of small mirror attached to the coil along with lamp, as shown in figure. A beam of light from the lamp falls on mirror of galvanometer. After reflection from mirror it produces a spot on a transparent scale placed at a distance of one meter from the galvanometer. When the coil rotates, the mirror attached to the 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.



ii) Pivoted Galvanometer

In this, the coil is pivoted between two jewelled bearings. The restoring torque is provided by two hair springs which also act as current leads. An aluminium pointer is attached to the coil which moves over a scale, as shown in figure. Such galvanometer is called Western-type Galvanometer.

Q.13 Define current sensitivity of galvanometer. How it can be increased?

Ans. **CURRENT SENSITIVITY OF GALVANOMETER**

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

OR

The angular twist per unit current is called current sensitivity of galvanometer.

Mathematically

$$\text{Sensitivity} = \frac{\theta}{I} = \frac{BAN}{C}$$

How to make galvanometer more sensitive.

- By increasing the number of turns of the coil N, but if it is increased beyond a certain limit then the coil become heavy.
- By increasing magnetic flux density B, placing the soft iron cylinder inside the coil. This change is most effective to increase the sensitivity.
- By increasing the area A but it can make the coil bulky and unmanageable.
- By decreasing C, a suspension wire should have large length and small radius.

Dead Beat Galvanometer

A sensitive coil is not stable; its coil oscillates many times before coming to rest, although the current through the coil is stopped. But in some galvanometers the coil comes to rest very soon, as the current stops to flow through it.

A galvanometer, in which the coil comes to rest quickly after passage of current through it, is called stable or dead beat galvanometer.

How to make a Galvanometer Dead Beat

When current passes through the coil it starts rotating about central axis. The flux through frame of coil changes so (by Faraday's law) an emf and hence a (eddy) current is induced in the frame which opposes it cause (i.e. the rotation of coil). In this way the oscillations are damped.

MCQ's From Past Board Papers

1. The effective way to increase the sensitivity of moving/coil galvanometer is: (Lhr 2016 Group I, Bwp 2015 Mtn 2014)
(A) Increase the area of Coil (B) Increase the number of Turns
(C) Increase the magnetic field (D) Increase the value of constant C

2. In order to increase sensitivity of galvanometer the value of C may by (D. G. Khan 2015 G – I)
(A) Increase (B) Decrease
(C) Neither increase nor decrease (D) remains same

3. The sensitivity of galvanometer can be increased by (Mir-II-13/2 Rwp 2015)
(A) Increasing $\frac{C}{BAN}$ factor (B) Decreasing $\frac{C}{BAN}$ factor
(C) Increasing angle θ (D) Decreasing angle θ

4. The deflecting couple in a galvanometer is given by (Fed 2012, Grw 2015 Fsd 2011)
(A) $\frac{NI}{AB}$ (B) NIBA (C) $\frac{ABI}{N}$ (D) None of these

5. The torque on Cement Carrying Coil is: (Grw 2013, 2015, Fsd 2014)
(A) τ =NIAB cos α (B) τ = BIL sin α (C) τ = NIAB sin α (D) τ = BIL cos α

6. Sensitivity of a galvanometer can be increased by: (Grw 10, 14 Lhr 2014 G II Bwp 2010, Mtn 2011)
(A) Decreasing the value of torsional couple (B) Decreasing number of turns
(C) Decreasing area of plane of coil (D) Decreasing magnetic field

7. The sensitivity of galvanometer directly depends upon: (Fsd 2013, Lhr 2013, Sgd 2014)
(A) Magnetic field (B) Area of coil (C) Both A & B (D) None of A, B, C

8. A current carrying coil placed in uniform magnetic field experiences maximum torque when angle between plane of coil and magnetic field is: (Grw 2011, 14 Bwp 2014)
(A) 0° (B) 45° (C) 60° (D) 90°

9. The relation for maximum value of deflecting couple is given by: (Lhr 2012 G I, 2015)
(A) τ = B/NIA (B) τ = BINA (C) τ = BNA (D) τ = BNA sin θ

10. The relation between current I and angle of deflection θ in a moving coil galvanometer is: (Rwp 2015)
(A) $I \propto \theta$ (B) $I \propto \frac{1}{\theta}$ (C) $I \propto \sin\theta$ (D) $I \propto \cos\theta$

11. Torque is produced in a current carrying coil when it is placed in a (Sgd 2016 Group I)
(A) Magnetic field (B) Electric field (C) Gravitational field (D) Nuclear field

12. The effective way to increase the sensitivity of moving coil galvanometer is: (Bwp 2015)
(A) Increase the area of Coil (B) Increase the number of Turns
(C) Increase the magnetic field (D) Increase the value of constant C

13. In order to increase sensitivity of galvanometer the value of C may by (D.G.Khan 2015 Group I)
(A) increase (B) decrease
(C) neither increase nor decrease (D) remains same

14. The sensitivity of galvanometer is given by (D. G. Khan 2015 G – II Lhr 2015, Mirpur 2015)
(A) $\frac{CAN}{B}$ (B) $\frac{C}{BAN}$ (C) $\frac{BAN}{C}$ (D) $\frac{BN}{CA}$

Answer Keys	1.	C	2.	B	3.	A	4.	B	5.	A	6.	A	7.	C
	8.	A	9.	B	10.	A	11.	A	12.	C	13.	B	14.	C

Q.14 What is an ammeter? Explain how a galvanometer can be converted into ammeter? Lhr – 09

Ans. AMMETER

Ammeter is an electrical device which is used to measure the current.

It is the **modified** form of galvanometer. It is a **low resistance** galvanometer.

It is always connected in **series** with circuit to measure current. An ideal ammeter has **zero** resistance.

Meter movement

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

Note

Mostly, the galvanometer gives full scale deflection even when a few milliampere current passes through it. So for large current measurement, it should be modified.

Do You Know?

The pointer of dead beat galvanometer gives a steady deflection because of the eddy currents produced in the conducting frame over which the wire is wound.

Do You Know?

The cylindrical pole pieces used in the moving coil galvanometer provide a magnetic field which is radial in the gap between the pole pieces and the soft iron cylinder.

CONVERSION OF GALVANOMETER INTO AMMETER MCQ

shunt (bypass) resistor

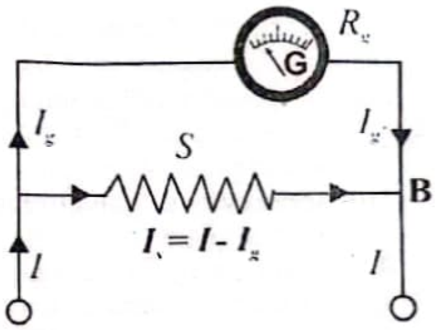
A galvanometer can be converted into ammeter by connecting a low resistance R_s called shunt (bypass) resistor in **parallel** with the meter-movement (coil) of galvanometer. put with series circuit

Range of Ammeter

Let, I be the range of ammeter

Calculation of Shunt Resistance

Shunt resistance provides another path for flow of current. The value of R_s is so adjusted that the current which gives full scale deflection passes through galvanometer and remaining current passes through R_s.



An ammeter is a galvanometer which is shunted by a proper low resistance.

Let

Resistance of galvanometer = R_g

Full scale deflection current = I_g

The current passing through $R_s = I - I_g$

Now, potential difference across the R_g is,

$$V_g = I_g R_g \quad \text{———— (1)}$$

Similarly, potential difference across the R_s is,

$$V_s = I_s R_s$$

OR

$$V_s = (I - I_g)R_s \quad \text{———— (2)} \quad [\text{Since } I_s = I - I_g]$$

Since the galvanometer resistance R_g and the shunt resistance R_s are connected in parallel, so the potential difference across them must be same i.e.,

$$V_s = V_g$$

Putting values, we get

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

Or

$$\boxed{R_s = \frac{I_g R_g}{I - I_g}} \quad \text{———— (3)}$$

For Your Information

If an ammeter is connected in parallel to a circuit, it is likely to be damaged due to excess of current.

Note

The value of shunt R_s is very small. We can use a copper wire for this purpose which should be connected in parallel across the galvanometer. In order to increase the range of ammeter R_s should be **decreased.**

Q.15 What is voltmeter? How galvanometer can be converted into voltmeter?

Ans.

VOLTMETER

Voltmeter is an electrical device which is used to measure the potential difference between two points.

It is the **modified** form of galvanometer. It is a **high resistance** galvanometer. It is always connected in **parallel** with the circuit component. An ideal voltmeter has **infinite** resistance.

Conversion of galvanometer into voltmeter

MCQ

High Resistance

A galvanometer can be converted into voltmeter by connecting a very high resistance R_h in **series** with meter-movement (coil) of galvanometer.) => parallel circuit

Range of voltmeter

Let, the range of the voltmeter = V (volts)

Calculation of High resistance (R_h)

The value of high resistance R_h should be such that galvanometer gives full scale deflection when it is connected across V volt.

Let,

The resistance of meter-movement= R_g

Full scale deflection current = I_g.

Since R_g and R_h are in series, so

The combined resistance of meter- movement and R_h = $R_g + R_h$

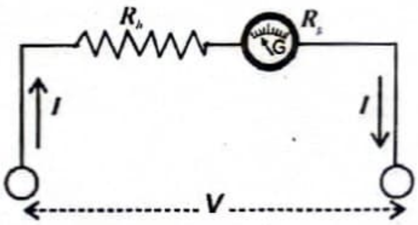
Applying Ohm's law, we have

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

$$V = I_gR_g + I_gR_h$$

or $$I_gR_h = V - I_gR_g$$

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



A galvanometer in series with a high resistance acts as a voltmeter.

This equation gives the value of high resistance R_h which is used to convert the galvanometer into voltmeter. The scale is calibrated from 0 to V to measure the voltage. In order to increase the range of voltmeter, **R_h should be increased.**

Note

The resistance of voltmeter should be greater than the circuit resistance otherwise it will change the value of potential difference which is to be measured.

Q.17 What is ohmmeter? How galvanometer can be converted into ohmmeter?

Ans. **Ohmmeter**

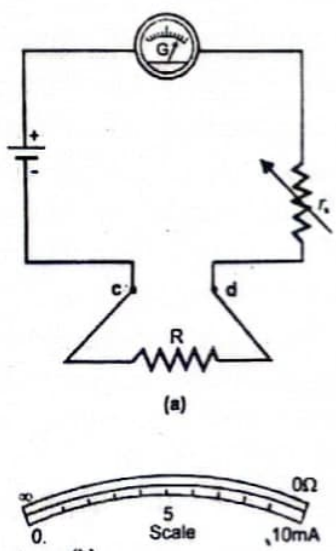
Ohmmeter is an electrical device which is used to measure the value of unknown resistance.

MCQ

Conversion of galvanometer into ohmmeter

A galvanometer can be converted into ohmmeter by connecting an adjustable resistance r and a cell in series with galvanometer.)

Shunt r, in series



A moving coil galvanometer is converted into an ohmmeter.

How to measure an unknown resistance

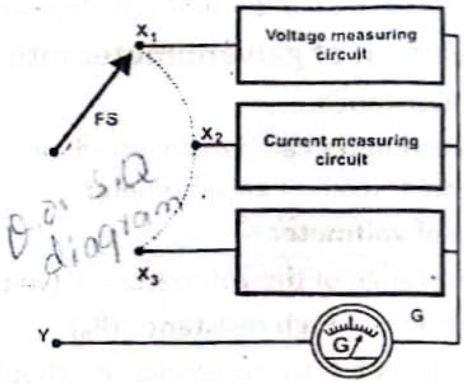
Calibration

First of all, the terminals c and d are short circuited (i.e. $R = 0$) Adjust the resistance r such that the galvanometer gives full scale deflection. The full scale deflection is marked as 0 for resistance measurement. Now, the terminals c and d are open circuited (i.e. $R = \infty$). No current passes through galvanometer and thus the deflection is zero. Zero deflection is marked as infinity for resistance measurement.

Next, a known resistance R is connected between terminals c and d. The galvanometer gives deflection to some intermediate point. This point is calibrated as R. In this way, the whole scale is calibrated into resistance.

Unknown resistance

Now, to measure an unknown resistance, it is connected between the terminals c and d. The deflection on the calibrated scale gives the value of resistance directly.



Q.18 What is an AVO meter? Explain the Different Functions of an AVO meter. Diff b/w DMM and Avometer

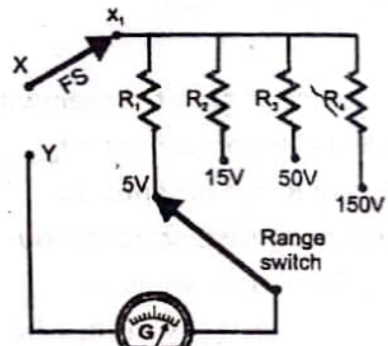
AVO METER - MULTIMETER. ✓

AVO-meter ***is an electrical instrument which can measure the current in amperes, potential difference in volts and resistance in ohms.***

Construction Analog device

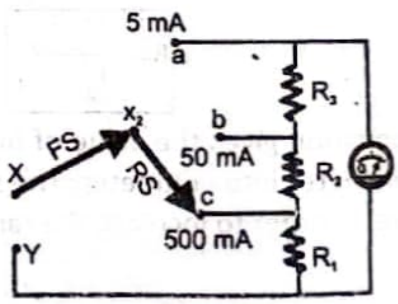
Avometer basically consists of a sensitive moving coil galvanometer which can be converted into a

i) multirange ammeter by connecting a current measuring circuit with it.
ii) multirange voltmeter by connecting a voltage measuring circuit with it.
iii) multirange ohmmeter by connecting a resistance measuring circuit with it.



Function Switch

For this purpose, a switch called function switch is used. FS is the function selector switch, which connects the galvanometer with the relevant measuring circuit.



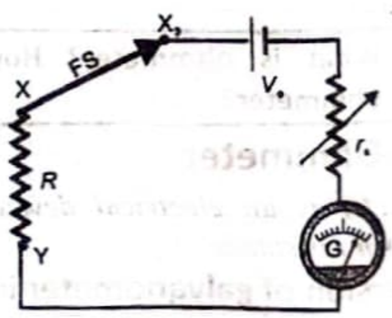
Different parts of AVO meter

Following parts describe the working of AVO meter.

1. Voltage Measuring Part of AVO Meter:

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

The value of each resistance depends upon the range of voltmeter, which it controls; these series resistance are called multipliers. We can measure AC voltage with AVO-meter. For this purpose, AC is first converted into DC and then measured.



Can we measure AC voltage with AVO meter?

Yes, for this AC is first converted into DC and then measured.

Current Measuring Part of AVO Meter:

The current measuring part of AVO meter is multi-range ammeter. It consists of a number of low resistances connected in parallel with the galvanometer. The value of these resistances depends upon the range of ammeter. This circuit also has range selection switch SR which is used to select the particular range.

Analog multimeter

Resistance Measuring Part of AVO Meter:

The resistance measuring part of AVO meter is multi range ohmmeter. It consists of a battery of emf V_0 and a variable resistance r_s connected in series with the galvanometer of resistance R_g. When the function switch is switched to be position X_3, then the circuit is connected with X, Y terminals, of AVO-Meter.

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

Digital Multimeter (DMM) S-Q

It is an electronic instrument which is used to measure current, resistance and voltage in a circuit.

Digital multimeter

The important features of digital multimeter are:

(i) It is digital version of an AVO meter.
(ii) It is very accurate device.
(iii) It is very easy to operate.
(iv) It is much easier to read.
(v) It removes the reading error.
(vi) It shows the digital values with decimal point, polarity and the unit of V, A or Ω.

MCQ's From Past Board Papers

1. Shunted galvanometer is called. **(Lhr 2015, Fsd 2015, Sgd 2015 G – II)**
(A) Ammeter (B) Voltmeter (C) Ohm meter (D) Potentiometer

2. An ideal voltmeter has **(D.G.Khan 2014 Mir-II-13, 14)**
(A) Zero Ohm resistance (B) 100 Ohm resistance (C) 1000 Ohm resistance (D) Infinite resistance

3. To convert a Weston-Type galvanometer into voltmeter, the series resistance is given by _____. **(Fed 2013)**
(A) $R_h = \frac{V}{I_g} + R_g$ (B) $R_h = \frac{V}{I_g} - R_g$ (C) $R_h = \frac{V}{R_g} - I_g$ (D) $R_h \frac{V}{R_g} + I_g$

4. Resistance of a voltmeter should be _____ as compared to the resistance across with it is connected. **(Grw 2012, Bwp 2014, 15, Lhr 12 G II)**
(A) High (B) Very high (C) Low (D) Very low

5. When a small resistance is connected parallel to the galvanometer, the resulting is: **(Grw 2015, Lhr 2013)**
(A) Voltmeter (B) Wheatstone bridge (C) Ammeter (D) Potentiometer

6. An avometer is also called: **(Rwp 2015, Sgd 2014 Grw 2013 G II)**
(A) An ammeter (B) A voltmeter (C) A multimeter (D) An ohm–meter

7. To measure the current in a circuit ammeter is always connected in: **(Bwp 2011, 15 Lhr 10, 15)**
(A) Parallel (B) Series

(C) some times series (D) Neither parallel nor series

8. The galvanometer can be made sensitive by making the factor $\frac{BAN}{C}$: (Lhr 2016 Group II)
(A) Large (B) Small (C) Constant (D) Zero

9. An avometer can also be called as (Sgd 2016 Group II)
(A) Digital multimeter (B) digital voltmeter (C) Digital ammeter (D) digital ohm-meter

10. Useful device to measure resistance, current and voltage is an electronic instrument called: (Bwp 2016)
(A) Voltmeter (B) Ammeter (C) Ohmmeter (D) Digital Multimeter

11. A proper combination of a galvanometer and a series of resistance acts as: (Bwp 2016)
(A) Voltmeter (B) Ammeter (C) Ohmmeter (D) digital Multimeter

12. If a high resistance is connected in series to a galvanometer, then galvanometer is converted into (D.G.Khan 2016 Group II)
(A) Ammeter (B) Voltmeter (C) Ohm meter (D) Multi meter

13. In case of conversion of galvanometer into ammeter the shunt resistance is connected (Sgd 2015 Group I, Mirpur 2015, Mirpur 2016)
(A) In parallel (B) In series
(C) Neither parallel nor series (D) Both (A) and (B)

14. Shunted galvanometer is called (Sgd 2015 Group II)
(A) Ammeter (B) Voltmeter (C) Ohm meter (D) Potentiometer

15. Which of the following is not accurate measuring device? (Rwp 2016)
(A) Digital multimeter (B) CRO (C) Potentiometer (D) Voltmeter

Answer Keys	1.	A	2.	D	3.	B	4.	B	5.	C	6.	C	7.	B	8.	A
	9.	A	10.	D	11.	A	12.	B	13.	A	14.	A	15.	D		

DMM
=> Digital
=> It is free from H. error
=> It gives accurate value.

Avometer
Analog
It have a human error
It may have approximation in reading.

FORMULAE

1	Magnetic force acting on a current carrying conductor	$\vec{F} = I(\vec{L} \times \vec{B})$	$\vec{F} = ILB\sin\theta \cdot \hat{n}$	$F = ILB\sin\theta$
2	Magnetic induction	$B = \frac{F}{IL}$	$B = \frac{F}{qv}$	
3	Magnetic flux	$\phi = \vec{B} \cdot \vec{A}$	$\phi = BA\cos\theta$	
4	Magnetic flux density	$B = \frac{\phi}{A}$		
5	Ampere's law	$\sum_{i=1}^{n} (\vec{B} \cdot \vec{\Delta \ell})_i = \mu_o I$		$B = \frac{\mu_o I}{2\pi r}$
6	Magnetic field due to solenoid	$B = \mu_o nI$	$B = \mu_o \frac{N}{\ell} I$	
7	Magnetic force acting on a charged particle moving in a magnetic field	$\vec{F} = q(\vec{v} \times \vec{B})$	$\vec{F} = qvB\sin\theta \cdot \hat{n}$	$F = qvB\sin\theta$
8	Lorentz force	$\vec{F} = \vec{F}_e + \vec{F}_b$	$\vec{F} = q\vec{E} + q(\vec{v} \times \vec{B})$	$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$
9	e/m of electron	$e/m = \frac{v}{Br}$	$e/m = \frac{2V}{B^2r^2}$	
10	Velocity selector	$v = \frac{E}{B}$		
11	Torque acting on a current carrying loop in magnetic field	$\tau = IBA\cos\alpha$		
12	Torque acting on a current carrying coil in magnetic field	$\tau = NIAB\cos\alpha$		
13	Deflecting torque acting galvanometer coil	$\tau = NIAB$		
14	Restoring torque acting galvanometer coil	$\tau = c\theta$		
15	Torsional constant	$c = \frac{\tau}{\theta}$		
16	Relation between Current and deflecting angle in galvanometer	$I = \frac{c}{BAN}\theta$		

17	Sensitivity of galvanometer	$\frac{\theta}{I}=\frac{BAN}{c}$		
18	Shunt resistance for the conversion galvanometer into ammeter	$R_s=\frac{I_g R_g}{I-I_g}$		
19	High resistance for the conversion galvanometer into voltmeter	$R_h=\frac{V}{I_g}-R_g$		

UNITS

1	Magnetic induction(B)	$Nm^{-1}A^{-1}$	tesla	
2	Magnetic flux	NmA^{-1}	weber	
3	Magnetic flux density	Wb/m^2	$Nm^{-1}A^{-1}$	tesla
4	Permeability of free space(μ_o)	$Wbm^{-1}A^{-1}$		
5	Relative Permeability(μ_r)	No unit		
6	e/m of electron	Ckg^{-1}		
7	Torsional constant(c)	Nm/rad		

CONSTANTS

1	Permeability of free space(μ_o)	$4\pi\times10^{-7}\,Wbm^{-1}A^{-1}$

Solved 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° with the direction of magnetic field, find the magnitude of the force acting on the wire.

Given data:

Length of the wire = L = 20.0 cm

= 0.20 m

Current in the wire = I = 10.0 A

Strength of magnetic field = B = 0.30 T

Angle between $\vec{L}$ and $\vec{B}$ = α = 40°

To find:

Magnitude of the force = F = ?

B-Manual

Calculations:

Using the formula

$$F = ILBSin\ \alpha$$

Putting the values, we get

$$F = 10 \times 0.20 \times 0.30 \times \sin 40^o$$

$$F = 0.60 \times 0.642$$

$$\boxed{F = 0.39\ N}$$

Example 14.2:

The magnetic field in a certain region is given by $\vec{B} = (40\hat{i} - 18\hat{k})$ Wbm^{-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?

per to $\hat{k}$ (z)

Given data:

Magnetic induction = $\vec{B} = (40\hat{i} - 18\hat{k})$Wb m^{-2}

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

To find:

Magnetic flux = ϕ_B = ?

Calculations:

As we know that

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

Putting the values, we get

$$\phi_B = (40\hat{i} - 18\hat{k}) \cdot (5 \times 10^{-4}\hat{k})$$

$$\phi_B = (40)(0) - (18 \times 5 \times 10^{-4})$$

$$\phi_B = 0 - 90 \times 10^{-4}\ Wb$$

$$\boxed{\phi_B = -90 \times 10^{-4}\ Wb}$$

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?

Given data:

Length of solenoid = L = 15.0 cm = 0.15 m

Total number of turns = N = 300

Current = I = 5.0 A

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

To find:

Magnitude of magnetic field = B = ?

Calculations:

As magnetic field inside the solenoid is given by the formula

$$B = \mu_o nI \qquad ......(1)$$

Number of turns per unit length = $n = \frac{N}{L}$

$$n = \frac{300}{0.15} = 2000\ \text{turns/m}$$

Putting the values in equation (1), we get

$$B = 4\pi \times 10^{-7} \times 2000 \times 5$$

$$B = 125.6 \times 10^{-4}\ \text{Wb m}^{-2}$$

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

Example 14.4:

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

Given data:

Speed of electron = $v = 2.0 \times 10^7\ \text{ms}^{-1}$

Magnetic field strength = $B = 1.20 \times 10^{-3}$ T

Mass of the electron = $m = 9.11 \times 10^{-31}$ kg

Charge on electron = $e = 1.61 \times 10^{-19}$ C

To find:

Radius of the orbit = r = ?

Calculations:

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

or $$r = \frac{vm}{eB}$$

Putting the values, we get

$$r = \frac{2\times10^{7}\times9.11\times10^{-31}}{1.61\times10^{-19}\times1.20\times10^{-3}}$$

$$r = \frac{18.22\times10^{-24}}{1.932\times10^{-22}}$$

$$r = 9.43 \times 10^{-24+22}$$

$$\boxed{r = 9.43 \times 10^{-2}\ \text{m}}$$

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?

Given data:

Electric intensity = $E = 300\ \text{Vm}^{-1}$

Magnetic induction = $B = 0.20$ T

To find:

Selected speed of particle = v = ?

Calculations:

Only those particles will move undeviated through the field for which

Electric force = Magnetic force

$$qE = qvB$$

or $$E = vB$$

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

Putting the values, we get

$$v = \frac{300}{0.20}$$

$$\boxed{v = 1500\ ms^{-1}}$$

Thus, alpha particles having a speed of $1500\ ms^{-1}$ will move undeviated 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?

Given data:

Resistance of galvanometer = R_g = 50.0 Ω

Current for full scale deflection = I_g = 2.0 mA

$= 2.0 \times 10^{-3}$ A

Current to be measured = I = 10.0 A

To find:

Shunt resistance = R_s = ?

Calculations:

Using the relation

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

Putting the values, we get

$$R_s = \frac{2\times10^{-3}}{10-2\times10^{-3}} \times 50$$

$$R_s = \frac{100\times10^{-3}}{10-2\times10^{-3}}$$

$$R_s = \frac{0.1}{10-0.002}$$

$$R_s = \frac{0.1}{9.998}$$

$$\boxed{R_s = 0.01\ \Omega}$$

Short Questions of the Exercise

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

dir

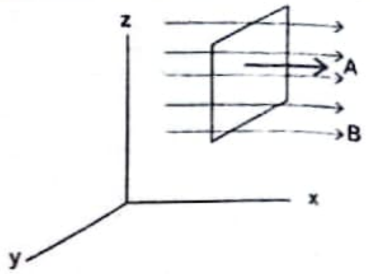
(Lhr 2014, 15 G II, 16 G I, Bwp 2013, 15, Rwp 2015, Grw 14, 16)

Ans. (a) Maximum flux

When plane of loop is held ***perpendicular*** to direction of $\vec{B}$, flux is maximum. In other words, when the loop is in yz-plane, flux is maximum.

Explanation

In this case θ = 0°.



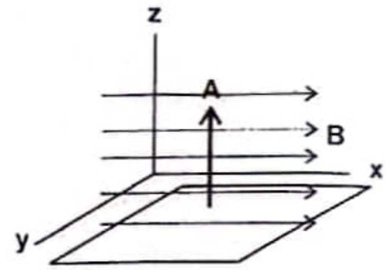
Thus $\Phi_B = \vec{B} \cdot \vec{A}$

OR $\Phi_B = BA\cos 0^\circ$

$\Phi_B = BA$ (maximum)

(b) Minimum flux

When the plane of loop is held ***parallel*** to direction of $\vec{B}$, In other words, when the loop is in xy or xz–plane, flux will be minimum.



Explanation

In this case $\theta = 90^\circ$.

Thus $\Phi_B = BA\cos\theta$

$\Phi_B = BA\cos 90^\circ$

$\Phi_B = 0$ (minimum)

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. **(a)** Magnetic field due to stationary charges is ***zero.***

Reason

As magnetic field due to straight current carrying conductor is,

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

$$B = 0 \qquad \text{[since I=0]}$$

(b) Moving charges produce ***magnetic field.***

Reason

This is because moving charges constitute current and magnetic field is produced.

$$B \neq 0 \qquad \text{[since } I \neq 0\text{]}$$

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 of turns is doubled, but the length remains the same.

(Lhr 2015, Bwp 2015, Rwp 2014, Grw 2009, 13, DG khan 2009, 2014)

Ans. (a) In this case, magnetic field is reduced to ***half.***

Explanation

As field due to solenoid is

$$B = \mu_o n I$$

OR $B = \mu_o \frac{NI}{\ell}$ $\quad (\because n = \frac{N}{\ell})$

If $\ell' = 2\ell$, then

$$B' = \mu_o \frac{NI}{2\ell}$$

$$B' = \frac{1}{2}\mu_o \frac{NI}{\ell}$$

OR $$\mathbf{B' = \frac{1}{2} B}$$

(b) In this case, magnetic field is increased to ***doubled.***

Explanation

As field due to solenoid is

$$B = \mu_o nI$$

OR $$B = \mu_o \frac{NI}{\ell} \qquad (\because n = \frac{N}{\ell})$$

If $N' = 2N$, then

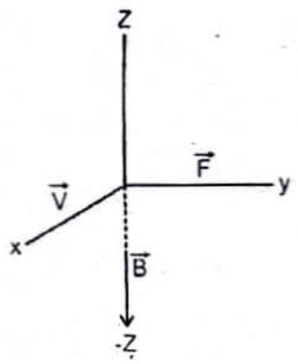
$$B' = \mu_o \frac{2N}{\ell} I$$

$$B' = 2\mu_o \frac{N}{\ell} I$$

OR $$\mathbf{B' = 2B}$$

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

Ans. **(Mtn 2016 G I, Rwp 2015, 2016, Lhr 2012, 15 G II, 2016 G I, Bwp 2015, , Grw 2016)**



(a) Magnetic force is directed along ***positive y-direction.***

Reason

As magnetic force acting on proton is given by

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

By right hand rule, $\vec{F}$ is directed ***perpendicular*** to the plane containing $\vec{v}$ and $\vec{B}$ i.e., along (positive y-direction)

(b) No, it will move along a ***circle.***

Reason

As the proton experiences a force that acts at ***right angle*** to its velocity, so it will change only ***direction*** of velocity. Thus under the action of this force proton moves in a circle.

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 two particles are ***oppositely*** charged.

Reason

The magnetic force acting on a charged particle q moving in a magnetic field $\vec{B}$ with velocity $\vec{v}$ is

$$\vec{F} = q(\vec{v} \times \vec{B}) \qquad \text{[for +ve charge]}$$

$$\vec{F} = -q(\vec{v} \times \vec{B}) \quad \text{[for -ve charge]}$$

This force is a deflecting force. If q is positive, it is deflected in one direction and if q is negative then it is deflected in opposite direction.

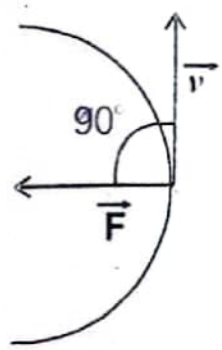
14.6 Suppose that a charge q is moving in a uniform magnetic field with a velocity v. Why is there no work done by the magnetic force that acts on the charge q?

(Grw 2010, Bwp 2008, DG khan 2009)

Ans. Reason

The magnetic force acting on a charged particle 'q' is given by

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



As magnetic force is always perpendicular to $\vec{v}$ (i.e., $\vec{d}$)

Therefore, angle between $\vec{F}$ and $\vec{d}$ is 90°

Hence $$W = \vec{F} \cdot \vec{d}$$

$$W = Fd\cos\theta$$

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

$$\boxed{W = 0}$$

So no work is done by magnetic force.

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

(Sgd 16 G II, Mirpur 2016, Bwp 2014, Fsd 2013, Mtn 2016)

Ans. <u>No,</u> it may or may not be ***zero.***

Reason

The magnetic force acting on a charged particle is given by

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

or $$\vec{F} = qvB\sin\theta\,\hat{n}$$

Now, $\vec{F} = 0$, if:

(i) $\vec{B} = 0$

(ii) $\theta = 0^\circ$ (i.e the charged particle moves ***<u>parallel</u>*** to magnetic field)

(iii) $\theta = 180^\circ$ (i.e the charged particle moves ***<u>opposite</u>*** to magnetic field)

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

(Grw 2011, 15 Lhr 2009,10,15,DG khan 2009, Fsd 2011)

Ans.

We know that the picture on a TV screen is formed due to the beam of electrons.

When a magnet is brought near screen, the magnetic field of magnet ***<u>interacts</u>*** with the magnetic field around the beam of electrons. So a ***<u>magnetic force</u>*** acts on the beam, which is given by,

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

Due to this force electron beam is deflected. Hence the picture is distorted.

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.

(Grw 2009,12, Lhr 2015 G I, Bwp 2014)

Ans. ***Yes,*** it is possible.

Explanation

We know that torque acting on a current loop in a uniform magnetic field is given by

$$\tau = IAB\cos\alpha$$

when the plane of loop is held ***perpendicular*** to magnetic field. (i.e $\alpha = 90^\circ$) then

$$\tau = IAB\cos 90^\circ$$

$$\tau = 0$$

So, loop will not tend to rotate in this case.

14.10 How can a current loop be used to determine the presence of a magnetic field in a given region of space? **(Rwp 2015, Fsd 2016, Grw,16, Lhr 16 G I)**

Ans. Torque acting on current carrying loop in uniform magnetic field is,

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

So, if a current loop is ***deflected*** in given region of space, then it shows the presence of magnetic field. (other than $\alpha = 90^\circ$).

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

(Lhr 2014 G II, Bwp 2014, Mtn 2016 G I, DG. Khan 2015 G II)

Ans. **Explanation (Separation of isotopes)**

For this purpose, the ions of an element are passed through a uniform and perpendicular field. A magnetic force acts on them.

Under the action of this force, the ions move along circular paths of ***different*** radii due to their different masses as explained below.

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

OR

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

Since m, q, and B are constant

Therefore $\boxed{r \propto m}$

In this way isotopes of an element can be separated.

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

(Lhr 2011, Grw 2014)

Ans. (a) when the plane of current carrying coil is held ***parallel*** to the field, torque will be maximum.

Explanation

As $\tau = NIAB\cos\alpha$

Then $\tau = NIAB\cos 0^\circ$ (since $\alpha = 0^\circ$)

$\tau = NIAB$ (maximum)

(b) When the plane of current carrying coil is held ***perpendicular*** to the magnetic field, torque will be minimum.

Explanation

As $\tau = NIAB \cos\alpha$

Then $\tau = N\,I\,A\,B \cos 90^\circ$ (since $\alpha = 90^\circ$)

$\tau = 0$ (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. In both cases (A.C and D.C) the plane of the loop will ***not rotate***.

Reason

Since in both cases the plane of the loop and magnetic field are ***perpendicular***. So the torque will be zero. i.e.

$\tau = NIAB \cos\alpha$

OR $\tau = NIAB \cos 90^\circ$ (since $\alpha = 90^\circ$)

$\tau = 0$

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

(Grw 2015, Lhr 2016 G II, DG khan 2014, Bwp 2016)

Ans. Reason

As ammeter is connected is ***series*** with a circuit to measure the current. That's why it should have very low resistance because if the resistance of the ammeter is high then it will become a load and will ***change (decrease)*** the circuit current. So the current will not be measured accurately.

14.15 Why the voltmeter should have a very high resistance?

(Grw 2008, Lhr 2009,11, Mirpur 2011)

Ans. Reason

In order to measure the potential difference between two points, the voltmeter is always connected in ***parallel.*** If the resistance of the voltmeter is very low then it will ***short*** the circuit and becomes a ***load***. So it will not measure the potential difference accurately.

Exercise Problems

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

Given data:

Maximum force = $F_{max} = 7.0 \times 10^{-3}$ N

Length of wire = L = 20.0 cm = 20×10^{-2} m

100

Current = I = 10 A

To find:

Magnetic field = B = ?

Calculations:

As $\vec{F} = I\vec{L} \times \vec{B}$

$F = ILB \sin\theta$

For maximum force $\theta = 90^\circ$

$F_{max} = ILB \sin 90^\circ$

$F_{max} = ILB$

or $B = \dfrac{F_{max}}{IL}$

Putting the values, we get

$$B = \frac{7.0\times10^{-3}}{10\times20\times10^{-2}} = \frac{7\times10^{-3}}{2\times10^{2}\times10^{-2}}$$

$\boxed{B = 3.5 \times 10^{-3}\ T}$ ($\because$ T = Tesla = N/Am)

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?

✓I

Given data:

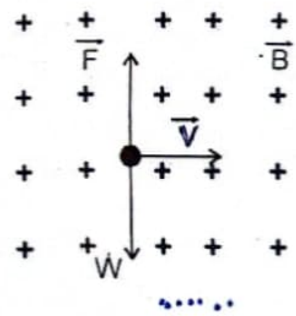
Magnetic field = $B = 2.50 \times 10^{-3}$ T

Mass of proton = $m = 1.67 \times 10^{-27}$ kg 9.11×10^{-31}

Charge on proton = $q = 1.60 \times 10^{-19}$ C

To find:

Speed of proton = v = ?



Calculations:

As Magnetic force = F = qVB

Weight = W = mg

According to given condition

Magnetic force = weight

$F = W$

$qvB = mg$

or $v = \dfrac{mg}{qB}$

Putting values, we get

$$v = \frac{1.67\times10^{-27}\times9.8}{1.60\times10^{-19}\times2.50\times10^{-3}}$$

$\boxed{v = 4.09\times10^{-5}\ m/sec}$ ✓

14.3 A velocity selector has a 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?

Given data:

Magnetic field = B = 0.30 T

Electric field = E = 10,000 v/m

To find:

Speed of particle = v = ?

Calculations:

The particle will pass through the selector if

Magnetic force = Electric force

$$qvB = qE$$

$$vB = E$$

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

Putting the values, we get

$$v = \frac{10,000}{0.30}$$

$$\boxed{v = 3.3\times10^4 \text{ m/sec}}$$

✓

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.

Given data:

Area of coil = $A = 0.1 \text{ m} \times 0.1 \text{ m} = 0.01 \text{ m}^2$

Number of turns = N = 200 turns

Current = $I = 1.0 \text{ mA} = 1.0 \times 10^{-3}$ A

Magnetic field = B = 0.1 T

To find:

Maximum torque = τ_{max} = ?

Calculations:

As $\tau = BINA \cos\alpha$

Torque is max. if $\alpha = 0^\circ$ and $\cos 0^\circ = 1$, so

$$\tau_{max} = BINA$$

Putting the values, we get

$$\tau_{max} = 0.1 \times 1.0 \times 10^{-3} \times 200 \times 0.01$$

$$\tau_{max} = 0.2 \times 10^{-3}$$

or. $$\boxed{\tau_{max} = 2.0 \times 10^{-4} \text{ N m}}$$

✓ I

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

Given data:

Height of power line = $h = r$ = 10.0 m (i.e., distance of wire from ground)

Current = I = 200 A

To find:

Magnetic field of wire at the ground = B = ?

Calculations:

As, according to Ampere's law

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

Substituting the values, we get

$$B = \frac{4\pi \times 10^{-7} \times 200}{2\pi \times 10.0}$$ [As $\mu_o = 4\pi \times 10^{-7}$ wb/A.m]

$$B = 40 \times 10^{-7}$$

or $\boxed{B = 4 \times 10^{-6}\ T}$ ✓

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.

Given data:

Magnetic field = B = 0.10 T

Maximum current = I = 10.0 A

To find:

Number of turns per unit length = n = ?

Calculations:

As for solenoid $B = \mu_o nI$

or $n = \frac{B}{\mu_o I}$

Where $\mu_o = 4\pi \times 10^{-7}\ wbA^{-1}\ m^{-1}$

Putting the values, we get

$$n = \frac{0.1}{4\pi \times 10^{-7} \times 10}$$

$$n = \frac{\cancel{0.1}}{4 \times 3.14 \times 10^{-7} \times \cancel{10}}$$

$$n = \frac{10^5}{4 \times 3.14}$$

$$n = 0.796 \times 10^5$$

$$n = \frac{0.1 \times 10^7}{125.6}$$

$$n = 0.000796 \times 10^7$$

$\boxed{n = 7.96 \times 10^3 \text{ turn/length}}$ ✓

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

Given data:

Length of the solenoid = L = 0.5 m

Strength of magnetic field = B = 0.4 T

Number of turns = N = 10,000

Permeability of free space = $\mu_o = 4\pi \times 10^{-7}\ wbA^{-1}\ m^{-1}$

To find:

Current passing through solenoid = I = ? B = MonI

Calculations:

As for solenoid $B = \mu_o nI$

or $I = \frac{B}{\mu_o n}$

Here $n = \frac{N}{L} = \frac{10000}{0.5} = 20000$

Putting the values, we get

$$I = \frac{0.4}{4\pi\times10^{-7}\times20000}$$

$$I = 0.0159\times10^{3}$$

or $\boxed{I = 16\ A}$

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.

Given data:

Resistance of galvanometer = $R_g = 15.0\ \Omega$

Current for full scale deflection = I_g = 20.0 mA = 20×10^{-3} A

Current to be measured = I = 10.0 A

To find:

Shunt Resistance = R_s =?

Calculations:

As for converting galvanometer into Ammeter expression is

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

Putting the values, we get

$$R_s = \frac{20\times10^{-3}\times15}{10-20\times10^{-3}}$$

$$R_s = \frac{0.02\times15}{10-0.02} = \frac{0.30}{9.98}$$

$$\boxed{R_s = 0.03\Omega}$$

14.9 The resistance of a 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.

Given data:

Resistance of galvanometer = $R_g = 50.0\ \Omega$

Current for full scale deflection = I_g = 2.0 mA = 2.0×10^{-3} A

Voltage to be measured = V = 200 Volts

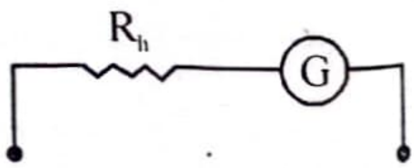
To find:

High resistance = R_h = ?

Calculations:

For converting galvanometer into voltmeter expression is

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



Putting the values, we get

or $$R_h = \frac{200}{2\times10^{-3}} - 50$$

$$R_h = 100\times10^{3} - 50$$

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

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

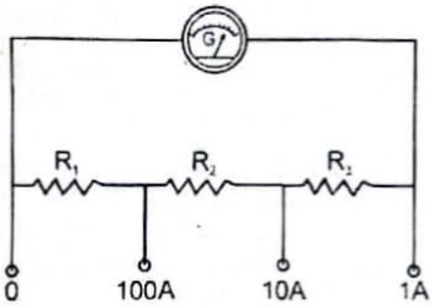


Fig. P. 14.10

Given data:

Resistance of galvanometer = $R_g = 10.0\ \Omega$

Current for full scale deflection = $I_g = 1.0$ mA

$= 1 \times 10^{-3}$ A = 0.001 A

Different current ranges of ammeter = $I_1 = 100$ A

$I_2 = 10$A

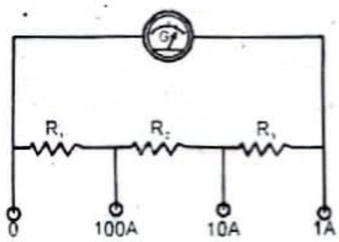
$I_3 = 1.0$ A

To find:

Shunt resistance, R_1 = ?

Shunt resistance, R_2 = ?

Shunt resistance, R_3 = ?



Calculations:

(i) **Shunt resistance R_1,** in order to convert galvanometer into ammeter of range 100 A is given by

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

Putting the value, we get

$$R_1 = \frac{0.001 \times 10}{100 - 0.001} = \frac{0.01}{99.999}$$

$$\boxed{R_1 = 0.0001\ \Omega}$$

(ii) **Shunt resistance R_2,** for ammeter of range 10 A is

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

Putting the value, we get

$$R_2 = \frac{0.001 \times 10}{10 - 0.001} = \frac{0.01}{9.999}$$

$$\boxed{R_2 = 0.001\ \Omega}$$

(iii) **Shunt resistance R_3,** for ammeter of range 1.0 A is

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

Putting the value, we get

$$R_3 = \frac{0.001 \times 10}{1.0 \times 0.001} = \frac{0.01}{0.999}$$

$$\boxed{R_3 = 0.01\ \Omega}$$

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