CHAPTER 4
MOVING CHARGES AND MAGNETISM

1. Who discovered that a magnetic field set up around a carrying conductor?
Ans: Christian Oersted

2. Define electric Lorentz force.
Ans: It is the force experienced by a charged particle at rest or moving in an electric field.

$$\vec{F_E} = q\vec{E}$$

3. Define Magnetic Lorentz force.
Ans: It is the force acting on a charged particle moving in a magnetic field.

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

$$F_B = qvB\sin\theta$$

$\vec{v}$ = velocity of the particle

4. Define Lorentz Force.
Ans: It is the total force acting on a charged particle moving in the combined effect of electric and magnetic fields.

$$\vec{F} = \vec{F_E} + \vec{F_B}$$

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

5. What is the work done by magnetic field on a charged particle?
Ans: The magnetic force $\vec{F_B} = q(\vec{v} \times \vec{B})$
From the equation it is clear that the magnetic force is perpendicular to velocity ($\vec{v}$). So it is perpendicular to displacement ($\vec{S}$).Therefore the work done,

$$W = FS\cos 90^\circ$$
$$= 0$$

6. What is the change in kinetic energy of a charged particle, when it moves in a magnetic field?
Ans: Since the magnetic force is perpendicular to the velocity of the charged particle, no work is done by it on the charged particle. So there is no change in the kinetic energy of the charged particle.

7. Can a magnetic field change the velocity of a charged particle?
Ans: Yes, magnetic field can change the direction of velocity but can't change its magnitude.

8. Can a charged particle move in a magnetic field, without experiencing any force?
Ans: Yes it can. But only when it moves parallel or anti parallel to the field.
<u>When it moves parallel to the field,</u>
$\theta = 0$

$F_B = qvB\sin 0 = 0$

<u>When it moves antiparallel to the magnetic field,</u>

$\theta = 180^\circ$

$F_B = qvB\sin 180^\circ = 0$

9. What are the units of magnetic induction (magnetic flux density)?
Ans: SI unit is tesla (T)
Tesla is a rather large unit. A smaller unit called gauss is also used.
1 gauss = 10^{-4} tesla.

10. Definition of 1 tesla.
Ans: We have

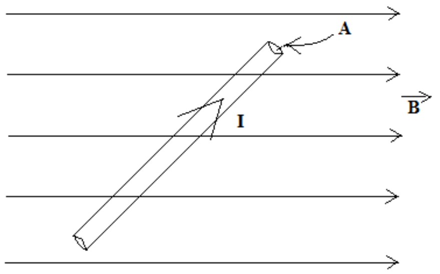
$$\vec{F} = q(\vec{v} \times \vec{B})$$

$$F = qvB\sin\theta$$

If, q = 1C, $\theta = 90^0$
v = 1m/s and F = 1N, then B = 1 tesla
"The magnetic induction (B) in a region is said to be one tesla if the force acting on a unit charge (1C) moving perpendicular to the magnetic field ($\vec{B}$) with a speed of 1m/s is one Newton".

11. Derive an expression for the magnetic force acting on a current carrying conductor placed in a uniform magnetic field.

Ans:



Consider a conductor of area of cross section A and length l placed in a uniform magnetic field. Let 'n' be the no. of free electrons per unit volume of the conductor.

Total number of electrons in the conductor = Volume × n

= Aln

Total charge, q = Alne

Force on the conductor

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

$v_d \rightarrow$ drift velocity

$F = Alne\left(\vec{v}_d \times \vec{B}\right)$

$= Anev_d\left(\vec{l} \times \vec{B}\right)$ [But $neAv_d = I$]

$= I\left(\vec{l} \times \vec{B}\right)$

$$\boxed{\vec{F} = I\left(\vec{l} \times \vec{B}\right)}$$

The direction of this force is given by Flemming's left hand rule.

12. State Flemming's left hand rule.

Ans: Stretch the three fingers in your left hand in three mutually perpendicular directions. *If the forefinger gives the direction of magnetic field and the middle finger gives the direction of current, then the thumb will give the direction of force on the conductor.*

13[P]. What is the magnetic force per unit length of a wire carrying a current of 8A and making an angle of 30^0 with the direction of a uniform m.f of 0.15 T?

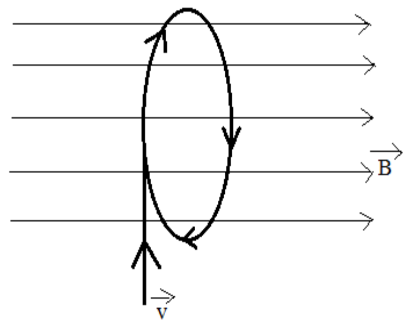
14[P]. A 3.0 cm wire carrying a current of 10A is placed inside a solenoid perpendicular to its axis. The m.f inside the solenoid is given to be 0.27T. What is the magnetic force on the wire?

15. What will be the path of a charged particle, which enter the magnetic field in a direction perpendicular to it? Derive the expression for the frequency of revolution of the charged particle.

Ans: When $\vec{v}$ perpendicular to $\vec{B}$

The perpendicular force, F= $q\left(\vec{v} \times \vec{B}\right)$

=qvBsin90 = qvB acts as centripetal force and produces a circular motion in a plane perpendicular to the magnetic field.



Centripetal force = magnetic Lorentz force

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

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

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

The above equation shows that the velocity is proportional to the radius.

Velocity, $v = \frac{qBr}{m}$

But angular frequency $\omega = \frac{v}{r} = \frac{qB}{m}$

Linear frequency $\upsilon = \frac{\omega}{2\pi} = \frac{qB}{2\pi m}$

$$\boxed{\upsilon = \frac{qB}{2\pi m}}$$

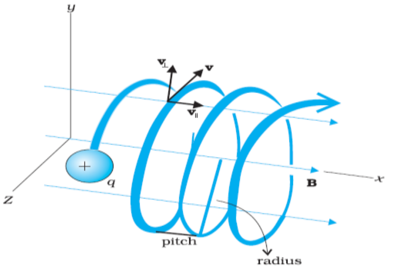
From the above equation it is very clear that the frequency of revolution, υ is independent of velocity or energy. This independence has important application in the design of cyclotron.

16[Q]. You are sitting in a room in which a uniform magnetic field B exists. At the centre of the room a charged particle is suddenly projected horizontally and it starts circular motion in the horizontal plane. What should be the direction of the magnetic field for this to happen?

Ans:

17. If velocity of the charged particle has a component along $\vec{B}$, what is the shape of the path? Derive an expression for the pitch of the helix.

Ans: If velocity of the charged particle has a component along $\vec{B}$,
this component remains unchanged. The motion in a plane perpendicular to B is a circular one, there by producing a **helical motion.**



The time taken for one revolution is $T = \frac{2\pi}{\omega} = \frac{1}{\upsilon} = \frac{2\pi m}{qB}$

The distance moved along the magnetic field in one revolution is called pitch 'P'

$P = V_{||}T = \frac{2\pi m V_{||}}{qB}$

$V_{||} \rightarrow$ velocity parallel to magnetic field.

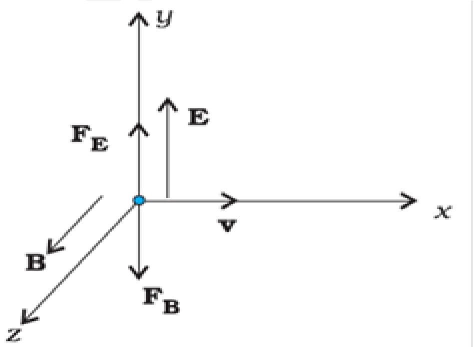
CROSSED ELECTRIC AND MAGNETIC FIELD - VELOCITY SELECTOR.

18. Explain the motion of a charged particle in a combined electric and magnetic field.

Ans: A charged particle moving in the combined effect of an electric field $(\vec{E})$ and a magnetic field $(\vec{B})$, experiences a force

$\vec{F} = \vec{F}_E + \vec{F}_B = q\vec{E} + q(\vec{v}\times\vec{B})$

$= q\left(\vec{E} + \vec{v}\times\vec{B}\right)$



Consider the simple case in which electric and magnetic fields are perpendicular to each other and also perpendicular to the velocity of the particle.

$\vec{E} = E\hat{j},\ B = B\hat{k},\ v = v\hat{i}$

$\vec{F}_E = q\vec{E} = qE\hat{j}$

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

$= q(v\hat{i}\times B\hat{k})$

$= q(v\hat{i}\times B\hat{k})$

$= qvB(\hat{i}\times\hat{k})$

$= qvB(-\hat{j})$

$= -qVB\hat{j}$

The total Lorentz force, $\vec{F} = \vec{F}_E + \vec{F}_B$

$\vec{F} = \mathbf{q(E - vB)}\,\hat{j}$

Here electric and magnetic forces are in opposite directions.

Suppose we adjust the value of E and B such that the magnitudes of the two forces are equal. Then total force on the charged particle is zero and the charge will move undeflected through the fields.

This happens when,

$$\mathbf{qE = qvB}$$

$$\Rightarrow E = vB$$

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

19. Why crossed electric and magnetic field is called velocity selector? Write some of its applications.

Ans: Particles with speed $\frac{E}{B}$ pass undeflected through the region of crossed electric and magnetic fields. This condition is used to select charged particles of a particular velocity out of a beam containing charges moving with different speeds. The crossed (perpendicular) E and B fields, therefore act as a velocity selector.

Applications

(i) This method was employed by J. J. Thomson in 1897 to measure the charge to mass ratio (e/m) of electron.

(ii) This principle is also employed in Mass spectrometer – a device that separates charged particles, usually ions, according to their charge to mass ratio.

CYCLOTRON

20. What is the use of a cyclotron? Write its principle. Derive expressions for maximum kinetic energy and cyclotron frequency. Explain its construction and working.

Ans:

Use:- **Cyclotron** is a particle accelerator used to accelerate charged particles to very high energy.

Principle:-

The frequency of revolution of the charged particle in a magnetic field is independent of its energy.

In a perpendicular magnetic field, a charged particle moves in a circular path. The necessary centripetal force for the revolution of the particle is provided by the magnetic force (F= qvB)

The charged particle gets accelerated by the electric field.

Expression for KE:-

Centripetal force = Magnetic Lorentz force

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

$$\frac{mv}{r} = qB \Rightarrow v = \frac{qBr}{m}$$

From the above equation, it is clear that r α v i.e., when velocity increases, radius of the circular path also increases.

KE of the particle,

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

$$= \frac{1}{2}m\left(\frac{qBr}{m}\right)^2$$

$$KE = \frac{1}{2}\frac{q^2B^2r^2}{m}$$

KE is maximum when r approaches R, the radius of the dees.

$$\mathbf{KE_{max}} = \frac{1}{2}\frac{q^2B^2R^2}{m}$$

Cyclotron Frequency (ν_c):-

The angular frequency of the charged particle $\omega = \frac{v}{r} = \frac{qB}{m}$

Therefore, the time period of revolution, of the particle

$T = \frac{2\pi}{\omega} = \frac{2\pi m}{qB}$

For resonance the time period of the R.F oscillator must be same as the time period of revolution of the particle.

So the time period of the R.F. oscillator should be $T = \frac{2\pi m}{qB}$

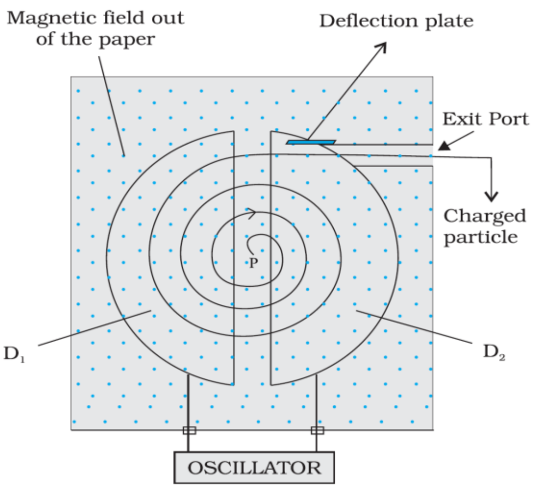
Frequency of the cyclotron

$$\nu = \frac{1}{T} = \frac{qB}{2\pi m}$$

$$\nu_c = \frac{qB}{2\pi m}$$

This frequency is called cyclotron frequency or resonance frequency.

Construction:-



Cyclotron consist of *(i) two semicircular D-shaped chambers called Dees (ii) an R.F oscillator to supply AC voltage (electric field) of particular frequency (iii) an ion source at the centre to produce ions (iv) a deflector and (v) a perpendicular magnetic field.*

The whole arrangement is placed in an evacuated chamber to minimize collisions between ions and air molecules.

Working:-

Consider at any instant a positive ion produced at the centre. Let at that time **D_1** is positive and **D_2** is negative. The positive ion enters **D_2**, completes a semi-circular path and reaches the gap. When the particle reaches the gap, the polarities of the Dees are reversed and **D_1** becomes negative. The positive ion enters **D_1** and it completes a circular path. This process repeats. Inside the Dees the particles travel in a region free of electric field due to electrostatic shielding. The increase in the KE each time they cross from one Dee to another is **qV**. Since the velocity of the ion increases the radius of the circular path also increases. Finally, when the radius of the circular path becomes nearly equal to the radius of the Dee, the ion is deflected by the deflector and it hits the target.

21. Write the Applications of cyclotron.

Ans: Cyclotron is used to bombard nuclei with energetic particles, so accelerated by it, and study the resulting nuclear reactions.

It is also used to implant ions into solids and modify their properties or even synthesize new materials.

It is used in hospitals to produce radioactive substances which can be used in diagnosis and treatment.

22. Who invented cyclotron?

Ans: Cyclotron was invented by **E.O. Lawrence** and **M.S. Livingston** in 1934.

23. What are the limitations of cyclotron?

Ans: Following are the limitations of cyclotron

(i) Cyclotron cannot be used to accelerate uncharged particles.

Reason: - When q = 0,

$\vec{F}_E = q\vec{E} = 0$ and $\vec{F}_B = q(\vec{V}\times\vec{B}) = 0$

So neither electric field nor magnetic field can exert force on the particle.

(ii) Cyclotron cannot accelerate charged particles to a speed near to the speed of light (relativistic speed).

Reason: - If a particle is accelerated to a speed near to the speed of light its mass increases according to the equation $m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$ .Therefore the frequency of revolution $\nu_c = \frac{qB}{2\pi m}$ will not be a constant.

(iii) Electron cannot be accelerated using a cyclotron.

Reason: - Since electron has very low mass, its velocity increases to a very high value even on the application of a small e.f. Therefore, electron cannot be in phase with the R.F. Oscillator.

24. What are the functions of magnetic field and electric field in a cyclotron?

Ans: Magnetic field produces circular motion of the charged particle. Electric field accelerates the charged particle.

25. A cyclotrons oscillator frequency is 10 M Hz. What should be the operating magnetic field for accelerating protons?

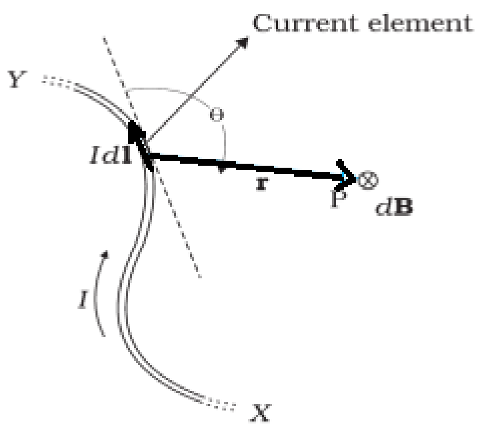
$e=1.6\times10^{-19}C$, $m_p=1.67\times10^{-27}Kg$

26. Find the energy of emergent protons (in MeV) coming from a cyclotron having dees of radius 2 metres, when a magnetic field of 0.8T is applied. (Mass of proton $=1.67\times10^{-27}$ Kg)

BIOT – SAVART LAW

27. State Biot – Savart Law.

Ans:



Biot-Savart law states that **"the magnetic field at a point due to the small element of a current carrying conductor is directly proportional to**

1. The current flowing through the conductor (I)

2. The length of the element $(\vec{dl})$

3. Sine of the angle between $\vec{r}$ **and** $(\vec{dl})$

And inversely proportional to the square of the distance of the point from $\vec{dl}$ **(r^2)**

$$dB \,\alpha\, \frac{Idl\sin\theta}{r^2}$$

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{r^2}$$

In vector form,

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta\times r}{r^2\times r}$$

$$= \frac{\mu_0}{4\pi}\frac{I(dl\, r\sin\theta)}{r^3}$$

$$\vec{dB} = \frac{\mu_0}{4\pi}\frac{I\left(\vec{dl}\times\vec{r}\right)}{r^3}$$

The direction of this field is given by right hand rule.

μ_0 is called the permeability of free space (or vacuum)

$\mu_0 = 4\Pi \times 10^{-7}$ Tm/A

28. Derive the relation between ε_0 and μ_0.

Ans: $\varepsilon_0\mu_0 = (4\,\Pi\varepsilon_0)\left(\frac{\mu_0}{4\pi}\right)$

$$= \frac{1}{9\times10^9}\times10^{-7}$$

$$= \frac{1}{9\times10^{16}} = \frac{1}{(3\times10^8)^2} = \frac{1}{c^2}$$

$$c^2 = \frac{1}{\varepsilon_0\mu_0} \Rightarrow$$

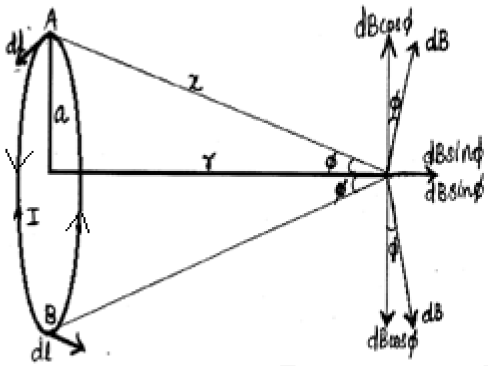
Or

$$c = \frac{1}{\sqrt{\varepsilon_0\mu_0}}$$

$$\boxed{c = \frac{1}{\sqrt{\varepsilon_0\mu_0}}}$$

29. Using Biot-Savart law, find the magnetic field on the axis of a circular current loop (circular coil)

Ans:



Magnetic field at 'P' due to the small element 'dl' at A,

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin 90^0}{x^2}$$

$$= \frac{\mu_0}{4\pi}\frac{Idl}{x^2}$$

$$= \frac{\mu_0}{4\pi}\frac{Idl}{r^2+a^2}$$

$\vec{dB}$ can be split into two components $dB\cos\phi$ and $dB\sin\phi$. If we consider another element B of the loop at diametrically opposite end B, $dB\cos\phi$ components cancel each other.

So the total magnetic field at 'P',

$$B = \int dB\sin\phi$$

$$= \int\frac{\mu_0}{4\pi}\frac{Idl}{r^2+a^2}\sin\phi$$

But $\sin\phi = \frac{a}{x}$

$$= \frac{a}{(r^2+a^2)^{1/2}}$$

Substituting,

$$B = \int\frac{\mu_0}{4\pi}\frac{Idl}{r^2+a^2}\frac{a}{(r^2+a^2)^{1/2}}$$

$$B = \frac{\mu_0 Ia}{4\pi(r^2+a^2)^{3/2}}\int dl$$

$$= \frac{\mu_0 Ia}{4\pi(r^2+a^2)^{3/2}}\times2\pi a$$

$$= \frac{\mu_0 Ia^2}{2(r^2+a^2)^{3/2}}$$

For a coil of N turns,

$$\boxed{\mathbf{B = \frac{\mu_0 NIa^2}{2(r^2+a^2)^{3/2}}}}$$

Magnetic field at the centre of the circular coil:

It is obtained by putting r = 0

$$B = \frac{\mu_0 NIa^2}{2(a^2)^{3/2}} \Rightarrow B = \frac{\mu_0 NIa^2}{2a^3}$$

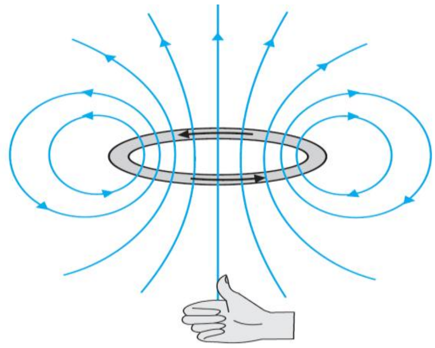
$$\Rightarrow \boxed{\mathbf{B = \frac{\mu_0 NI}{2a}}}$$

At the centre of a circular loop,

$$\boxed{\mathbf{B = \frac{\mu_0 I}{2a}}}$$

The direction of this m.f. is given by the **right-hand thumb rule**

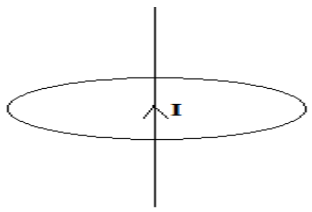
Right-hand thumb rule states that **"Curl the palm of your right hand around the circular wire with the fingers pointing in the direction of current. Then the right hand thumb gives the direction of m.f."**



30[P]. A circular coil of wire consisting of 100 turns, each of radius 8.0 cm carries a current of 0.40 A. What is the magnitude of magnetic field $\vec{B}$ at the centre of the coil?

AMPERE'S LAW

31. State Ampere's circuital law.
Ans:



Ampere's circuital law states that **"the line integral of magnetic field over a closed path is equal to μ₀ times the total current enclosed by the path"**

$$\oint_{\ell} \vec{B}.\vec{dl} = \mu_0 I$$

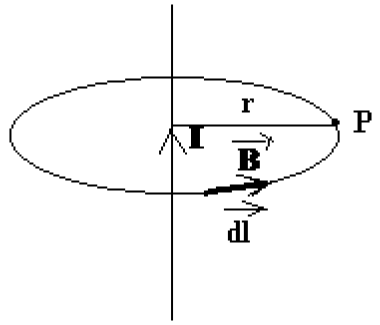
32. What are the applications of Ampere's law?
Ans: Amperes law can be applied to find the magnetic field due to:

(i) a straight infinitely long conducting wire.

(ii) a solenoid

(iii) a toroid

33. Applying Amperes law, derive an expression for the magnetic field due to a straight infinite current carrying wire.
Ans: To find the m.f. due to the straight current carrying conductor at a point P, distant 'r' from the conductor, imagine an amperian loop of radius 'r'.



Over the amperian loop both $\vec{B}$ and $\vec{dl}$ are along the same direction Therefore θ= 0

$\oint_{\ell} \vec{B}.\vec{dl}$

$= \oint_{\ell} Bdl\cos 0$

$= \oint_{\ell} Bdl$

$= B\oint_{\ell} dl$ [Since B is constant over the amperian loop]

$= B \times 2\pi r$

Substituting in Ampere's theorem,

$\oint_{\ell} \vec{B}.\vec{dl} = \mu_0 I$

$\Rightarrow B \times 2\pi r = \mu_0 I$

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

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

34. How can you find direction of the magnetic field due to the straight current carrying wire?
Ans: The direction of this magnetic field is given by right hand grip rule.

Right hand grip rule

If we grasp the current carrying conductor in the right hand with the thumb giving the direction of current, then the curled fingers will give the direction of magnetic field.

35[P]. A long straight wire carries a current of 35A. What is the field B at a point 20cm from the wire?

36[P]. A long straight wire in the horizontal plane carries a current of

50A in north to south direction. Give the magnitude and direction of $\vec{B}$ at a point 2.5 m east of the wire.

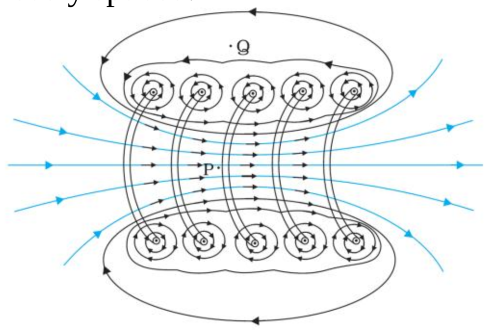
37[P]. A horizontal overhead power line carries a current of 90A in east to west direction. What is the magnitude and direction of m.f due to the current 1.5cm below the line?

SOLENOID AND TOROID

38. What is a solenoid?

Ans:

Solenoid is a long insulated wire wound in the form of a helix where the neighbouring turns are closely spaced.

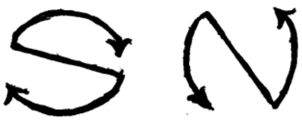


When current flows through the solenoid, it behaves as a bar magnet.

For a long solenoid, the field outside is nearly zero. The field inside is everywhere parallel to the axis.

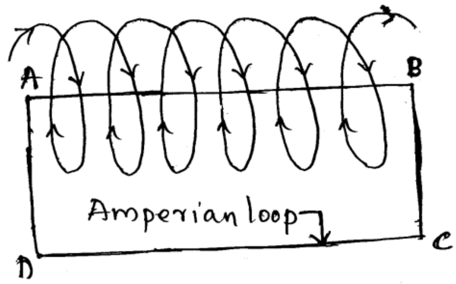
39. How will you find the polarity of a current carrying solenoid?

Ans: If the current at one end of the solenoid is in the anticlockwise direction it will be the North Pole and if the current is in the clockwise direction it will be the South Pole.



40. Derive expressions Application Magnetic field due to a long solenoid.

Ans:



According to Ampere's law

$$\oint_l \vec{B}.\vec{dl} = \mu_0 NI$$

N is the total no of the turns of the solenoid.

$$\Rightarrow \int_A^B \vec{B}.\vec{dl} + \int_B^C \vec{B}.\vec{dl} + \int_C^D \vec{B}.\vec{dl} + \int_D^A \vec{B}.\vec{dl} = \mu_0 NI$$

$$\Rightarrow \int_A^B Bdl\cos 0 + \int_B^C Bdl\cos 90 + \int_C^D \vec{0}.\vec{dl} + \int_D^A Bdl\cos 90 = \mu_0 NI$$

$$\Rightarrow \int_A^B Bdl = \mu_0 NI$$

$$\Rightarrow B\int_A^B dl = \mu_0 NI$$

$$\Rightarrow B \times \ell = \mu_0 NI \Rightarrow B = \frac{\mu_0 NI}{\ell}$$

But $\frac{N}{\ell} = n$, no. of turns per unit length.

$$\Rightarrow \boxed{B = \mu_0 nI}$$

This is the expression for magnetic field inside a long solenoid.

41. How can you increase the m.f. of a solenoid?

Ans: The magnetic field due to a solenoid can be increased by

i) Increasing the no. of turns per unit length (n)

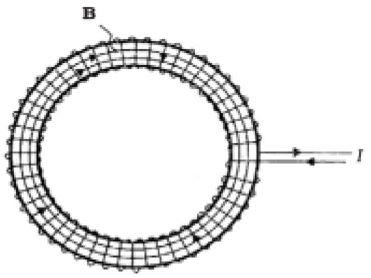
ii) Increasing the current (I)

iii) Inserting a soft iron core into the solenoid.

42[P]. A closely wound solenoid 80 cm long has 5 layers of windings of 400 turns each. The diameter of the solenoid is 1.8 cm. If the current carried is 8.0A, estimate the magnitude of $\vec{B}$ inside the solenoid near its centre.

43. What is a toroid?

Ans: It is a long solenoid bent into the form of a circle



44. Applying Ampere's law derive an expression for the magnetic field due to a toroid.

Ans: Consider a toroid of average radius 'r'

Case 1

Applying Ampere's law over the closed loop C_1,

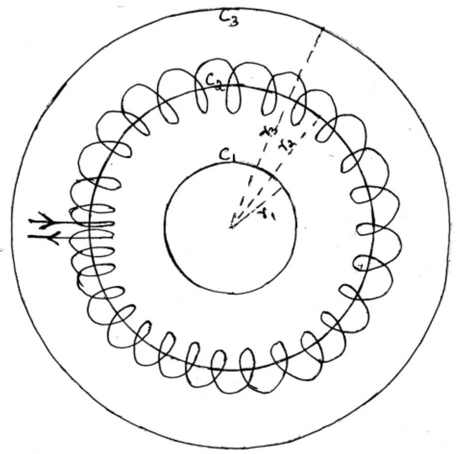
$\oint_{C_1} \vec{B}.\vec{dl} = \mu_0 I$

But current enclosed by the loop,

$I = 0$

$B(2\pi r\ell) = 0 \Rightarrow B = 0$

There is no m.f. at the centre of the toroid



Case 2:-

Applying Ampere's law over the closed loop C_2,

$\oint_{C_2} \vec{B}.\vec{dl} = \mu_0 NI$

$\oint_{C_2} Bdl\cos 0 = \mu_0 NI$

$\Rightarrow B \times 2\pi r_2 = \mu_0 NI$

$\Rightarrow B = \frac{\mu_0 NI}{2\pi r_2}$ but $\frac{N}{2\pi r_2} = n$

$\Rightarrow$ $\mathbf{B = \mu_0 nI}$

Case3 :-

Over the closed loop C_3

$\oint_{C_3} \vec{B}.\vec{dl} = \mu_0 NI$

But I = 0

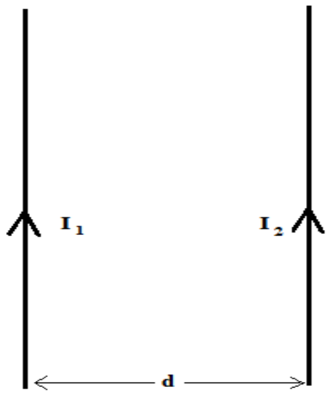
$\oint_{C_3} Bdl = 0 \Rightarrow B \times 2\pi r_3 = 0$

$\Rightarrow B = 0$

There is no m.f. outside the toroid.

45. Derive an expression for the force between two parallel straight current carrying conductors.

Ans: Consider two straight parallel conductors of lengths ℓ_1, ℓ_2 and carrying currents I_1 and I_2 placed at a separation d



M.f. at a distance'd' due to the first current carrying conductor

$B_1 = \frac{\mu_0 I_1}{2\pi d}$

The second conductor is placed in the m.f. of the first conductor. Then the force on it

$F = I_2\left(\vec{\ell}_2 \times \vec{B}_1\right)$

$= I_2 \ \ell_2 B_1 \sin 90$

$= I_2 \ell_2 B_1 = I_2 \ell_2 \frac{\mu_0 I_1}{2\pi d}$

$= \frac{\mu_0 I_1 I_2 \ell_2}{2\pi d}$

Force per unit length of the conductor

$f = \frac{F}{\ell_2} = \frac{\mu_0 I_1 I_2}{2\pi d}$

$$f = \frac{\mu_0 I_1 I_2}{2\pi d}$$

Nature (or type) of force

⇒ If the currents are in the same direction, the force is attractive

⇒ If the currents are in the opposite directions, the force is repulsive

46. Define 1 Ampere.

Ans: The force per unit length between two current carrying straight conductors,

$$f = \frac{\mu_0 I_1 I_2}{2\pi d}$$

Put $I_1 = I_2 = 1A$ and $d = 1m$

Then $f = \frac{\mu_0 \times 1 \times 1}{2\pi \times 1} = \frac{4\pi \times 10^{-7}}{2\pi}$

$= 2 \times 10^{-7}$ N/m

One ampere is the value of that steady current which, when maintained in each of the two long, straight, parallel conductors of negligible area of cross section, placed 1m apart in vacuum, would produce a force of 2×10^{-7} N/m on each conductor.

47[P]. Two long and parallel straight wires A and B carrying currents of 8.0A and 5.0A in the same direction are separated by a distance of 4cm. Estimate the force on a 10 cm section of wire A.

48. Define magnetic dipole moment due to a current.

Ans: Magnetic moment

m = Current × Area

m = IA

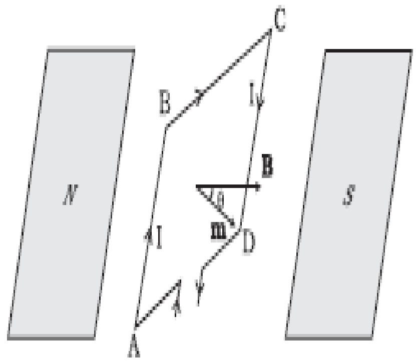
For a coil having n turns **N** turns

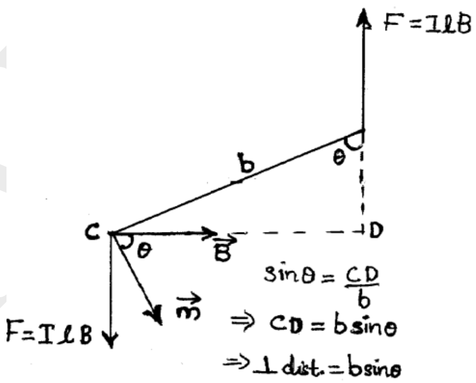
m = IAN

49. Derive an expression for the torque on a rectangular current loop in a m.f.

Ans:

Consider a rectangular loop of wire, carrying current is placed in a uniform magnetic field.





Forces on the sides BC and AD are equal and are acting in opposite directions. Also they are collinear. So the cancel each other without producing any torque.

Force on the side AB (of length l)

F = IlB (directed inwards the plane of the paper)

Force on the side CD

F = IlB (directed outwards the plane of the paper)

The forces on sides AB and CD are equal and opposite but they are not collinear. So they constitute a torque.

$\tau = F \times \perp^{r}$ distance

$= IlB \times b\sin\theta$

where 'θ' is the angle made by the area vector of the rectangular loop with the m.f.

$\tau = I\,(l \times b)\,B\sin\theta$

$= IAB\sin\theta$

If the loop has N turns,

Torque $\tau = NIAB\sin\theta$

$$\boxed{\tau = ABIN\sin\theta}$$

But IAN = m, magnetic dipole moment

Therefore, $\tau = mB\sin\theta$

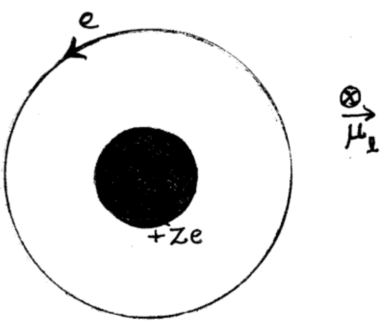
In vector form,

$\tau = \vec{m} \times \vec{B}$

50. A square coil of side 10 cm consists of 20 turns and carries a current of 12A. The coil is suspended vertically and the normal to the plane of the coil makes an angle of 30^0 with the direction of uniform horizontal m.f of magnitude 0.80 T. What is the magnitude of torque experienced by the coil?

51. Derive an expression for the magnetic moment of a revolving electron. What is Bohr magneton?

Ans:



Current due to the revolution of electron, $I = \frac{q}{t} = \frac{e}{T}$

Where T is the time period of revolution of electron.

But $T = \frac{2\pi r}{v}$ $\quad v \rightarrow$ orbital speed

$$I = \frac{e}{\left(\frac{2\pi r}{v}\right)} = \frac{ev}{2\pi r}$$

magnetic moment, $\mu_\ell = IA$

Here μ_ℓ is the orbital angular moment

$$\mu_\ell = \frac{ev}{2\pi r} \times \pi r^2$$

$= \frac{evr}{2}$ (μ_ℓ is directed in to the plane of the paper)

$= \frac{e(m_e vr)}{2m_e} \Rightarrow \mu_\ell = \frac{el}{2m_e}$

$\therefore \frac{\mu_l}{\ell} = \frac{e}{2m_e}$ =constant, called gyromagnetic ratio.

Its value is 8.8×10^{10} C/kg

According to Bohr model of H atom, $\ell = \frac{nh}{2\pi}$, n is a natural number.

n = 1, 2, 3, ...

$$\mu_\ell = \frac{e\frac{nh}{2\pi}}{2m_e} = \frac{enh}{4\pi m_e}$$

For n = 1,

$\mu_\ell = \frac{eh}{4\pi m_e}$ This is the minimum value of μ_ℓ

(μ_ℓ)min =

$$\frac{eh}{4\pi m_e} = \frac{1.6 \times 10^{-19} \times 6.626 \times 10^{-34}}{4 \times 3.14 \times 9.1 \times 10^{-31}}$$

$= 9.27 \times 10^{-24}$ Am^2

Thus value is called Bohr magneton

$$\boxed{\text{Bohr magneton} = \frac{eh}{4\pi m_e}}$$

MOVING COIL GALVANOMETER

52. What is the use of a Moving coil Galvanometer (MCG)?

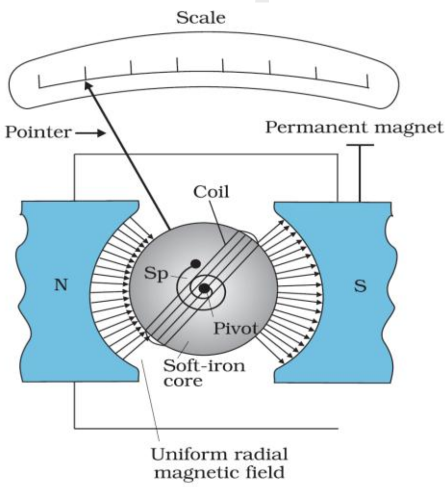
Ans:

Use:- Moving coil galvanometer is used to detect the presence of small electric current and to give its direction.

With simple modifications, it can be used to measure current and voltage.

Construction

MCG consists of a rectangular coil of several turns wound on a soft iron cylinder. The cylinder is free to rotate between two concave shaped magnetic poles, which produce radial magnetic field. One end of the cylinder is attached to a spring, which produces a restoring couple. At the other end a pointer is pivoted.



Principle

When current flows through the coil, a torque acts on it. In the radial magnetic field maximum torque is experienced.

The torque, $\tau = ABIN$

Because of this torque, the coil rotates, and then a restoring torque is developed in the spring.

Restoring torque,

$$\tau_{rest} = C\theta$$

where C is the couple per unit twist.

($C \rightarrow$ restoring torque developed per unit twist)

and θ is the angle of twist

At equilibrium,

$$C\,\theta = ABIN$$

$$\Rightarrow \theta = \left(\frac{ABN}{C}\right) I$$

$$\Rightarrow \ \theta = kI$$

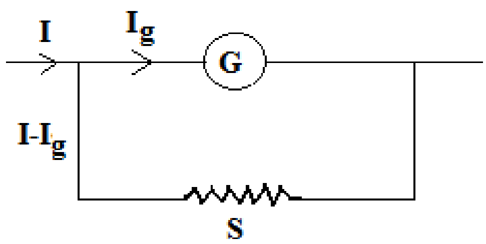
$$\Rightarrow \ \theta \,\alpha\, I$$

ie., deflection α current

$k = \dfrac{ABN}{C}$ is called galvanometer constant.

53. How can you convert a galvanometer into an ammeter?

Ans: Galvanometer can be converted into ammeter by connecting a very small resistance (called shunt resistance) in parallel with it.



We have,

$$I_g G = (I - I_g)S$$

$$\Rightarrow S = \frac{I_g G}{I - I_g}$$

54. What is the total resistance of an ammeter?

Ans: $\text{Total Resistance} = \dfrac{GS}{G+S}$

55. Define current sensitivity of a galvanometer?

Ans: $\frac{\theta}{I} = \frac{ABN}{C}$ is called current sensitivity.

56. What is the SI unit of current sensitivity?
Ans: radian/ampere

57. How can you increase the current sensitivity?
Ans: Current sensitivity $\frac{\theta}{I} = \frac{ABN}{C}$ can be increased by

i) Increasing the area of the coil (A)

ii) Increasing the m.f strength (B)

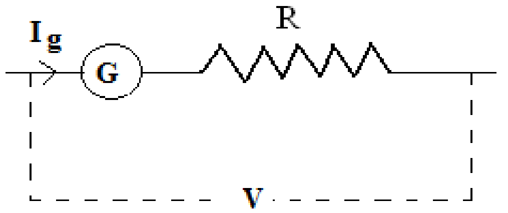
iii) Increasing the number of turns (N)

iv) Decreasing the couple per unit twist (C)

58. What is an ideal ammeter?
Ans: An ideal ammeter is an ammeter having zero resistance.

59. A galvanometer coil has a resistance of 15Ω and the meter shows full scale deflection for a current of 4mA. How will you convert the meter into an ammeter of range 0 to 6A? What is the total resistance of the ammeter?

60. How can you convert a galvanometer into voltmeter?
Ans: Galvanometer can be converted into voltmeter by connecting a large resistance in series with it.



We have,

$V = I_gG + I_gR$

$I_gR = V - I_gG$

$\Rightarrow R = \frac{V}{I_g} - G$

$R = \frac{V}{I_g} - G$

61. What is the total resistance of a voltmeter?
Ans: $\text{Total Resistance} = G + R$

62. Define voltage sensitivity voltage sensitivity of a galvanometer.
Ans: $\frac{\theta}{I} \times \frac{I}{R} = \frac{ABN}{C} \times \frac{1}{R}$

$\Rightarrow \frac{\theta}{V} = \frac{ABN}{CR}$ is called voltage sensitivity.

63. What is the SI unit of voltage sensitivity?
Ans: radian/volt

64. How can you increase the voltage sensitivity of a galvanometer?
Ans: voltage sensitivity $\frac{\theta}{V} = \frac{ABN}{CR}$ can be increased by

i) Increasing the area of the coil (A)

ii) Increasing the strength of the m.f. (B)

iii) Decreasing the couple per unit twist (C)

65. Increasing the no. of turns (N) will not increase the voltage sensitivity. Why?
Ans: We have voltage sensitivity, $\frac{\theta}{V} = \frac{ABN}{CR}$

When 'N' is increased, length of the wire increases. So the resistance also increases. And so $\frac{N}{R}$ is a constant.

66. Increasing the current sensitivity may not increase voltage sensitivity. Why?

Ans: We have voltage sensitivity,

$$\frac{\theta}{V} = \frac{ABN}{CR}$$

When we increase N, current sensitivity increases but since $\frac{N}{R}$ is constant, voltage sensitivity does not increase.

67. A galvanometer coil has a resistance of 12Ω and the meter shows full scale deflection for a current of 3mA. How will you convert the meter into a voltmeter of range 0 to 18V? What is the total resistance of the voltmeter?

68. How ammeter and voltmeter are connected in a circuit?

Ans: Ammeter is a low resistance device. So it is connected in series with a circuit. Voltmeter is a high resistance device. So it is connected parallel with a circuit.

69. What is the use of concave shaped magnetic poles in a moving coil galvanometer?

Ans: Concave shaped magnetic poles produces radial magnetic field.

70. What is the use of radial magnetic field in a MCG?

Ans: In radial magnetic field, the magnetic field is always parallel to the plane of the coil. So in radial magnetic field, maximum torque is experienced by the coil.

71. What is the use of soft iron core in a MCG?

Ans: Soft iron core has high permeability. So it increases the strength of the magnetic field. Hence it increases the sensitivity of the galvanometer.