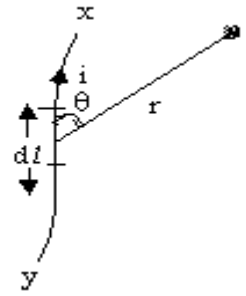
ELECTROMAGNETICS

1. CURRENT CARRYING CONDUCTORS

POINTS TO REMEMBER

1. A stationary charge will produce only electric field.
2. A moving charge will produce both electric and magnetic fields.
3. According to Oersted experiment, when a magnetic needle is kept at different points around the current carrying conductor, it shows the deflection. This concludes that a magnetic field will exist around the current carrying conductor and perpendicular to the plane of the conductor.
4. The direction of deflection of needle can be known from Ampere's swimming rule
5. Imagine a person swimming along the direction of current keeping his face towards the needle. Then the north pole of the needle deflects towards the left hand of the person.
6. **Maxwell's right hand cork – screw rule:**If a right handed cork screw is moved along the direction of current, then the direction of rotation of the screw will give the direction of magnetic lines of force.
7. **Ampere's right hand thumb rule :**Imagine a current carrying conductor is held with the right hand such that the thumb represents the direction of current. Then remaining fingers represent the direction of magnetic lines of force.
8. **Ampere's Circuital Law :**The line integral of intensity of magnetic field around any closed path is equivalent to μ_0 times the current enclosed by that closed path. Mathematically,
   $\int B.dl = \mu_0 i$
9. **Biot - Savart Law :** $dB = \frac{\mu_0}{4\pi}.\frac{idl\sin\theta}{r^2}$

   Or $\vec{B} = \frac{\mu_0}{4\pi}.\frac{i\left(\vec{dl}\times\vec{r}\right)}{r^3}$



10. **Magnetic field induction at any point on the axis of circular coil** $B = \frac{\mu_0 n i r^2}{2\left(x^2 + r^2\right)^{3/2}}$

    At the centre of the coi, x = 0, $B_C = \frac{\mu_0 ni}{2r}$ i

11. **Force experienced by a conductor in magnetic field** $F = Bil\sin\theta$

    Vectorially, $\vec{F} = i\left(\vec{l}\times\vec{B}\right)$

12. **Force experienced by the moving charge** $F = Bqv\sin\theta$

    (v=velocity of the particle)

    Vertorially, $\vec{F} = q\left[\vec{V}\times\vec{B}\right]$

13. The total force experienced by a charged particle in a region of combined electric and magnetic fields is called Lorenz force and it is given by,

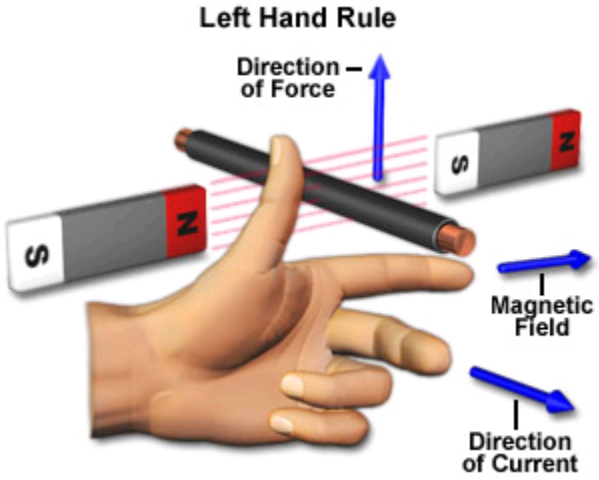
$$F = q\left[\vec{E} + \left(\vec{V} \times \vec{B}\right)\right]$$

13. **Flemings left hand rule :** Stretch fore finger, middle finger and thumb of the left hand in mutually perpendicular directions. if the fore finger represents the direction of magnetic field, middle finger represents electric field, then the thumb represent the direction of force (or) motion of the conductor.
14. **Force between two long straight parallel conductors carrying currents** i_1 and i_2 is given by $F = \frac{\mu_0 i_1 i_2 l}{2\pi r}$

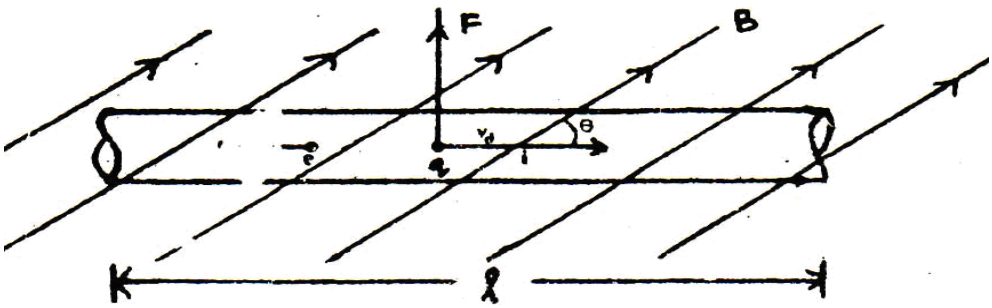
LONG ANSWER QUESTIONS

1. **Explain Fleming's left hand rule. Deduce an expression for the force on a current carrying conductor in a magnetic field.**
   Derive an expression for the force between two parallel conductors carrying current. (May2009)

Ans: This law helps to determine the direction of force acting on.
1) A moving positive charge placed in a magnetic field and
2) A current carrying conductor placed in a magnetic field.
Fleming's left hand rule: Stretch fore finger, middle finger and thumb of the left hand in mutually perpendicular directions. If the fore finger represents the direction of magnetic field, middle finger represents electric field and then the thumb represents the direction of force (or) motion of the conductor.



Force acting on a current carrying conductor in a magnetic field.
Consider a straight conductor of length 'l' and cross sectional area A carrying a current 'i' placed in a uniform magnetic field of induction $\overline{B}$ as shown in figure.



The potential difference across the conductor makes the electrons to move with an average velocity called drift velocity υ_d. The conventional current flows opposite to the drift velocity υ_d.

The positive charge 'q' moves in the direction of conventional current 'i'. Let the conductor makes an angle $'\theta'$ with the magnetic field induction $\vec{B}$. Then force acting on the charge 'q' is given by

$F^1 = q\upsilon_d \ B\sin\theta$ This force is along the positive z-axis.

If 'n' be the number of moving charges per unit volume of the conductor, then magnitude of the current through the conductor $i = nq\ \upsilon_d A$

The total number of electrons (N) in the length (l) of the conductor is N=nlA

$\therefore$ Total force acting on the conductor $F = F^1 N = (q\upsilon_d B\sin\theta)(nlA)$

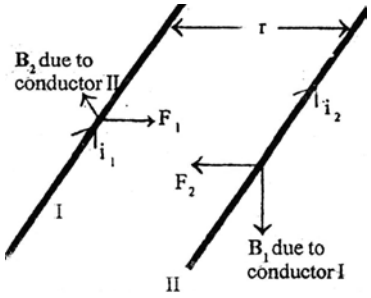
$= (nq\upsilon_d A)\ (lB\sin\theta)$

$F = i\,l\,B\sin\theta$

In vector from $\vec{F} = i\left(\vec{l}\times\vec{B}\right)$

Force between two parallel conductors:-

Conductor two long thin straight parallel conductors I and II placed in vacuum at a distance 'r' apart in the plane of the paper. Let i_1 and i_2 be the currents flowing through the conductors in the same direction. Due to the current i_1, The magnetic induction at a distance r from the first conductor $B_1 = \dfrac{\mu_0 i_1}{2\pi r}$



B_1 perpendicular into the plane of the paper

Now the force acting on second conductor for a length 'l' due to B_1 is

$$F_2 = i_2\, lB_1 = i_2 l\left(\frac{\mu_0 i}{2\pi r}\right) = \frac{\mu_0}{2\pi}\,\frac{i_1 i_2}{r}\,l$$

$\therefore$ Force per unit length is

$\dfrac{F_2}{l} = \dfrac{\mu_0}{2\pi}\,\dfrac{i_1 i_2}{r}$ (Towards second conductor)

$\therefore \dfrac{F_1}{l} = \dfrac{F_2}{l} = \dfrac{F}{l} = \dfrac{\mu_0 i_1 i_2}{2\pi r}$

Hence when the currents are in the same direction, the conductors experience mutual forces of attraction. If they carry unlike currents, they experience mutual forces of repulsive.

SHORT ANSWER QUESTIONS

1. State and explain Biot – Savart's law.

Ans. Biot - Savart Law :

The magnetic field induction at any point around the current carrying conductor due to a small element is directly proportional to the current passing through the conductor, length of the small element and sine of the angle between the small element and the line joining small element and the point and inversely proportional to the square of the distance between the small element and the point. This is called Biot – Savart law which is analogous to coulomb's inverse square law in electrostatics.

Explanation : Consider a conductor xy through which a current 'i' is passing.In order to calculate the magnetic field induction at 'P', due to a small element,

assume a small element of length 'dl', that is at a distance 'r' from 'p'.Then according to Biot – savart's law, the magnetic field induction at 'P' due to the small element is dB and

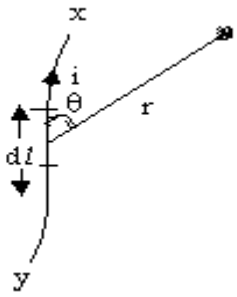
$dB \propto i$

$dB \propto dl$

$dB \propto \sin\theta$

$dB \propto \frac{1}{r^2}$

$\Rightarrow dB \propto \frac{idl\sin\theta}{r^2}$



$\Rightarrow dB = \frac{\mu_0}{4\pi}.\frac{idl\sin\theta}{r^2}$

$\vec{B} = \frac{\mu_0}{4\pi}.\frac{i\left(\vec{dl}\times\vec{r}\right)}{r^3}$

In order to calculate the magnetic field induction due to the total length of the conductor, integrate the above expression for the length limits.

$$B = \int dB = \frac{\mu_0 i}{4\pi r^2}(dl\sin\theta)$$

2. State and prove Ampere's law.

Ans. **<u>Ampere's law:</u>** the line integral of $\vec{B}.\vec{dl}$ taken over the entire closed path of induction in a given perpendicular plane is equal to μ_0 times the total current enclosed in the closed path.

$$\int \vec{B}.\vec{dl} = \mu_0 i$$

<u>Explanation:</u> the magnetic field produced by a straight current carrying conductor is radially symmetric. Consider a circular loop in a plane perpendicular to the straight conductor. The field at any point on the circle is along the tangent drawn at that point in the direction of $\vec{d}\,l$.

From Ampere's law $\int \vec{B}.\vec{d}\,l = \mu_0 i \Rightarrow \int B.dl\,\cos 0 = \mu_0 i$

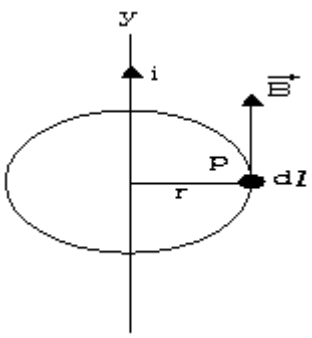
$\Rightarrow \int B.dl = \mu_0 i \qquad (\because \theta = 0)$

But line integral $\int \vec{d}\,l = 2\pi r$ (i.e. the length of circular path)

$\therefore B(2\pi r) = \mu_0 i$ or $B = \frac{\mu_0}{2\pi}\frac{i}{r}$

3. Find Intensity of magnetic induction 'B' due to along current carrying conductor?

Ans. Consider a long straight conductor carrying a current 'I'. Let 'P' be a point at a perpendicular distance 'r' from the conductor. Assume a circle of radius 'r' with the centre on the conductor. The field at any point on the circle is along the tangent drawn at that point in the direction of 'd*l*.Then according to Ampere's circuital law,



$\int \vec{B}.\vec{dl} = \mu_0 i \Rightarrow \int Bdl\cos\theta = \mu_0 i$

$\Rightarrow \int Bdl\cos 0^\circ = \mu_0 i \Rightarrow \int Bdl = \mu_0 i$

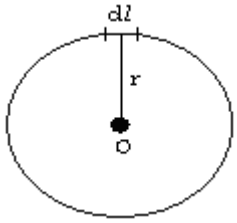
$\Rightarrow B\int dl = \mu_0 i \Rightarrow B(2\pi r) = \mu_0 i$

$$\therefore B = \frac{\mu_0 i}{2\pi r}$$

Vectorially, $B = \frac{\mu_0 i}{2\pi r} \times \hat{r} \quad \Rightarrow B = \frac{\mu_0 i}{2\pi r^2} . \vec{r}$

4. Deduce an expression for the intensity of magnetic induction field at the centre of a circular current carrying coil using Biot-Savart law.

Ans. Consider a circular coil with centre 'O' and radius 'r'. In order to calculate the magnetic field induction at the centre, assume a small element of length 'dl' and always $\vec{dl}$ is perpendicular to $\vec{r}$. The magnetic field induction at the centre of the coil due to the small element dl is given by $dB = \frac{\mu_0}{4\pi} \frac{idl \sin\theta}{r^2}$



Where θ is angle, it is maximum i.e., $\theta = 90^0 \Rightarrow \sin 90^0 = 1$

$$dB = \frac{\mu_0}{4\pi} \frac{idl}{r^2}$$

$\therefore$ The magnetic field induction due to the total circular coil is given by

$$\int dB = \int \frac{\mu_0}{4\pi} . \frac{idl}{r^2} \qquad \Rightarrow B = \frac{\mu_0 i}{4\pi r^2} \int dl$$

$$\Rightarrow B = \frac{\mu_0 i}{4\pi r^2} (2\pi r) \qquad \Rightarrow B = \frac{\mu_0 i}{2r}$$

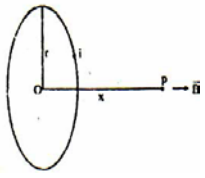
If the coil has 'n' turns, then $B = \frac{\mu_0 ni}{2r}$

5. Obtain an expression for the magnetic dipole moment of a current loop.

Sol: The intensity of magnetic field on the axial line of a circular coil carrying current at a distance 'X' from its centre is,

$$B = \frac{\mu_0 nir^2}{2(r^2 + X^2)^{3/2}}$$

If X>>>r the intensity of magnetic induction field on axis of coil is



$B = \frac{\mu_0 nir^2}{2x^3}$, multiplying both numerator & denominator by 2π.

$$B = \frac{\mu_0 ni 2\pi r^2}{4\pi r^3} = \left(\frac{\mu_0}{4\pi}\right) \frac{2ni(\pi r^2)}{x^3} = \frac{\mu_0}{4\pi} \left(\frac{2niA}{x^3}\right) (\because A = \pi r^2)$$

Comparing the above equation with intensity of magnetic induction field on axis of a short bar magnet, $B = \frac{\mu_0}{4\pi} \left(\frac{2M}{x^3}\right)$ the magnetic moment of current carrying coil is M = niA.

6. Derive an expression for the magnetic dipole moment of a revolving electron.

Sol: Consider an electron revolving in a circular orbit of radius r with a speed V and frequency υ. Consider a point P on the circle. The electron crosses the point once in every revolution. In one revolution, the electron travels distance $2\pi r$. The number of revolutions made by electron in one second is,

$$\upsilon = \left(\frac{V}{2\pi r}\right)$$

The electric current $i = e\upsilon = \left(\frac{eV}{2\pi r}\right)$

This produces magnetic field and the electronic orbit can be taken as a circular loop, $\left[A = \pi r^2\right]$, its magnetic dipole moment is,

$$M = iA = \frac{eV}{2\pi r}(\pi r^2) = \left(\frac{erV}{2}\right)$$

VERY SHORT ANSWER QUESTIONS

1. What is the importance of Oersted's experiment?

Ans. According to Oersted experiment, when a magnetic needle is kept at different points around the current carrying conductor, it shows the deflection. This concludes that a magnetic field will exist around the current carrying conductor and perpendicular to the plane of the conductor.
This observation led to the phenomenon of electromagnetic induction.

2. State Ampere's law and Biot –Savart's law

Ans. **Ampere's law :** The total magnetic flux coming out of a current carrying conductor in a perpendicular plane is μ_0 times the current flowing through it.

$$\int \vec{B}.\vec{dl} = \mu_0 i$$

Biot –Savart's law : The magnetic induction at any point P due to a current carrying conductor is given by $dB = \frac{\mu_0}{4\pi}\frac{id/\sin\theta}{r^2}$

In vector form, $dB = \frac{\mu_0}{4\pi r^2}\left(\bar{dl}\times\bar{r}\right)$

3. State Ampere's swimming rule.

Ans. **Ampere's swimming rule:** Imagine a person swimming along the direction of current keeping his face towards the needle. Then the north pole of the needle deflects towards the left hand of the person.

4. State the expression for the intensity of magnetic induction field at any point on the axis of a circular coil carrying current. Hence, obtain an expression for the magnetic induction at the centre of the circular coil.

Ans. The magnetic induction B at point at distance 'x' on the axis from the centre of circular current carrying coil of 'n' turns of radius 'r' carrying a current 'i' is

$$B = \frac{\mu_0}{2}.\frac{nir^2}{(r^2+x^2)^{3/2}}$$

At the centre of the coil, x = 0

$$B = \frac{\mu_0 ni}{2r}$$

5. A circular coil of 'n' turns carries a current 'i' ampere. If its radius 'r' is very small, what is its magnetic moment?

Ans. Magnetic moment of the coil $\vec{M} = niA = ni(\pi r^2)$ $\vec{M}$ is along the axis of the coil.

6. A current of 10A passes through 2 wires infinitely long and separated by a distance of 1m. What is the force between them per unit length?

$i_1 = i_2 = 10A$; d = 1m

Force between the wires, $F = \frac{\mu_0}{2\pi}\frac{i_1 i_2}{d} = \frac{(2\times10^{-7})\times10\times10}{1} = 20\times10^{-6}\ N$

7. What is the force on a conductor of length 'l' carrying current 'i' when it is situated in a magnetic field of induction B? when it is maximum?

Ans. The force on a conductor of length 'l' carrying 'i' when it is situated in a magnetic field of induction B is given by $F = Bil\sin\theta$.

This will be maximum when $\theta = 90^0$

$F = Bil\sin 90^0$; $F = Bil$

8. What is the force on a charged particle of charge strength q moving with a velocity 'v' in a uniform magnetic field of induction B? When is it maximum?

Ans. When a particle of charge 'q' enters a uniform magnetic field of induction 'B' with a constant velocity 'v' making an angle 'θ' with the direction of the field, it experiences a force in a direction perpendicular to the plane containing 'B' and 'V'. The magnitude of force is given by.

$F = q\,v\,B\sin\theta = q\left(\vec{V}\times\vec{B}\right)$

If $\theta = 90^0$ then, force will be maximum. $F_{\text{maximum}} = qV\,B$

9. State Fleming's left hand rule.

Ans. **<u>Fleming's left hand rule:</u>** Stretch fore finger, middle finger and thumb of the left hand in mutually perpendicular directions. If the fore finger represents the direction of magnetic field, middle finger represents electric field and then the thumb represents the direction of force (or) motion of the conductor.

SOLVED PROBLEMS

1. A current of 10A is flowing through a long straight brass wire. Find the magnetic induction at a distance 0.5cm from the wire.

i = 10A; (r) = 0.5m $= 0.5\times10^{-2}\,m$; $(\mu_0) = 4\pi\times10^{-7}\ Hm^{-1}$

$$B = \frac{\mu_0 i}{2\pi r} = \frac{4\pi\times10^{-7}\times10}{2\pi\times0.5\times10^{-2}} = 4\times10^{-4}\ Wbm^{-2}$$

2. A wire carrying a current of 140 ampere is bent into the form of a circle of radius 6cm. Calculate the flux density at a distance of 8cm on the axis passing through the centre of the coil and perpendicular to its plane.

Sol: r = 6cm $= 6\times10^{-2}\,m$, n = 1; I = 140 A; $\mu_0 = 4\pi\times10^{-7}\ Hm^{-1}$ and x = 8 cm $= 8\times10^{-2}\,m$

$$B = \frac{\mu_0 nir^2}{2(r^2+x^2)^{3/2}}$$

$$\therefore B = \frac{4\pi\times10^{-7}\times140\times(6\times10^{-2})^2}{2\times\left[\left(6\times10^{-2}\right)^2+\left(8\times10^{-2}\right)^2\right]^{3/2}} = 3.17\times10^{-4}\ Wbm^{-2}$$

3. A circular coil of radius 25 cm, carries a current of 50 ampere. If it has 35 turns, calculate the flux density at the centre of the coil.

Sol: **r** = 25cm $= 25\times10^{-2}\,m$; N = 35 ; i = 50A

$$B=\frac{\mu_0 ni}{2r}=\frac{4\pi\times10^{-7}\times35\times50}{2\times25\times10^{-2}}=4.4\times10^{-3}\,Wbm^{-2}$$

4. **The intensity of magnetic induction at the centre of a circular coil is B. What happens to the induction, if the number of turns and radius is doubled?**

Sol: $B_1=\frac{\mu_0 n_1 i}{2r_1}$ and $B_2=\frac{\mu_0 n_2 i}{2r_2}$

5. **A straight wire of length 10 cm is kept in a uniform magnetic induction 0.02 T. The angle between the conductor and the field direction is 30^0. A current of 5A is passed through the conductor. Calculate force on the conductor.**

Sol: l = 10 cm = 10^{-1} m; B = 0.02 T; $\theta=30^0$; i = 5A; F = ?

F=Bi $l\sin\theta=0.02\times5\times10^{-1}\times\sin30^0=5.0\times10^{-3}\,N$.

6. **What is the magnitude of force between a pair of conductors, Each of length 110 cm, carrying a current of 10A and separated by a distance of 10 cm?**

Sol: $i_1=i_2$=10A, r = 10 cm = 0.1m, l =110 cm =1.1 m, $\mu_0=4\pi\times10^{-7}\,H/m$.

$$F=\frac{\mu_0 i_1 i_2 l}{2\pi r}=\frac{4\pi\times10^{-7}\times10\times10\times1.1}{2\pi\times0.1}=22\times10^{-5}\,N.$$

7. **Two parallel conductors carrying 5A each, repel with a force of 0.25 N m^{-1} per unit length. Find the distance between them?**

Sol: $i_1=i_2=5$ A, $\frac{F}{l}=0.25Nm^{-1}$, r = ?

$$\frac{F}{l}=\frac{\mu_0 i_1 i_2}{2\pi r}$$

$$\therefore r=\frac{\mu_0}{2\pi}\frac{i_1 i_2}{(F/l)}=\frac{4\pi\times10^{-7}\times5\times5}{2\pi\times0.25}=2\times10^{-5}\text{ m.}$$

8. **If an electron is revolving in a circular orbit of radius 0.5 a with a velocity of $2.2\times10^6\,m/s$, find the magnetic dipole moment of the revolving electron?**

Sol: **v** = 2.2×10^6 m/s, r=0.5 QA=0.5×10^{-10} m, e = $1.6\times10^{-19}\,C$.

$$M=\frac{evr}{2}=\frac{1.6\times10^{-19}\times2.2\times10^6\times0.5\times10^{-10}}{2}=8.8\times10^{-24}\,Am^{2.}$$

9. **If a circular coil of 100 turns and radius 10 cm carries a current of 1A find its magnetic dipole moment?**

Sol: n =100, r = 10cm = 0.1 m, i = 1A.

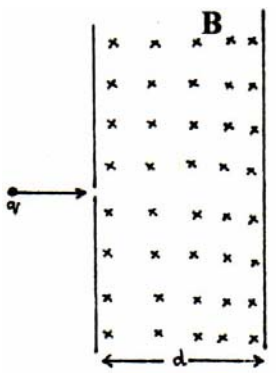
M = n i A= $ni\pi r^2=100\times1\times\pi(0.10)^2=3.14\,Am^2$.

$$\frac{B_2}{B_1}=\frac{n_2}{n_1}\times\frac{r_1}{r_2}$$

$n_2=2n_1$, $r_2=2r_1$, $\frac{B_2}{B_1}=\frac{2n_1}{n_1}\times\frac{r_1}{2r_1}=1$

$\therefore B_2=B_1$, hence, no change occurs in the magnetic induction.

9. **A particle with charge q and mass m is shot with kinetic energy K into the region between two plates as shown in figure. If the magnetic field between the plates is B as shown how large B must be if the particle is to miss collision with the opposite plate?**



Sol: To just miss the opposite plate, the particle must move in a circular path of radius'd' so that,

$$Bqv = \frac{mv^2}{d}$$

$$Bqd = mv \qquad ..(1)$$

But $K = \frac{1}{2}mv^2$

$$K = \frac{1}{2}mv^2 \times \frac{m}{m} = \frac{1}{2}\frac{m^2v^2}{m}$$

$$2Km = m^2v^2$$

$$\sqrt{2Km} = mv \quad .....(2)$$

Substituting (2) in (1) Bqd = $\sqrt{2Km}$

$$B = \frac{\sqrt{2Km}}{qd}$$

10. At the equator, the earth's magnetic field is nearly horizontal, directed from southern to northern hemisphere. Its magnitude is about $5\times10^{-5}T$. Find the force (direction and magnitude) on a 20 m wire carrying a current of 30A parallel to the earth(a) from east to west(b) from north to south.

Sol: **a) F = ilB** $\sin\theta = 30\times20\times5\times10^{-5}\times1 = 0.030N$ downwards.

b) $F = 30\times20\times\left(5\times10^{-5}\right)\times0 = 0$

11. A parabolic section of wire, as shown in figure is located in the X-Y plane and carries a current of 12 A. A uniform magnetic field B = 0.4 T making an angle of 60^0 with X-axis exists throughout the plane. Calculate the total force acting on a wire between the origin and the point x = 0.25 m, y = 1.00 m.

Sol: **I = 12A:** $\ell = 0.25\,\hat{i} + 1.00\,\hat{j}$:

$B = 0.4T$ making on angle 60^0 with X-axis

Hence $B_x = 0.4\times\cos 60^0 = 0.4\times\frac{1}{2} = 0.2T$

$$B_y = 0.4\times\sin 60^0 = 0.4\frac{\sqrt{3}}{2} = 0.2\sqrt{3}T$$

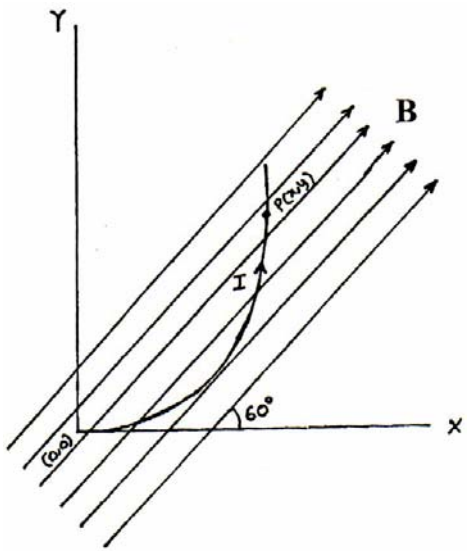
$$\therefore B = 0.2\hat{i} + 0.2\sqrt{3}\,\hat{j}\,T$$

$$\therefore F = il\times B$$

$$F = 12\begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0.25 & 1.00 & 0 \\ 0.2 & 0.2\sqrt{3} & 0 \end{vmatrix}$$

$$= 12\left[\hat{k}\,(0.25\times0.2\sqrt{3} - 1.00\times0.2)\right]$$

$$F = -1.36\hat{k}\,N$$



12. Two straight parallel wires each of length 20cm placed one above the other are separated by 5cm distance. Same current flows through the wires in the opposite direction such that upper wire is suspended without falling. If the mass of the wire is 5g find the current in the wire.

Sol: The magnetic force exerted by lower conductor on upper conductor is equal to the weight of upper conductor **i.**e., F = mg
The repulsive force F is given by

$$F = \frac{\mu_0}{2\pi}\frac{i^2}{r}\times l = \frac{4\pi\times10^{-7}}{2\pi}\times\frac{i^2\times(20\times10^{-2})}{5\times10^{-2}}$$

$$F = 8\times10^{-7}\, i^2$$

$$\because F = mg$$

$$8\times10^{-7}\, i^2 = (5\times10^{-3})\times9.8$$

$$i^2 = \frac{5\times10^{-3}\times9.8}{8\times10^{-7}}$$

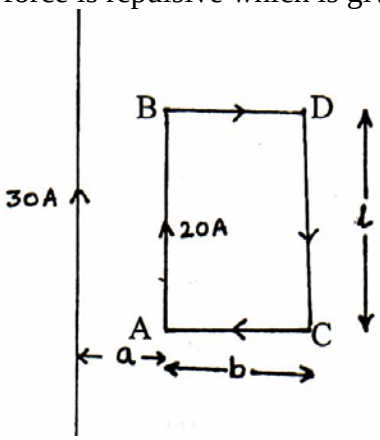
i = 247.5A

13. Figure shows a long wire carrying a current of 30A and a rectangular loop ABCD carrying a current of 20A. Calculate the resultant force acting on the loop. Assume that a = 1cm b = 80cm and *l* = 30 cm.

Sol: The currents in the wire and AB part of rectangular loop are in same direction. So, there if force of attraction between them given by

$$F_1 = \frac{\mu_0 i_1 i_2\, l}{2\pi a} \text{.....(1)}$$

The current between the wire and CD part of rectangular loop are in opposite directions. Hence, the force is repulsive which is given by



$$F_2 = \frac{\mu_0 i_1 i_2\, l}{2\pi(a+b)} \text{.....(2)}$$

There is no contribution to force due to horizontal branches of the loop.
∴ Resultant force F is given by

$$F = \frac{\mu_0 i_1 i_2 l}{2\pi a} - \frac{\mu_0 i_1 i_2 l}{2\pi(a+b)} = \frac{\mu_0 i_1 i_2}{2\pi}\left[\frac{1}{a} - \frac{1}{a+b}\right]$$

$$= \frac{\mu_0 i_1 i_2\, l}{2\pi}\left[\frac{b}{a(a+b)}\right] \quad = \frac{(4\pi\times10^{-7})(30)(20)(0.3)(0.08)}{2\pi(0.01)(0.01+0.08)}$$

$F = 3.2\times10^{-3}\, N$ Directed towards long wire.

UNSOLVED PROBLEMS

1. A long straight wire carries a current of 35 ampere. What is the magnitude of intensity of magnetic induction at a point 20cm from the wire?

Sol: I = 35 amp. d = 20cm = 0.2 m

Magnetic induction, $B = \frac{\mu_0}{2\pi}\frac{i}{r} = 2\times10^{-7}\times\frac{35}{0.2} = 3.5\times10^{-5}\, T$

2. A wire carrying a current of 100 amperes is bent into the form of a circle of radius 5cm. Calculate the flux density at the centre of the coil.

Sol: I = 100 amp; N = 1 and $r = 5\times10^{-2} m$

$$B = \frac{\mu_0 Ni}{2r} = \frac{4\pi\times10^{-7}\times1\times100}{2\times5\times10^{-2}} = 125.7\times10^{-5}\, Wbm^{-2}$$

3. A current of 2A is flowing through a circular coil of radius 10cm containing 100 turns. Find the magnetic flux density at the centre of the coil.

Sol: I = 2amp; N = 100 and $r = 10^{-1} m$

$$B = \frac{\mu_0 Ni}{2r} = \frac{4\pi\times10^{-7}\times100\times2}{2\times10^{-1}} = 0.1256\times10^{-2} T$$

4. A wire carrying a current of 4A in the form of a circle. It is necessary to have a magnetic field of induction $10^{-6}T$ at the centre. What should be the radius?

Sol: i = 4A; $B = 10^{-3} T$, r = ?

$$B = \frac{\mu_0 i}{2r} \quad \Rightarrow r = \frac{\mu_0 i}{2B} = 2\pi\times10^{-7}\times\frac{4}{10^{-6}} = 8\pi\times10^{-1} m$$

$$\therefore r = 2.51m$$

5. Two conductors each of length 12 m lie parallel to each other in air. The centre to centre distance between the two conductors is 15×10^{-2} m and the current in each conductor is 300 amperes. Determine the force in Newton tending to pull the conductors together. (June2010)

Sol: l = 12m, $d = 15\times10^{-2} m$, $i_1 = i_2 = 300A$

$$F = \frac{\mu_0 i_1 i_2 l}{2\pi d} = \frac{2\times10^{-7}\times300\times12}{15\times10^{-2}} = 1.44\text{N}$$

6. A long straight conductor carrying a current of 2A is in parallel to another conductor of length 5cm and carrying a current of 3A. They are separated by a distance of 10 cm. Calculate (a) B due to first conductor. (b) The force on the short conductor.

Sol: $i_1 = 2\,amp$, $i_2 = 3\,amp$; l = 5 cm = 0.05m ; r = 10cm = 0.1 m

a) $B = \frac{\mu_0 i_1}{2\pi r} \Rightarrow B = 2\times10^{-7}\times\frac{2}{0.1} = 4\times10^{-6} T$

b) $F = \frac{\mu_0}{2\pi}\frac{i_1 i_2 l}{r} \Rightarrow F = \frac{2\times10^{-7}\times2\times3\times0.05}{0.01} = 6\times10^{-7}\, N$

7. Two parallel conductors A and B separated by 5cm carry electric current of 6A and 2A in the same direction. Find the point between A and B where the field is zero.

Sol: $i_1 = 6\,amp$, $i_2 = 2\,amp$; r = 5cm $= 5\times10^{-2} m$

At the point where the field is zero, $B_1 = B_2$

Let $r_1 = x$ and $r_2 = 5 - x$

$$\therefore \frac{\mu_0}{2\pi}\frac{i_1}{x} = \frac{\mu_0}{2\pi}\frac{i_2}{5-x} \quad \Rightarrow \quad x = 3.75cm$$

ASSESS YOURSELF

1. An electric current flows in a wire from east to west. What will be the direction of the magnetic field due to this wire at a point north of the wire? South of the wire?

Ans. Vertically upwards, vertically downwards.

2. Does a current carrying circular coil produce uniform magnetic field?

Ans. No, magnetic field produced is not uniform. However, it may be considered as uniform at the centre of a circular coil.

3. A copper wire is bent into a semi circle. What is the magnetic field at the centre?

Ans. $n = \frac{1}{2}$ in $B = \frac{\mu_i}{4r}$ is the magnetic induction at the centre.

4. What is the work done in taking a north pole of strength m around a long and straight conductor in a circular path at perpendicular distance of r from the straight conductor?

Ans. **W =** μ_0 i m, since the force acting on the north pole is $F = mB = \frac{m\mu_0 i}{2\pi r}$ along the tangent and the work done $= \vec{F}.\vec{S} = FS\cos 0$ as the force and displacement are along the sane direction. Hence, work done $= \frac{m\mu_0 i}{2\pi r}(2\pi r) = \mu_0 im$.

7. When a charged particle moves in a uniform magnetic field at right angles to the direction of the field, which of the following changes?
Speed of the particle, energy of the particle of Path of the particle.

Ans. Path of the particle.

8. An electron is not deflected, while moving through a certain region of space. Can we say that there is no magnetic field in the region?

Ans. No. The electron may be moving parallel to the direction of magnetic field.

9. What will be the path of a charged particle moving along the direction of a uniform magnetic field?

Ans. It will be moving along a straight line path because the magnetic force on the charged particle is zero.

10. An electron beam is moving horizontally towards east. If this beam passes through a uniform magnetic field directed upwards, then in which direction will them beam be deflected?

Ans. Towards north.

11. Two parallel long wires separated by a distance 'd' carry equal current 'i'. What is the magnetic induction at a point mid way between the wires if
a) currents are in the same direction?
b) currents are in opposite direction?

Ans. a) zero b) $\frac{\mu_0 i}{2\pi\, d/2} + \frac{\mu_0 i}{2\pi\, d/2} = \frac{2\mu_0 i}{\pi d}$