

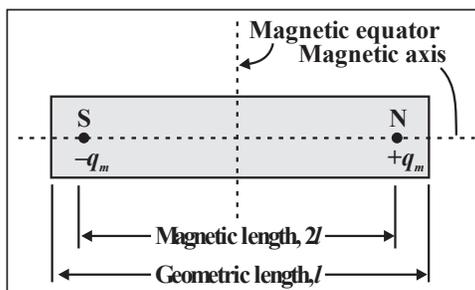
## Syllabus

- 11.1 Introduction.
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## 11.1 Introduction

## Recap of 11th Std

- i. **Magnetic dipole** : Two equal and opposite poles separated by finite distance is called magnetic dipole.



- ii. **Pole Strength** :
- a. These are the region of apparently concentrated magnetic strength in a magnet where the magnetic attraction is maximum.
  - b. Poles of magnet are not exactly at the ends but present before that.
  - c. Symbol : For N-pole  $+q_m$   
For S-pole  $-q_m$
  - d. SI Unit : Ampere – meter
  - e. Dimension :  $[L^1 A^1]$

- iii. **Magnetic length** :

- a. In a magnetic dipole, the finite distance between the two poles is called its magnetic length.
- b. It is denoted by  $2l$ .
- c. Magnetic length  $= \frac{5}{6}$  geometric length,  
 $\therefore (2l) = \frac{5}{6}L$
- d. SI unit : meter
- e. Dimension :  $[L^1]$

- iv. **Magnetic axis** : The line through the two poles of a magnetic dipole is called the magnetic axis of the dipole.

- v. **Magnetic equator** : A line through the centre of a magnetic dipole and perpendicular to its magnetic axis is called a magnetic equator of the dipole.

- vi. **Magnetic dipole moment** :

- a. The magnitude of magnetic dipole moment is defined as the product of its pole strength and its magnetic length .
- b. Symbol :  $m$
- c.  $\therefore m = q_m \times 2l$
- d. It is a vector quantity having direction : from South-pole to North-pole along the axis
- e. SI unit :  $Am^2$
- f. Dimension  $[M^0 L^2 T^0 A^1]$

## 11.2 Torque Acting on a Magnetic Dipole in a Uniform Magnetic Field

## Note:

- i. Force acting on unit positive pole (N-pole) in uniform magnetic field is

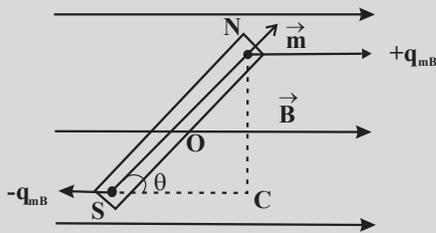
$$F = q_m B$$

On N-pole, force is acting in the direction of field ( $F = q_m B$ )

On S-pole force is acting opposite to direction of field ( $F = -q_m B$ )

- ii. When bar magnet is suspended in uniform magnetic field. Torque acts on bar magnet which is given by

$$\tau = mB \sin \theta$$



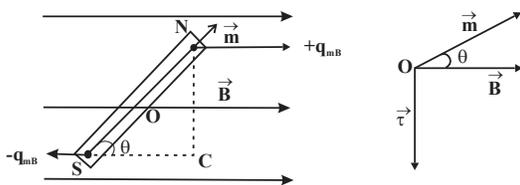
**Q.1 Obtain expression for the potential energy of a bar magnet placed in uniform magnetic field.**

**Ans.**

- i. When a magnetic dipole is placed in a uniform magnetic field  $\vec{B}$  at angle  $\theta$  with it, it experiences a torque

$$\tau = mB \sin \theta$$

This torque tends to align the dipole in the direction of  $\vec{B}$



- ii. If the dipole is rotated against the action of this torque work has to be done. This work is stored as potential energy of the dipole.

- iii. The work done in turning the dipole through a small angle  $d\theta$  is

$$dW = \tau d\theta = mB \sin \theta d\theta$$

- iv. If the dipole is rotated from an initial position  $\theta_1$  to the final position  $\theta_2$ , then the total work done will be

$$W = \int_{\theta_1}^{\theta_2} dW = \int_{\theta_1}^{\theta_2} \tau d\theta$$

$$W = \int_{\theta_1}^{\theta_2} mB \sin \theta d\theta = mB [-\cos \theta]_{\theta_1}^{\theta_2}$$

$$W = -mB (\cos \theta_2 - \cos \theta_1)$$

- v. This work done is stored as the potential energy ( $U_m$ ) of the dipole

$$\therefore U_m = -mB (\cos \theta_2 - \cos \theta_1)$$

- vi. The potential energy of the dipole is zero

when  $\vec{m} \perp \vec{B}$ . So potential energy of the dipole in any orientation  $\theta$  can be obtained

by putting  $\theta_1 = 90^\circ$  and  $\theta_2 = \theta$  in the above equation.

$$\therefore U_m = -mB (\cos \theta - \cos 90^\circ)$$

or 
$$U_m = -mB \cos \theta = -\vec{m} \cdot \vec{B}$$

**Special Cases**

**Case 1** - When  $\theta = 0^\circ$ ,  $\cos 0 = 1$

$$U_m = -mB$$

This is the position when  $\vec{m}$  and  $\vec{B}$  are parallel and bar magnet possess **minimum potential energy** and is in the most stable state.

**Case 2** - When  $\theta = 180^\circ$ ,  $\cos 180^\circ = -1$

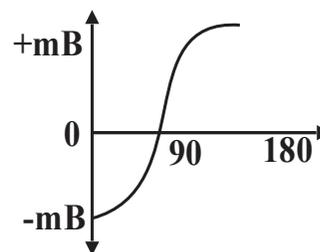
$$U_m = mB.$$

This is the position when  $\vec{m}$  and  $\vec{B}$  are antiparallel and bar magnet possesses **maximum potential energy** and is the most unstable state.

**Case 3** - When  $\theta = 90^\circ$ ,  $\cos 90^\circ = 0$

$$U_m = 0$$

This is the position when bar magnet is aligned perpendicular to the direction of magnetic field.



**Type - I**  
**Numerical based on work done**  
**in magnetic field**

**Formulae used**

1.  $\tau = mB \sin \theta = \vec{m} \times \vec{B}$
2.  $U_m = W = -mB(\cos \theta_2 - \cos \theta_1)$
3. If initially dipole is perpendicular to magnetic field  
 $U_m = -mB \cos \theta = -\vec{m} \cdot \vec{B}$
4. Conversion between gauss and tesla  
 $1 \text{ G} = 10^{-4} \text{ T}$

★ 1) A short bar magnet is placed in an external magnetic field of 700 gauss. When its axis make an angle of  $30^\circ$  with the external magnetic field, it experience a torque of 0.014 Nm. Find the magnetic moment of the magnet, and the work done in moving it from its most stable to most unstable position.

**Data:**  $B = 700 \text{ gauss} = 700 \times 10^{-4} \text{ T} = 7 \times 10^{-2} \text{ T}$ ,  
 $\tau = 0.014 \text{ Nm}$ ,  $\theta = 30^\circ$ ,

**To find:** i.  $m$   
ii. Work done in moving it from its most stable to most unstable position ( $W$ ).

**Formula:** i.  $\tau = mB \sin \theta$   
ii.  $W = mB(\cos \theta_1 - \cos \theta_2)$

**Solution:**

i.  $\tau = mB \sin \theta$   
 $0.014 = m \times 7 \times 10^{-2} \times \sin 30^\circ$

$\therefore m = \frac{2 \cancel{14} \times 10^{-3} \times 2}{\cancel{7} \times 10^{-2}} = 0.4 \text{ Am}^2$

ii. We know that, most stable position of magnet is when  $\theta_1 = 0^\circ$  and most unstable position of magnet is when  $\theta_2 = 180^\circ$

$$W = mB(\cos \theta_1 - \cos \theta_2)$$

$$W = 0.4 \times 7 \times 10^{-2} \times [\cos 0^\circ - \cos 180^\circ]$$

$$= 2.8 \times 10^{-2} \times [1 - (-1)]$$

$$= 2.8 \times 10^{-2} \times [2]$$

$$= 5.6 \times 10^{-2}$$

$$= 0.056 \text{ J}$$

**Ans:** i. Magnetic moment of the magnet is  $0.4 \text{ Am}^2$ .  
ii. Required work done is  $0.056 \text{ J}$ .

★ 2) The work done for rotating a magnet with magnetic dipole moment, through  $90^\circ$  from its magnetic meridian is  $n$  times the work done to rotate it through  $60^\circ$ . Find the value of  $n$ .

**Data:**

$$\left[ \begin{array}{l} \text{Work done in} \\ \text{rotating} \\ \text{dipole by } 90^\circ \text{ from} \\ \text{magnetic meridian} \end{array} \right] = n \left[ \begin{array}{l} \text{Work done in} \\ \text{rotating} \\ \text{dipole by } 60^\circ \text{ from} \\ \text{magnetic meridian} \end{array} \right]$$

$\therefore W_{90^\circ} = nW_{60^\circ}$

**To Find :**  $n$

**Formula:**  $W = mB(\cos \theta_1 - \cos \theta_2)$

**Solution:**

i. When magnet is kept parallel to magnetic meridian  $\theta = 0^\circ$

ii. Now when magnet is rotated from magnetic meridian to angle  $\theta$   
 $\theta_1 = 0^\circ$  and  $\theta_2 = \theta$

$\therefore W = mB [\cos 0 - \cos \theta]$   
 $W = mB [1 - \cos \theta]$

iii. Work done for rotating a magnet with magnetic dipole moment  $m$ , through  $90^\circ$  from its magnetic meridian

$$W_{90^\circ} = mB (1 - \cos \theta)$$

$$= mB (1 - \cos 90^\circ) = mB$$

vi. Work done for rotating it through  $60^\circ$  from its magnetic meridian

$$W_{60^\circ} = mB (1 - \cos \theta)$$

$$= mB \left( 1 - \frac{1}{2} \right) = \frac{mB}{2}$$

v. From given condition

$$W_{90^\circ} = nW_{60^\circ}$$

$\therefore mB = n \times \frac{mB}{2}$

$\therefore n = 2$

**Ans:** The value of  $n$  is 2

- ★3) A magnetic needle is suspended freely so that it can rotate freely in the magnetic meridian. In order to keep it in the horizontal position, a weight of 0.2 g is kept on one end of the needle. If the pole strength of this needle is 20 Am, find the value of the vertical component of the earth's magnetic field. ( $g = 9.8 \text{ m s}^{-2}$ )

**Data:** Pole strength ( $q_m$ ) = 20 Am  
Weight ( $f$ ) =  $0.2 \text{ g} = 0.2 \times 9.8 \times 10^{-3} \text{ N}$   
 $= 1.96 \times 10^{-3} \text{ N}$

**To find:** ( $B_v$ )

**Formula:** i.  $\tau = l \times f$     ii.  $\tau = m \times B$

**Solution:**

i. Magnetic moment ( $m$ ) =  $q_m \times 2l = 20 \times 2 \times l$

ii. Weight suspended at one end of needle produces torque which is given by

$$\tau_{\text{needle}} = l \times f$$

$$\tau_{\text{needle}} = l \times 1.96 \times 10^{-3} \text{ Nm}$$

iii. Torque due to vertical component of earth's magnetic field.

$$\tau_{\text{restoring}} = m \times B_v$$

$$\tau_{\text{restoring}} = (20 \times l \times 2) \times B = (40 l B_v)$$

iv. At equilibrium, needle is in horizontal position

$$\therefore \tau_{\text{needle}} = \tau_{\text{restoring}}$$

$$l \times 1.96 \times 10^{-3} = 40 l B_v$$

$$B_v = \frac{1.96 \times 10^{-3}}{40}$$

$$= \frac{1.96}{4} \times 10^{-4} = 0.49 \times 10^{-4} \text{ T}$$

$$= 4.9 \times 10^{-5} \text{ T}$$

**Ans:** The vertical component of earth's magnetic field is  $4.9 \times 10^{-5} \text{ T}$

**Problem for Practice**

1. A short bar magnet is placed in an external magnetic field of 600 G. When its axis makes  $30^\circ$  with the external field, it experiences a torque of 0.012 Nm. What is the magnetic moment of the magnet.

**Ans: 0.4 Am<sup>2</sup>**

2. A short bar magnet placed with its axis at

$30^\circ$  with an external field of 800 G experience a torque of 0.016 Nm,

- (a) What is the magnetic moment of the magnet.  
(b) Find work done in moving it from its most stable to most unstable position.  
(c) The bar magnet is replaced by a solenoid of cross sectional area  $2 \times 10^{-4} \text{ T}$  and 1000 turns, but of the same magnetic moment. Determine the current flowing through the solenoid.

**Ans: 0.4 Am<sup>2</sup>,  $6.4 \times 10^{-2} \text{ J}$ , 2 A**

3. A magnetic needle is suspended by a thread at centre and it becomes horizontal when weight of 100 mg is placed on front end. If pole strength is 5 Am. Find vertical component of earth's magnetic field.

**Ans:  $0.98 \times 10^{-4} \text{ T}$**

**MULTIPLE CHOICE QUESTIONS**

**Entrance Corner (Set 1)**

1. A short bar magnet placed with its axis at  $30^\circ$  with a uniform external magnetic field of 0.16 Tesla experiences a torque of magnitude 0.032 Joule. The magnetic moment of the bar magnet will be  
a. 0.23 Joule / Tesla  
b. 0.40 Joule / Tesla  
c. 0.80 Joule / Tesla  
d. Zero
2. A bar magnet when placed at an angle of  $30^\circ$  to the direction of magnetic field induction of  $5 \times 10^{-2} \text{ T}$ , experiences a moment of couple  $25 \times 10^{-6} \text{ N-m}$ . If the length of the magnet is 5 cm its pole strength is  
a.  $2 \times 10^{-2} \text{ A-m}$       b.  $5 \times 10^{-2} \text{ A-m}$   
c. 2 A-m                      d. 5 A-m
3. A magnet of magnetic moment  $2 \text{ JT}^{-1}$  is aligned in the direction of magnetic field of 0.1 T. What is the net work done to bring the magnet normal to the magnetic field  
a. 0.1 J                      b. 0.2 J  
c. 1 J                         d. 2 J

4. The torque on a bar magnet due to the earth's magnetic field is maximum when the axis of the magnet is  
 (a) Perpendicular to the field of the earth  
 (b) Parallel to the vertical component of the earth's field  
 (c) At an angle of  $33^\circ$  with respect to the N-S direction  
 (d) Along the North-South (N-S) direction
5. A bar magnet of magnetic moment  $1.5 \text{ J/T}$  is aligned with the direction of a uniform magnetic field of  $0.22 \text{ T}$ . The work done in turning the magnet so as to align its magnetic moment opposite to the field and the torque acting on it in this position are respectively.  
 a.  $0.33\text{J}, 0.33\text{N-m}$       b.  $0.66\text{J}, 0.66\text{N-m}$   
 c.  $0.33\text{J}, 0$                   d.  $0.66\text{J}, 0$
6. A bar magnet of length  $0.2 \text{ m}$  and pole strength  $5 \text{ A.m.}$  should be kept in a uniform magnetic field of induction  $15 \text{ tesla}$  at angle ..... radians to the field so that the torque experienced by it will be  $7.5\text{N-m}$   
 a.  $\frac{\pi}{2}$       b.  $\frac{\pi}{3}$       c.  $\frac{\pi}{6}$       d.  $\frac{\pi}{4}$
7. When a bar magnet is placed at  $90^\circ$  in a uniform magnetic field, then it is acted upon by a maximum couple. For the couple to be half the maximum value, the magnet should be inclined to the magnetic field at an angle of  
 a.  $45^\circ$       b.  $60^\circ$       c.  $15^\circ$       d.  $30^\circ$
8. The couple acting on a bar magnet of pole strength  $2 \text{ A.m.}$  when kept in a magnetic field of intensity  $10 \text{ A/m}$ , such that axis of the magnet makes an angle  $30^\circ$  with the direction of the field is  $80 \times 10^{-7} \text{ Nm}$ . The distance between the poles of the magnet is  
 a.  $8 \times 10^{-9} \text{ m}$                   b.  $\frac{\pi}{2} \text{ m}$   
 c.  $63.36 \text{ m}$                       d.  $\frac{1}{2\pi} \text{ m}$
9. A bar magnet of magnetic moment  $M_1$  is suspended by a wire in a magnetic field. The top of the wire is rotated through  $180^\circ$ , then the magnet rotated through  $45^\circ$ . Under similar conditions another magnet of magnetic moment  $M_2$  is rotated through  $30^\circ$ , the ratio  $M_1:M_2$  is  
 a.  $9:10\sqrt{2}$                       b.  $1:\sqrt{2}$   
 c.  $1:1$                                   d.  $1:3$
10. A magnet of length  $0.1 \text{ m}$  has a pole strength of  $4 \text{ amp.m.}$  If it is making an angle  $45^\circ$  with the direction of uniform magnetic induction field strength of  $4 \text{ web/m}^2$ , the torque experienced by it is  
 a.  $1.13 \text{ N-m}$                       b.  $1.6 \text{ N.m}$   
 c.  $0.8 \text{ N.m}$                         d.  $1.32 \text{ N.m}$
11. A bar magnet of length  $10 \text{ cm}$  experiences a torque of  $\frac{\sqrt{2}}{10} \text{ N. m.}$  in an uniform magnetic field of induction  $0.4 \text{ Wb/m}^2$  when it is suspended making an angle  $45^\circ$  with the field. The pole strength of the magnet is (in amp.m).  
 a.  $50$       b.  $10$       c.  $2.5$       d.  $5$
12. A bar magnet when placed at an angle of  $30^\circ$  to the direction of Magnetic field induction  $5 \times 10^{-4} \text{ T}$  experiences a moment of couple of  $25 \times 10^{-6} \text{ N-m}$ . If the length of the Magnet is  $5 \text{ cm}$ , its pole strength is  
 a.  $2 \times 10^{-2} \text{ amp. m}$               b.  $5 \times 10^{-2} \text{ amp m}$   
 c.  $2 \text{ amp m}$                         d.  $5 \text{ amp m}$
13. A bar Magnet of pole strength  $2 \text{ amp- m}$  is kept in a magnet field of induction  $4 \times 10^{-5} \text{ web/m}^2$  such that the axis of magnet makes on angle  $30^\circ$  with the direction of the field. The couple acting on the magnet is found to be  $80 \times 10^{-7} \text{ N-m}$ . Then the distance between the two poles of the magnet is  
 a.  $20\text{m}$       b.  $2 \text{ m}$       c.  $3 \text{ cm}$       d.  $20 \text{ cm}$
14. A magnet of magnetic moment  $M$  is rotated through  $360^\circ$  in a magnetic field  $H$ . work done will be  
 a.  $0$       b.  $2 \text{ MH}$       c.  $\text{MH}$       d.  $2\pi \text{ MH}$
15. A magnetic needle of pole strength  $20\sqrt{3} \text{ Am}$  is pivoted at its centre. Its N-pole is pulled eastward by a string. The horizontal force required to produce a deflection of  $30^\circ$  from magnetic meridian (take  $BH = 10^{-4} \text{ T}$ ) is

- a.  $4 \times 10^{-3} N$                       b.  $2 \times 10^{-3} N$   
 c.  $\frac{2}{\sqrt{3}} \times 10^{-3} N$                   d.  $4\sqrt{3} \times 10^{-3} N$

**Q.2 Show that the oscillations of a freely suspended magnet in a uniform magnetic field are simple harmonic. hence deduce an expression for its time period.**

**Ans:**

i. In the position of equilibrium, the magnetic dipole lies along  $\vec{B}$ . When it is slightly rotated from this position and released, it begins to vibrate about the field direction under the restoring torque

$$\tau = -mB \sin \theta$$

The negative sign indicates that the direction of torque  $\tau$  is such so as to decrease  $\theta$ . i.e restoring torque is opposite to that of  $\theta$

ii. For small angular displacement  $\theta$ ,  $\sin \theta \approx \theta$

$$\therefore \tau = -mB\theta \quad \dots (1)$$

iii. If  $I$  is the moment of inertia of the magnet, then the deflecting torque on the magnet is

$$\tau = I\alpha = I \frac{d^2\theta}{dt^2} \quad \dots (2)$$

iv. In the equilibrium condition,  
Deflecting torque = restoring torque

$$\therefore I \frac{d^2\theta}{dt^2} = -mB\theta$$

$$\therefore \frac{d^2\theta}{dt^2} = -\left(\frac{mB}{I}\right)\theta \quad \dots (3)$$

$$\therefore \frac{d^2\theta}{dt^2} \propto \theta.$$

Hence the oscillation of a freely suspended magnetic dipole in a uniform magnetic field is simple harmonic.

v. Differential equation of angular S.H.M is

$$\frac{d^2\theta}{dt^2} = -\omega^2\theta \quad \dots (4)$$

vi. Comparing equation (3) and (4) we get,

$$\omega^2 = \frac{mB}{I}$$

$$\therefore \omega = \sqrt{\frac{mB}{I}}$$

vii. The time period of oscillation is given by

$$T = \frac{2\pi}{\omega} = 2\pi \sqrt{\frac{I}{mB}}$$

**Key Point**

**Vibration Magnetometer**

- i. It is an instrument
  - a. To determine the horizontal component of earth's magnetic induction at a given place.
  - b. To compare the magnetic moments of two bar magnets.
  - c. To compare the horizontal components of earth's magnetic induction at different places.
- ii. When a bar magnet is suspended freely in a uniform magnetic field, moment of couple is applied by the external force and restoring torque is developed by the earth's magnetic field ( $B_H$ ). As a result the magnet execute angular simple harmonic motion.
- iii. A freely suspended bar magnet experiences a torque and executes angular S.H.M. Time period of oscillation is

$$T = 2\pi \sqrt{\frac{I}{mB_H}}$$

where  $I$  moment of inertia,  $m$  magnetic moment and  $B_H$  Horizontal component of earth magnetic induction moment of inertia of bar magnet

iv.  $I = M \frac{(l^2 + b^2)}{12}$  for a thin bar magnet

$I = \frac{MI^2}{12}$  where  $M$  is mass of the magnet

v. For small percentage changes in moment of

inertia  $\frac{\Delta T}{T} \times 100 = \frac{1}{2} \frac{\Delta I}{I} \times 100$

vi. For small percentage changes in magnetic

moment

$$\frac{\Delta T}{T} \times 100 = \frac{-1 \Delta m}{2 m} \times 100$$

vii. If  $T_1, T_2$  are the time periods of two magnets of moments  $M_1, M_2$ . Comparison of magnetic moments:

$$m_1 / m_2 = (T_2 / T_1)^2$$

viii. If  $T_1$  is the time period with like poles of two magnets together and  $T_2$  is the time period with unlike poles together, then

$$\frac{T_1}{T_2} = \left( \frac{m_1 + m_2}{m_1 - m_2} \right)^{1/2} \quad \frac{m_1}{m_2} = \frac{T_2^2 + T_1^2}{T_2^2 - T_1^2}$$

ix. Comparison of earth's magnetic fields at different places:  $B_{H1} / B_{H2} = (T_2 / T_1)^2$

### Type - II

Numerical based on time period of bar magnet

#### Formulae used

$$T = \frac{2\pi}{\omega} = 2\pi \sqrt{\frac{I}{mB}}$$

★1) A magnetic needle placed in uniform magnetic field has magnetic moment of  $2 \times 10^{-2} \text{ A m}^2$ , and moment of inertia of  $7.2 \times 10^{-7} \text{ kg m}^2$ . It performs 10 complete oscillations in 6 s. What is the magnitude of the magnetic field?

**Data:**  $m = 2 \times 10^{-2} \text{ Am}^2$ ,  
 $I = 7.2 \times 10^{-7} \text{ kgm}^2$ ,  
As there are 10 oscillations per 6 second  
Time for one oscillation,

$$T = \frac{6}{10} = \frac{3}{5} \text{ s}$$

**To find:** B

**Formula:**  $T = 2\pi \sqrt{\frac{I}{mB}}$

**Solution :** Squaring the formula, we get

$$T^2 = 4\pi^2 \frac{I}{mB}$$

$$\begin{aligned} \therefore B &= \frac{4\pi^2 I}{mT^2} \\ &= \frac{4 \times \pi^2 \times 7.2 \times 10^{-7} \times 25}{2 \times 10^{-2} \times 9} \\ &= \frac{2 \cancel{4} \times (3.14)^2 \times 0.8 \cancel{7.2} \times 10^{-7} \times 25}{\cancel{2} \times 10^{-2} \times \cancel{9}_1} \end{aligned}$$

$$\therefore B = 3.948 \times 10^{-3} \text{ Wb/m}^2$$

**Ans :** The magnitude of the magnetic field is  $3.948 \times 10^{-3} \text{ Wb / m}^2$

★2) A bar magnet of moment of inertia of  $500 \text{ g cm}^2$  makes 10 oscillations per minute in a horizontal plane. What is its magnetic moment, if the horizontal component of earth's magnetic field is 0.36 gauss?

**Data:**  $I = 500 \text{ g cm}^2 = 500 \times 10^{-7} \text{ kg m}^2$ ,  
 $n = 10 \text{ osc per min} = \frac{10}{60} \text{ osc per sec}$ ,

$$T = \frac{1}{n} = 6 \text{ s}$$

$$B_H = B = 0.36 \text{ gauss} = 0.36 \times 10^{-4} \text{ T}$$

**Formula:**  $T = 2\pi \sqrt{\frac{I}{mB}}$

**Solution:**  $T = 2\pi \sqrt{\frac{I}{mB}}$

Squaring both sides, we get

$$T^2 = 4\pi^2 \frac{I}{mB}$$

$$\therefore m = \frac{4\pi^2 I}{T^2 B}$$

$$m = \frac{4 \times (3.142)^2 \times 500 \times 10^{-7}}{6^2 \times 0.36 \times 10^{-4}}$$

$$\therefore m = 1.524 \text{ Am}^2$$

**Ans :** Magnetic moment of bar magnet is  $1.524 \text{ Am}^2$ .

**Problem for Practice**

1. A magnet makes 55 vibrations in one minute where horizontal component of earth's field is 0.36 G. If moment of inertia of bar magnet is  $10^{-5} \text{ kg m}^2$ . Find magnetic moment of bar magnet

**Ans : 7.61 NmT<sup>-1</sup>**

2. A magnetic needle placed in uniform magnetic field has magnetic moment of  $6.7 \times 10^{-2} \text{ A m}^2$ , and moment of inertia of  $15 \times 10^{-6} \text{ kg m}^2$ . It performs 10 complete oscillations in 6.70 s. What is the magnitude of the magnetic field?

**Ans: 0.02 T**

3. A magnetic needle placed in uniform magnetic field has magnetic moment of  $5.0 \times 10^{-2} \text{ A m}^2$ , and moment of inertia of  $7.8 \times 10^{-6} \text{ kg m}^2$ . It performs 12 complete oscillations in 6.0 s. What is the magnitude of the magnetic field?

**Ans: 0.0016 T**

**MULTIPLE CHOICE QUESTIONS**

**Entrance Corner (Set 2)**

1. Two bar magnets of the same mass, length and breadth but magnetic moments  $M$  and  $2M$  respectively, when placed in same position, time period is 3 sec. What will be the time period when they are placed in different position
- a.  $\sqrt{3}$  sec                      b.  $3\sqrt{3}$  sec  
c. 3 sec                              d. 6 sec
2. A magnet is suspended in such a way that it oscillates in the horizontal plane. It makes 20 oscillations per minute at a place where dip angle is  $30^\circ$  and 15 oscillations per minute at a place where dip angle is  $60^\circ$ . The ratio of total earth's magnetic field at the two places is
- a.  $3\sqrt{3} : 8$                       b.  $16 : 9\sqrt{3}$   
c.  $4 : 9$                               d.  $2\sqrt{3} : 9$
3. The time period of oscillation of a magnet in a vibration magnetometer is 1.5 seconds. The time period of oscillation of another magnet similar in size, shape and mass but having one-fourth magnetic moment than that of first magnet, oscillating at same place will be
- a. 0.75 s                              b. 1.5 s

- c. 3.0 s                              d. 6.0 s

4. Two magnets A and B are identical in mass, length and breadth but have different magnetic moments. In a vibration magnetometer, if the time period of B is twice the time period of A. The ratio of the magnetic moments  $M_A / M_B$  of the magnets will be
- a. 1/2                                  b. 2  
c. 4                                      d. 1/4
5. At two places A and B using vibration magnetometer, a magnet vibrates in a horizontal plane and its respective periodic time are 2 sec and 3 sec and at these places the earth's horizontal components are  $H_A$  and  $H_B$  respectively. Then the ratio between  $H_A$  and  $H_B$  will be
- a. 9 : 4                                  b. 3 : 2  
c. 4 : 9                                  d. 2 : 3

**Try yourself**

6. The time period of a bar magnet suspended horizontally in the earth's magnetic field and allowed to oscillate
- a. Is directly proportional to the square root of its mass  
b. Is directly proportional to its pole strength  
c. Is inversely proportional to its magnetic moment  
d. Decreases if the length increases but pole strength remains
7. Magnets A and B are geometrically similar but the magnetic moment of A is twice that of B. If  $T_1$  and  $T_2$  be the time periods of the oscillation when their like poles and unlike poles are kept together respectively, then  $\frac{T_1}{T_2}$  will be
- a.  $\frac{1}{3}$                                       b.  $\frac{1}{2}$   
c.  $\frac{1}{\sqrt{3}}$                                   d.  $\sqrt{3}$
8. A small bar magnet A oscillates in a horizontal plane with a period  $T$  at a place where the



ii. If the electron travels a distance  $2\pi r$  in time  $T$  then, its orbital speed  $v = 2\pi r/T$

iii. Magnitude of circulating current is given by,

$$I = e \left( \frac{1}{T} \right)$$

$$\text{But, } T = \frac{2\pi r}{v}$$

$$\therefore I = e \left( \frac{1}{2\pi r / v} \right) = \frac{ev}{2\pi r} \quad \dots(1)$$

iv. The orbital magnetic moment associated with orbital current loop is given by,

$$m_{\text{orb}} = IA = \frac{ev}{2\pi r} \times \pi r^2$$

[ $\because$  Area of current loop,  $A = \pi r^2$ ]

$$\therefore \boxed{m_{\text{orb}} = \frac{e v r}{2}} \quad \dots(2)$$

v. The angular momentum of an electron due to its orbital motion is given by,

$$L = m_e v r \quad \dots(3)$$

vi. Multiplying and dividing the R.H.S. of equation (2) by  $m_e$ ,

$$m_{\text{orb}} = \frac{e}{2m_e} \times m_e v r$$

$$\therefore \boxed{m_{\text{orb}} = \frac{eL}{2m_e}} \quad \dots(4)$$

vii. This equation shows that orbital magnetic moment is proportional to the angular momentum. But as the electron bears negative charge, the orbital magnetic moment and orbital angular momentum are in opposite directions and perpendicular to the plane of the orbit.

viii. Using vector notation,  $\vec{m}_{\text{orb}} = - \left( \frac{e}{2m_e} \right) \vec{L}$

#### Q.4 What is gyromagnetic ratio?

Ans :

i. The ratio of magnetic dipole moment with angular momentum of revolving electron is called the gyromagnetic ratio.

ii. Gyromagnetic ratio is given by,  $\frac{m_{\text{orb}}}{L} = \frac{e}{2m_e}$

Its value is  $8.8 \times 10^{10}$  C/kg.

#### Q.5 Derive the quantity for Bohr Magneton

Ans :

i. According to Bohr's theory, an electron in an atom can revolve only in certain stationary orbits in which angular momentum ( $L$ ) of electron is an integral multiple ( $n$ ) of  $\frac{h}{2\pi}$ , where  $h$  is planck's constant.

$$L = m_e v r = \frac{nh}{2\pi} \quad \dots(1)$$

ii. The orbital magnetic momentum of an

$$\text{electron is given as, } m_{\text{orb}} = \frac{eL}{2m_e} \quad \dots(2)$$

iii. Substituting equation (1) and (2), we have,

$$m_{\text{orb}} = n \left( \frac{eh}{4\pi m_e} \right) \quad \dots(3)$$

iv. For the 1<sup>st</sup> orbit,  $n = 1$ ,

$$m_{\text{orb}} = \frac{eh}{4\pi m_e}$$

v. The quantity  $\frac{eh}{4\pi m_e}$  is called Bohr Magneton and its value is  $9.274 \times 10^{-24}$  Am<sup>2</sup>.

vi. The magnetic moment of an atom is stated in terms of Bohr magnetons (B.M.).

#### Type - III

#### Numerical based on magnetic moment of electron

##### Formulae used

$$1. \quad m_{\text{orb}} = \frac{e v r}{2} = \frac{eL}{2m_e}$$

$$2. \quad \text{Gyromagnetic ratio} = \frac{m_{\text{orb}}}{L} = \frac{e}{2m_e}$$

$$3. \quad \text{Bohr magneton} = \frac{eh}{4\pi m_e} \\ = 9.274 \times 10^{-24} \text{ Am}^2.$$

★1) Calculate the gyromagnetic ratio of electron. (Given:  $e = 1.6 \times 10^{-19}$  C,  $m_e = 9.1 \times 10^{-31}$  kg)

Data:  $e = 1.6 \times 10^{-19}$  C,  $m_e = 9.1 \times 10^{-31}$  kg

**To find:** Gyromagnetic ratio

**Formula:** Gyromagnetic ratio =  $\frac{e}{2m_e}$

**Solution :**

$$\text{Gyromagnetic ratio} = \frac{e}{2m_e}$$

$$\begin{aligned} \text{Gyromagnetic ratio} &= \frac{1.6 \times 10^{-19}}{2 \times 9.1 \times 10^{-31}} \\ &= \frac{8 \times 10^{-20}}{9.1 \times 10^{-31}} \\ &= 0.88 \times 10^{-20+31} \\ &= 0.88 \times 10^{-11} \\ &= 8.8 \times 10^{10} \text{ Ckg}^{-1} \end{aligned}$$

**Ans:** Gyromagnetic ratio of electron is  $8.8 \times 10^{10} \text{ Ckg}^{-1}$

★ 2) An electron in an atom is revolving round the nucleus in a circular orbit of radius  $5.3 \times 10^{-11} \text{ m}$ , with a speed of  $2 \times 10^6 \text{ ms}^{-1}$ . Find the resultant orbital magnetic moment and angular momentum of electron. (charge on electron  $e = 1.6 \times 10^{-19} \text{ C}$ , mass of electrons  $m = 9.1 \times 10^{-31} \text{ kg}$ .)

**Data :**  $r = 5.3 \times 10^{-11} \text{ m}$ ,  $v = 2 \times 10^6 \text{ ms}^{-1}$ ,  
 $e = 1.6 \times 10^{-19} \text{ C}$ ,  $m_e = 9.1 \times 10^{-31} \text{ kg}$

**To find:** i.  $m_{\text{orb}}$   
ii.  $L$

**Formula:** i.  $m_{\text{orb}} = \frac{e v r}{2}$     ii.  $L = m v r$

**Solution:**

i.  $m_{\text{orb}} = \frac{e v r}{2}$

$$m_{\text{orb}} = \frac{1.6 \times 10^{-19} \times 2 \times 10^6 \times 5.3 \times 10^{-11}}{2}$$

$$= 8.48 \times 10^{-24} \text{ Am}^2$$

ii.  $L = m v r$

$$L = 9.1 \times 10^{-31} \times 2 \times 10^6 \times 5.3 \times 10^{-11}$$

$$= 96.46 \times 10^{-36}$$

$$L \approx 9.65 \times 10^{-35} \text{ Nms}$$

**Ans:** i. Orbital magnetic moment is  $8.48 \times 10^{-24} \text{ Am}^2$   
ii. Angular momentum of electron is  $9.65 \times 10^{-35} \text{ Nms}$

**Problem for Practice**

1. An electron revolves around the nucleus of an atom in a circular orbit of radius  $4 \text{ \AA}$  with a speed of  $5 \times 10^6 \text{ m/s}$ . What is the angular momentum of the electron?

**Ans:**  $1.8 \times 10^{-33} \text{ kgm}^2/\text{s}$

2. An electron in an atom revolves around the nucleus in an orbit of radius  $0.53 \text{ \AA}$ . Calculate the equivalent magnetic moment, if the frequency of revolution of electron is  $6.8 \times 10^9 \text{ MHz}$  (Given :  $e = 1.6 \times 10^{-19} \text{ C}$ ).

**Ans:**  $9.603 \times 10^{-24} \text{ Am}^2$

3. The electron in hydrogen atom is moving with a speed at  $2.3 \times 10^6 \text{ m/s}$  in an orbit of radius  $0.53 \text{ \AA}$ . Calculate the magnetic moment of the revolving electron.

**Ans :**  $9.753 \times 10^{-24} \text{ Am}^2$

4. What is orbital magnetic moment of electron revolving in innermost orbit of H-atom.

**Ans :**  $0.0927 \times 10^{-22} \text{ Am}^2$

**11.4 Magnetization and Magnetic Intensity**

**Q.6 Define magnetization. State its formula and S.I unit.**

**Ans:**

i. The ratio of magnetic moment to the volume of material is called magnetization.

ii. It is denoted by  $\vec{M}$ .

iii. Magnetization =  $\frac{\text{Net magnetic moment}}{\text{Volume}}$

$$\therefore \vec{M} = \frac{M_{\text{net}}}{\text{volume}}$$

iii. It is a vector quantity.

iv. Unit:  $\text{Am}^{-1}$  in SI system.

v. Dimension:  $[\text{M}^0 \text{L}^{-1} \text{T}^0 \text{I}^1]$

**Note:**

i. **Magnetic permeability :** It is the degree or extent to which magnetic lines of force can enter a substance and is denoted by  $m$ .

a.  $\mu_0 =$  absolute permeability of air or free space =  $4\pi \times 10^{-7} \text{ tesla} \times \text{m} / \text{amp}$ .

b.  $\mu_r =$  Relative permeability of the magnetic material

$$\mu_r = \frac{\mu}{\mu_0}$$

$$m = \mu_0 \mu_r;$$

where  $m =$  permeability of the medium

ii. **Magnetic Intensity (H) :**

i) The strength of magnetic field at a point in terms of vector quantity called as magnetic intensity

ii) Magnetic intensity is given by,

$$H = nI = \frac{B_0}{\mu_0}$$

where,

$$n = \frac{N}{L} \text{ i.e. no. of turns / unit length}$$

It is a vector quantity

iii) S.I. unit : A / m

$$\text{Dimensions : } [M] = [M^0 L^{-1} T^0 I^1]$$

**C) Magnetic susceptibility ( $\chi$ ) :**

i. Magnetic Susceptibility ( $\chi$ ) is the indicator of measure of the response of a given material to the external applied magnetic field.

ii. In other words it indicates as to how much magnetization will be produced in a given substance when kept in an external magnetic field.

iii. Again it is analogous to electrical susceptibility. This means when the substance is kept in a magnetic field, the atomic dipole moments either align or oppose the external magnetic field.

iv. If the atomic dipole moments of the substance are opposing the field,  $\chi$  is observed to be negative, and if the atomic dipole moments align themselves in the direction of field,  $\chi$  is observed to be positive.

v. The number of atomic dipole moments of getting aligned in the direction of the applied magnetic field is proportional to  $\chi$ . It is large for soft iron ( $\chi > 1000$ ).

**Q.7 Obtain the relation between magnetic field intensity (H) and magnetization (M) for a magnetic material placed in a magnetizing field.**

**Ans:**

i. Consider current carrying solenoid of turns density  $n$ . Let us consider a magnetic material placed inside magnetising field produced by solenoid

ii. The magnetic field inside the solenoid is given by,

$$B_0 = \mu_0 nI \quad \dots(1)$$

iii. The magnetic field inside the rod is given as

$$\therefore B_M = \mu_0 M \quad \dots (2)$$

Where  $M =$  magnetization of the material

iv. The net magnetic field inside the rod is expressed as,

$$B = B_0 + B_M \quad \dots (3)$$

$$\therefore B = \mu_0 nI + \mu_0 M$$

$$\therefore B = \mu_0 H + \mu_0 M$$

Where  $H = nI =$  Magnetic field intensity

$$B = \mu_0 (H + M)$$

$$\boxed{H = \frac{B}{\mu_0} - M}$$

This is required relation

**Q.8 Obtain the relation between permeability and susceptibility of a substance.**

**Ans:**

i. We know that ,

The net magnetic field inside the rod is expressed as,

$$B = B_0 + B_M$$

$$\therefore B = \mu_0 nI + \mu_0 M$$

$$\therefore B = \mu_0 H + \mu_0 cH (\because M = \chi H)$$

$$\therefore B = \mu_0 H (1 + c) \dots(1)$$

ii. Now,  $B = mH$

$$\therefore mH = \mu_0 H (1 + c)$$

$$\therefore \frac{\mu}{\mu_0} = 1 + \chi$$

$$\therefore \boxed{\mu_r = 1 + \chi}$$

where  $\mu_r =$  Relative permeability of the magnetic material

**Type - IV**

**Numerical based on material magnetism**

**Formulae used**

1.  $\phi = BA$
2.  $M = \frac{m_{\text{net}}}{v}$
3.  $B = \mu H$
4.  $\mu_r = \frac{\mu}{\mu_0}$
5.  $\mu_r = \chi + 1$
6.  $M = \chi H$
7.  $B = \mu_0 (M + H)$

- ★ 1) A rod of magnetic material of cross section  $0.25 \text{ cm}^2$  is located in  $4000 \text{ Am}^{-1}$  magnetising field. Magnetic flux passing through the rod is  $25 \times 10^{-6} \text{ Wb}$ . Find out
- i. relative permeability
  - ii. magnetic susceptibility and
  - iii. magnetisation of the rod

**Data:**  $A = 0.25 \text{ cm}^2 = 0.25 \times 10^{-4} \text{ m}^2$ ,  
 $= 25 \times 10^{-6} \text{ m}^2$ ,  
 $\phi_B = 25 \times 10^{-6} \text{ Wb}$ ,  $H = 4000 \text{ Am}^{-1}$ ,

- To find:** i.  $\mu$   
 ii.  $\chi$   
 iii.  $M$

**Formula:** i.  $\phi = BA$     ii.  $B = \mu H$   
 iii.  $\mu_r = \frac{\mu}{\mu_0}$     iv.  $\mu_r = \chi + 1$   
 v.  $M = \chi H$

**Solution :**

i.  $\phi = BA$   
 $25 \times 10^{-6} = B \times 25 \times 10^{-6}$   
 $B = \frac{25 \times 10^{-6}}{25 \times 10^{-6}} = 1 \text{ T}$

ii.  $B = \mu H$   
 $1 = \mu \times 4000$   
 $\mu = 2.5 \times 10^{-4}$

iii.  $\mu_r = \frac{\mu}{\mu_0}$

$$\mu_r = \frac{2.5 \times 10^{-4}}{4 \times 3.142 \times 10^{-7}}$$

$$\mu_r = 1.99 \times 10^{-1} \times 10^3 = 199$$

iv.  $\mu_r = \chi + 1$   
 $199 = \chi + 1$   
 $\chi = 198$

v.  $M = \chi H$   
 $M = 198 \times 4000$   
 $M = 7.92 \times 10^5 \text{ Am}^{-1}$

**Ans :** i. Relative permeability of the material is 199.  
 ii. Magnetic susceptibility of the material is 198.  
 iii. Magnetisation of the rod is  $7.92 \times 10^5 \text{ Am}^{-1}$

- ★ 2) When a piece of magnetic material of size  $10 \text{ cm} \times 0.5 \text{ cm} \times 0.2 \text{ cm}$  (length, breadth and thickness respectively) is located in magnetising field of  $0.5 \times 10^4 \text{ Am}^{-1}$  then a magnetic moment of  $5 \text{ Am}^2$  is induced in it. Find out magnetic induction in rod.

**Data**  $l = 10 \text{ cm} = 10^{-1} \text{ m}$ ,  
 $b = 0.5 \text{ cm} = 5 \times 10^{-3} \text{ m}$ ,  
 $h = 0.2 \text{ cm} = 2 \times 10^{-3} \text{ m}$ ,  
 $H = 0.5 \times 10^4 \text{ Am}^{-1} = 5 \times 10^3 \text{ Am}^{-1}$ ,  
 $m_{\text{net}} = 5 \text{ Am}^2$

**To Find:**  $B$

**Formula:** i.  $M = \frac{m_{\text{net}}}{v}$   
 ii.  $B = \mu_0 (M + H)$

**Solution:**

i.  $M = \frac{m_{\text{net}}}{v}$      $M = \frac{5}{10^{-1} \times 5 \times 10^{-3} \times 2 \times 10^{-3}}$   
 $= 5 \times 10^6 \text{ Am}^{-1}$

ii.  $B = \mu_0 (M + H)$   
 $B = 4 \times 3.142 \times 10^{-7} [5 \times 10^6 + 5 \times 10^3]$   
 $= 12.568 \times 10^{-7} \times 5 \times 10^3 [10^3 + 1]$   
 $= 6.284 \times 10^{-3} \times 1001 = 6.29 \text{ T}$

**Ans :** Magnetic induction in the rod is  $6.29 \text{ T}$ .

- 3) The region inside a current carrying toroid winding is filled with Aluminium having susceptibility  $\chi = 2.3 \times 10^{-5}$ . What is the percentage increase in the magnetic field in the presence of

**Aluminium over that without it?**

**Solution:**

The magnetic field inside the solenoid without Aluminium  $B_0$  is given as,  $\mu_0 H$ .

The magnetic field inside the solenoid with Aluminium  $B$  is given as,  $\mu H$ .

Relative change in magnetic field,

$$\frac{B - B_0}{B_0} = \frac{\mu H - \mu_0 H}{\mu_0 H} = \frac{\mu - \mu_0}{\mu_0} \quad \dots(i)$$

$$\therefore \mu = \mu_0(1 + \chi)$$

$$\therefore \frac{\mu}{\mu_0} - 1 = \chi$$

$$\frac{\mu - \mu_0}{\mu_0} = \chi \quad \dots(ii)$$

From (i) and (ii),

$$\frac{B - B_0}{B_0} = \chi$$

Percentage increase in the magnetic field after inserting Aluminium is

$$\begin{aligned} \frac{B - B_0}{B_0} \times 100 \\ = 2.3 \times 10^{-5} \times 100 = 0.0023\% \end{aligned}$$

**Ans:** Percentage change in magnetic field is 0.0023%

**+4) A domain in ferromagnetic iron is in the form of cube of side 1  $\mu\text{m}$ . Estimate the number of iron atoms in the domain, maximum possible dipole moment and magnetisation of the domain. The molecular mass of iron is 55 g/mole and density is 7.9 g/cm<sup>3</sup>. Assume that each iron atom has a dipole moment of  $9.27 \times 10^{-24}$  Am<sup>-2</sup>.**

**Data:** Side of cube,  $a = 1 \mu\text{m}$ ,  
Molecular mass = 55 g/mol,  
 $\rho_{\text{iron}} = 7.9 \text{ gcm}^{-3}$ ,  
 $m_{\text{iron}} = 9.27 \times 10^{-24} \text{ Am}^2$ ,

**To find:** i. Number of iron atoms in the domain  
ii. Maximum dipole moment  
iii. Magnetisation of domain

**Formula:** i.  $V = a^3$   
ii.  $\text{mass} = \rho V$   
iii.  $m_{\text{net}} = N \times m_{\text{iron}}$

$$\text{iv. } M = \frac{m_{\text{net}}}{\text{domain volume}}$$

**Solution:**

$$\text{i. } V = a^3$$

$$V = (10^{-6})^3 \text{ m}^3 = 10^{-18} \text{ m}^3$$

$$\text{ii. } \text{mass} = \rho V$$

$$\text{mass} = 7.9 \times 10^{-12} = 7.9 \times 10^{-12} \text{ g}$$

Number of atoms in the domain,

$$N = n \times N_A \text{ (where } n = \text{number of mole)}$$

Substituting for  $n$ ,

$$N = \frac{\text{mass}}{\text{Molecular mass}} \times N_A$$

$$= \frac{7.9 \times 10^{-12}}{55} \times 6.023 \times 10^{23}$$

$$= \frac{7.9 \times 6.023 \times 10^{11}}{55}$$

$$N = 8.650 \times 10^{-1} \times 10^{11} = 8.65 \times 10^{10}$$

iii. The maximum possible dipole moment  $m_{\text{max}}$  is achieved for the case when all the atomic moments are perfectly aligned.

$$\text{iii. } m_{\text{max}} = N \times m_{\text{iron}}$$

$$m_{\text{max}} = 8.65 \times 10^{10} \times 9.27 \times 10^{-24}$$

$$m_{\text{max}} = 8.02 \times 10^{-13} \text{ Am}^2$$

$$\text{iv. } M = \frac{m_{\text{max}}}{\text{domain volume}}$$

$$M = \frac{8.02 \times 10^{-13}}{10^{-18}} = 8.02 \times 10^5 \text{ Am}^{-1}$$

$$M = 8.02 \times 10^5 \text{ Am}^{-1}$$

**Ans:** i. The number of iron atoms in the domain is

$$8.65 \times 10^{10}$$

ii. The maximum dipole moment is  $8.02 \times 10^{-13} \text{ Am}^2$

iii. Magnetisation is  $8.02 \times 10^5 \text{ Am}^{-1}$

**Problem for Practice**

1. The space within a current carrying toroid is filled with tungsten of susceptibility is  $6.8 \times 10^{-5}$ . What is the percent increase in the magnetic field  $B$ ?

**Ans: 0.0068%**

2. Find the magnetization of a bar magnet of length 5 cm and cross-sectional area 2 cm<sup>2</sup>, if the

magnetic moment is  $1 \text{ Am}^2$ . [Oct.2014]

**Ans:  $1 \times 10^5 \text{ A/m}$**

3. An electron in an atom revolves around the nucleus in an orbit of radius  $0.5 \text{ \AA}$ . Calculate the equivalent magnetic moment, if the frequency of revolution of electron is  $10^{10} \text{ MHz}$ .

**Ans:  $1.257 \times 10^{-23} \text{ Am}^2$**

4. Find the percent increase in the magnetic field  $B$  when the space within a current-carrying toroid is filled with aluminum. The susceptibility of aluminum is  $2.1 \times 10^{-5}$ .

**Ans:  $2.1 \times 10^{-3}$**

5. A bar magnet made of steel has magnetic moment of  $2.5 \text{ Am}^2$  and a mass of  $6.6 \times 10^3 \text{ kg}$ . If the density of steel is  $7.9 \times 10^3 \text{ kg/m}^3$ , find the intensity of magnetization of the magnet.

**Ans:  $2.992 \times 10^6 \text{ A/m}$**

6. The susceptibility of annealed iron at saturation is 5500. Find the permeability of annealed iron at saturation. [Oct. 2013]

**Ans:  $6.914 \times 10^{-3} \text{ T} \cdot \text{m/A}$**

7. The susceptibility of magnesium at  $300 \text{ K}$  is  $1.2 \times 10^{-5}$ . At what temperature will the susceptibility increase to  $1.8 \times 10^{-5}$ ? [Feb.2014]

**Ans:  $200 \text{ K}$**

### 11.5 Magnetic properties of material

- Q.9 What are diamagnetic, substances ? State their properties.**

**Ans : Diamagnetic substances :**

The substances which are weakly repelled by the magnetic field are called diamagnetic substances.

**Properties of diamagnetic substances :**

- If a thin and long rod made up of diamagnetic is freely suspended in external uniform magnetic field., it comes to rest with its length perpendicular to the direction of the field.
- Diamagnetic substance when placed in external non-uniform magnetic field, it tend to move from stronger part of the field to the weaker part of the field.
- Diamagnetic substance lose their magnetism

on removal of external magnetic field.

- When a solution of a diamagnetic substance is taken in a watch glass and is kept in between two dissimilar poles of the magnet, there is a small depression at the middle.
- When a diamagnetic liquid is taken in a U-shaped glass tube and one of its arms is held in between two dissimilar poles of a magnet, liquid level in that arm is lowered.
- When a diamagnetic gas is passed through two poles of a magnet, it spreads at right angles to the magnetic field.
- Silver, lead, silicon, nitrogen, sodium chloride, bismuth, copper, antimony, gold, mercury, water, air, hydrogen are the examples of the diamagnetic substances.
- Their susceptibility is small and negative.
- Their susceptibility is independent of temperature.
- Their permeability is less than one.
- In these substances the magnetic lines of force are farther than air.

**Q.10 Explain the origin of paramagnetism.**

**Origin of paramagnetism :**

- For paramagnetic substances, the magnetic dipole moment of the electrons in an atom do not cancel each other. Therefore, each atom has a resultant magnetic moment.
- Each atom in a paramagnetic substance acts as a small magnetic dipole, called 'atomic magnet'.
- In the absence of a magnetic field, atomic magnets are randomly oriented ; therefore, paramagnetic substances have zero resultant magnetic moment.
- In an external magnetic field, atomic magnets tend to align parallel to the applied field and show temporary magnetization.  
Hence, the paramagnetic substances get magnetized in the external field.
- When the external magnetic field is removed, the paramagnetic substance loses its magnetism.

**Q.11 What are paramagnetic substances. State its properties.**

**Ans: Paramagnetic substances :**

The substances which are weakly attracted by the magnetic field are called paramagnetic substances.

**Properties of paramagnetic substances :**

- i. substance kept in a uniform magnetic field comes to rest with its length parallel to the direction of the magnetic field.
- ii. When a rod of a paramagnetic substance is suspended in a non-uniform magnetic field, it moves from the weaker part to the stronger part of the field.
- iii. In the absence of external magnetic field, the dipole moments of the atoms are randomly oriented and hence the net dipole moment of the paramagnetic substance is zero.
- iv. When paramagnetic substance is kept in an external magnetic field, the tiny atomic magnets tend to align its axis parallel to the applied field and show magnetic effects. As soon as the external field is removed, the atomic magnets again get randomly oriented and the substance loses its magnetism.
- v. Para magnetic materials can not be used to make permanent magnets because they losses magnetism on removal of external magnetic field.
- vi. When the solutions of the paramagnetic substances are taken in a watch glass and kept between two dissimilar poles of the magnet, there is a small rise at the middle.
- vii. If a paramagnetic liquid is taken in a U- shaped tube and one of its arms is held in between two dissimilar poles, there is a rise in liquid level of that arm.
- viii. If the paramagnetic gas is passed through two poles of a magnet, it spreads in a direction of magnetic field.
- ix. Aluminium, manganese, chromium, platinum, oxygen, sodium, calcium, lithium, copper chloride, tungsten, niobium etc; are the examples of the paramagnetic substances.
- x. Their susceptibility is small and positive.

- xi. Their susceptibility is inversely proportional to the absolute temperature i.e.  $1/T$ .
- xii. Their permeability is slightly greater than 1.
- xiii. At above curie temperature, paramagnetic substances changes to diamagnetic substances.
- xiv. In these substances the magnetic lines of force are closer than in air.

**Q.12 What are ferromagnetic substances. State its properties.**

**Ans: Ferromagnetic substances :**

The substances which are strongly attracted by a magnet are called ferromagnetic substances.

**Properties of ferromagnetic substances :**

- i. These materials when placed in an external uniform magnetic field, get strongly magnetized in the direction of the external magnetic field.
- ii. These materials when placed in an external non uniform magnetic field, tend to move from the weaker part to the stronger part of the field.
- iii. All the atoms of the ferromagnetic materials have a resultant magnetic moment even in the absence of external magnetic field.
- iv. When a thin rod of a ferromagnetic substance is kept between two conical pole pieces of an electromagnet, it comes to rest with its axis parallel to the magnetic induction between the two poles.
- v. Iron, nickel, cobalt, gadolinium, dysprosium and their alloys etc., are the elemental ferromagnetic substances
- vi. When the external field is removed, it does not loose magnetism completely.
- vii. At curie temperature the ferromagnetic substance is converted into a paramagnetic substance.
- viii. Their susceptibility is very large and positive.
- ix. Their permeability is very greater than 1

**Q.13 What are magnetic domains? Explain ferromagnetism on the basis of domain theory.**

**Ans: Magnetic domains :** A small region in which

all atomic magnetic moments are aligned in the same direction is called a domain. Each domain has a resultant magnetic dipole moment.

**Explanation of ferromagnetism :**

- i. According to Domain theory,
  - a. A ferromagnetic material consists of number of small regions, called domains.
  - b. All the atomic magnets have the same magnetic dipole moment direction so that the domain has a resultant magnetic dipole moment.
- ii. In the absence of an external magnetic field, the domains are randomly oriented. Therefore, the substance has zero resultant magnetic dipole moment. [Fig. (a) ]
- iii. In a weak external magnetic field, the domains having magnetic moment in the direction of external field begin to grow in size. There is a shift of the boundaries between the domains, and the substance gets magnetized. When the external field is removed, the boundaries return to their original positions and the material loses its magnetism. [ Fig. (b) ]
- iv. In a strong magnetic field the domains rotate in the direction of the applied field and the substance gets strongly magnetized. When the external magnetic field is removed, the domains and their magnetic moments do not return to their original position. [ Fig. (c) ]

**Q.14 Explain Curie law of magnetization for paramagnetic sample.**

**Ans:** According to Curie, the magnetization of a paramagnetic sample is

- a. directly proportional to the external magnetic field i.e.  $M_z \propto B$
- b. inversely proportional to the absolute temperature

$$\therefore M \propto \frac{1}{T}$$

$$\therefore M \propto \frac{B}{T}$$

$$\therefore M = C \times \frac{B}{T}$$

This equation is known as Curie law.

where, C - called Curie's constant.

$$M = C \frac{B}{T}$$

$$B = \mu_0 H$$

Substituting in Curie's law

$$M = C \frac{\mu_0 H}{T}$$

$$\frac{M}{H} = \chi = C \frac{\mu_0}{T}$$

$$\chi = \mu_r - 1 = C \frac{\mu_0}{T}$$

$$\chi \propto \frac{1}{T}$$

Thus when we increase the applied magnetic field and reduce the temperature, more number of magnetic moments align themselves in the direction of magnetic field resulting in increase in magnetization.

**Q.15 What is Curie temperature ? What happens above Curie temperature ?**

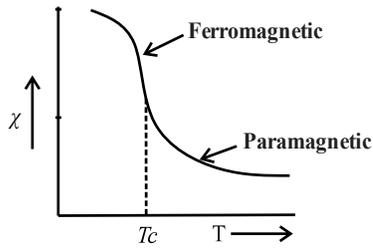
**Ans:**

- i. When a ferromagnetic substance is heated at a certain temperature, the domain structure breaks completely and each domain loses its large magnetic moment.
- ii. The temperature at which the domain structure gets destroyed is called the Curie temperature.
- iii. Curie temperature is different for different substances. e.g. For Cobalt = 1394 K, For Iron = 1043K, For Nickel = 631K, For Gadolinium = 317 K, For  $Fe_2O_3$  = 893 K,
- iv. If the substance is heated above the Curie temperature, the ferromagnetic substance is converted into the paramagnetic substance, since the force of interaction between the atomic magnets responsible for ferromagnetism disappears.

The relation between the magnetic susceptibility of a material when it has acquired paramagnetic property and the temperature T is given by

$$\chi = \frac{C}{T - T_c} \text{ for } T > T_c$$

where C is a constant.



Curie Temperature  $T_c$  of some Ferromagnetic material.

**Type - V**

**Numerical based on curie Temperature**

- 1) **The susceptibility of a paramagnetic material is  $\chi$  at  $27^\circ\text{C}$ . At what temperature its susceptibility be  $\frac{\chi}{3}$ .**

**Data:**  $T_1 = 27^\circ\text{C} = 27 + 273 = 300\text{k}$   
 $\chi_1 = \chi$

$$\chi_2 = \frac{\chi}{3}$$

**To find:** Temperature ( $T_2$ )

**Formula:**  $\chi = \frac{C\mu_0}{T}$

**Solution:**  $\chi_1 = \frac{C\mu_0}{T_1} \dots(1)$

$$\chi_2 = \frac{C\mu_0}{T_2} \dots(2)$$

Dividing (1) by (2) we get

$$\frac{\chi_1}{\chi_2} = \frac{T_2}{T_1}$$

$$\frac{\chi}{\chi/3} = \frac{T_2}{300}$$

$$T_2 = 3 \times 300 = 900\text{ K}$$

$$= 900 - 273 = 627^\circ\text{C}$$

**Ans:** The temperature at which its susceptibility will be  $\frac{\chi}{3}$  is  $627^\circ\text{C}$

**MULTIPLE CHOICE QUESTIONS**

**Entrance Corner (Set 3)**

- Which of the following is most suitable for the core of electromagnets
  - Soft iron
  - Steel
  - Copper-nickel alloy
  - Air
- If a diamagnetic substance is brought near north or south pole of a bar magnet, it is
  - Attracted by the poles
  - Repelled by the poles
  - Repelled by the north pole and attracted by the south pole
  - Attracted by the north pole and repelled by the south pole
- The material of permanent magnet has
  - High retentivity, low coercivity
  - Low retentivity, high coercivity
  - Low retentivity, low coercivity
  - High retentivity, high coercivity
- Temperature above which a ferromagnetic substance becomes paramagnetic is called
  - Critical temperature
  - Boyle's temperature
  - Debye's temperature
  - Curie temperature
- Magnetic permeability is maximum for
  - Diamagnetic substance
  - Paramagnetic substance
  - Ferromagnetic substance
  - All of these
- The magnetic susceptibility does not depend upon the temperature in
  - Ferrite substances
  - Ferromagnetic substances
  - Diamagnetic substances
  - Paramagnetic substances
- A diamagnetic material in a magnetic field moves
  - From weaker to the stronger parts of the field
  - Perpendicular to the field
  - From stronger to the weaker parts of the field

- d. In none of the above directions
8. If a magnetic substance is kept in a magnetic field, then which of the following is thrown out
- Paramagnetic
  - Ferromagnetic
  - Diamagnetic
  - Antiferromagnetic
9. The magnetic susceptibility is negative for
- Paramagnetic materials
  - Diamagnetic materials
  - Ferromagnetic materials
  - Paramagnetic and ferromagnetic materials
10. Which of the following statements is incorrect about hysteresis
- This effect is common to all ferromagnetic substances
  - The hysteresis loop area is proportional to the thermal energy developed per unit volume of the material
  - The hysteresis loop area is independent of the thermal energy developed per unit volume of the material
  - The shape of the hysteresis loop is characteristic of the material
11. A superconductor exhibits perfect
- Ferrimagnetism
  - Ferromagnetism
  - Paramagnetism
  - Diamagnetism
12. Curie temperature is the temperature above which
- A paramagnetic material becomes ferromagnetic
  - A ferromagnetic material becomes paramagnetic
  - A paramagnetic material becomes diamagnetic
  - A ferromagnetic material becomes diamagnetic
13. A frog can be levitated in a magnetic field produced by a current in a vertical solenoid

placed below the frog. This is possible because the body of the frog behaves as

- Paramagnetic
- Diamagnetic
- Ferromagnetic
- Antiferromagnetic

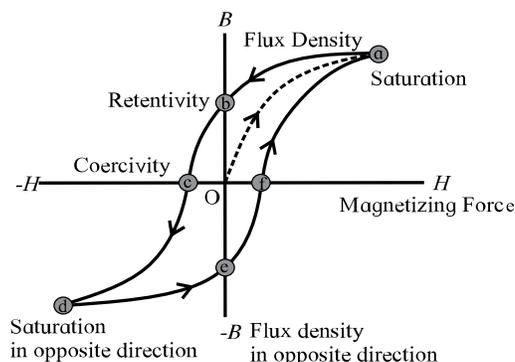
14. When a piece of a ferromagnetic substance is put in a uniform magnetic field, the flux density inside it is four times the flux density away from the piece. The magnetic permeability of the material is
- 1
  - 2
  - 3
  - 4

### 11.6 Hysteresis

**Q.16 Explain the behaviour of a ferromagnetic material in an external magnetic field with the help of hysteresis graph.**

**Ans:**

- The behaviour of ferromagnetic material when placed in external magnetic field is nonlinear and provides information of magnetic history of the sample.
- let us consider an unmagnetized ferromagnetic material in the form of a rod placed inside a solenoid. On passing the current through solenoid, magnetic field is generated which magnetises the rod.



**Hysteresis cycle (loop).**

- At point O in the graph the material is in non-magnetised state. As the strength of external magnetic intensity  $H$  is increased,  $B$  also increases as shown by the dotted line. But the increase is non-linearly.
- At point a:** Near point a, the magnetic field

is at its maximum value which is the saturation magnetization condition of the rod. This represents the complete alignment and merger of the domains. If  $H$  is increased further, (by increasing the current flowing through the solenoid) there is no increase in  $B$ .

v. **Point b:**

At point a, if the current in the solenoid is reduced, the earlier path of the graph is not retraced. When  $H = 0$  (current through the solenoid is made zero, point b in the figure) we do not get  $B = 0$ . The value of  $B$  when  $H = 0$  is called **retentivity or remanence**. This means some domain alignment is still retained even when  $H = 0$ .

vi. **Point c:**

Next, when the current in the solenoid is increased in the reverse direction, point c in the graph is reached, where  $B = 0$  at a certain value of  $H$ . This value of  $H$  is called **coercivity**.

vii. **Point d:** If the current is further increased, in the reverse direction,  $B$  increases and again reaches a saturation state (point d). Here if  $H$  is increased further,  $B$  does not increase.

viii. **Point e:** From this point d onwards, when  $H$  is reduced,  $B$  also reduces along the path de. At this point e, again  $H = 0$  but  $B$  is not zero. It means domain structure is present but the direction of magnetisation is reversed.

ix. **Again point a:** Further increase in the current, gives the curve efa. On reaching point a, one loop is complete. This loop is called hysteresis loop and the process of taking magnetic material through the loop once is called hysteresis cycle

**Q.17 What does the hysteresis graph represent?**

**Ans:** The hysteresis curve represents the relation between magnetic induction ( $\vec{B}$ ) of a ferromagnetic material and magnetic intensity ( $H$ )

**Q.18 What should be retentivity and coercivity of permanent magnet?**

**Ans:**

i. A permanent magnet should have high

retentivity in order to retain the magnetization to a larger extent. i.e., remain magnetized in the absence of magnetising field.

ii. A permanent magnet should have high coercivity so as to not get demagnetised easily.

**11.7 Permanent magnet and Electromagnet**

**Q.19 Which property of soft iron makes it used for preparing electromagnet?**

**Ans:**

i. Soft iron has large value of permeability ( $>1000$ )

ii. Soft iron has small amount of retaining magnetization. Hence, it is said to have high susceptibility but low retentivity.

iii. These properties of soft iron make it useful for preparing electromagnet.

**Q.20 Explain one application of electromagnet.**

**Ans:** Electromagnets are used in transformers which are electrical devices which convert low alternating voltage at high current to high alternating voltage at low current and vice versa.

**Explanation:** For detailed explanation of the transformer, students.

**11.8 Magnetic Shielding**

**Q.21 What is magnetic shielding. State its uses**

**Ans:**

i. When a soft ferromagnetic material is kept in a uniform magnetic field, large number of magnetic lines crowd up inside the material leaving a few outside.

ii. For a closed spherical shell of iron kept in magnetic field, very few lines of force pass through the enclosed space. Most of the lines will be crowded into the iron shell. This effect is known as magnetic shielding.

iv. The instrument which needs to be protected from magnetic field is completely surrounded by a soft ferromagnetic substance.

**Uses:**

i. This technique is being used in space ships.

ii. Some scientific experiments require the experiment to be protected from magnetic field in the laboratory.

**AnswerKey**
**Set - 1 ( MCQ)**

1	b	2	a	3	b	4	a	5	d
6	c	7	d	8	a	9	a	10	a
11	d	12	c	13	d	14	a	15	a

**Set - 2 ( MCQ)**

1	b	2	b	3	c	4	c	5	a
---	---	---	---	---	---	---	---	---	---

**Try Yourself**

6	c	7	c	8	a	9	a	10	c
---	---	---	---	---	---	---	---	----	---

**Set - 3 ( MCQ)**

1	a	2	b	3	d	4	d	5	c
6	c	7	c	8	c	9	b	10	c
11	d	12	b	13	b	14	d		

**Board Questions :**

1. Explain ferromagnetism on the basis of domain theory. (Oct. 2008, Oct. 2011) (3)
2. Define magnetization. State its formula and S.I.unit. (March 2013) (2)
3. What is - (a) Magnetization and (b) Magnetic intensity? (Oct. 2013, Feb. 2015) (2)
4. Show that the orbital magnetic dipole moment of a revolving electron is  $\frac{eVr}{2}$  (Feb. 2014) (2)
5. Give any 'two' points of differences between diamagnetic and ferromagnetic substances. (Oct. 2015) (2)
6. Distinguish between 'paramagnetic' and 'ferromagnetic' substances.(Feb. 2016) (2)
7. Draw the diagrams showing the dipole moments in paramagnetic substance when external magnetic field is (a) absent (b) Strong.(July 2016) (2)
8. Distinguish between diamagnetic and paramagnetic substances. (July 2017) (2)
9. Define magnetization. Write its SI unit and

dimensions.(March 2018 ) (2)

10. What happens to a ferromagnetic substance heated above Curle temprature? (March 2019) (1)

**Problems:**

1. A circular coil of 250 turns and diameter 18 cm carries a current of 12A. What is the magnitude of magnetic moment associated with the coil?(March 2013) (2)
2. The magnetic susceptibility of annealed iron at saturation is 4224. Find the permeability of annealed iron at saturation. ( $\mu_0 = 4\pi \times 10^{-7}$  S.I.unit ) (2)
3. The susceptibility of magnesium at 300 K is  $2.4 \times 10^{-5}$ . At what temperature will the susceptibility increase to  $3.6 \times 10^{-5}$ ? (Feb. 2014) (2)
4. The magnetic moment of a magnet of dimensions 5 cm  $\times$  2.5 cm  $\times$  1.25cm is 3 Am<sup>2</sup>. Calculate the intensity of magnetization. (Oct. 2014) (2)
5. A circular coil of 300 turns and average area  $5 \times 10^{-3}$  m<sup>2</sup> carries a current of 15 A. Calculate the magnitude of magnetic moment associated with the coil. (Feb. 2015) (2)
6. An iron rod of area of cross-section 0.1 m<sup>2</sup> is subjected to a magnetising field of 1000 A/m. Calculate the magnetic permeability. of the iron rod. [Magnetic susceptibility of iron = 59.9, magnetic permeability of vacuum =  $4\pi \times 10^{-7}$  S.I. Unit.](Oct. 2015) (2)
7. The susceptibility of magnesius at 200 K is  $1.8 \times 10^{-5}$ . At what temperature will the susceptibility decrease by  $6 \times 10^{-6}$ ? (Feb. 2016) (2)
8. The susceptibility of magnesium at 300 K is  $1.2 \times 10^{-5}$ . At what temperature will the susceptibility increase to  $1.8 \times 10^{-5}$ ? (July 2016) (2)
9. Find the magnetization of a bar magnet of length 10 cm abd cross- sectional area 4 cm<sup>2</sup>,

if the magnetic moment is  $2 \text{ Am}^2$ . (July 2017)  
(2)

10. The susceptibility of magnesium at 300 K is  $1.2 \times 10^{-5}$ . What will be its susceptibility at 200 K?(March 2019) (2)



**Set 1 :**

1. **Solution (b)**

$$\tau = MB_H \sin\theta \Rightarrow 0.032 = M \times 0.16 \times \sin 30^\circ$$

$$\Rightarrow M = 0.4 \text{ J/tesla}$$

2. **Solution (a)**

$$\tau = MB \sin \theta \Rightarrow \tau = (mL) B \sin \theta$$

$$\Rightarrow 25 \times 10^{-6}$$

$$= (m \times 5 \times 10^{-2}) \times 5 \times 10^{-2} \times \sin 30$$

$$\Rightarrow m = 2 \times 10^{-2} \text{ A-m} \cdot$$

3. **Solution (b)**

$$W = MB(1 - \cos\theta)$$

$$= 2 \times 0.1 \times (1 - \cos 90^\circ) = 0.2 \text{ J}$$

4. **Solution (a)**

Torque on a bar magnet in earth's magnetic field ( $B_H$ ) is  $\tau = MB_H \sin\theta$ .  $\tau$  will be maximum if  $\sin \theta = \text{maximum}$  i.e.  $\theta = 90^\circ$ . Hence axis of the magnet is perpendicular to the field of earth.

5. **Solution (d)**

$$\tau = MB \sin \theta, M = mx2l \text{ (d)}$$

Given:  $m = 1.5 \text{ J/T}$   
 $B = 0.22 \text{ T}$

$$w = -mB (\cos \theta_2 - \cos \theta_1)$$

$$\theta_1 = 0^\circ \text{ (along the field)}$$

$$\theta_2 = 90^\circ \text{ (Perpendicular to the field)}$$

$$w = -0.33(0 - 1) \text{ J} = 0.33 \text{ J}$$

$$\theta_1 = 0^\circ, \theta_2 = 180^\circ$$

$$w = -0.15 \times 0.22 (\cos 180^\circ - \cos 0^\circ)$$

$$w = 0.66 \text{ J}$$

$$\therefore \text{Torque} = mB \sin \theta$$

$$\theta = 90^\circ$$

$$\Rightarrow \tau = 0.33 \text{ Nm}$$

$$\tau = mB \sin 180^\circ$$

$$= 0 \text{ Nm.}$$

6. **Solution. (c)**

$$l = 0.2$$

$$B = 15 \text{ T}$$

$$p = 50 \text{ m}$$

$$z = 7.5 \text{ Nm}$$

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

$$= IP$$

$$z = m B \sin \theta$$

$$7.5 = 0.2 \times 5 \times 15 \times \sin \theta$$

$$\sin \theta = \frac{1}{2}$$

$$\theta = \frac{\pi}{6}$$

**7. Solution (d)**

The torque on a magnetic dipole placed in a uniform magnetic field  $\vec{M} \times \vec{B}$

$$\Rightarrow \vec{\tau} = \vec{M} \times \vec{B}$$

$$|\vec{\tau}| = MB \sin \theta$$

$$\theta = 90^\circ,$$

The couple to be half the maximum value

$$\text{i.e. } \frac{1}{2} MB$$

$$\Rightarrow MB \sin \theta = \frac{1}{2} MB$$

$$\sin \theta = \frac{1}{2}$$

$$\Rightarrow \theta = 30^\circ$$

**8. Solution (a)**

$$M = 2 \text{ Am}$$

$$B = \mu_0 M$$

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

$$= 4\pi \times 10^{-6} \text{ wb/m}^2$$

$$\tau = MB \sin \theta$$

$$8 \times 10^{-8} = M \times 4\pi \times 10^{-6} \times \frac{1}{2}$$

$$160 \times 10^{-8} = M \times 4\pi \times 10^{-6}$$

$$m = \frac{160 \times 10^{-8}}{4\pi \times 10^{-6}} = \frac{4}{\pi} \text{ Am}^2$$

$$m \times \ell = \frac{4}{\pi}$$

$$\ell = \frac{4}{2\pi} = \frac{2}{\pi} \text{ m}$$

**9. Solution (a)**

$$\text{K.E} = \text{P.E} = MB$$

$$c(\alpha - \theta) = MB \sin \theta$$

$$c(180^\circ - 45^\circ) = M_1 B \sin 45^\circ \quad \dots(1)$$

$$c(180^\circ - 30^\circ) = M_2 B \sin 30^\circ \quad \dots(1)$$

$$\Rightarrow \frac{135}{150} = \frac{M_1}{M_2} \frac{\frac{1}{\sqrt{2}}}{\frac{1}{2}}$$

$$\Rightarrow \frac{9}{10} = \frac{M_1}{M_2} \sqrt{2}$$

$$\Rightarrow \frac{M_1}{M_2} = \frac{9}{10\sqrt{2}}$$

**10. Solution (a)**

$$C = MB \sin \theta$$

$$m = 4 \text{ Am}$$

$$\ell = 0.1 \text{ m}$$

$$\theta = 45^\circ$$

$$B = 4 \text{ web/m}^2$$

$$\tau = MB \sin \theta$$

$$\tau = (m \ell) \times B \sin \theta$$

$$\tau = 4 \times 0.1 \times 4 \times \sin 45^\circ$$

$$\tau = 1.13 \text{ Nm}$$

**11. Solution (d)**

$$C = m(2\ell)B \sin \theta$$

$$\text{Torque on the magnet} = MB$$

$$m \ell B \sin \theta = \frac{\sqrt{2}}{10} \text{ Nm}$$

$$\Rightarrow m \times 0.1 \times 0.4 \times \sin 45^\circ = \frac{\sqrt{2}}{10}$$

$$\therefore m = 5 \text{ cm}$$

**12. Solution (c)**

$$C = MB \sin \theta$$

$$\tau = 2.5 \times 10^{-6} \text{ N}$$

$$B = 5 \times 10^{-5} \text{ T}$$

$$L = 0.05 \text{ m}$$

$$2.5 \times 10^{-6} = M \times 5 \times 10^{-5} \times \frac{1}{2}$$

$$M = 10^{-1}$$

$$M = mL$$

$$10^{-1} = m \times 0.05$$

$$m = 2 \text{ Am}$$

**13. Solution (d)**

$$C = m(2l)B \sin \theta$$

$$\tau = MB \sin \theta$$

$$\tau = m l B \sin \theta$$

$$80 \times 10^{-7} = 2 \times l \times 4 \times 10^{-5} \times \sin 30^\circ$$

$$80 \times 10^{-7} = l \times 4 \times 10^{-5}$$

$$l = \frac{80 \times 10^{-7}}{4 \times 10^{-5}}$$

$$l = 20 \times 10^{-2} \text{ m}$$

$$l = 20 \text{ cm}$$

**14. Solution (a)**

$$\theta_1 = 0^\circ$$

$$\theta_2 = 360^\circ$$

$$U_1 = -mB \cos 0 = -mB$$

$$U_2 = -mB \cos 360 = mB$$

$$w = U_2 - U_1$$

$$w = 0$$

**15. Solution (a)**

$$m(2l) B_H \sin \theta = Fl \cos \theta$$

Given :  $BH = 10^{-4} \text{ T}$

$$m = 20 \sqrt{3}$$

$$\theta = 30^\circ$$

$$F = MB \quad \dots(1)$$

The magnetic meridian B

$$B_H = B \cos \theta$$

$$B = \frac{B_H}{\cos \theta} = \frac{10^{-4}}{\cos 30^\circ}$$

$$B = 1.1547 \times 10^{-4} \text{ T}$$

From equation (1)

$$F = 20 \sqrt{3} \times 1.1547 \times 10^{-4}$$

$$F = 4 \times 10^{-3} \text{ N}$$

**Set 2 :**

**1. Solution(b)**

In sum position  $T \propto \frac{1}{\sqrt{M_1 + M_2}}$  and in

difference position  $T \propto \frac{1}{\sqrt{M_1 - M_2}}$

$$\Rightarrow \frac{3^2}{T^2} = \frac{2M - M}{2M + M} \Rightarrow T^2 = 9 \times 3 \text{ sec}^2$$

$$\therefore T = 3\sqrt{3} \text{ sec}$$

**2. Solution (b)**

Given

$$v_1 = \frac{20}{60} = \frac{1}{3} \text{ sec}^{-1} \text{ and } v_2 = \frac{15}{60} = \frac{1}{4} \text{ sec}^{-1}$$

Now

$$v = \frac{1}{2\pi} \sqrt{\frac{MB_H}{I}} = \frac{1}{2\pi} \sqrt{\frac{MB \cos \phi}{I}}$$

$$(\because B_H = B \cos \phi)$$

$$\therefore \frac{v_1}{v_2} = \sqrt{\frac{B_1 \cos \phi_1}{B_2 \cos \phi_2}} \Rightarrow$$

$$\frac{B_1}{B_2} = \left( \frac{v_1}{v_2} \right)^2 \left( \frac{\cos \phi_2}{\cos \phi_1} \right)^2$$

$$\Rightarrow \frac{B_1}{B_2} = \left( \frac{1/3}{1/4} \right)^2 \frac{\cos 60^\circ}{\cos 30^\circ} = \frac{16}{9} \times \frac{1/2}{\sqrt{3}/2} = \frac{16}{9\sqrt{3}}$$

**3. Solution (c)**

$$T \propto \frac{1}{\sqrt{M}} \Rightarrow \frac{T_1}{T_2} = \sqrt{\frac{M_2}{M_1}} \Rightarrow \frac{1.5}{T_2} = \sqrt{\frac{M_1/4}{M_1}} = \frac{1}{2}$$

$$\Rightarrow T_2 = 3 \text{ sec}$$

**4. Solution (c)**

No. of oscillation per minute =  $\frac{1}{2\pi} \sqrt{\frac{MB_H}{I}}$

$$\Rightarrow T = 2\pi \sqrt{\frac{I}{MB_H}}$$

$$\Rightarrow T \propto M^{-1/2}$$

$$\Rightarrow M_B M_A = T_{A2} T_{B2} = 14$$

**5. Solution (a)**

$$T = 2\pi \sqrt{\frac{I}{MH}} \Rightarrow T \propto \frac{1}{\sqrt{H}} \Rightarrow \frac{T_A}{T_B} = \sqrt{\frac{H_B}{H_A}}$$

$$\frac{H_A}{H_B} = \left( \frac{T_B}{T_A} \right)^2 = \left( \frac{3}{2} \right)^2 = \frac{9}{4}$$

**6. Solution (c)**

$$T = 2\pi \sqrt{\frac{I}{MB_H}} \text{ and } I = \frac{w(l^2 + b^2)}{12}$$

$$\therefore T \propto \sqrt{w}$$

(w = Mass of the magnet)

**7. Solution (c)**

$$T_{\text{Sum}} = 2\pi \sqrt{\frac{(I_1 + I_2)}{(M_1 + M_2)B_H}}$$

$$T_{\text{diff}} = 2\pi \sqrt{\frac{I_1 + I_2}{(M_1 - M_2)B_H}}$$

$$\Rightarrow \frac{T_s}{T_d} = \frac{T_1}{T_2} = \sqrt{\frac{M_1 - M_2}{M_1 + M_2}} = \sqrt{\frac{2M - M}{2M + M}} = \frac{1}{\sqrt{3}}$$

**8. Solution (a)**

$$T = 2\pi \sqrt{\frac{I}{MB}} \Rightarrow \frac{T}{T'} = \sqrt{\frac{B'}{B}} = \sqrt{\frac{B}{B_H}}$$

$$\Rightarrow \frac{T}{T'} = \sqrt{\frac{1}{\cos\phi}} = \sqrt{\frac{1}{\cos 60^\circ}} = \sqrt{2} \Rightarrow T' = \frac{T}{\sqrt{2}}$$

**9. Solution (a)**

$$T = 2\pi \sqrt{\frac{I}{MB_H}}; I \rightarrow 3 \text{ times and}$$

$$M \rightarrow \frac{1}{3} \text{ times}$$

$$\text{So } T \rightarrow 3 \text{ times i.e. } T' = 3T_0$$

**10. Solution (c)**

$$T \propto \frac{1}{\sqrt{B_H}} = \frac{1}{\sqrt{B \cos\phi}} \Rightarrow \frac{T_1}{T_2} = \sqrt{\frac{B_2 \cos\phi_2}{B_2 \cos\phi_1}}$$

$$\Rightarrow \frac{B_1}{B_2} = \frac{T_2^2}{T_1^2} \times \frac{\cos\phi_2}{\cos\phi_1} = \left(\frac{3}{2}\right)^2 \times \frac{\cos 60}{\cos 30}$$

$$\Rightarrow \frac{B_1}{B_2} = \frac{9}{4\sqrt{3}}$$

**➤ Set 3 :**

**1. Solution (a)**

Soft iron is highly ferromagnetic.

**2. Solution (b)**

Repelled due to induction of similar poles.

**3. Solution. (d)**

From the characteristic of  $B-H$  curve.

**4. Solution (d)**

**5. Solution. (c)**

**6. Solution.(c)**

**7. Solution. (c)**

**8. Solution. (c)**

Diamagnetic substances are repelled by magnetic field.

**9. Solution (b)**

**10. Solution (c)**

The energy lost per unit volume of a substance in a complete cycle of magnetization is equal to the area of the hysteresis loop.

**11. Solution. (d)**

**12. Solution. (b)**

When we increase the temp above the curie temp ferromagnetic material becomes paramagnetic

**13. Solution (b)**

Diamagnetic substances are repelled by the magnetic field.

**14. Solution (d)**

$$\mu_r = \frac{B}{B_0} = 4$$

