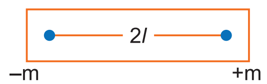
Magnetism and Matter

basic concepts

1. Magnetic Dipole Moment of a Current Loop and Revolving Electron



Magnetic dipole moment of a magnet is given as , $M = m\ 2l$, where m is pole strength, $2l$ is separation between poles. Its SI unit is ampere (metre)^2 abbreviated as Am^2. Magnetic dipole moment of a current loop is

$$M = NIA$$

The direction of M is perpendicular of the plane of loop and given by right hand thumb rule.

Magnetic dipole moment of a revolving electron

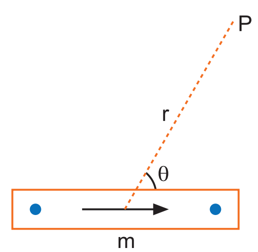
$$= IA = \frac{ev}{2\pi r} \times \pi r^2 = \frac{evr}{2}$$

where v is velocity, r is radius of orbit

$$M = \frac{e}{2m_e} L \text{ amp m}^2$$

where $L = m_e vr$ is angular momentum of revolving electron.

2. Magnetic Field Intensity due to a Magnetic Dipole



Magnetic field intensity at a general point having polar coordinates (r, θ) due to a short magnet is given by

$$B = \frac{\mu_0}{4\pi} \frac{M}{r^3} \sqrt{1 + 3\cos^2\theta}$$

where M is the magnetic moment of the magnet.

Special Cases

(*i*) At axial point $\theta = 0$,

$$B_{axis} = \frac{\mu_0}{4\pi} \frac{2M}{r^3}$$

(*ii*) At equatorial point $\theta = 90°$

$$B_{eqt.} = \frac{\mu_0}{4\pi} \frac{M}{r^3}$$

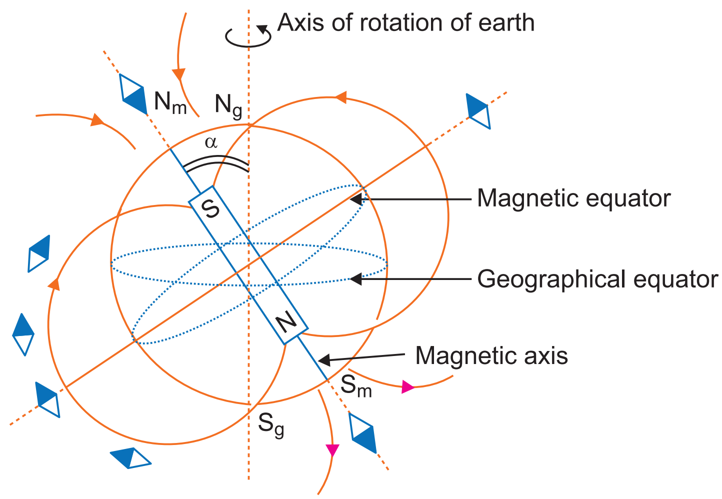
3. Gauss's law in magnetism

The net magnetic flux through any closed surface is zero.

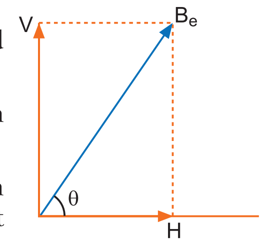
$$\oint \vec{B} . \vec{ds} = 0$$

4. Earth's Magnetism

The earth's magnetic field may be approximated by a magnetic dipole lying at the centre of earth such that the magnetic north pole N_m is near geographical north pole N_g and its magnetic south pole S_m is near geographical south pole S_g. In reality, the north magnetic pole behaves like the south pole of a bar magnet inside the earth and vice versa. The magnitude of earth's magnetic field at earth's surface is about 4×10^{-5} T.



5. Elements of Earths' Magnetic Field



Earth's magnetic field may be specified completely by three quantities called the elements of earth's magnetic field. These quantities are

(*i*) **Angle of declination (α):** It is the angle between geographical meridian and the magnetic meridian planes.

(*ii*) **Angle of dip (θ) :** It is the angle made by resultant magnetic field B_e with the horizontal. The angle of dip is 0° at magnetic equator and 90° at magnetic poles. Angle of dip is measured by dip circle. It is also called as magnetic inclination

(*iii*) **Horizontal component (H) of earth's magnetic field (B_e)**

$$H = B_e \cos\theta \qquad \ldots(i)$$

Vertical component of B_e is $V = B_e \sin\theta \qquad \ldots(ii)$

$$\therefore \quad B_e = \sqrt{H^2 + V^2} \qquad \ldots(iii)$$

and $\tan\theta = \dfrac{V}{H} \qquad \ldots(iv)$

6. Important Terms in Magnetism

(*i*) **Magnetic permeability (μ):** It is the ability of a material to allow magnetic lines of force to pass through it and is equal to $\mu = \dfrac{B}{H}$, where B is the magnetic field strength and H is the magnetic field intensity.

The relative magnetic permeability $\mu_r = \dfrac{B}{B_0} = \dfrac{\mu}{\mu_0}$

where μ_0 is the permeability of free space and B_0 is the magnetic field strength in vacuum.

(*ii*) **Intensity of magnetisation ($\vec{M}$):** It is defined as the magnetic moment per unit volume of a magnetised material. Its unit is Am^{-1}.

i.e., $\vec{M} = \dfrac{\vec{m}}{V}$

(*iii*) **Magnetising field intensity (H):** It is the magnetic field used for magnetisation of a material. If I is the current in the solenoid, then magnetising field intensity $H=nI$, where n = number of turns per metre. Its unit is Am^{-1}.

(*iv*) **Magnetic susceptibility:** It is defined as the intensity of magnetisation per unit magnetising field, *i.e.*,

$$\chi_m = \frac{M}{H}$$

It has no unit.

It measures the ability of a substance to take up magnetisation when placed in a magnetic field.

7. Classification of Magnetic Materials

Magnetic materials may be classified into three categories :

(*i*) **Diamagnetic substances:** These are the substances in which feeble magnetism is produced in a direction opposite to the applied magnetic field. These substances are repelled by a strong magnet. These substances have small negative values of susceptibility χ and positive low value of relative permeability μ_r, *i.e.*,

$$-1 \le \chi_m < 0 \quad \text{and} \quad 0 \le \mu_r < 1$$

The examples of diamagnetic substances are bismuth, antimony, copper, lead, water, nitrogen (at STP) and sodium chloride.

(*ii*) **Paramagnetic substances:** These are the substances in which feeble magnetism is induced in the same direction as the applied magnetic field. These are feebly attracted by a strong magnet. These substances have small positive values of M and χ and relative permeability μ_r greater than 1, *i.e.*,

$$0 < \chi_m < \varepsilon, \quad 1 < \mu_r < 1 + \varepsilon$$

where ε is a small positive number. The examples of paramagnetic substances are platinum, aluminium, calcium, manganese, oxygen (at STP) and copper chloride.

(*iii*) **Ferromagnetic substances:** These are the substances in which a strong magnetism is produced in the same direction as the applied magnetic field. These are strongly attracted by a magnet. These substances are characterised by large positive values of M and χ and values of μ_r much greater than 1, ***eg***. Iron, cobalt, nickel and alloy like alnico.

i.e., $\chi_m >> 1, \quad \mu_r >> 1$

Distinction between Dia–, Para– and Ferromagnetics

	Property	Diamagnetic	Paramagnetic	Ferromagnetic	Remark
(*i*)	Magnetic induction B	$B < B_0$	$B > B_0$	$B >> B_0$	B_0 is magnetic induction in free space
(*ii*)	Intensity of magnetisation $M = \frac{m}{V}$	small and negative	small and positive	very high and positive	m is magnetic moment
(*iii*)	Magnetic susceptibility $\chi = \frac{M}{H}$	small and negative	small and positive	very high and positive	
(*iv*)	Relative permeability $\mu_r = \frac{\mu}{\mu_0}$	$\mu_r < 1$	$\mu_r > 1$	$\mu_r >> 1$ (of the order the thousands)	

8. Curie Law

It states that the magnetic susceptibility of paramagnetic substances is inversely proportional to absolute temperature, *i.e.*,

$$\chi_m \propto \frac{1}{T} \Rightarrow \chi = \frac{C}{T} \text{ where } C \text{ is called Curie constant}$$

9. Curie Temperature

When temperature is increased continuously, the magnetic susceptibility of ferromagnetic substances decrease and at a stage the substance changes to paramagnetic. The temperature of transition at which a ferromagnetic substance changes to paramagnetic is called Curie temperature. It is denoted by T_C. It is different for different materials. In paramagnetic phase the susceptibility is given by

$$\chi_m = \frac{C}{T - T_C}$$

10. Diamagnetism is universal properties of all substances but it is weak in para and ferromagnetic substances and hence difficult to detect.

11. Electromagnets and Permanent Magnets

Electromagnets are made of soft iron which is characterised by low retentivity, low coercivity and high permeability. The hysteresis curve must be narrow. The energy dissipated in magnetisation and demagnetisation is consequently small.

Permanent magnets are made of steel which is characterised by high retentivity, high permeability and high coercivity**.**

They can retain their attractive property for a long period of time at room temperatures.

Selected NCERT Textbook Questions

Magnetism

Q. 1. A short bar magnet placed with its axis at 30° with a uniform external magnetic field of 0.25 T experiences a torque of magnitude equal to 4.5 × 10^{-2} N–m. What is the magnitude of magnetic moment of the magnet?

Ans. Given, $B = 0.25$ T, $\tau = 4.5 \times 10^{-2}$ N-m, $\theta = 30°$

We have $\tau = mB \sin\theta$

$\Rightarrow$ Magnetic moment $m = \dfrac{\tau}{B\sin\theta} = \dfrac{4.5\times10^{-2}}{0.25\times\sin 30°} = \dfrac{4.5\times10^{-2}}{0.25\times0.5}$ = **0.36 A–m^2**

Q. 2. A short bar magnet of magnetic moment m = 0.32 JT^{-1} is placed in a uniform magnetic field of 0.15 T. If the bar is free to rotate in the plane of the field, which orientation would correspond to its (*i*) stable and (*ii*) unstable equilibrium? What is the potential energy of the magnet in each case?

Ans. Given $m = 0.32$ JT^{-1}, $B = 0.15$ T

Potential energy of magnet in magnetic field

$$U = -mB\cos\theta$$

(*i*) In stable equilibrium the potential energy of magnet is the minimum; so

$$\cos\theta = 1 \quad \text{or} \quad \theta = 0°$$

Thus in stable equilibrium position, the bar magnet is so aligned that its magnetic moment is along the direction of magnetic field ($\theta = 0°$).

$$U_m = -mB = -0.32 \times 0.15 = \mathbf{-4.8 \times 10^{-2}\ J}$$

(*ii*) In unstable equilibrium, the potential energy of magnet is the maximum.

Thus in unstable equilibrium position, the bar magnetic is so aligned that its magnetic moment is opposite to the direction of the magnetic field, *i.e.*, $\cos\theta = -1$ or $\theta = 180°$.

In this orientation potential energy, $U_{max} = +mB$ = **+ 4.8 × 10^{-2} J.**

Q. 3. (*a*) **Closely wound solenoid of 800 turns and area of cross-section 2.5 × 10^{-4} m^2 carries a current of 3.0 A. Explain the sense in which solenoid acts like a bar magnet. What is the associated magnetic moment?**

(*b*) **If the solenoid is free to turn about the vertical direction in an external uniform horizontal magnetic field at 0.25 T, what is the magnitude of the torque on the solenoid when its axis makes an angle of 30° with the direction of the external field.**

Ans. (*a*) If solenoid is suspended freely, it stays in N-S direction. The polarity of solenoid depends on the sense of flow of current. If to an observer looking towards an end of a solenoid, the current appears anticlockwise, the end of solenoid will be N-pole and other end will be S-pole.

Magnetic moment, $m = NIA = 800 \times 3.0 \times 2.5 \times 10^{-4}$ = **0.60 A-m^2**

(*b*) Torque on solenoid $\tau = mB\sin\theta$

$$= 0.60 \times 0.25 \sin 30°$$

$$= 0.60 \times 0.25 \times 0.5 = \mathbf{7.5 \times 10^{-2}\ N–m}$$

Q. 4. A bar magnet of magnetic moment 1.5 JT^{-1} lies aligned with the direction of a uniform magnetic field of 0.22 T.

(a) What is the amount of work required by an external torque to turn the magnet so as to align its magnetic moment

(i) normal to the field direction? and (ii) opposite to the field direction?

(b) What is the torque on the magnet in cases (i) and (ii)?

Ans. (a) Work done in aligning a magnet from orientation θ_1 to θ_2 is given by

$$W = U_2 - U_1 = -mB\cos\theta_2 - (-mB\cos\theta_1)$$

$$= -mB(\cos\theta_2 - \cos\theta_1) \quad \ldots(i)$$

(i) Here $\theta_1 = 0°, \theta_2 = 90°$

$\therefore \quad W = mB(\cos 0° - \cos 90°) = mB(1 - 0) = mB$

$= 1.5 \times 0.22 = \mathbf{0.33\ J}$

(ii) Here $\theta_1 = 0°, \theta_2 = 180°$

$\therefore \quad W = mB(\cos 0° - \cos 180°) = 2mB$

$= 2 \times 1.5 \times 0.22 = \mathbf{0.66\ J}$

(b) Torque $\tau = mB\sin\theta$

In (i) $\theta = 90°$, $\tau = mB\sin 90° = mB = 1.5 \times 0.22 = \mathbf{0.33\ N\text{-}m}$

This torque tends to align the magnet along the direction of field direction.

In (ii) $\theta = 180°$, $\tau = mB\sin 180° = \mathbf{0}$

Q. 5. A closely wound solenoid of 2000 turns and area of cross-section 1.6×10^{-4} m^2, carrying a current of 4.0 A is suspended through its centre allowing it to turn in a horizontal plane.

(a) What is the magnetic moment associated with the solenoid?

(b) What are the force and torque on the solenoid if a uniform magnetic field of 7.5×10^{-2} T is set up at an angle of 30° with the axis of the solenoid?

Ans. Given $N = 2000$, $A = 1.6 \times 10^{-4}\ m^2$, $I = 4.0$ A

(a) Magnetic moment of solenoid, $m = NIA$

$$= 2000 \times 4.0 \times 1.6 \times 10^{-4} = \mathbf{1.28\ A\text{-}m^2}$$

(b) Net force on current carrying solenoid (or magnetic dipole) in uniform magnetic field is always zero.

Given, $B = 7.5 \times 10^{-2}$ T, $\theta = 30°$

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

$$\tau = 1.28 \times 7.5 \times 10^{-2} \times \sin 30°$$

$$= 1.28 \times 7.5 \times 10^{-2} \times 0.5$$

$$= \mathbf{4.8 \times 10^{-2}\ N\text{-}m}$$

Q. 6. A short bar magnet has a magnetic moment of 0.48 JT^{-1}. Give the magnitude and direction of the magnetic field produced by the magnet at a distance of 10 cm from the centre of magnet on (a) the axis, (b) equatorial lines (normal bisector) of the magnet.

Ans. Given $m = 0.48\ JT^{-1}$, $r = 10$ cm $= 0.10$ m

(a) Magnetic field at axis, $B_1 = \frac{\mu_0}{4\pi}\frac{2m}{r^3}$

$$= (10^{-7}) \times \frac{2 \times 0.48}{(0.10)^3} = 0.96 \times 10^{-4}\ T$$

$= \mathbf{0.96\ G}$ along S-N direction

(b) Magnetic field at equatorial line

$$B_2 = \frac{\mu_0}{4\pi}\frac{m}{r^3} = 0.48 \times 10^{-4}\ T$$

$= \mathbf{0.48\ G}$ along N-S direction

Q. 7. A magnetic dipole is under the influence of two magnetic fields. The angle between the field directions is 60° and one of the fields has a magnitude of 1.2×10^{-2} T. If the dipole comes to stable equilibrium at an angle of 15° with this field, what is the magnitude of other field?

Ans. For equilibrium, the net torque on magnetic field must be zero. Therefore, the torques exerted by fields B_1 and B_2 on the dipole must be equal and opposite.

$$\tau_1 = \tau_2$$

$$mB_1 \sin\theta_1 = mB_2 \sin\theta_2$$

$$\Rightarrow \quad B_2 = \frac{B_1 \sin\theta_1}{\sin\theta_2}$$

Given $B_1 = 1.2 \times 10^{-2}$ T $\theta_1 = 15°$, $\theta_2 = (60° - 15°) = 45°$

$$\therefore \quad B_2 = 1.2\times10^{-2}\times\frac{\sin 15°}{\sin 45°} = 1.2\times10^{-2}\times\frac{0.2588}{0.7071} = \mathbf{4.4\times10^{-3}\ T}$$

Earth's Magnetism

Q. 8. A magnetic needle free to rotate in a vertical plane parallel to the magnetic meridian has its north tip pointing down at 22° with the horizontal. The horizontal component of the earth's magnetic field at a place is known to be 0.35 G. Determine the magnitude of the earth's magnetic field at the place. (Given cos 22° = 0.927, sin 22° = 0.375).

Ans. By definition, angle of dip $\theta = 22°$

Given $H = 0.35$ G

We have $H = B_e \cos\theta$ or $B_e = \dfrac{H}{\cos\theta} = \dfrac{0.35}{\cos 22°}$ G

or $B_e = \dfrac{0.35}{0.927} = \mathbf{0.38\ G}$

Q. 9. At a certain location in Africa, compass points 12° west of geographical north. The north top of magnetic needle of a dip circle placed in the plane of the magnetic meridian points 60° above the horizontal. The horizontal component of earth's magnetic field is measured to be 0.16 gauss. Specify the direction and magnitude of earth's magnetic field at the location.

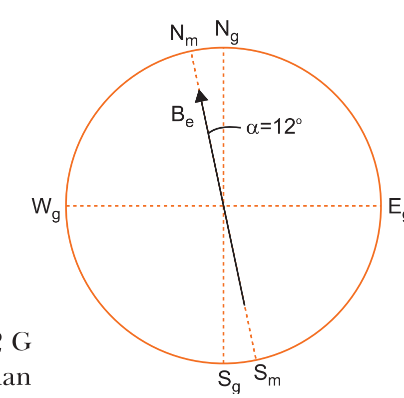
Ans. This problem illustrates how the three elements of earth's field : angle of declination (α) angle of dip (θ) and horizontal component H; determine the earth's magnetic field completely.

Here angle of declination $(\alpha) = 12°$

Angle of dip $\theta = 60°$

and horizontal component, $H = 0.16$ gauss

$= 0.16 \times 10^{-4}$ T



If B_e is the total earth's magnetic field, then the relation between B_e and H is $H = B_e \cos\theta$ gauss

$$\Rightarrow B_e = \frac{H}{\cos\theta} = \frac{0.16\times10^{-4}}{\cos 60°} = \frac{0.16\times10^{-4}}{0.5} = \mathbf{0.32\times10^{-4}\ T}$$

Thus, the magnitude of earth's field is 0.32×10^{-4} T = 0.32 G and it lies in a vertical plane 12° west of geographical meridian making an angle of 60° (upwards) with the horizontal direction.

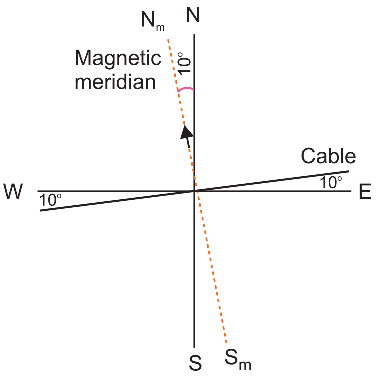
Q. 10. A long straight horizontal cable carries a current of 2.5 A in the direction 10° south of west to 10° north of east. The magnetic meridian of the place happens to be 10° west of the geographical meridian. The earth magnetic field at the location is 0.33 G and the angle of dip is zero. Locate the line of neutral points (Ignore the thickness of the cable).

Ans. Given $B_e = 0.33$ G, $I = 2.5$ A

Angle of dip, $\theta = 0$

$\therefore H = B_e \cos 0° = 0.33 \text{ G} = 0.33 \times 10^{-4}$ T, $V = B_e \sin 0° = 0$

Magnetic field due to current carrying cable $B_c = \dfrac{\mu_0 I}{2\pi r}$



The cable is perpendicular to magnetic meridian. For neutral point, the magnetic produced by cable must be equal and opposite to earth's magnetic field, *i.e.*,

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

$$r = \frac{\mu_0 I}{2\pi H} = \frac{4\pi \times 10^{-7} \times 2.5}{2\pi \times 0.33 \times 10^{-4}} = 1.5 \times 10^{-2} \text{m} = \mathbf{1.5\ cm}$$

That is the line of neutral points is parallel to cable at a distance 1.5 cm above the plane of paper.

Q. 11. A telephone cable at a place has four long straight horizontal wires carrying a current of 1.0 A in the same direction east to west. The earth's angle of dip is 35°. The magnetic declination is nearly zero. What are the resultant magnetic fields at points 4.0 cm. below and above the cable?

Ans. Given $B_e = 0.39$ G, $\theta = 35°$

(*i*) Below the Cable

The magnetic field due to horizontal wires.

$$B_1 = 4 \times \frac{\mu_0 I}{2\pi R} = 4 \times \frac{4\pi \times 10^{-7} \times 1.0}{2\pi \times 4 \times 10^{-2}} = 2.0 \times 10^{-5} \text{ T}$$

$$= 0.2 \times 10^{-4} \text{ T} = 0.2 \text{ G}$$

This is directed along $\overrightarrow{NS}$ direction.

The earth's horizontal magnetic field is directed from south to north

$$H = B_e \cos\theta = 0.39 \cos 35° = 0.39 \times 0.82 = 0.32 \text{ G}$$

$\therefore$ Net horizontal magnetic field

$$B_H = H - B_1 = 0.32 - 0.2 = 0.12 \text{ G.}$$

Vertical component of earth's magnetic field

$$B_V = B_e \sin\theta = 0.39 \sin 35° = 0.39 \times 0.57 = 0.22 \text{ G}$$

Resultant magnetic field $B_R = \sqrt{B_H^2 + B_V^2}$

$$= \sqrt{(0.12)^2 + (0.22)^2} = \mathbf{0.25\ G}$$

Angle made by resultant field with horizontal

and $\phi = \tan^{-1}\dfrac{B_V}{B_H} = \tan^{-1}\left(\dfrac{0.22}{0.12}\right) = \tan^{-1}(1.8333) = 61.4°$

(*ii*) Above the Cable: If point is above the cable the direction of magnetic field $\vec{B_1}$ will be along $\overrightarrow{SN}$ direction. So $\vec{H}$ and $\vec{B_1}$ will be added.

$\therefore$ $B_H = 0.32 + 0.2 = 0.524$

$$B_V = 0.22 \text{ G}$$

$\therefore$ Resultant magnetic field $B_R = \sqrt{B_H^2 + B_V^2}$

$$= \sqrt{(0.52)^2 + (0.22)^2} = \mathbf{0.57\ G}$$

and $\phi = \tan^{-1}\dfrac{B_V}{B_H} = \tan^{-1}\dfrac{0.22}{0.524} = \tan^{-1}(0.4230) = 22.9°$

Multiple Choice Questions [1 mark]

Choose and write the correct option(s) in the following questions.

1. Magnetism in substances is caused by

(*a*) orbital motion of electrons only

(*b*) spin motion of electrons only

(*c*) due to spin and orbital motions of electrons both

(*d*) hidden magnets

2. A magnetic needle is kept in a uniform magnetic field. It experiences

(*a*) a force and a torque (*b*) a force but not a torque

(*c*) a torque but not a force (*d*) neither a torque nor a force

3. A magnetic needle is kept in a non-uniform magnetic field. It experiences

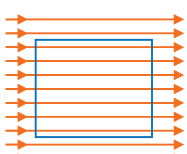
(*a*) a force and a torque (*b*) a force but not a torque

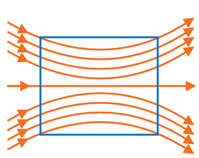
(c) a torque but not a force (*d*) neither a force nor a torque

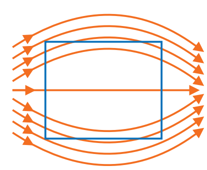
4. A bar magnet of magnetic moment $\vec{m}$ is placed in a uniform magnetic field of induction $\vec{B}$. The torque exerted on it is

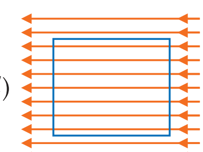
(*a*) $\vec{m}\,.\,\vec{B}$ (*b*) $-\vec{m}\,.\,\vec{B}$ (*c*) $\vec{m}\times\vec{B}$ (*d*) $-\vec{m}\times\vec{B}$

5. A uniform magnetic field exists in space in the plane of paper and is initially directed from left to right. When a bar of soft iron is placed in the field parallel to it, the lines of force passing through it will be represented by

(*a*) 

(*b*) 

(*c*) 

(*d*) 

6. Points A and B are situated perpendicular to the axis of a 2 cm long bar magnet at large distances *x* and 3*x* from its centre on opposite sides. The ratio of the magnetic fields at A and B will be approximately equal to

(*a*) 1: 9 (*b*) 2: 9 (*c*) 27: 1 (*d*) 9: 1

7. A paramagnetic sample shows a net magnetisation of 8 Am^{-1} when placed in an external magnetic field of 0.6 T at a temperature of 4 K. When the same sample is placed in an external magnetic field of 0.2 T at a temperature of 16 K, the magnetisation will be [*NCERT Exemplar*]

(*a*) $\frac{32}{3}Am^{-1}$ (*b*) $\frac{2}{3}Am^{-1}$ (*c*) 6 Am^{-1} (*d*) 2.4 Am^{-1}

8. A toroid of *n* turns, mean radius *R* and cross-sectional radius *a* carries current *I*. It is placed on a horizontal table taken as *X*-*Y* plane. Its magnetic moment $\vec{m}$ [*NCERT Exemplar*]

(*a*) is non-zero and points in the *Z*-direction by symmetry.

(*b*) points along the axis of the toroid ($\vec{m} = m\phi$).

(*c*) is zero, otherwise there would be a field falling as $\frac{1}{r^3}$ at large distances outside the toroid.

(*d*) is pointing radially outwards.

9. A long solenoid has 1000 turns per metre and carries a current of 1 A. It has a soft iron core of $\mu_r = 1000$. The core is heated beyond the Curie temperature, T_c, then [*NCERT Exemplar*]

(*a*) the *H* field in the solenoid is (nearly) unchanged but the *B* field decreases drastically.

(*b*) the *H* and *B* fields in the solenoid are nearly unchanged.

(*c*) the magnetisation in the core reverses direction.

(*d*) the magnetisation in the core diminishes by a factor of about 10^8.

10. The magnetic field of Earth can be modelled by that of a point dipole placed at the centre of the Earth. The dipole axis makes an angle of 11.3° with the axis of Earth. At Mumbai, declination is nearly zero. Then, [*NCERT Exemplar*]

(*a*) the declination varies between 11.3° W to 11.3° E.
(*b*) the least declination is 0°.
(*c*) the plane defined by dipole axis and Earth axis passes through Greenwich.
(*d*) declination averaged over Earth must be always negative.

11. In a plane perpendicular to the magnetic meridian, the dip needle will be

(*a*) vertical
(*b*) horizontal
(*c*) inclined equal to the angle of dip at that place
(*d*) pointing in any direction

12. The meniscus of a liquid contained in one of the limbs of a narrow U-tube is placed between the pole-pieces of an electromagnet with the meniscus in a line with the field. When the electromagnet is switched on, the liquid is seen to rise in the limb. This indicates that the liquid is

(*a*) ferromagnetic (*b*) paramagnetic
(*c*) diamagnetic (*d*) non-magnetic

13. Electro-magnets are made of soft iron because soft iron has

(*a*) small susceptibility and small retentivity
(*b*) large susceptibility and small retentivity
(*c*) large permeability and large retentivity
(*d*) small permeability and large retentivity.

14. In a permanent magnet at room temperature [*NCERT Exemplar*]

(*a*) magnetic moment of each molecule is zero.
(*b*) the individual molecules have non-zero magnetic moment which are all perfectly aligned.
(*c*) domains are partially aligned.
(*d*) domains are all perfectly aligned.

15. If a magnetic substance is kept in a magnetic field, then which of the following substances is thrown out?

(*a*) Paramagnetic (*b*) Ferromagnetic
(*c*) Diamegnetic (*d*) Antiferromagnetic

16. Above Curie's temperature ferromagnetic substances becomes

(*a*) paramagnetic (*b*) diamagnetic
(*c*) superconductor (*d*) no change

17. In the hysteresis cycle, the value of H needed to make the intensity of magnetisation zero is called

(*a*) retentivity (*b*) coercive force
(*c*) Lorentz force (*d*) none of the above

18. A permanent magnet attracts

(*a*) all substances (*b*) only ferromagnetic substances
(*c*) some substances and repels others (*d*) ferromagnetic substances and repels all others

19. Susceptibility is positive for

(*a*) paramagnetic substances (*b*) ferromagnetic substances
(*c*) non-magnetic substances (*d*) diamagnetic substances

20. If the horizontal and vertical components of earth's magnetic field are equal at a certain place, the angle of dip is

(*a*) 90° (*b*) 60° (*c*) 45° (*d*) 0°

Answers

1. (*c*)	**2.** (*c*)	**3.** (*a*)	**4.** (*c*)	**5.** (*b*)	**6.** (*c*)
7. (*b*)	**8.** (*c*)	**9.** (*a*), (*d*)	**10.** (*a*)	**11.** (*a*)	**12.** (*b*)
13. (*b*)	**14.** (*c*)	**15.** (*c*)	**16.** (*a*)	**17.** (*b*)	**18.** (*b*)
19. (*a*), (*b*)	**20.** (*c*)				

Fill in the Blanks [1 mark]

1. The unit of magnetic dipole moment is ______________.
2. Diamagnetic substances when placed in a magnetic field, are magnetised in the direction ______________ to the magnetic field.
3. Paramagnetic materials when placed in a magnetic field are magnetised in the direction ______________ to the magnetic field.
4. The angle between the magnetic moment of a bar magnet and its magnetic field at an equatorial point is ______________.
5. The ability of a material to retain magnetism after removal of magnetizing field is called as ______________.
6. SI unit of magnetic pole strength is ______________.
7. Inside the body of a magnet the direction of magnetic field lines is from ______________.
8. For paramagnetic materials magnetic susceptibility is related with temperature as inversely proportional to ______________.
9. There is no effect of temperature on ______________ type of materials.
10. Ferromagnetism can be explained on the basis of formation of ______________ within the materials.

Answers

1. Am^2	**2.** opposite	**3.** parallel	**4.** 180°
5. retentivity	**6.** ampere-meter	**7.** South pole to North pole	
8. T	**9.** diamagnetic	**10.** domain	

Very Short Answer Questions [1 mark]

Q. 1. Where on the earth's surface is the value of angle of dip maximum?

OR

Where on the surface of earth is the angle of dip 90°? [*CBSE (AI) 2011*]

Ans. Angle of dip (90°) is maximum at magnetic poles.

Q. 2. A magnetic needle, free to rotate in a vertical plane, orients itself vertically at a certain place on the Earth. What are the values of (*i*) horizontal component of Earth's magnetic field and (*ii*) angle of dip at this place? [*CBSE (F) 2012*]

Ans. (*i*) 0 (*ii*) 90°

Q. 3. Where on the earth's surface is the value of vertical component of earth's magnetic field zero? [*CBSE (F) 2011*]

Ans. Vertical component of earth's magnetic field is zero at magnetic equator.

Q. 4. The horizontal component of the earth's magnetic field at a place is *B* and angle of dip is 60°. What is the value of vertical component of earth's magnetic field at equator? [*CBSE Delhi 2012*]

Ans. Zero

Q. 5. A small magnet is pivoted to move freely in the magnetic meridian. At what place on earth's surface will the magnet be vertical? **[*CBSE (F) 2012*]**

Ans. Magnet will be vertical at the either magnetic pole of earth.

Q. 6. Which of the following substances are diamagnetic?

Bi, Al, Na, Cu, Ca and Ni **[*CBSE Delhi 2013*]**

Ans. Diamagnetic substances are (*i*) Bi (*ii*) Cu.

Q. 7. What are permanent magnets? Give one example. **[*CBSE Delhi 2013*]**

Ans. Substances that retain their attractive property for a long period of time at room temperature are called permanent magnets.

Examples: Those pieces which are made up of steel, alnico, cobalt and ticonal.

Q. 8. Mention two characteristics of a material that can be used for making permanent magnets. **[*CBSE Delhi 2010*]**

Ans. For making permanent magnet, the material must have high **retentivity** and high **coercivity** (*e.g.*, steel).

Q. 9. Why is the core of an electromagnet made of ferromagnetic materials? **[*CBSE Delhi 2010*]**

Ans. Ferromagnetic material has a high permeability. So on passing current through windings it gains sufficient magnetism immediately.

Q. 10. The permeability of a magnetic material is 0.9983. Name the type of magnetic materials it represents. **[*CBSE Delhi 2011*]**

Ans. μ is <1 and > 0, so magnetic material is diamagnetic.

Q. 11. The susceptibility of a magnetic materials is -4.2×10^{-6}. Name the type of magnetic materials it represents. **[*CBSE Delhi 2011*]**

Ans. Susceptibility of material is negative, so given material is diamagnetic.

Q. 12. In what way is the behaviour of a diamagnetic material different from that of a paramagnetic, when kept in an external magnetic field? **[*CBSE Central 2016*]**

Ans. A diamagnetic specimen would move towards the weaker region of the field while a paramagnetic specimen would move towards the stronger region.

Q. 13. At a place, the horizontal component of earth's magnetic field is *B* and angle of dip is 60°. What is the value of horizontal component of the earth's magnetic field at equator? **[*CBSE Delhi 2017*]**

Ans. Here, $B_H = B$ and $\delta = 60°$

We know that

$$B_H = B_E \cos\delta$$

$$B = B_E \cos 60° \qquad \Rightarrow B_E = 2B$$

At equator $\delta = 0°$

$\therefore \quad B_H = 2B \cos 0° = 2B$

Q. 14. What is the angle of dip at a place where the horizontal and vertical components of the Earth's magnetic field are equal? **[*CBSE (F) 2012*]**

Ans. We know

$$\frac{B_V}{B_H} = \tan\delta$$

Given $B_V = B_H$ then $\tan\delta = 1$

Angle of dip, $\delta = 45°$

Q. 15. The magnetic susceptibility of magnesium at 300 K is 1.2×10^5. At what temperature will its magnetic susceptibility become 1.44×10^5? **[*CBSE 2019 (55/2/1)*]**

Ans. The susceptibility of a paramagnetic substance is inversely proportional to the absolute temperature.

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

$$\chi = \frac{C}{T} \quad \text{(where C is curie constant)}$$

Here $\chi_1 = 1.2 \times 10^5, T_1 = 300$ K

$\chi_2 = 1.44 \times 10^5, T_2 = ?$

$$\chi_1 = \frac{C}{T_1} \Rightarrow C = \chi_1 T_1 \quad ...(i)$$

$$\chi_2 = \frac{C}{T_2} \quad ...(ii)$$

$$T_2 = \frac{C}{\chi_2} = \frac{\chi_1 T_1}{\chi_2} = \frac{1.2 \times 10^5}{1.44 \times 10^5} \times 300 = \mathbf{250\ K}$$

Q. 16. The magnetic susceptibility χ of a given material is – 0.5. Identify the magnetic material. *[CBSE 2019 (55/2/1)]*

Ans. The susceptibility of material is – 0.5, which is negative. Hence, material is diamagnetic substance.

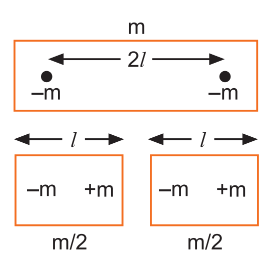
Q. 17. Write one important property of a paramagnetic material. *[CBSE 2019 (55/5/1)]*

Ans. It moves from weaker magnetic field towards stronger magnetic field.

Q. 18. Do the diamagnetic substances have resultant magnetic moment in an atom in the absence of external magnetic field? *[CBSE 2019 (55/5/1)]*

Ans. No, diamagnetic substances have no resultant magnetic moment in the absence of external magnetic field.

Q. 19. How does the (*i*) pole strength and (*ii*) magnetic moment of each part of a bar magnet change if it is cut into two equal pieces transverse to length?

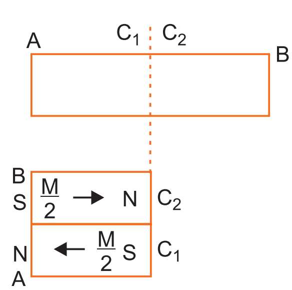


Ans. When a bar magnet of magnetic moment $(\vec{M} = m2\vec{l})$ is cut into two equal pieces transverse to its length,

(*i*) the pole strength remains unchanged (since pole strength depends on number of atoms in cross-sectional area).

(*ii*) the magnetic moment is reduced to half (since $M \propto$ length and here length is halved).

Q. 20. A hypothetical bar magnet (*AB*) is cut into two equal parts. One part is now kept over the other, so that the pole C_2 is above C_1. If *M* is the magnetic moment of the original magnet, what would be the magnetic moment of the combination, so formed?



Ans. The magnetic moment of each half bar magnet is $\frac{M}{2}$ but oppositely directed, so net magnetic moment of combination $= \frac{M}{2} - \frac{M}{2} = 0$ (zero).

Short Answer Questions–I [2 marks]

Q. 1. The susceptibility of a magnetic material is 2.6×10^{-5}. Identify the type of magnetic material and state its two properties. *[CBSE Delhi 2012]*

Ans. The material having positive and small susceptibility is paramagnetic material.

Properties

(*i*) They have tendency to move from a region of weak magnetic field to strong magnetic field, *i.e.*, they get weakly attracted to a magnet.

(*ii*) When a paramagnetic material is placed in an external field the field lines get concentrated inside the material, and the field inside is enhanced.

Q. 2. The susceptibility of a magnetic material is -2.6×10^{-5}. Identify the type of magnetic material and state its two properties. [*CBSE Delhi 2012*]

Ans. The magnetic material having negative susceptibility is diamagnetic in nature.

Properties:

(*i*) This material has + ve but low relative permeability.

(*ii*) They have the tendency to move from stronger to weaker part of the external magnetic field.

Q. 3. A magnetic needle free to rotate in a vertical plane parallel to the magnetic meridian has its north tip down at 60° with the horizontal. The horizontal component of the earth's magnetic field at the place is known at to be 0.4 G. Determine the magnitude of the earth's magnetic field at the place. [*CBSE Delhi 2011*]

Ans. Angle of dip, $\theta = 60°$

$$H = 0.4 \text{ G} = 0.4 \times 10^{-4} \text{ T}$$

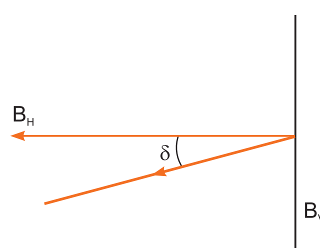
If B_e is earth's magnetic field, then

$$H = B_e \cos\theta.$$

$$\Rightarrow \quad B_e = \frac{H}{\cos\theta} = \frac{0.4\times10^{-4}\text{T}}{\cos 60°} = \frac{0.4\times10^{-4}\text{T}}{0.5} = 0.8\times10^{-4} \text{ T} = \mathbf{0.8\ G}$$

Q. 4. A compass needle, free to turn in a vertical plane orients itself with its axis vertical at a certain place on the earth. Find out the values of (*i*) horizontal component of earth's magnetic field and (*ii*) angle of dip at the place. [*CBSE Delhi 2013*]

Ans. If compass needle orients itself with its axis vertical at a place, then



(*i*) $B_H = 0$ because $B_V = |B|$

(*ii*) $\tan\delta = \dfrac{B_V}{B_H} = \infty$

$\Rightarrow$ Angle of dip $\delta = 90°$,

Concept: It is possible only on magnetic north or south poles.

Q. 5. Write two properties of a material suitable for making (*a*) a permanent magnet, and (*b*) an electromagnet. [*CBSE (AI) 2017*]

Ans. (*a*) Two properties of material used for making permanent magnets are

(*i*) High coercivity (*ii*) High retentivity

(*iii*) High permeability

(*b*) Two properties of material used for making electromagnets are

(*i*) High permeability (*ii*) Low coercivity

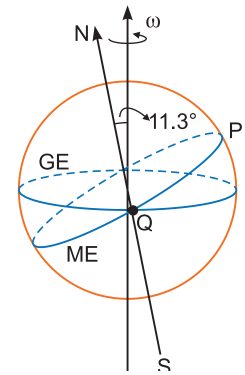
(*iii*) Low retentivity

Q. 6. From molecular view point, discuss the temperature dependence of susceptibility for diamagnetism, paramagnetism and ferromagnetism.

Ans. Diamagnetism is due to orbital motion of electrons developing magnetic moments opposite to applied field and hence is not much affected by temperature.

Paramagentism and ferromagnestism is due to alignments of atomic magnetic moments in the direction of the applied field. As temperature increases, this alignment is disturbed and hence susceptibilities of both decrease as temperature increases.

Q. 7. Consider the plane *S* formed by the dipole axis and the axis of earth. Let *P* be point on the magnetic equator and in *S*. Let *Q* be the point of intersection of the geographical and magnetic equators. Obtain the declination and dip angles at *P* and *Q*.



Ans. In following figure:

(*i*) *P* is in *S* (needle will point both north)

Declination = 0

P is also on magnetic equator.

∴ Dip = 0°

(*ii*) *Q* is on magnetic equator.

∴ Dip = 0°

but declination = 11.3

Q. 8. What is the basic difference between the atom and molecule of a diamagnetic and a paramagnetic material? Why are elements with even atomic number more likely to be diamagnetic?

Ans. Atoms/molecules of a diamagnetic substance contain even number of electrons and these electrons form the pairs of opposite spin; while the atoms/molecules of a paramagnetic substance have excess of electrons spinning in the same direction.

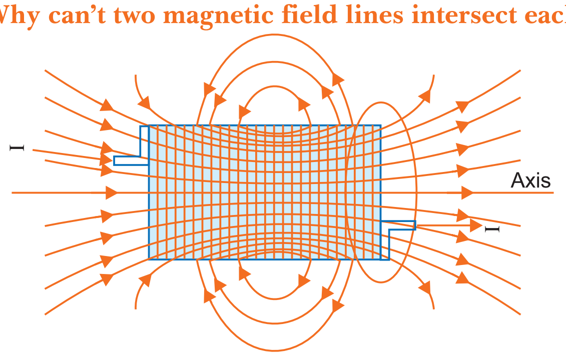
The elements with even atomic number Z has even number of electrons in its atoms/molecules, so they are more likely to form electrons pairs of opposite spin and hence more likely to be diamagnetic.

Short Answer Questions–II [3 marks]

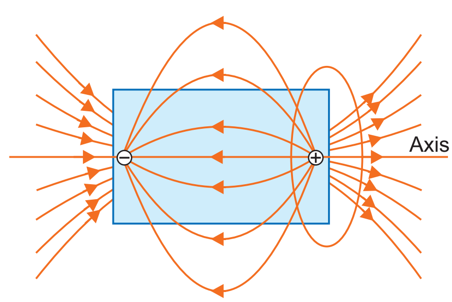
Q. 1. Depict the field-line pattern due to a current carrying solenoid of finite length.

(*i*) In what way do these lines differ from those due to an electric dipole?

(*ii*) Why can't two magnetic field lines intersect each other? [*CBSE (F) 2009*]



Field lines of a current carrying solenoid



Field lines of an electric dipole

Ans. (*i*) **Difference:** Field lines of a solenoid form continuous current loops, while in the case of an electric dipole the field lines begin from a positive charge and end on a negative charge or escape to infinity.

(*ii*) Two magnetic field lines cannot intersect because at the point of intersection, there will be two directions of magnetic field which is impossible.

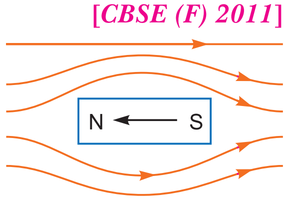
Q. 2. Explain the following:

(*i*) Why do magnetic field lines form continuous closed loops?

(*ii*) Why are the field lines repelled (expelled) when a diamagnetic material is placed in an external uniform magnetic field? [*CBSE (F) 2011*]

Ans. (*i*) Magnetic lines of force form continuous closed loops because a magnet is always a dipole and as a result, the net magnetic flux of a magnet is always zero.

(*ii*) When a diamagnetic substance is placed in an external magnetic field, a feeble magnetism is induced in opposite direction. So, magnetic lines of force are repelled.



Q. 3. (*i*) **Mention two properties of soft iron due to which it is preferred for making an electromagnet.**

(*ii*) **State Gauss's law in magnetism. How is it different from Gauss's law in electrostatics and why?** [*CBSE South 2016*]

Ans. (*i*) Low coercivity and high permeability

(*ii*) **Gauss's Law in magnetism:** The net magnetic flux through any closed surface is zero.

$$\oint B.ds = 0$$

Gauss's Law in electrostatics: The net electric flux through any closed surface is $\frac{1}{\varepsilon_0}$ times the net charge enclosed by the surface.

$$\oint E.ds = \frac{q}{\varepsilon_0}$$

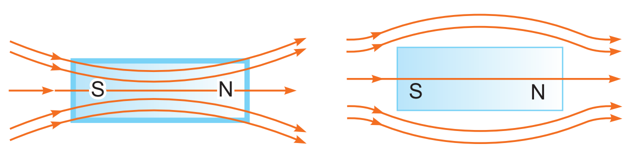
The difference between the Gauss's law of magnetism and that for electrostatic is a reflection of the fact that magnetic monopole do not exist *i.e.*, magnetic poles always exist in pairs.

Q. 4. **Show diagrammatically the behaviour of magnetic field lines in the presence of (*i*) paramagnetic and (*ii*) diamagnetic substances. How does one explain this distinguishing feature?**

OR [*CBSE (AI) 2014*]

Draw the magnetic field lines distinguishing between diamagnetic and paramagnetic materials. Give a simple explanation to account for the difference in the magnetic behaviour of these materials. [*CBSE Bhubaneshwar 2015, Central 2016*]

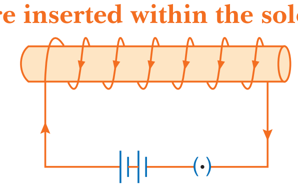
Ans.



Paramagnetic substance (i) Diamagnetic substance (ii)

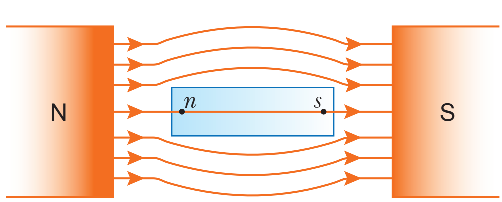
- A paramagnetic material tends to move from weaker field to stronger field regions of the magnetic field. So, the number of lines of magnetic field increases when passing through it. Magnetic dipole moments are induced in the direction of magnetic field. Paramagnetic materials has a small positive susceptibility.
- A diamagnetic material tends to move from stronger field to weaker field region of the magnetic field. So, the number of lines of magnetic field passing through it decreases. Magnetic dipole moments are induced in the opposite direction of the applied magnetic field. Diamagnetic materials has a negative susceptibility in the range $(-1 \leq \chi < 0)$.

Q. 5. **Draw the magnetic field lines for a current carrying solenoid when a rod made of (*a*) copper, (*b*) aluminium and (*c*) iron are inserted within the solenoid as shown.**

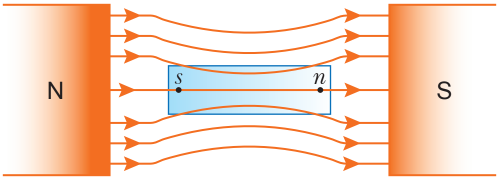


[*CBSE Sample Paper 2018*]

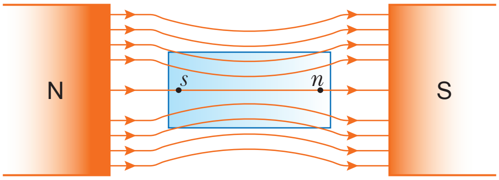
Ans. (*a*) When a bar of diamagnetic material (copper) is placed in an external magnetic field, the field lines are repelled or expelled and the field inside the material is reduced.



(*b*) When a bar of paramagnetic material (Aluminium) is placed in an external field, the field lines gets concentrated inside the material and the field inside is enhanced.



(*c*) When a ferromagnetic material (Iron) is placed in an internal magnetic field, the field lines are highly concentrated inside the material.



Q. 6. In what way is Gauss's law in magnetism different from that used in electrostatics? Explain briefly.

The Earth's magnetic field at the equator is approximately 0.4 G. Estimate the Earth's magnetic dipole moment. Given: Radius of the Earth = 6400 km. [*CBSE Patna 2015*]

Ans. As we know that

Isolated positive or negative charge exists freely. So, Gauss's law states that $\oint \vec{E} \cdot d\vec{S} = \frac{1}{\varepsilon_0}[q]$

Isolated magnetic poles do not exist. So, Gauss's law states that

$$\oint \vec{B} \cdot \overrightarrow{dS} = 0$$

Magnetic field intensity at the equator is

$$B = \frac{\mu_0}{4\pi} \cdot \frac{m}{R^3} = 10^{-7} \frac{m}{R^3}$$

$$\therefore \quad m = 10^7 \, . \, BR^3$$

$$= 10^7 \times 0.4 \times 10^{-4} \times (6400 \times 10^3)^3$$

$$= \mathbf{1.05 \times 10^{23} \ Am^2}$$

Q. 7. A bar magnet of magnetic moment 6 J/T is aligned at 60° with a uniform external magnetic field of 0·44 T. Calculate (*a*) the work done in turning the magnet to align its magnetic moment (*i*) normal to the magnetic field, (*ii*) opposite to the magnetic field, and (*b*) the torque on the magnet in the final orientation in case (*ii*). [*CBSE Examination Paper 2018*]

Ans. (*a*) Work done $= mB(\cos\theta_1 - \cos\theta_2)$

(*i*) $\theta_1 = 60°, \theta_2 = 90°$

$\therefore$ Work done $= mB(\cos 60° - \cos 90°)$

$$= mB\left(\frac{1}{2} - 0\right) = \frac{1}{2} mB$$

$$= \frac{1}{2} \times 6 \times 0.44 \text{ J} = \mathbf{1.32 \ J}$$

(*ii*) $\theta_1 = 60°, \theta_2 = 180°$

$\therefore$ Work done $= mB(\cos 60° - \cos 180°)$

$$= mB\left(\frac{1}{2} - (-1)\right) = \frac{3}{2} mB$$

$$= \frac{3}{2} \times 6 \times 0.44 \text{ J} = \mathbf{3.96 \ J}$$

(*b*) Torque = $|\vec{m} \times \vec{B}| = mB \sin\theta$

For $\theta = 180°$ and B = 0.44 T we have

Torque = 6 × 0.44 sin 180° = **0**

Q. 8. (*a*) An iron ring of relative permeability μ_r has windings of insulated copper wire of *n* turns per metre. When the current in the windings is *I*, find the expression for the magnetic field in the ring.

(*b*) The susceptibility of a magnetic material is 0.9853. Identify the type of magnetic material. Draw the modification of the field pattern on keeping a piece of this material in a uniform magnetic field. **[*CBSE Examination Paper 2019*]**

Ans. (*a*) From Ampere's circuital law, we have,

$$\oint \vec{B}.\vec{dl} = \mu_0 \mu_r I_{enclosed} \quad ...(i)$$

For the field inside the ring, we can write

$$\oint \vec{B}.\vec{dl} = \oint Bdl = B.2\pi r \quad (r = \text{radius of the ring})$$

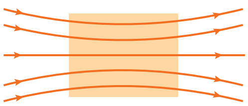
Also, $I_{enclosed} = (2\pi rn)I$

$\therefore \quad B.2\pi r = \mu_0 \mu_r.(n.2\pi r)I$ [Using equation (*i*)]

$\therefore B = \mu_0 \mu_r.nI$

(*b*) The material is paramagnetic.

The field pattern gets modified as shown in the figure below.



Q. 9. (*a*) Show that the time period (*T*) of oscillations of a freely suspended magnetic dipole of magnetic moment (*m*) in a uniform magnetic field (*B*) is given by $T = 2\pi\sqrt{\frac{I}{mB}}$, where *I* is a moment of inertia of the magnetic dipole.

(*b*) Identify the following magnetic materials:

(*i*) A material having susceptibility $(\chi_m) = -0.00015$

(*ii*) A material having susceptibility $(\chi_m) = 10^{-5}$ **[*CBSE 2019 (55/3/1)*]**

Ans. (*a*) Let us consider a uniform magnetic field $\vec{B}$ exists in the region, in which a magnet of dipole moment $\vec{m}$ is placed. The dipole is making small angle θ with the magnetic field. The torque acts on the magnet is given by

$\vec{\tau} = -mB\sin\theta$ (Restoring torque)

$= -mB\theta$ ($\because \theta$ in small) ...(*i*)

Also the torque on dipole try to restore its initial position *i.e.*, along the direction of magnetic field. (I = moment of inertia)

In equilibrium

$$I\frac{d^2\theta}{dt^2} = -mB\sin\theta \quad ...(ii)$$

Negative sign implies that restoring torque is in opposition to deflecting torque.

$$\frac{d^2\theta}{dt^2} = \frac{-mB}{I}\theta \quad ...(iii)$$

Comparing with equation of angular SHM

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

We have

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

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

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

(*b*) (*i*) Diamagnetic substance. (*ii*) Paramagnetic substance.

Q. 10. Write three points of differences between para-, dia- and ferro- magnetic materials, giving one example for each. **[*CBSE 2019 (55/1/1)*]**

Ans.

	Diamagnetic	Paramagnetic	Ferromagnetic
1	$-1 \le \chi < 0$	$0 < \chi < \varepsilon$	$x \gg 1$
2	$0 \le \mu_r < 1$	$1 \le \mu_r < (1 + \varepsilon)$	$\mu_r \gg 1$
3	$\mu < \mu_0$	$\mu > \mu_0$	$\mu \gg \mu_0$

Where ε is any positive constant.

Examples:

Diamagnetic materials: Bi, Cu, Pb, Si, water, NaCl, Nitrogen (at STP)

Paramagnetic materials: Al, Na, Ca, Oxygen (at STP), Copper chloride

Ferromagnetic materials: Fe, Ni, Co, Alnico. (*Any one*)

Q. 11. (*a*) State Gauss's law for magnetism. Explain its significance. **[*CBSE 2019 (55/1/1)*]**

(*b*) Write the four important properties of the magnetic field lines due to a bar magnet.

Ans. (*a*) Gauss's law for magnetism states that "The total flux of the magnetic field, through any closed surface, is always zero."

Alternatively

$$= \oint_s \vec{B}.\vec{d}s = 0$$

This law implies that magnetic monopoles do not exist. Also magnetic field lines form closed loops.

(*b*) Four properties of magnetic field lines

(*i*) Magnetic field lines always form continuous closed loops.

(*ii*) The tangent to the magnetic field line at a given point represents the direction of the net magnetic field at that point.

(*iii*) The larger the number of field lines crossing per unit area, the stronger is the magnitude of the magnetic field.

(*iv*) Magnetic field lines do not intersect.

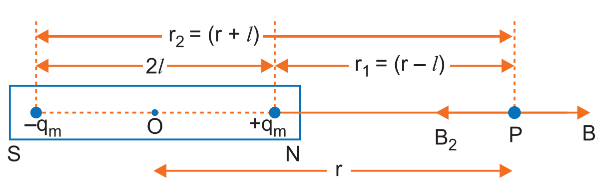
Long Answer Questions [5 marks]

Q. 1. Derive an expression for magnetic field intensity due to a magnetic dipole at a point on its axial line.

Ans. Consider a magnetic dipole (or a bar magnet) *SN* of length 2*l* having south pole at *S* and north pole at *N*. The strength of south and north poles are $-q_m$ and $+q_m$ respectively.

Magnetic moment of magnetic dipole $m = q_m 2l$, its direction is from *S* to *N*.

Consider a point *P* on the axis of magnetic dipole at a distance *r* from mid point *O* of dipole.



The distance of point *P* from *N*-pole,

$r_1 = (r - l)$

The distance of point P from S-pole, $r_2 = (r + l)$

Let B_1 and B_2 be the magnetic field intensities at point P due to north and south poles respectively. The directions of magnetic field due to north pole is away from N-pole and due to south pole is towards the S-pole. Therefore,

$$B_1 = \frac{\mu_0}{4\pi}\frac{q_m}{(r-l)^2} \text{ from } N \text{ to } P \text{ and } B_2 = \frac{\mu_0}{4\pi}\frac{q_m}{(r+l)^2} \text{ from } P \text{ to } S$$

Clearly, the directions of magnetic field strengths $\vec{B}_1$ and $\vec{B}_2$ are along the same line but opposite to each other and $B_1 > B_2$.

Therefore, the resultant magnetic field intensity due to bar magnet has magnitude equal to the difference of B_1 and B_2 and direction from N to P.

$$i.e., \qquad B = B_1 - B_2 = \frac{\mu_0}{4\pi}\frac{q_m}{(r-l)^2} - \frac{\mu_0}{4\pi}\frac{q_m}{(r+l)^2}$$

$$= \frac{\mu_0}{4\pi} q_m\left[\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2}\right] = \frac{\mu_0}{4\pi} q_m\left[\frac{(r+l)^2-(r-l)^2}{(r^2-l^2)^2}\right]$$

$$= \frac{\mu_0}{4\pi} q_m\left[\frac{4rl}{(r^2-l^2)^2}\right] = \frac{\mu_0}{4\pi}\frac{2(q_m 2l)r}{(r^2-l^2)^2}$$

But $q_m\, 2l = m$ (magnetic dipole moment)

$$\therefore \qquad B = \frac{\mu_0}{4\pi}\frac{2m.r}{(r^2-l^2)^2} \qquad \ldots(1)$$

If the bar magnet is very short and point P is far away from the magnet, the $r >> l$, therefore, equation (1) takes the form

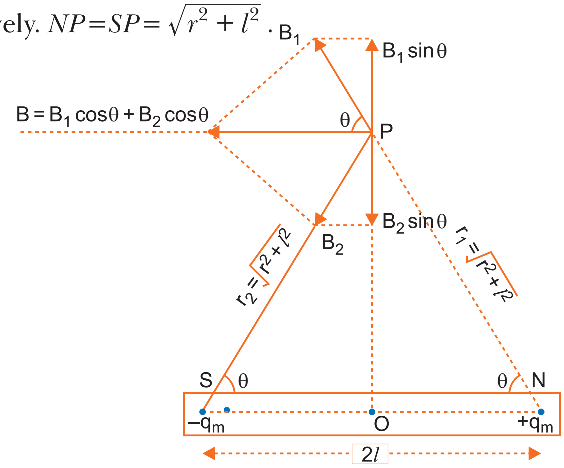
$$B = \frac{\mu_0}{4\pi}\frac{2mr}{r^4}$$

$$\text{or} \qquad \boxed{B = \frac{\mu_0}{4\pi}\frac{2m}{r^3}} \qquad \ldots(2)$$

This is the expression for magnetic field intensity at axial position due to a short bar magnet.

Q. 2. Derive an expression for magnetic field intensity due to a magnetic dipole at a point lies on its equatorial line.

Ans. Consider a point P on equatorial position (or broad side on position) of short bar magnet of length $2l$, having north pole (N) and south pole (S) of strength $+q_m$ and $-q_m$ respectively. The distance of point P from the mid point (O) of magnet is r. Let B_1 and B_2 be the magnetic field intensities due to north and south poles respectively. $NP = SP = \sqrt{r^2 + l^2}$.



$$\vec{B}_1 = \frac{\mu_0}{4\pi}\frac{q_m}{r^2+l^2} \text{ along } N \text{ to } P$$

$$\vec{B}_2 = \frac{\mu_0}{4\pi}\frac{q_m}{r^2+l^2} \text{ along } P \text{ to } S$$

Clearly, magnitudes of $\vec{B}_1$ and $\vec{B}_2$ are equal

$$i.e., \qquad |\vec{B}_1| = |\vec{B}_2| \quad \text{or} \quad B_1 = B_2$$

To find the resultant of $\vec{B}_1$ and $\vec{B}_2$, we resolve them along and perpendicular to magnetic axis SN. Components of $\vec{B}_1$ along and perpendicular to magnetic axis are $B_1 \cos\theta$ and $B_2 \sin\theta$ respectively.

Components of $\vec{B}_2$ along and perpendicular to magnetic axis are $B_2 \cos\theta$ and $B_2 \sin\theta$ respectively.

Clearly, components of $\vec{B}_1$ and $\vec{B}_2$ perpendicular to axis SN. $B_1 \sin\theta$ and $B_2 \sin\theta$ are equal in magnitude and opposite in direction and hence, cancel each other; while the components of $\vec{B}_1$

and $\vec{B}_2$ along the axis are in the same direction and hence, add up to give to resultant magnetic field parallel to the direction $\overrightarrow{NS}$.

$\therefore$ Resultant magnetic field intensity at *P*.

$$B = B_1 \cos\theta + B_2 \cos\theta$$

But $$B_1 = B_2 = \frac{\mu_0}{4\pi}\frac{q_m}{r^2+l^2} \text{ and } \cos\theta = \frac{ON}{PN} = \frac{l}{\sqrt{r^2+l^2}} = \frac{l}{(r^2+l^2)^{1/2}}$$

$$\therefore \quad B = 2B_1\cos\theta = 2\times\frac{\mu_0}{4\pi}\frac{q_m}{(r^2+l^2)}\times\frac{l}{(r^2+l^2)^{1/2}} = \frac{\mu_0}{4\pi}\frac{2q_m l}{(r^2+l^2)^{3/2}}$$

But $q_m.2l = m$, magnetic moment of magnet

$$\therefore \quad B = \frac{\mu_0}{4\pi}\frac{m}{(r^2+l^2)^{3/2}} \qquad \ldots(1)$$

If the magnet is very short and point *P* is far away, we have $l << r$; so l^2 may be neglected as compared to r^2 and so equation (1) takes the form

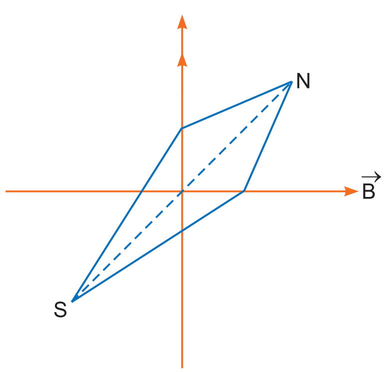
$$\boxed{B = \frac{\mu_0}{4\pi}\frac{m}{r^3}} \qquad \ldots(2)$$

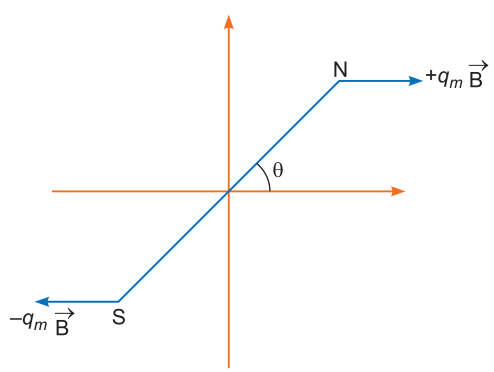
This is expression for magnetic field intensity at equatorial position of the magnet.

Q. 3. (*a*) A small compass needle of magnetic moment '*m*' is free to turn about an axis perpendicular to the direction of uniform magnetic field '*B*'. The moment of inertia of the needle about the axis is '*I*'. The needle is slightly disturbed from its stable position and then released. Prove that it executes simple harmonic motion. Hence deduce the expression for its time period.

(*b*) A compass needle, free to turn in a vertical plane orients itself with its axis vertical at a certain place on the earth. Find out the values of (*i*) horizontal component of earth's magnetic field and (*ii*) angle of dip at the place. **[*CBSE Delhi 2013*]**

Ans. (*a*) If magnetic compass of dipole moment $\vec{m}$ is placed at angle θ in uniform magnetic field, and released it experiences a restoring torque.





Restoring torque, $\vec{\tau}$ = – magnetic force × perpendicular distance

$$= -q_m B\,.\,(2a\sin\theta),$$

$\tau = -mB.\sin\theta$, where q_m = pole strength, $m = q_m.2a$ (magnetic moment)

Negative sign shows that restoring torque acts in the opposite direction to that of defecting torque.

In equilibrium, the equation of motion,

$$\Rightarrow \quad I\frac{d^2\theta}{dt^2} = -mB\theta \qquad \text{(For small angle } \sin\theta \approx \theta\text{)}$$

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

Since $$\frac{d^2\theta}{dt^2} \propto \theta \Rightarrow \frac{d^2\theta}{dt^2} = -\omega^2\theta$$

It represents the simple harmonic motion with angular frequency

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

(*b*) If compass needle orients itself with its axis vertical at a place, then

(*i*) $B_H = 0$ because $B_V = |B|$

(*ii*) $\tan\delta = \frac{B_V}{B_H} = \infty$

Angle of dip $\delta = 90°$,

Concept: It is possible only on magnetic north or south poles.

Self-Assessment Test

Time allowed: 1 hour **Max. marks: 30**

1. Choose and write the correct option in the following questions. **(3 × 1 = 3)**

(*i*) A permanent magnet

(*a*) attracts all substances

(*b*) attracts only ferromagnetic substances

(*c*) attracts ferromagnetic substances and repels all others

(*d*) attracts some substances and repels others

(*ii*) If a diamagnetic substance is brought near the north or the south pole of a bar magnet, it is

(*a*) repelled by the north pole and attracted by the south pole

(*b*) attracted by the north pole and repelled by the south pole

(*c*) attracted by both the poles

(*d*) repelled by both the poles

(*iii*) A bar magnet having a magnetic moment of 2×10^4 J T^{-1} is free to rotate in a horizontal plane. A horizontal magnetic field $B = 6 \times 10^{-4}$ T exists in the space. The work done in taking the magnet slowly from a direction parallel to the field to a direction 60° from the field is

(*a*) 12 J (*b*) 6 J (*c*) 2 J (*d*) 0.6 J

2. Fill in the blanks. **(2 × 1 = 2)**

(*i*) The temperature of transition from ferromagnetic to paramagnetism is called the ________.

(*ii*) Substances which at room temperature retain their ferromagnetic property for a long period of time are called ____________.

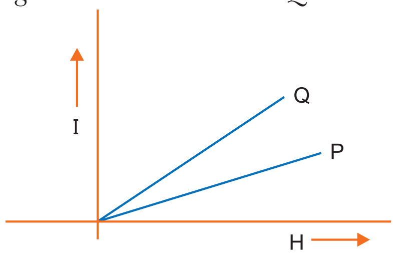
3. (*i*) Name the three elements of the earth's magnetic field.

(*ii*) Where on the surface of the earth is the vertical component of the earth's magnetic field zero? **1**

4. The susceptibility of a magnetic material is 1.9×10^{-5}. Name the type of magnetic materials it represents. **1**

5. Depict the behaviour of magnetic field lines in the presence of a diamagnetic material. **1**

6. The given graph shows the variation of intensity of magnetisation *I* with strength of applied magnetic field *H* for two magnetic materials *P* and *Q*.



(*i*) Identify the materials *P* and *Q*.

(*ii*) For material *P*, plot the variation of intensity of magnetisation with temperature. Justify your answer. **2**

7. Explain the following:

(*i*) Why do magnetic lines of force form continuous closed loops?

(*ii*) Why are the field lines repelled (expelled) when a diamagnetic material is placed in an external uniform magnetic field? **2**

8. The relative magnetic permeability of a magnetic material is 800. Identify the nature of magnetic material and state its two properties. **2**

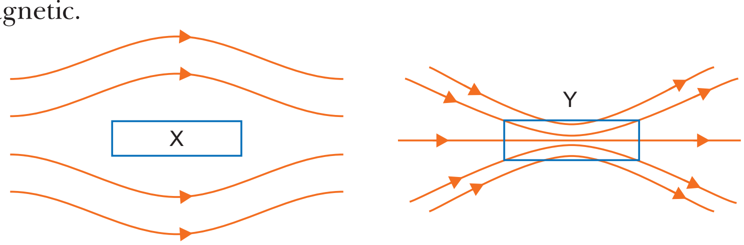
9. A magnetic needle free to rotate in a vertical plane parallel to the magnetic meridian has its north tip down at 60° with the horizontal. The horizontal component of the earth's magnetic field at the place is known at to be 0.4 G. Determine the magnitude of the earth's magnetic field at the place. **2**

10. A closely wound solenoid of 2000 turns and cross sectional area 1.6×10^{-4} m^2 carrying a current of 4.0 A is suspended through its centre allowing it to turn in a horizontal plane. Find (*i*) the magnetic moment associated with the solenoid, (*ii*) magnitude and direction of the torque on the solenoid if a horizontal magnetic field of 7.5×10^{-2} T is set up at an angle of 30° with the axis of the solenoid. **3**

11. A uniform conducting wire of length 12*a* and resistance *R* is wound up as a current carrying coil in the shape of (*i*) an equilateral triangle of side *a*; (*ii*) a square of sides *a* and, (*iii*) a regular hexagon of sides *a*. The coil is connected to a voltage source V_0. Find the magnetic moment of the coils in each case. **3**

12. (*i*) How does angle of dip change as one goes from magnetic pole to magnetic equator of the Earth?

(*ii*) A uniform magnetic field gets modified as shown below when two specimens *X* and *Y* are placed in it. Identify whether specimens *X* and *Y* are diamagnetic, paramagnetic or ferromagnetic.



(*iii*) How is the magnetic permeability of specimen *X* different from that of specimen *Y*? **3**

13. (*a*) Draw the magnetic field lines due to a circular loop of area *A* carrying current *I*. Show that it acts as a bar magnet of magnetic moment $\vec{m} = I\vec{A}$.

(*b*) Derive the expression for the magnetic field due to a solenoid of length '2*l*', radius '*a*' having '*n*' number of turns per unit length and carrying a steady current '*I*' at a point on the axial line, distant '*r*' from the centre of the solenoid. How does this expression compare with the axial magnetic field due to a bar magnet of magnetic moment '*m*'? **5**

Answers

1. (*i*) (*b*) (*ii*) (*d*) (*iii*) (*b*)

2. (*i*) curie temperature (*ii*) permanent magnets

9. B_e = 0.8 G **10.** Magnetic moment = 1.28 A–m^2, Torque = 0.048 N–m

11. (*i*) $M_1 = \sqrt{3}\ a^2 I$ (*ii*) $M_2 = 3a^2 I$ (*iii*) $M_3 = 3\sqrt{3}\ a^2 I$