Magnetic Effects of Current & Magnetism

MAGNETIC EFFECT OF CURRENT

C1 MAGNETIC FIELD OF UNIFORMLY MOVING CHARGE

A moving electric charge creates a magnetic field in the space around it. The law defining the magnetic field $\vec{B}$ of a point charge moving at a constant non-relativistic velocity $\vec{v}$ is written as $\vec{B} = \frac{\mu_0}{4\pi} q \frac{(\vec{v} \times \vec{r})}{r^3}$

where μ_0 is the magnetic constant, the coefficient $\frac{\mu_0}{4\pi} = 10^{-7}\ H/m$, and $\vec{r}$ is the radius vector from the point charge q to the point where the field is to be determined as shown in figure. The direction of $\vec{B}$ can be obtained by applying screw rule on $\vec{v} \times \vec{r}$.

Practice Problem :

1. **A positive point charge q = 3.00 μC has velocity $\vec{v} = (4 \times 10^6\ m/s)\hat{i}$ relative to a reference frame. At the instant when the point charge is at the origin in this frame, the magnetic field $\vec{B}$ that it produces at (0.5, 0, 0) m is**

(a) **0 mT** **(b)** **1 mT** **(c)** **0.5 mT** **(d)** **2.5 mT**

[Answers : (1) a]

C2 MAGNETIC FIELD OF A CURRENT ELEMENT

The law of Biot and Savart gives the magnetic field created by a small elements of length dl carrying a current I. According to this law : $d\vec{B} = \frac{\mu_0}{4\pi} I \frac{d\vec{l} \times \vec{r}}{r^3}$ where $d\vec{l}$ vector points in the direction of current I. The vector $\vec{r}$ goes from the current element to the point where the field $d\vec{B}$ can be obtained by applying the screw rule $(d\vec{l} \times \vec{r})$. This law can be used to find the magnetic field created by any configuration of current carrying wire.

C3 MAGNETIC FIELD FOR SOME IMPORTANT CONFIGURATION

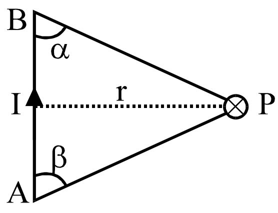
1. **A straight current carrying wire**

case a :

Consider a wire AB carrying current I as shown in figure. For points along the length of the wire the field is always zero.

case b :

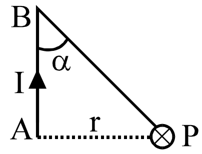
The magnetic field at point P is given by $B = \frac{\mu_0}{4\pi} \frac{I}{r}(\cos\alpha + \cos\beta)$



case c :

If the wire is of infinite length then the field at P is $B = \frac{\mu_0}{4\pi} \frac{2I}{r}$.

case d :



The magnetic field at point P is given by $B = \frac{\mu_0}{4\pi}\frac{I\cos\alpha}{r}$

case e :

If the wire is of semi infinite length then the field at P is given by $B = \frac{\mu_0}{4\pi}\frac{I}{r}$.

2. A circular current loop

Consider a current loop of radius r carrying a current I and having N turns.

(a) Field at centre of the loop : $B = \frac{\mu_0}{4\pi}\frac{2\pi NI}{r}$

(b) Field at axis passing through the centre and perpendicular to the plane of the loop : $B = \frac{\mu_0}{4\pi}\frac{2\pi NIr^2}{(r^2 + x^2)^{3/2}}$

Note that only axial component of the field will exist.

3. A Current Arc

Field at centre of the arc is $B = \frac{\mu_0}{4\pi}\frac{I\theta}{r} = \frac{\mu_0}{4\pi}\frac{Il}{r^2}$,

where *l* is the length of the arc and θ is the angle made by the arc at the centre.

4. Solenoid

If several turns of an insulated wires are wounded around the cylinder then the resulting coil is called a solenoid.

Field at an axial point of a solenoid is given by

$$B = \frac{\mu_0}{4\pi}(2\pi nI)[\cos\alpha + \cos\beta]$$

Here n is then number of turns per unit length.

case a : If the solenoid is of infinite length then B = $\mu_0 nI$

case b : Field near the end of an infinite solenoid is $\frac{1}{2}\mu_0 nI$.

case c : Field outside the solenoid is zero.

Conventionally the direction of the field perpendicular to the plane of the paper is represented by ⊗ if into the page and ⊙ if out of the page.

<u>Practice Problems :</u>

1. A square coil of side a carries a current I. The magnetic field at the centre of the coil is

(a) $\frac{\mu_0 I}{a\pi}$ (b) $\frac{\sqrt{2}\mu_0 I}{a\pi}$ (c) $\frac{\mu_0 I}{\sqrt{2}a\pi}$ (d) $\frac{2\sqrt{2}\mu_0 I}{a\pi}$

2. Two circular coils have number of turns in the ratio 1 : 2 and radii in the ratio 2 : 1. If the same current flows through them, the magnetic fields at their centres will be in the ratio

(a) 1 : 1 (b) 1 : 2 (c) 2 : 1 (d) 1 : 4

3. **The magnetic field inside a current carrying toroidal solenoid is B. If its radius is doubled and the current through it is also doubled, the magnetic field inside the solenoid will be**

   (a) B/2 **(b)** B **(c)** 2B **(d)** 4B

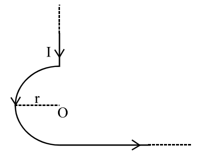
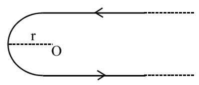
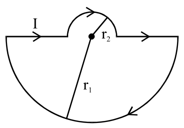
4. **Two identical coils have a common centre and their planes are at right angles to each other. They carry equal currents. If the magnitude of the magnetic field at the centre due to one of the coils is B then that due to the combination is**

   (a) B **(b)** $\sqrt{2}B$ **(c)** $B/\sqrt{2}$ **(d)** 2B

5. **A current of 1 A is flowing in the sides of an equilateral triangle of side 4.5×10^{-2} m. The magnetic field at the centroid of the triangle is**

   (a) 2×10^{-5} T **(b)** 4×10^{-5} T **(c)** 8×10^{-5} T **(d)** 1.2×10^{-4} T

6. **Match the following column :**

Column-I		Column-II	
(p)		(i)	$\dfrac{\mu_0 I}{4r} + \dfrac{\mu_0 I}{4\pi r}$ out of the page
(q)		(ii)	$\dfrac{\mu_0 I}{4r}\left(1 + \dfrac{2}{\pi}\right)$ out of the page
(r)		(iii)	$\dfrac{\mu_0 I}{4}\left(\dfrac{r_1 + r_2}{r_1 r_2}\right)$ into the page

(a) (p)-(i), (q)-(ii), (r)-(iii) **(b)** (p)-(ii), (q)-(i), (r)-(iii)

(c) (p)-(iii), (q)-(ii), (r)-(i) **(d)** (p)-(i), (q)-(iii), (r)-(ii)

[Answers : (1) d (2) d (3) c (4) b (5) b (6) a]

C4 MAGNETIC FORCE ON MOVING CHARGES

A magnetic field exerts a force on a moving charge but not on a stationary charged particle. The force on a charge q moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$ is given by $\vec{F} = q(\vec{v} \times \vec{B})$. F = |q v B| sin ϕ where ϕ is the angle between the $\vec{B}$ and velocity $\vec{v}$. The direction of $\vec{F}$ is given by right hand screw rule. The force on a positive charge is in the direction of $\vec{v} \times \vec{B}$ but the force on a negative charge is opposite to the vector $\vec{v} \times \vec{B}$.

For $\vec{v} \parallel \vec{B}$, F = 0 and for $F = |qvB|$

Note that force $\vec{F}$ is always perpendicular to $\vec{v}$, so it cannot change the magnitude of velocity, only its direction. So the magnetic field can never do work on the particle and this is true even if the magnetic field is not uniform. Hence the kinetic energy of the particle is constant.

MOTION OF CHARGED PARTICLE IN A MAGNETIC FIELD

Case I Motion in Straight Line

A charged particle projected into a magnetic field with a velocity parallel or antiparallel to the field, experiences a zero force. Hence the velocity of this particle in this case is constant and hence it travels in a straight line.

Case II Motion on a Circular Path

A charged particle of charge q, projected into a magnetic field B with initial velocity v perpendicular to the field, experiences a force F = qvB. Under the action of such force the particle moves in a circular path with constant speed. The plane of the circular path is perpendicular to the lines of force of the magnetic field. The magnetic force provides the centripetal force. According to Newton's Second Law

$qvB = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{qB}$ where r is the radius of the circular path. T gives the time period of revolution which is given by $\frac{2\pi r}{v} = \frac{2\pi m}{qB}$.

Note that time period is independent of velocity.

Case III Helical Motion

Consider a positive charged q has velocity components both perpendicular $(v_\perp)$ and parallel $(v_\parallel)$ to a magnetic field B then it moves in a path, shown in figure, called helical path. The $(v_\parallel)$ and $(v_\perp)$ component is responsible for linear motion and circular motion respectively of the particle and hence the resulting motion is helical.

Radius of helix, $r = \frac{mv_\perp}{qB}$. Time period of revolution, $T = \frac{2\pi m}{qB}$.

Pitch of the helix (the displacement parallel to the field in one revolution) is $p = v_\parallel T = \left(\frac{2\pi m}{qB}\right)v_\parallel$

<u>**Practice Problems :**</u>

1. **A charged particle enters a magnetic field such that the direction of initial velocity is different from the direction of the field. Which of the following characteristics of the particle doesn't change with time ?**

   (a) **momentum** **(b)** **kinetic energy**
   (c) **acceleration** **(d)** **direction of motion**

2. **Choose the correct statement for the magnetic force acting on a charged particle**

   (a) **The maximum mgnetic force will be when the velocity of the charged particle is perpendicular to the direction of magnetic field.**
   (b) **Power acted by the magnetic force is always zero**
   (c) **Work done by the magnetic force is always zero**
   (d) **All are correct**

3. **Ions of different momenta (p), having the same charge, enter normally a uniform magnetic field. The radius of the orbit of an ion is proportional to**

   (a) **p** **(b)** **1/p** **(c)** **p^2** **(d)** **$1/p^2$**

4. **A proton and an α-particle, moving with the same kinetic energy, enter a uniform magnetic field normally. The radii of their circular paths will be in the ratio**

   (a) **1 : 1** **(b)** **2 : 1** **(c)** **1 : 2** **(d)** **4 : 1**

5. **Two particles X and Y having same charge, after being accelerated through the same potential difference enter a region of uniform magnetic field and describe circular paths of radii R_1 and R_2 respectively. The ratio of the mass of X to that of Y is**

   (a) **$(R_1 / R_2)^{1/2}$** **(b)** **R_2/R_1** **(c)** **$(R_1 / R_2)^2$** **(d)** **R_1/R_2**

6. **An electron is injected into a uniform magnetic field with components of velocity parallel to and normal to the field direction. The path of the electron is a**

   (a) helix (b) circle (c) parabola (d) straight line

7. **A proton and an α-particle enter a uniform magnetic field perpendicularly, with the same speed. If the proton takes 25 microseconds to make 5 revolutions, the periodic time for the α-particle would be**

   (a) 50 μs (b) 25 μs (c) 10 μs (d) 5 μs

8. **If a particle of charge 10^{-12}C moving along the x-direction with a velocity 10^5 m/s experiences a force of 10^{-10} N in y-direction, then the minimum magnetic field is**

   (a) 6.25×10^3 T in the positive z-direction (b) 10^{-15} T in the negative z-direction

   (c) 10^{-3} T in the positive z-direction (d) 10^{-3} T in the negative z-direction

   [Answers : (1) b (2) d (3) a (4) a (5) c (6) a (7) c (8) d]

C5 LORENTZ FORCE

When a charged particle moves through a region of space where both electric and magnetic field are present, both fields exerts forces on the particle. The total force $\vec{F}$ is the vector sum of the electric and magnetic force on a charged particle of charge q is given by $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$, this force is known as Lorentz force.

Practice Problems :

1. **A uniform electric field and a uniform magnetic field exist in a region in the same direction. An electron is projected with velocity pointed in the same direction. The electron will follow a**

   (a) straight path (b) circular path

   (c) Helix path (d) Cycloidal path

2. **A proton moving with a constant velocity passes through a region of space without any change in its velocity. If E and B represent the electric and magnetic fields respectively, this region of space may not have**

   (a) E = 0, B = 0 (b) E = 0, B ≠ 0 (c) E ≠ 0, B = 0 (d) E ≠ 0, B ≠ 0

3. **A charged particle enters a region where a uniform electric field E and a uniform magnetic field B exist. If E and B are perpendicular to each other and also perpendicular to the velocity u of the particle, then the particle will move undeviated if u equals**

   (a) 2E/B (b) E/B (c) E/2B (d) E/3B

   [Answers : (1) a (2) c (3) b]

C6 Velocity Selector

When a charged particle is passed through undeflected in the presence of crossed electric field and magnetic field (perpendicular to each other) then the velocity of charged particle is given by the ratio of electric field to magnetic field i.e., v = E/B. The velocity of charged particle is perpendicular to both electric field and magnetic field. This condition can be used to select charged particles of a particular velocity out of a beam containing charges moving with different speeds (irrespective of their charge and mass). The crossed E and B fields, therefore, serve as a velocity selector. Only particles with speed E/B pass undeflected through the region of crossed fields. This method was employed by J.J. Thomson in 1897 to measure the charge of mass ratio (e/m) of an electron. The principle is also employed in Mass Spectrometer-a device that separates charged particles, usually ions, according to their charge to mass ratio.

C7 Cyclotron

The cyclotron is use to accelerate the charged particles or ions to very high energy.

The key to the operation of the cyclotron is that the frequency f at which the proton circulates in the field (and that does not depend on its speed) must be equal to the fixed frequency f_{osc} of the electrical oscillator.

This resonance condition says that, if the energy of the circulating proton is to increase, energy must be fed to it at a frequency f_{osc} that is equal to the natural frequency f at which the proton circulates in the magnetic field.

Practice Problems :

1. **A cyclotron's oscillator frequency is 10 MHz. The operating magnetic field for accelerating protons equals to**

(e = 1.6 × 10^{-19}C, m_p = 1.67 × 10^{-27} kg, 1 MeV = 1.602 × 10^{-13}J).

(a) 0.33 T (b) 0.66 T (c) 0.99 T (d) 1.25 T

2. **If the radius of its 'dees' is 60 cm in the above cyclotrone, the kinetic energy of the proton beam produced by the accelerator equals to**

(a) 2.5 MeV (b) 6.2 MeV (c) 7.4 MeV (d) 8.9 MeV

[Answers : (1) b (2) c]

C8 FORCE ON A CURRENT CARRYING CONDUCTOR

The force experienced by current element of length d*l* carrying current I placed in a magnetic field B is given by $d\vec{F} = Id\vec{l} \times \vec{B}$. The total force on a current carrying conductor is given by $\vec{F} = \int I(d\vec{l} \times \vec{B})$.

If the field $\vec{B}$ is uniform and current I is steady, then $\vec{F} = I(\int d\vec{l}) \times \vec{B} = I\vec{l} \times \vec{B}$

where $\vec{l}$ is the vector whose magnitude is *l* and the direction is same as that of current. Hence the force on a wire of arbitrary shape is same as that on a straight wire joining the end points of the wire of arbitrary shape. From the above statement we can conclude that the force acting on a closed loop carrying steady state current placed in a uniform field is zero.

FORCE BETWEEN TWO PARALLEL CURRENT CARRYING WIRES

Consider two long wires kept parallel to each other, distance d apart, and carrying currents I_1 and I_2 respectively, then

(i) if they carry currents in the same direction then there will be force of attraction between them.

(ii) if they carry current in the opposite direction then there will force of repulsion between them.

The magnitude of force experienced by each wire on a unit length is given as force per unit length = $\frac{\mu_0}{4\pi}\frac{2I_1I_2}{d}$.

Practice Problems :

1. **A horizontal wire of length 10 cm and mass 0.3 g carries a current of 5A. The magnitude of the magnetic field which can support the weight of the wire is (g = 10 m/s²).**

(a) 3 × 10^{-3}T (b) 6 × 10^{-3} T (c) 3 × 10^{-4} T (d) 6 × 10^{-4} T

2. **A vertical wire carrying a current in the upward direction is placed in a horizontal magnetic field directed towards north. The wire will experience a force towards**

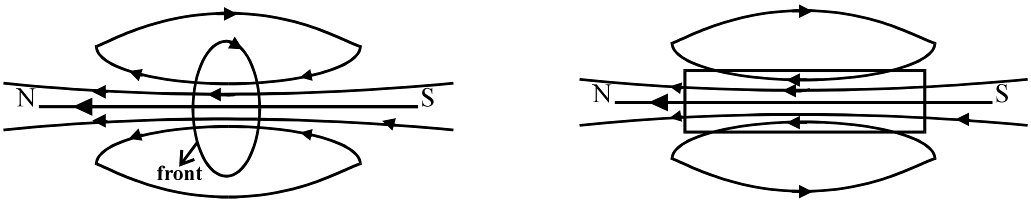
(a) North (b) South (c) East (d) West

3. **A wire of length *l* carries a current I along the positive x-axis, placed along the x-axis. A magnetic field exists which is given by $\vec{B} = B_0(\hat{i} + \hat{j} + \hat{k})$. The force acting on the wire is**

(a) $IB_0 l(\hat{k} - \hat{j})$ (b) $IB_0 l(\hat{k} + \hat{j})$ (c) $IB_0 l(\hat{j} - \hat{k})$ (d) $-IB_0 l(\hat{k} + \hat{j})$

[Answers : (1) b (2) d (3) a]

C9 MAGNETIC DIPOLE



Consider a small current carrying loop of N turns and area A carrying a current I has similar pattern of lines of force as bar magnet, as shown in figure. That's why a current loop has magnetic dipole moment $\vec{\mu}$ which is defined as $\vec{\mu} = NI\vec{A}$.

The direction of $\vec{\mu}$ coincides with the direction of the area vector $\vec{A}$. The direction $\vec{A}$ is perpendicular to the plane of the loop. If we curl the fingers of the right hand along the current, the direction of thumb gives the direction of dipole moment.

Practice Problems :

1. **The magnetic moment associated with a coil of 1 turn, area of $10^{-4}m^2$, carrying a current of 2 A is**

   (a) 1×10^{-4} Am^2 (b) 2×10^{-4} Am^2 (c) 3×10^{-4} Am^2 (d) 4×10^{-4} Am^2

2. **An electron in an atom revolves around the nucleus in an orbit of radius 0.53 Å. The equivalent magnetic moment if the frequency of revolution of electron is 6.8×10^9 MHz is**

   (a) 10^{-21} Am^2 (b) 10^{-22} Am^2 (c) 10^{-23} Am^2 (d) 10^{-24} Am^2

[Answers : (1) b (2) c]

C10 MAGNETIC DIPOLE IN A UNIFORM MAGNETIC FIELD

A current loop of magnetic dipole in a uniform magnetic field experiences a zero force but non zero torque and the torque is given by $\vec{\tau} = \vec{\mu} \times \vec{B}$.

Potential energy of the dipole

When a dipole is placed in a uniform magnetic field, it posses potential energy given by

$$U = -\vec{\mu}.\vec{B}$$

For $\theta = 0 \Rightarrow U = -\mu B$

$\theta = \pi/2 \Rightarrow U = 0$

$\theta = \pi \Rightarrow U = +\mu B$

Hence for $\theta = 0$ i.e. when a dipole is placed along the direction of field, the dipole is in stable equilibrium whereas for $\theta = \pi$ the dipole is in unstable equilibrium.

Practice Problems :

1. **A conducting circular loop of radius r carries a constant current i. It is placed in a uniform magnetic field B such that B is perpendicular to the plane of the loop. The magnetic force, torque and potential energy of the loop is respectively**

   (a) $0, 0, -i\pi r^2B$ (b) 0, 0, 0 (c) $Bir, 0, -i\pi r^2B$ (d) $2Bir, 0, -i\pi r^2B$

2. **A circular coil of 100 turns has an effective radius 0.05 m and carries a current of 0.1 ampere. The plane of the coil is initially perpendicular to the magnetic field. The work required is to turn it in an external magnetic field of 1.5 Wb/m^2 through 180^0 about an axis perpendicular to the magnetic field is**

   (a) 0.436 J (b) 0.336 J (c) 0.236 J (d) 0.136 J

3. **A circular coil of 16 turns and radius 10 cm carrying a current of 0.75 A rests with its plane normal to an external field of magnitude 5.0×10^{-2}T. The coil is free to turn about an axis in its plane perpendicular to the field direction. When the coil is turned slightly and released, it oscillates about its stable equilibrium with a frequency of 2.0 s^{-1}. The moment of inertia of the coil about its axis of rotation is**

(a)	**1.4×10^{-4} kg m^2**	**(b)**	**1.2×10^{-4} kg m^2**
(c)	**1.0×10^{-4} kg m^2**	**(d)**	**0.8×10^{-4} kg m^2**

[Answers : (1) a (2) c (3) b]

C10 The moving coil galvanometer

The moving coil galvanometer can be used as a detector to check if a current is flowing in the circuit. Galvanometer can be converted into ammeter and volt meter.

Practice Problem :

1. **Which of the following will have higher resistance ?**

(a)	**ammeter**	**(b)**	**milliammeter**
(c)	**microammeter**	**(d)**	**all have same resistance**

2. **The deflection produced in the pointer attached to the spring of galvanometer depends on**

(a)	**number of terms of coil**	**(b)**	**area of coil**
(c)	**magnetic field of soft iron core**	**(d)**	**all the above**

3. **The most convenient way to increase the current sensitivity of galvanometer is**
   - **(a) to increase the magnetic field of soft iron core**
   - **(b) area of coil**
   - **(c) number of terms of coil**
   - **(d) any of the above**

4. **The voltage sensitivity of galvanometer depends on**
   - **(a) torsional constant of spring**
   - **(b) number of terms and area of coil**
   - **(c) resistance of galvanometer**
   - **(d) all of the above**

[Answers : (1) a (2) d (3) a (4) d]

C11 AMPERE'S LAW

Ampere's law states that the line integral of $\vec{B}$ around any closed path equals μ_0 times the net current (I) through the area enclosed by the path i.e. $\oint \vec{B}.d\vec{l} = \mu I$.

Using Ampere's law, one finds that the field inside a torodal coil and solenoid are

$$B = \frac{\mu_0 NI}{2\pi r} \text{ (toroid)}$$

$$B = \mu_0 \frac{N}{l} I = \mu_0 nI \text{ (solenoid)}$$

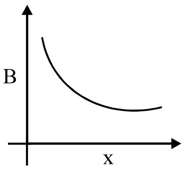
where N is the total number of turns, n is the number of turns per unit length and r is the radius of the toroidal coil.

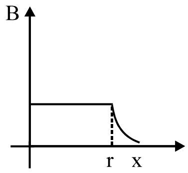
Practice Problems :

1. **A hollow cylinder of radius r carries a current I. Let the magnetic field inside the cylinder is B_1 and outside the cylinder is B_2. Then**

(a)	**$B_1 = 0, B_2 \neq 0$**	**(b)**	**$B_1 \neq 0, B_2 \neq 0$**	**(c)**	**$B_1 = 0, B_2 = 0$**	**(d)**	**$B_1 \neq 0, B_2 = 0$**

2. A solid cylinder of radius r carries a current I. Let the magnetic field from the axis of the cylinder is B. Which of the following graph will represent the variation of B with the distance (x) from the axis of the cylinder ?

(a)


(b)


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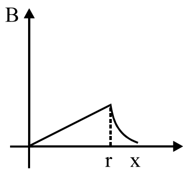
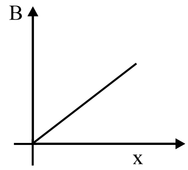


(d)


[Answers : (1) a (2) c]

C12 Magnetism :

There are two types of magnetic poles known as North and South pole. However, every effort to isolate the poles of a magnet have failed. Thus a magnetic monopole does not exist.

Pole Stength : In the study of bar magnets it is sometimes useful to introduce a quantity called magnetic pole strength (q_m) which is analogous to charge in electrostatics. In terms of q_m the magnetic moment M of bar magnet of length $2l$ can be written as $m = 2l\, q_m$. The unit of magnetic moment is Am^2 or J/T.

Practice Problems :

1. A bar magnet of magnetic moment M is cut into two parts of equal length. The magnetic moment of either part is

(a) **M** **(b)** **2M** **(c)** **M/2** **(d)** **zero**

[Answers : (1) c]

C13 Properties of electric and magnetic dipoles

Property	Electric Dipole	Magnetic Dipole
Field at distant point along axis	$\vec{E} = \frac{1}{4\pi \in_0} \frac{2\vec{p}}{x^3}$	$\vec{B} = \frac{\mu_0}{4\pi} \frac{2\vec{m}}{x^3}$
Field at distant point along perpendicular bisector (broad-side-on position)	$\vec{E} = \frac{1}{4\pi \in_0} \frac{\vec{p}}{x^3}$	$\vec{B} = \frac{\mu_0}{4\pi} \frac{\vec{m}}{x^3}$
Force in an external uniform field	zero	zero
Torque in an external field	$\vec{p} \times \vec{E}$	$\vec{m} \times \vec{B}$
potential energy in an external field	$-\vec{p}.\vec{E}$	$-\vec{m}.\vec{B}$
Work done in rotating the dipole in an external field from the equilibrium position	$p\,E\,(1 - \cos\theta)$	$mB(1 - \cos\theta)$

Practice Problems :

1. A magnetic needle lying parallel to a magnetic field requires W units of work to turn it through 60^0. The torque required to maintain the needle in this position is

(a) **$\sqrt{3}$ W** **(b)** $\frac{\sqrt{3}}{2}$W **(c)** **W** **(d)** **2 W**

2. The magnetic field at a point A on the axis of a small bar magnet is equal to the field at a point B on the equator of the same magnet. The ratio of the distances of A and B from the centre of the magnet is

(a) **2^{-3}** **(b)** **$2^{-1/3}$** **(c)** **2^3** **(d)** **$2^{1/3}$**

[Answers : (1) a (2) d]

C14 Time period of small oscillations of a magnet in a magnetic field : Vibration Magnetometer

Suppose a magnet of dipole moment m is suspended in a uniform magnetic field B. If it is given a slight rotation θ from its position of equilibrium, the restoring torque will be $\tau = -mB\sin\theta = -mB\theta$

Therefore the magnet will oscillate with a time period : $\mathbf{T = 2\pi\sqrt{\frac{I}{mB}}}$, where I is the moment of inertia of the magnet.

Practice Problems :

1. **The time period of oscillation of a freely suspended magnet is 4 s. It it is broken in length into two equal parts and one part is suspended in the same way, its time period will be**

   (a) 4 s (b) 2 s (c) 0.5 s (d) 0.25 s

2. **The time period of oscillation of a bar magnet suspended horizontally along the magnetic meridian is T_0. If this magnet is replaced by another magnet of the same size and pole strength, but with double the mass, the new time period will be**

   (a) $T_0/2$ (b) $T_0/\sqrt{2}$ (c) $\sqrt{2}T_0$ (d) $2T_0$

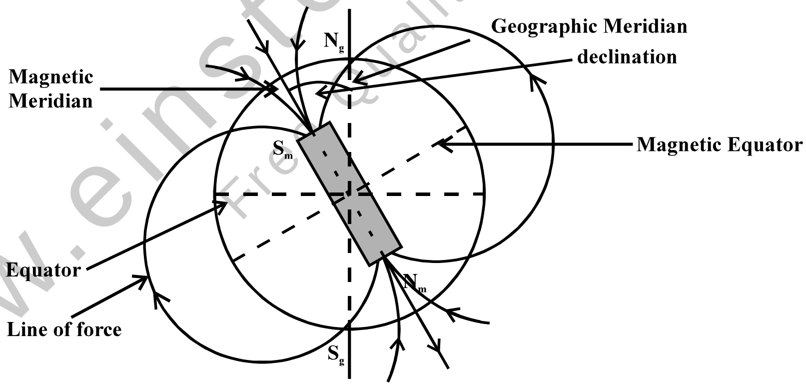
[Answers : (1) b (2) c]

C15 Gauss's Law of Magnetism

The law states that $\oint \vec{\mathbf{B}}.\overrightarrow{\mathbf{dS}} = 0$ for all closed surfaces. This is a precise expression of the fact that magnetic monopoles do not exist.

C16 The Magnetic Field of the Earth

Various observations indicate that there is a magnetic field associated with the earth. The field is approximately like that of a fictious huge bar magnet located deep inside the earth with its north pole nearly towards the geographic south and the south pole nearly towards the geographic north. The actual source of the field appears to be some molten charged metallic fluid giving rise to a current flowing inside the core of the earth.



Geographic meridian : It is the vertical plane passing through the axis of rotation of the earth.

Magnetic meridian : It is the vertical plane passing through the axis of a freely suspended magnet.

Declination : It is the angle between the geographic meridian and the magnetic meridian at a place.

Declination varies irregularly from place to place.

Dip (δ) : It is the angle between the earth's magnetic field and the horizontal direction at a place. It is 0^0 at the magnetic equator and 90^0 at the poles, varying gradually as one goes from equator to poles.

We have $\mathbf{\frac{B_V}{B_H} = \tan\delta}$, where B_H and B_V are the horizontal and vertical components of earth's field $\vec{\mathbf{B}}$.

Practice Problems :

1. At a certain place the horizontal component of earth's magnetic field is √3 times the vertical component. The angle of dip at that place is

(a) 75^0 (b) 60^0 (c) 45^0 (d) 30^0

[Answers : (1) d]

C17 Magnetic Properties of Materials :

On the basis of magnetic behaviour, all the materials can be classified into three categories : 1. diamagnetic, 2. Paramagnetic, 3. Ferromagnetic.

1. **Diamagnetic** substances are those which are feebly repelled by a magnet. When placed in a non-uniform magnetic field, they tend to move from stronger to weaker parts of the field.

   Examples : Bi, Cu, Zn, Hg, Au, Pb, NaCl, H_2O etc. In fact, most of the materials are diamagnetic.

2. **Paramagnetic** substances are those which are feebly attracted by a magnet. When placed in a non-uniform field they tend to move from weaker to stronger parts of the field.

   Examples : Al, Na liquid O_2, $CuCl_2$, wood etc.

3. **Ferromagnetic** substances are those which are strongly attracted by a magnet.

   Examples : Fe, Ni, Co etc.

C18 Curie Law

The variation of magnetic moment per unit volume, M, also called magnetisation, as a function of B/T, where T is the temperature and B is the magnetic field for low value of B/T is given by, $M \propto B/T$ or

$\mathbf{M = \frac{CB}{T}}$, where C is a constant. This is called the **Curie law**.

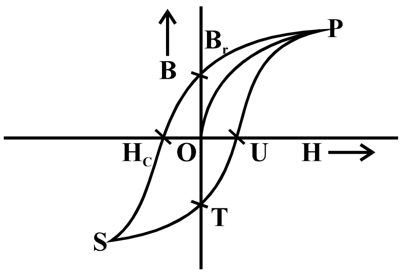
Curie Temperature : It is that temperature above which the ferromagnetic material becomes paramagnetic. For iron the Curie temperature is 1043 K.

C19 Relative Permeability (μ_r) and Magnetic Susceptibility (χ)

Relation between Relative Permeability (μ_r) and Magnetic Susceptibility is given by $\mu_r = 1 + \chi$

Material	μ_r	χ
Diamagnetic	slightly less than unity	small, negative
Paramagnetic	slightly more than unity	small, positive
Ferromagnetic	much greater than unity (~ 10^3)	large, positive.

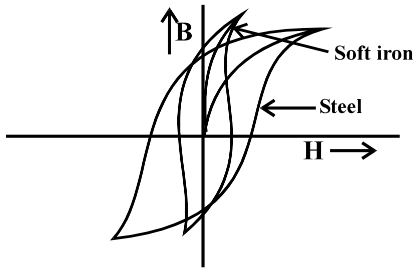
C20 Hysteresis : When a piece of ferromagnetic material is taken through a cycle of magnetisation, the variation of magnetic induction B with the magnetic intensity H is as shown in the diagram.



The value of B at which H (magnetic intensity) is zero is called remanence (B_r). The value of H at which B (magnetic field) is zero is called coercivity. The complete cycle of magnetisation is known as hysteresis loop.

The following important points concerning hysteresis loop should be noted :

1. The energy spent per cycle in taking a ferromagnetic material through a cycle of magnetisation is proportional to the area of the hysteresis loop. This area is very small for soft iron and is large for steel. Therefore soft iron is useful for cores of transformers and generators.



2. For steel, coercivity is very large and remanence is fairly large. Therefore, steel is used for making parmanent magnets. The area of the loop is large for steel, but it does not matter because a permanent magnet has not to be taken through a cycle of magnetisation.

For soft iron coercivity is small and area of the loop is also small. Therefore it is a suitable materials for making electromagnets.

<u>Practice Problems :</u>

1. Electromagnets are made of soft iron because soft iron has

(a) low susceptibility and low retentivity (b) high susceptibility and high retentivity

(c) high susceptibility and low retentivity (d) low permeability and high retentivity

2. The area of the B-H hysteresis loop is an indication of the

(a) permeability of the material (b) susceptibility of the material

(c) retentivity of the material (d) energy dissipated per cycle

3. The material of a permanent magnet has

(a) high retentivity, low coercivity (b) low retentivity, high coercivity

(c) low retentivity, low coercivity (d) high retentivity, high coercivity

[Answers : (1) c (2) d (3) d]