5 Magnetism and Matter

Facts that Matter

- The magnetism and magnetic force are basically the effects produced by electrical charges in motion. Long before the Christian era it was established that pieces of iron ore [Fe_3O_4] magnetite found in Magnesia have the property of attracting certain other substances and pointing in north-south direction when suspended freely. These pieces are called natural magnets and the phenomenon magnetism.

• Properties of Magnets

(*i*) **Attractive Property.** When a magnet is dipped into iron filings, it is found that the concentration of iron filings is more near to its ends. The regions in a magnet where this concentration or attracting power is maximum are called *poles* while the places of minimum attracting power is called the neutral region.

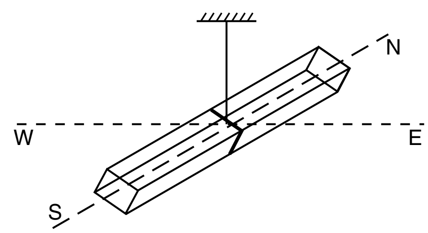

Fig. 5.1

(*ii*) **Directive Property.** When a magnet is suspended, its length becomes parallel to north-south direction of earth. The end pointing north is called north pole and the other end pointing south is called south pole. [Fig. 5.1]

• Magnetic Axis and Magnetic Meridian

The line joining the two poles of a magnet is called *magnetic axis* and the vertical plane passing through the axis of a freely suspended or pivoted magnet is called *magnetic meridian*. (Fig. 5.2)

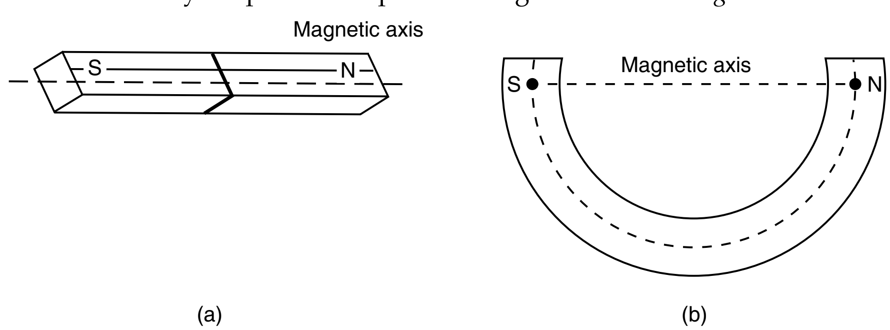

Fig. 5.2

• Poles Exist in Pairs

In a magnet there are two poles of equal strength and opposite nature. If a magnet is broken into pieces, each piece behaves as a magnet having two poles. Thus monopole of a magnet does not exist.

- **Consequent-pole and No-pole**

Though monopole does not exist and a magnet has two poles of same strength and of opposite nature; but there can be magnets with no pole for example a magnetised ring called toroid or solenoid of infinite length has properties of a magnet but not poles. [Fig. 5.3]

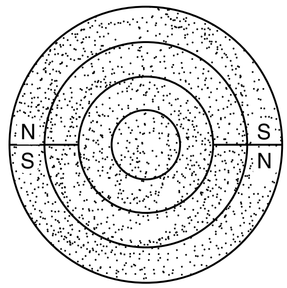

Fig. 5.3

There can be magnets with two similar poles. It is due to faulty magnetisation of a bar. Temporarily identical poles at the two ends with an opposite pole of double strength at the middle of the bar (called consequent pole) are developed. (Fig. 5.4)

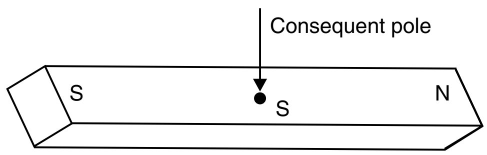

Fig. 5.4

- **Repulsion is a Sure Test of Polarity**

A pole of a magnet attracts the opposite pole while repels similar pole. But a pole also attracts iron bar, hence it cannot be decided that which one is magnet. In other hand a pole repels only a pole (similar) thus both are the magnets.

- **Pole Strength of a Magnet**

It is dipole moment per unit length of the magnet. It depends on the nature of the material of the magnet, state of magnetisation and area of cross-section. It is a scalar quantity. Its unit is Am (ampere metre).

- **Magnetic Dipole Moment**

It is product of the pole strength of either pole and length of the magnet. It is a vector quantity its direction is from south to north pole.

$$\vec{M} = 2\,m\vec{l}$$

Where m is pole strength and it is the length of the magnet. Its unit Am^2 or JT^{-1}.

- **Magnetic Field Lines**

Michael Faraday introduced the concept of field lines. According to him a field line is an imaginary curve; the tangent to which at a point gives the direction of magnetic field at that point.

  - Outside a magnet field lines are from north to south pole. They appear originated from north pole and terminated into south pole.

- Field lines never intersect each other.
- These are closed curve. They appear to converge or diverge at poles.
- The number of magnetic field lines originating or terminating on a pole is directly proportional to the pole strength.
- Magnetic field lines have a tendency to contract longitudinally between opposite poles and repel each other laterally between similar poles.
- Number of field lines per unit area, normal to the area at a point, represents the magnitude of magnetic field at that point.
- Magnetic field lines emanate from or enter in the surface of a magnetic material at any angle.
- Field lines exist inside every magnetised material.

A few of the magnetic field line patterns are given below:

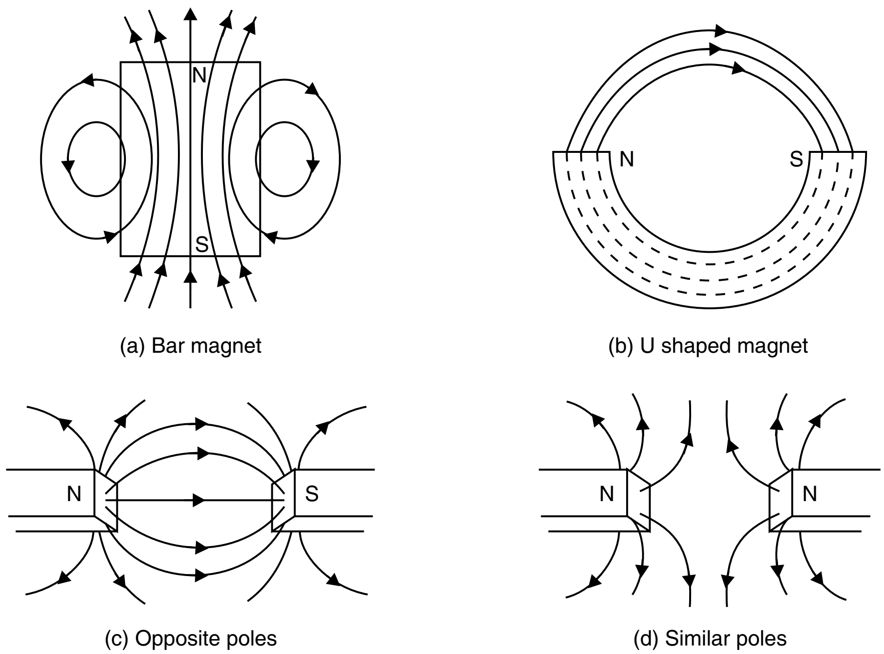

Fig. 5.5

• Magnetic Force Between Two Poles

The magnetic force between two poles of strength m_1 and m_2 separated by distance r is given as

$$F = \frac{\mu_o}{4\pi}\frac{m_1 m_2}{r^2}$$

In vector form,

$$\vec{F} = \frac{\mu_o}{4\pi}\frac{m_1 m_2 \vec{r}}{|\vec{r}|^3}$$

• Magnetic Field Intensity

The magnetic field intensity is the force experienced by a magnetic pole of strength unity.

If a pole of strength m_0 experience a force $F = \frac{\mu_o}{4\pi}\frac{mm_0}{r^2}$ due the pole of strength m at a distance r, then the magnetic field intensity

$$B = \frac{F}{m_0} = \frac{\mu_o}{4\pi}\frac{mm_0}{r^2}\Big/ m_0$$

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

In vector form,

$$\vec{B} = \frac{\mu_0\, m\, \vec{r}}{4\pi|\vec{r}|^3}.$$

- **Magnetic Field Due to a Dipole**

(*i*) **At axial point.** Let there be magnetic dipole of dipole movement $\vec{P} = m(\vec{Il})$ and a point P at the distance of r from the mild point of the dipole where magnetic field intensity is to be determined. The magnetic field intensity due to north pole at P,

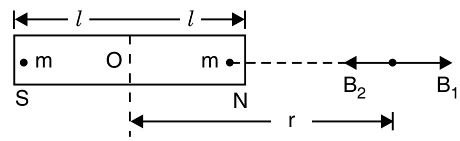

Fig. 5.6

$$B_1 = \frac{\mu_0}{4\pi}\frac{m}{(r-l)^2}(\vec{OP})$$

and magnetic field due to south pole

at P,
$$B_2 = \frac{\mu_0}{4\pi}\frac{m}{(r+l)^2}(\vec{OP})$$

The net magnetic field at P,

$$\vec{B} = \vec{B}_1 + \vec{B}_2$$

or
$$\vec{B} = \frac{\mu_0}{4\pi}m\left[\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2}\right](\vec{OP})$$

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

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

$$= \frac{\mu_0 2\vec{M}(r)}{4\pi(r^2-l^2)^2}(\vec{OP})$$

$\because \quad r >> l \quad \therefore \quad l^2$ can be neglected

$$\therefore \quad \vec{B} = \frac{\mu_0}{4\pi}\frac{2M(r)}{(r^4)}(\vec{OP})$$

$$\text{or} \quad \vec{B} = \frac{\mu_0}{4\pi}\frac{2\vec{M}}{r^3}$$

(*ii*) **At equatorial point.** The magnetic field at P due to a dipole of dipole moment $\vec{M} = (2l)\vec{m}$ at point P at the distance of l_1 from its mid point at equatorial position is to be determined the magnetic field due to north pole,

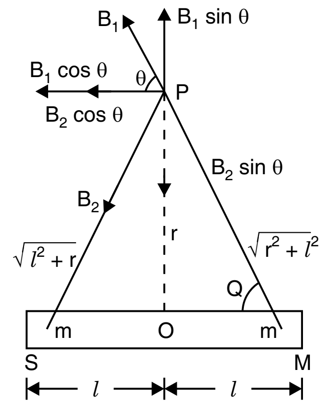

Fig. 5.7

$$B_1 = \frac{\mu_0}{4\pi}\frac{m}{\left(\sqrt{r^2+l^2}\right)^2}$$

and the magnetic field due to south pole at P,

$$B_2 = \frac{\mu_0}{4\pi}\frac{m}{\sqrt{r^2+l^2}}$$

The B_1 and B_2 can be resolved into two rectangular components. The components $B_1 \sin\theta$ and $B_2 \sin\theta$ being equal and opposite candle each other. Therefore net field at P,

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

$$\because \quad |\vec{B}_1| = |\vec{B}_2|$$

$$\therefore \quad \vec{B} = 2\vec{B}_1 \cos\theta$$

$$= 2\,\frac{\mu_o}{4\pi}\cdot\frac{m}{(r^2+l^2)^2}\,.\cos\theta$$

$$= \frac{2\mu_0 m\,(l)}{4\pi\,(r^2+l^2)\sqrt{(r^2+l^2)}}$$

$$\text{or} \quad B = \frac{\mu_0|\vec{M}|}{4\pi\,(r^2+l^2)^{3/2}}$$

If $r >> l$ then l^2 can be neglected, then

$$|\vec{B}| = \frac{\mu_0|\vec{M}|}{4\pi\, r^3}$$

- **Dipole in Uniform Magnetic Field**

When a magnetic dipole of dipole moment $\vec{M} = 2\vec{ml}$ is placed in uniform magnetic field of strength $\vec{B}$, its north pole experiences a force $m\vec{B}$ in the direction of field and south pole experiences the same force in opposite direction of field. As a result no net force acts on the dipole, but due to this pair of force a torque acts on the dipole. The torque is given by,

$$\tau = \text{force} \times \perp \text{distance}$$
$$= mB\ 2l \sin\theta$$
$$= |\vec{M}|\ B \sin\theta$$

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

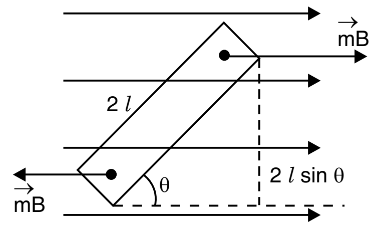

Fig. 5.8

The direction of the torque is perpendicular to the plane containing $\vec{M}$ and $\vec{B}$.

- **Work Done in Rotating the Dipole in Magnetic Field**

When a magnetic dipole is rotated in uniform magnetic field, the work done for small angular displacement $d\theta$,

$$dW = \tau \,.\, d\theta$$
$$= MB \sin\theta \,.\, d\theta$$

And net work done in rotating the dipole from θ_1 to θ_2

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

If $\theta_1 = 0$ the position of stable equilibrium and $\theta_2 = \theta$, then work done

$$W = MB[1 - \cos\theta]$$

- **Potential Energy of the Magnetic Dipole**

The potential energy of the dipole is defined as the work done in rotating the dipole from a direction perpendicular to the field to the given direction, *i.e.*,

$$U = W_\theta - W_{90°}$$
$$= MB(1 - \cos\theta) - MB(1 - \cos 90°)$$
$$= MB - MB\cos\theta - MB$$
$$= -MB\cos\theta$$

or $$W = -\vec{M} \,.\, \vec{B}$$

- **Dipole–Dipole Interaction**

(*i*) **When dipoles are along the line joining their centres.** If the opposite poles of two dipoles face each other as shown in Fig. 5.11(*a*), the field due to $\vec{M}_1$ at the position of $\vec{M}_2$,

$$\vec{B}_1 = \frac{\mu_0}{4\pi} \frac{2M_1}{r^3}$$

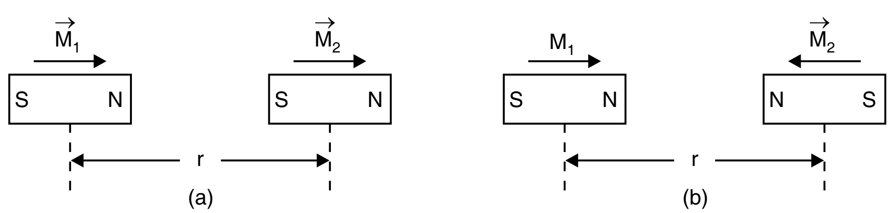

Fig. 5.9

$\therefore$ Torque on $\vec{M}_2$ due to $\vec{M}_1$

$$\tau_2 = \vec{M}_2 \times \vec{B}_1 = 0$$

Similarly, torgue on $\vec{M}_1$ due to $\vec{M}_2$

$$\vec{\tau}_1 = \vec{M}_1 \times \vec{B}_2 = 0$$

But potential energy of $\vec{M}_1$ in the field of $\vec{M}_2$ and of $\vec{M}_2$ in the field of M_1,

$$U = -\vec{M}_2 . \vec{B}_1 = -\frac{\mu_0}{4\pi}\frac{2M_1M_2}{r^3}$$

$$\because \quad F = -\frac{dU}{dr}$$

$\therefore$ Force on $\vec{M}_1$ due to $\vec{M}_2$ or on $\vec{M}_2$ due to $\vec{M}_1$

$$= -\frac{d}{dr}\left[-\frac{\mu_0}{4\pi}\frac{M_1M_2}{r^3}\right]$$

$$= -\frac{\mu_0}{4\pi}\frac{6M_1M_2}{r^3}$$

(*ii*) **When dipoles are perpendicular to the line joining their centres:** If the similar poles of the two dipoles face each other as shown in Fig. 5.10(*a*), the field due to M_1 at the position $\vec{M}_2$,

$$B_1 = \frac{\mu_0 M_1}{4\pi r_3}$$

and field due to $\vec{M}_2$ at position of $\vec{M}_1$,

$$B_2 = \frac{\mu_0 M_2}{4\pi r^3}$$

$\because$ $\vec{B}_1$ is anti-parallel to $\vec{M}_2$ and $\vec{B}_2$ is anti-parallel to $\vec{M}_1$

$\therefore$ Torque on $\vec{M}_1$ due to $\vec{M}_2$ and torque on $\vec{M}_2$ due to M_1

$\tau_1 = \vec{M}_1 \times \vec{B}_2$ and $\tau_2 = \vec{M}_2 \times \vec{B}_1$ respectively will be zero.

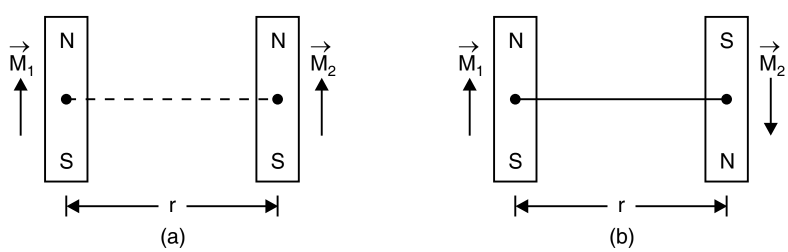

Fig. 5.10

But potential energy of the dipole $\vec{M}_1$ in the field of M_2 or of $\vec{M}_2$ in the field of M_1

$$U = -\vec{M}_2 \cdot \vec{B}_1 = -\vec{M}_1 \cdot \vec{B}_2 \qquad (\theta = 180°)$$

$$= \frac{\mu_0 M_1 M_2}{4\pi r^3}$$

Now

$$F = -\frac{dU}{dr} = -\frac{d}{dr}\left[\frac{\mu_0 M_1 M_2}{4\pi r^3}\right]$$

$$= \frac{\mu_0}{4\pi}\frac{3M_1 M_2}{r^3}$$

(*iii*) **When one dipole is along while the other perpendicular to the line joining their centres**

As shown in the Fig. 5.11 the magnetic field due to $\vec{M}_1$,

$$B_1 = \frac{\mu_0 M_1}{4\pi r^3}$$

and field due to $\vec{M}_2$,

$$B_2 = \frac{\mu_0 2M_1}{4\pi r^3}$$

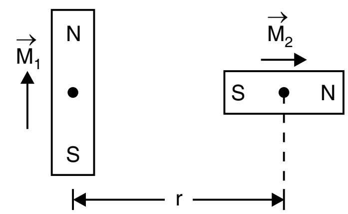

Fig. 5.11

$\vec{M}_2$ is on equatorial position of $\vec{M}_1$ and $\vec{M}_1$ is on end on position of $\vec{M}_2$.

∴ Torque on $\vec{M}_1$ due to $\vec{M}_2$

$$\vec{\tau} = \vec{M}_1 \times \vec{B}_2 = \frac{\mu_0}{4\pi}\frac{2M_1 M_2}{r^3}$$

and potential energy in the field of $\vec{M}_1$

$$U = -\vec{M}_2 \cdot \vec{B}_1$$

$$= 0$$

Let length of the dipole $\vec{M}_2$ is $2l$ so that the field due to $\vec{M}_1$ at south pole and north pole of $\vec{M}_2$ will be respectively,

$$B_S = \frac{\mu_0}{4\pi}\frac{M_1}{(r-l)^3} \text{ opposite to } B_1 \text{ and}$$

$$B_N = \frac{\mu_0}{4\pi}\frac{M_1}{(r+l)^3} \text{ in the direction of } B_1$$

∵ $$F = mB$$

∴ Force on south pole and north pole of M_2, due to field of M_1 will be

$$\vec{F}_s = \frac{\mu_0}{4\pi}\frac{M_1 m}{(r-l)^3} \text{ opposite to } \vec{B}_1,$$

and

$$\vec{F}_N = \frac{\mu_0}{4\pi}\frac{M_1 m}{(r-l)^3} \text{ in the direction of } \vec{B}_1,$$

the net force on $\vec{M}_2$,

$$\vec{F} = \vec{F}_s - \vec{F}_N$$

$$= \frac{\mu_0}{4\pi} M_1 m \left[\frac{1}{(r-l)^3} - \frac{1}{(r+l)^3} \right]$$

$$= \frac{\mu_0}{4\pi} \frac{3M_1 M_2}{r^3} \qquad (\because \quad l << r \text{ and } 2\vec{ml} = \vec{M}_2)$$

(Opposite to $\vec{B}_1$)

Similarly net force on $\vec{M}_1$ due $\vec{M}_2$,

$$\vec{F} = \frac{\mu_0 M_1 M_2}{4\pi r^3} \text{ in the direction or } \vec{B}_1.$$

• Earth's Magnetism

When a magnet is surpended freely it rests in north-south direction of earth. If it is displaced from its position, it regains this position again. It means the north pole of a magnet is attracted by geographical north of the earth and south pole of the magnet is attracted by geographical south of the earth. Since like poles repel and unlike poles attract, therefore, it can be concluded that earth acts as a magnet and its magnetic south is situated in geographical north and magnetic north is situated in geographical south Fig. 5.12.

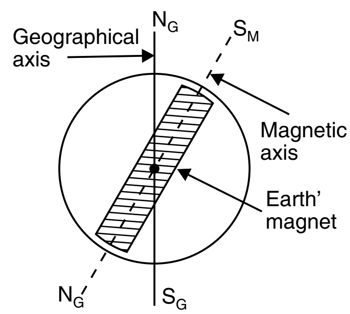

Fig. 5.12

- The vertical plane passing through the axis of a freely suspended magnet is called *magnetic meridian*. It in a plane which contains the place and the magnetic axis.
- The vertical plane passing through the geographical axis of the earth is called *geographical meridian*. It is a plane which contains the place and the axis of rotation of the earth.
- A circle with the centre of earth's centre on its surface which is perpendicular to the magnetic axis is called magnetic equator.
- The magnetic equator passing through *Trivandrum* in south India devides the earth into two hemispheres. The hemisphere containing south polarity of earth's magnetism is called northern hemisphere (NHS) while the other southern hemisphere (SHS).
- The angle between freely suspended magnet and horizontal axis of earth is called angle of dip. It is 0° at the equator of earth and 90° at the poles. [Fig. 5.13(*a*)]

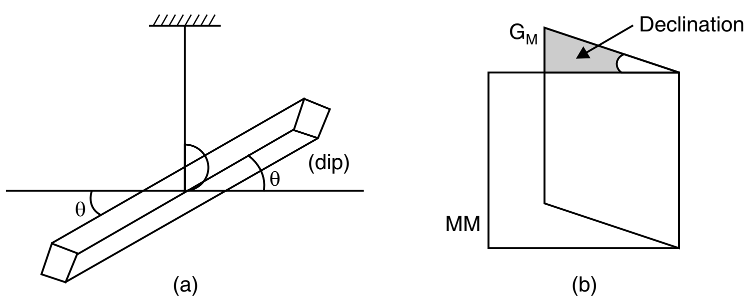

Fig. 5.13

- The angle between magnetic meridian and geographical meridian is called angle of declination [Fig. 5.13(*b*)]

- If at a place magnetic field of earth is *Be* and dip angle is θ, then a magnetic needle suspended freely will stay in the direction of magnetic field of earth. The magnetic field of earth can be resolved into two rectangular components called horizontal component (B_H) and vertical component (B_v).

  From Fig. 5.14. The horizontal component,

$$B_H = Be \cos\theta$$

  and vertical component,

$$B_v = Be \sin\theta.$$

$$\frac{B_v}{B_H} = \frac{Be\sin\theta}{Be\cos\theta} = \tan\theta$$

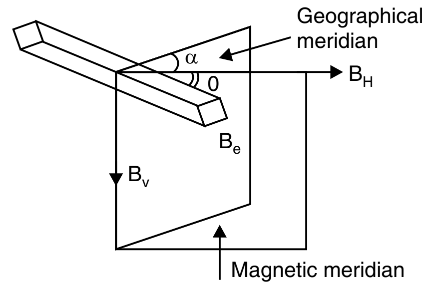

Fig. 5.14

  or $\boxed{B_v = B_H \tan\theta}$ This called tangent law.

  Also $B_H^2 + B_v^2 = (Be\cos\theta)^2 + (Be\sin\theta)^2$

  or $Be = \sqrt{B_H^2 + B_v^2}$

- As on a vertical plane at an angle α to the magnetic meridian

$$B_H' = B_H \cos\alpha \quad \text{and} \quad B_v' = B_v$$

  so angle of dip in a vertical plane making an angle α with magnetic meridian

$$\tan\theta' = \frac{B_v'}{B_H'} = \frac{B_v}{B_H \cos\alpha}$$

  i.e., $\tan\theta' = \dfrac{\tan\theta}{\cos\theta}$

- For a vertical plane other than magnetic meridian as α > 0, *i.e.,* cos α < 1, so θ′ > θ. Angle of dip will be larger
- For a plane perpendicular to the magnetic meridian, α = 90°,

$$\tan\theta = \frac{\tan\theta}{\cos 90^\circ} = \infty \quad \textit{i.e.,} \quad \theta' = 90^\circ$$

- In a plane perpendicular to magnetic meridian 'dip needle' will become vertical.
- If at a given place θ_1 and θ_2 are angles of dip in two arbitrary vertical planes which are perpendicular to each other, the true angle of dip (θ) is given by

$$\cot^2\theta = \cot^2\theta_1 + \cot^2\theta_2$$

- Angle of dip θ at a place having attitude α is given by

$$\tan\theta = 2\tan\lambda$$

- The lines joining the places of same value of dip or inclination are called *agonic* lines.
- The lines joining the places of same value of declination are called *isogonic lines*.
- The lines joining the places of same value of horizontal components of magnetic field are called *isoclinic lines.*

• Magnetic Materials

All materials are made up of atoms. In atoms electrons revolves around the nucleus and acts as a small current loop. This current loop produces magnetic field. Hence each current loop of electron behaves as a small magnetic dipole. Let an electron revolves around the nucleus of in orbit of radius R_1 with velocity v, then current in the loop.

$$I = \frac{q}{t} = \frac{e}{(2\pi R/v)}$$

or $$I = \frac{ev}{2\pi R}$$

The magnetic dipole moment of this loop,

$$\begin{aligned} M &= IA \\ &= I\,(\pi R^2) \\ &= \frac{ev}{2\pi R}(\pi R^2) \\ &= \frac{1}{2}evR \end{aligned}$$

In case of hydrogen atom it is called Bohr's magnetron.

Also, the angular momentum of the electron in its orbit,

$$L = mvR$$

or $$vR = \frac{L}{m}$$

Putting this value in the expression of dipole moment, (*i.e.*, orbital dipole moment)

$$M_V = \frac{1}{2}\frac{eL}{m}$$

Similarly, for spining moment for each half spin S, (*i.e.*, spining dipole moment)

$$M_s = \frac{1}{2}\frac{e\,(2S)}{m}$$

And net dipole moment

$$\begin{aligned} M &= \vec{M}_0 + \vec{M}_s \\ &= \frac{1}{2}\frac{e}{m}[\vec{L} + 2\vec{s}] \end{aligned}$$

- The magnetic field in which a magnetic material is placed for its magnitisation is called magnetising field. In a magnetising field the ratio of magnetising field $\vec{B}_0$ to the permeability of free space is called *intensity of magnetising field.*

  $$\vec{H} = \frac{\vec{B}_0}{\mu_0} \quad \text{or} \quad \vec{B}_0 = \mu_0 \vec{H}$$

  Its unit is Am.
- When a magnetic material is magnetised by placing it in a magnetising field, the induced dipole moment per unit volume in the material is called *intensity of magnetisation*.

  $$\vec{I} = \frac{\vec{M}}{V}$$

- The ratio of magnitude of intensity of magnetisation to that of magnetising field is called *magnetic susceptibility*.

  $$\chi = \frac{I}{H}$$

It is a scalar quantity having no unit.

- When a magnetic material is placed in a magnetic field, the ratio of magnitude of intensity of magnetising field is called *magnetic permiability.*

$$\mu = \frac{B}{H}$$

- The ratio of permeability of a medium to that of free space is called *relative permeability*

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

- When a material is placed in a magnetising field of intensity $\vec{H}$, induced field is developed of intensity $\vec{I}$ and net field becomes,

$$\vec{B} = \vec{H} + \vec{I}$$

or $$\frac{B}{H} = 1 + \frac{I}{H}$$

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

• Magnetic Materials

On the basis of atomic theory, the materials are classified into three categories.

(*i*) **Diamagnetic Materials.** The materials which when placed in magnetic field get feebly magnetised in the opposite direction of field are called diamagnetic materials. They are weakly repelled by the field and have tendency to move from strong field to weak field.

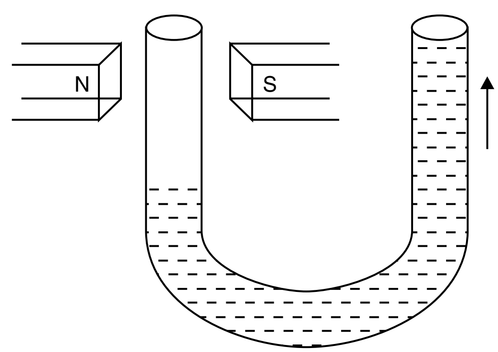

Fig. 5.15

- A diamagnetic rod sets itself perpendicular to the field if free to rotate between the poles of a magnet.
- A diamagnetic liquid in a *U*-tube depresses in the limits which is between the poles of a strong magnet as shown in Fig. 5.15.
- For diamagnetic substances magnetic susceptibility is small and negative
- For diamagnetic substances relative permeability is uses than one.
- The examples of diamagnetic substances are Bi, Cu, Ag, Hg, Pb, water, hydrogen and all inert gases (He, Me, etc,)

(*ii*) **Paramagnetic materials:** These are the materials which when placed in magnetic field get feebly magnetised in the direction of field. They have tendency to more from weak magnetic field to strong magnetic field.

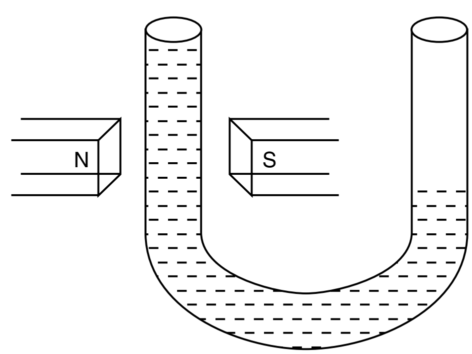

Fig. 5.16

- The intensity of magnetisation of paramagnetic materials is very small. Therefore, their relative permeability is small and greater than one.
- The magnetic susceptibility of paramagnetic material is positive and small.
- A paramagnetic rod sets itself parallel to the field if free to rotate between the poles of a strong magnet.
- A paramagnetic liquid in a *U*-tube ascends in the limit which is between the poles of a strong magnet as shown in Fig. 5.19.
- Magnetic susceptability of paramagnetic materials is independent of the field but varies inversely with absolute temperature.

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

  It is known as Curie's law.
- Paramagnetism arises due to parallel alignment of randomly oriented atomic dipoles along the field. So atoms of paramagnetic substances have permanent dipole moment. [Fig. 5.17]

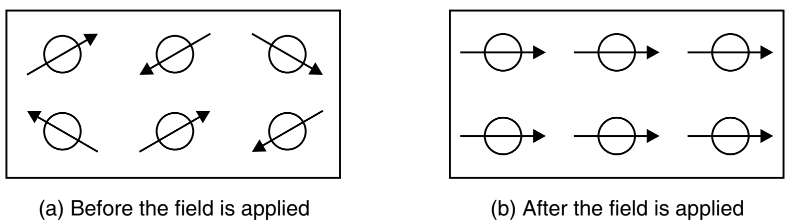

Fig. 5.17

- The examples of paramagnetic materials are Na, K, Mn, Al, Cr, Sn, Pt, Fe, Cl and liquid oxygen.

• Ferromagnetic materials

These are the material which when placed in magnetic field get strongly magnetised in the direction of field. They have tendency to move from weak magnetic field to strong magnetic field.

- The intensity of magnetisation is very large in ferromagnetic substances. Therefore, they have high relative permeability and high and positive magnetic susceptability.
- The variation of intensity of magnetisation is shown in Fig. 5.18 for ferromagnetic materials.

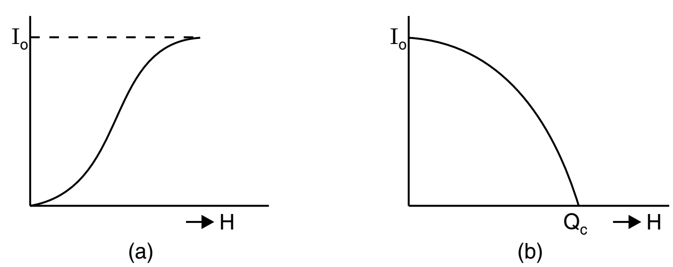

Fig. 5.18

- The susceptability of ferromagnetic material varies with temperature as

$$\chi = \frac{1}{(T - Q_c)}$$

where θ_c is the Curie temperature.

- The graphical representation of induced resultant field (B) and intersits of magnetisation is called $B-H$ curve.
- The area of the loop of $B-H$ curve gives the energy dissipated during magnetisation and demagnetisation.
- During magnetisation the left magnetism is called retaintivity (BO).

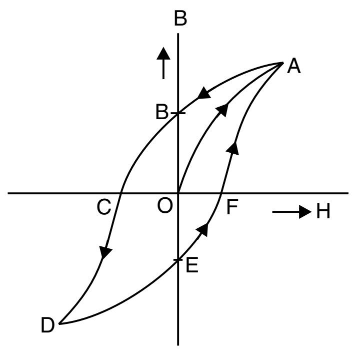

Fig. 5.19

- The magnetic field required to vanish the retaintivity is called corecivity, (CO)
- The $B-H$ curve for soft iron and hard iron are shown in Fig. 5.20.

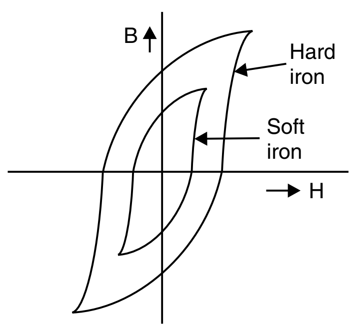

Fig. 5.20

QUESTIONS FROM TEXTBOOK

5.1. *Answer the following questions regarding earth's magnetism:*

(a) A vector needs three quantities for its specification. Name the three independent quantities conventionally used to specify the earth's magnetic field.

(b) The angle of dip at a location in southern India is about 18°. Would you expect a greater or smaller dip angle in Britain?

(c) If you made a map of magnetic field lines at Melbourne in Australia, would the lines seem to go into the ground or come out of the ground?

(d) In which direction would a compass free to move in the vertical plane point to, if located right on the geomagnetic north or south pole?

(e) The earth's field, it is claimed, roughly approximates the field due to a dipole of magnetic moment 8×10^{22} J T^{-1} located at its centre. Check the order of magnitude of this number in some way.

(f) Geologists claim that besides the main magnetic N-S poles, there are several local poles on the earth's surface oriented in different directions. How is such a thing possible at all?

Sol. (*a*) The three independent quantities conventionally used to specify the earth's magnetic field are—Magnetic declination, angle of dip and horizontal component of earth's magnetic field.

(*b*) Since Britain is closer to the magnetic north pole, we can expect a greater dip angle in Britain. It is about 70°.

(*c*) Field lines of $\vec{B}$ due to the earth's magnetism would seem to come out of the ground.

(*d*) A compass is free to move in a horizontal plane, while the earth's field is exactly vertical at the magnetic poles. So the compass can point in any direction there.

(*e*) Magnetic field B at an equatorial point of the earth's magnetic dipole is given by

$$B = \frac{\mu_0}{4\pi} \cdot \frac{m}{r^3}$$

Now $m = 8 \times 10^{22}$ JT^{-1}, $r = 6.4 \times 10^6$ m

$$B = 10^{-7} \times \frac{8 \times 10^{22}}{\left(6.4 \times 10^6\right)^3} \text{ T}$$

$$= 0.3 \times 10^{-4} \text{ T}$$

$$= 0.3 \text{ G}$$

Which is of the same order of magnitude as that of the observed field on the earth.

(*f*) The earth's field is only approximately a dipole field. Local *N-S* poles may arise due to, for instance, magnetised mineral deposits.

5.2. *Answer the following questions:*

(a) The earth's magnetic field varies from point to point in space. Does it also change with time ? If so, on what time scale does it change appreciably?

(b) The earth's core is known to contain iron. Yet geologists do not regard this as a source of the earth's magnetism. Why?

(c) The charged currents in the outer conducting regions of the earth's core are thought to be responsible for earth's magnetism. What might be the 'battery' (i.e., the source of energy) to sustain these currents?

(d) The earth may have even reversed the direction of its field several times during its history of 4 to 5 billion years. How can geologists know about the earth's field in such distant past ?

(e) The earth's field departs from its dipole shape substantially at large distances (greater than about 30,000 km). What agencies may be responsible for this distortion?

(*f*) *Interstellar space has an extremely weak magnetic field of the order of 10^{-12} T. Can such a weak field be of any significant consequence? Explain.*

*[**Note:** Question 5.2 is meant mainly to arouse your curiosity. Answers to some questions above are tentative or unknown. Brief answers wherever possible are given at the end. For details, you should consult a good text on geomagnetism.]*

Sol. (*a*) Yes, it does change with time. Time scale for appreciable change is roughly a few hundred years. But even on a much smaller scale of a few years, its variations are not completely negligible.

(*b*) Because *molten iron* (which is the phase of the *iron at the high temperatures* of the *core*) is not ferromagnetic due to temperature beyond Curie temp.

(*c*) Radioactivity may be one of the possible sources for the charged current in the outer conducting regions of the earth's core which are thought to be responsible for earth's magnetism.

(*d*) Earth's magnetic field gets weakly 'recorded' in certain rocks during solidification. Analysis of this rock magnetism offers clues to geomagnetic history.

(*e*) At large distance, the field gets modified due to the field of ions in motion (in the earth's ionosphere). The field of these ions, in turn, is sensitive to extraterrestrial disturbances such as the solar wind.

(*f*) From the relation $R = \frac{m\,v}{e\,B}$, $\left[\because \frac{mv^2}{R} = qvB\right]$ we find that an extremely minute field bends charged particles in a circle of very large radius. Over a small distance, the deflection due to the circular orbit of such large *R* may not be noticeable, but over the gigantic interstellar distances, the deflection can significantly affect the passage of charged particles, *e.g.*, cosmic rays.

5.3. *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} J. What is the magnitude of magnetic moment of the magnet?*

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

Using formula

$$\boxed{\tau = M.\,B \sin\theta}$$

$$\therefore \quad \boxed{M = 2ml} \qquad [m = \text{pole strength}]$$

$$\therefore \quad M = \frac{\tau}{B\sin\theta} = \frac{4.5\times10^{-2}}{0.25\times\sin 30°}$$

$$m = 0.36\ \text{JT}^{-1}$$

5.4. *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 (a) stable, and (b) unstable equilibrium? What is the potential energy of the magnet in each case?*

Sol. (*a*) If magnetic moment is parallel to $\vec{B}$, far stable equilibrium. Then

potential energy, $\boxed{U = -MB\cos\theta}$ $[\theta = 0°]$

$$= -0.32 \times 0.15 \text{ J}$$
$$= -4.8 \times 10^{-2} \text{ J}$$

(*b*) If magnetic moment is antiparallel to $\vec{B}$, for unstable equilibrium then

$$\theta = 180° \quad \text{so } \cos\theta = -1$$
$$U' = +MB = 0.32 \times 0.15$$
$$= 4.8 \times 10^{-2} \text{ J.}$$

5.5. *A closely wound solenoid of 800 turns and area of cross-section 2.5 × 10⁻⁴ m² carries a current of 3.0 A. Explain the sense in which the solenoid acts like a bar magnet. What is its associated magnetic moment?*

Sol. Given, $N = 800, \quad A = 2.5 \times 10^{-4} \text{ m}^2$

$$I = 3.0 \text{ A}$$

Magnetic dipole moment, $\boxed{M = NIA}$

Putting values, $M = 800 \times 3.0 \times 2.5 \times 10^{-4}$

$$= 0.6 \text{ JT}^{-1}$$

It is along the axis of the solenoid. The direction is determined by the sense of flow of the current. Solenoid acts like a bar magnet.

5.6. *If the solenoid in Question 5.5 is free to turn about the vertical direction and a uniform horizontal magnetic field of 0.25 T is applied, what is the magnitude of torque on the solenoid when its axis makes an angle of 30° with the direction of applied field?*

Sol. Given, $N = 800, \quad I = 3\text{A}, \quad A = 2.5 \times 10^{-4} \text{ m}^2$

$$B = 0.25 \text{ T}, \quad \theta = 30°$$

Magnetic moment, $\boxed{M = \text{N.I.A.}}$

$$= 800 \times 3.0 \times 2.5 \times 10^{-4}$$
$$= 0.6 \text{ JT}^{-1}$$

Torque, $\boxed{\tau = MB\sin\theta} = 0.6 \times 0.25 \times \sin 30°$

$$= 0.150 \times 0.5 = 7.5 \times 10^{-2} \text{ J.}$$

5.7. *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, (ii) opposite to the field direction?

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

Sol. $M = 1.5 \text{ JT}^{-1}, \quad B = 0.22 \text{ T}$

(*a*) (*i*) Work required to turn the magnet normal to the field direction

$$W_1 = -MB[\cos 90° - \cos 0°]$$
$$W_1 = +MB$$
$$W_1 = MB = 1.5 \times 0.22 = 0.33 \text{ J}$$

(*ii*) Work required to turn the magnet opposite to the field direction

$$W_2 = -MB[\cos 180° - \cos 0°]$$
$$W_2 = 2MB$$
$$W = -MB[\cos\theta_2 - \cos\theta_1]$$
$$W_2 = 2MB = 2 \times 0.33 = 0.66 \text{ J}$$

(*b*) (*i*) $\tau = MB\sin 90° = MB = 0.33 \text{ J.}$

It works in the direction that tends to align the magnetic moment vector along *B*.

(*ii*) $\tau = MB \sin\theta$

$\theta = 180°$

$\tau = 1.5 \times 0.22 \times \sin 180°$

$= 1.5 \times 0.22 \times 0 = 0.$

5.8. *A closely wound solenoid of 2000 turns and area of cross-section 1.6×10^{-4} m², 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 is the force and torque on the solenoid if a uniform horizontal magnetic field of 7.5×10^{-2} T is set up at an angle of 30° with the axis of the solenoid?

Sol. (*a*) Magnetic moment

$$\boxed{M = NIA} = 2000 \times 4 \times 1.6 \times 10^{-4}$$

$$= 1.28 \text{ Am}^2$$

The direction of $\vec{M}$ is along the axis of the solenoid in the direction related to the sense of current via the right handed screw rule.

(*b*) The magnetic field is given to be uniform. So, the force on the solenoid is zero.

$$\text{Torque, } \boxed{\tau = MB\sin\theta} = 1.28 \times 7.5 \times 10^{-2} \sin 30°$$

$$= 1.28 \times 7.5 \times 10^{-2} \times \frac{1}{2} \text{ J} = 0.048 \text{ J.}$$

The direction of the torque is such that the solenoid tends to align the axis of the solenoid (magnetic moment vector) along $\vec{B}$.

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

Sol. Here, $N = 16, \quad r = 10 \text{ cm} = 0.1 \text{ m}$

$I = 0.75 \text{ A}, \quad B = 5.0 \times 10^{-2} \text{ T}$

$\upsilon = 2.0 \text{ s}^{-1}$

$$\boxed{M = NIA} = NI\pi r^2$$

$$= 16 \times 0.75 \times \frac{22}{7}(0.1)^2$$

$$= 0.377 \text{ JT}^{-1}$$

Using formula

$$\boxed{\upsilon = \frac{1}{2\pi}\sqrt{\frac{MB}{I}}}$$

$\therefore$ $$\upsilon^2 = \frac{MB}{4\pi^2 I}$$

or $$I = \frac{MB}{4\pi^2\upsilon^2}$$

Putting values,

$$I = \frac{0.377 \times 5.0 \times 10^{-2}}{4 \times \left(\frac{22}{7}\right)^2 \times 2^2} = 1.2 \times 10^{-4} \text{ kg m}^2$$

5.10. *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 the place is known to be 0.35 G. Determine the magnitude of the earth's magnetic field at the place.*

Sol. Here, $\delta = 22°, \quad B_H = 0.35 \text{ G}$

Since, $B_H = B_E \cos \delta$

$$\therefore \quad B_E = \frac{B_H}{\cos \delta} = \frac{0.35}{\cos 22°} = \frac{0.35}{0.9272}$$

or, $B_E = 0.38$ G.

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

Sol. Given, declination, $\theta = 12°$ west

dip, $\delta = 60°$

$B_H = 0.16 \text{ gauss} = 0.16 \times 10^{-4} \text{ tesla}$

Since, $\boxed{B_H = B_E \cos \delta}$

$$\therefore \quad B_E = \frac{B_H}{\cos \delta} = \frac{0.16 \times 10^{-4}}{\cos 60°}$$

$$\text{or,} \quad B_E = \frac{0.16 \times 10^{-4}}{1/2} = 0.32 \times 10^{-4} \text{ T.}$$

The earth's field lies in a vertical plane 12° west of geographic meridian at an angle of 60° above the horizontal.

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

Sol. Given $M = 0.48 \text{ JT}^{-1}, \quad r = 10 \text{ cm} = 0.1 \text{ m}$

(*i*) Magnetic field at its axis

$$\boxed{B_a = \frac{\mu_0}{4\pi} \frac{2M}{r^3}}$$

$$\text{Putting values,} \quad B_a = \frac{4\pi \times 10^{-7} \times 2 \times 0.48}{4\pi \times (0.1)^3}$$

or, $B_a = 960 \times 10^{-7} \quad T = 960 \times 10^{-3}$ G

or, $B_a = 0.96$ G along *N-S* line.

(*ii*) Magnetic field along the equatorial line

$$\boxed{B_e = \frac{\mu_0}{4\pi} \frac{M}{r^3}}$$

or, $$B_e = \frac{4\pi \times 10^{-7} \times 0.48}{4\pi \times (0.1)^3}$$

or, $$B_e = 480 \times 10^{-7} \ T = 480 \times 10^{-3} \text{ G}$$

or, $$B_e = 0.48 \text{ G along } N\text{-}S \text{ line.}$$

5.13. *A short bar magnet placed in a horizontal plane has its axis aligned along the magnetic north-south direction. Null points are found on the axis of the magnet at 14 cm from the centre of the magnet. The earth's magnetic field at the place is 0.36 G and the angle of dip is zero. What is the total magnetic field on the normal bisector of the magnet at the same distance as the null point (i.e., 14 cm) from the centre of the magnet? (At null points, field due to a magnet is equal and opposite to the horizontal component of earth's magnetic field).*

Sol. Bar magnet is placed so that its axis is aligned along the magnetic *N-S* direction. As the null points are found on the axis of the magnet, it shows that south pole of magnet faces Geographical North (as shown in fig.).

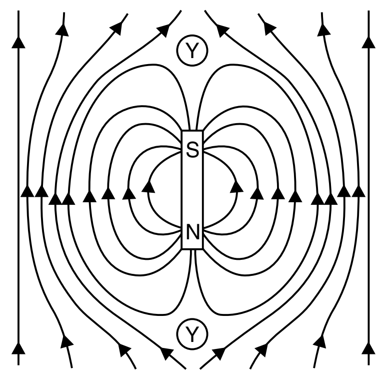

Fig. 5.21

In this case $\vec{M}$ is antiparallel to the earth's field. Since angle of dip is zero, the horizontal component of the earth's magnetic field equals the field itself. In this case

$$\frac{\mu_0 \, 2M}{4\pi r^3} = 0.36 \text{ G}$$

$$B_{ax} = -\ .36 \text{ G}$$

From the figure, total magnetic field at the normal bisector of the magnet at the same distance (r = 14 cm) from the centre of magnet is given by

$$= B_{eq} + B_H$$

$$= \frac{\mu_0 M}{4\pi r^3} + 0.36$$

$$= \frac{0.36}{2} + 0.36 = 0.54$$

i.e., total magnetic field is 0.54 G in the direction of earth's field.

5.14. *If the bar magnet in exercise 13 is turned around by 180°, where will the new null points be located?*

Sol. In this case, the neutral point will be on the equatorial line. If r' is the distance of the neutral point from the centre of the magnet, then

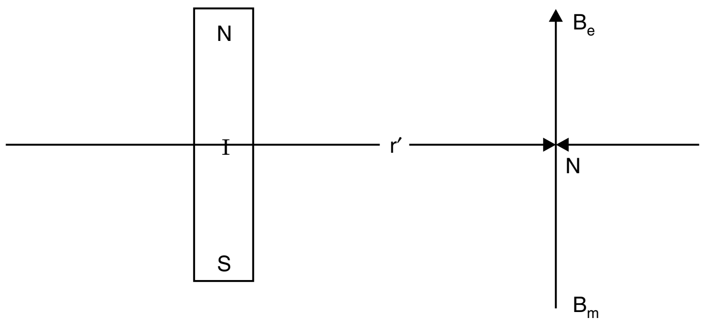

Fig. 5.22

$$\frac{\mu_0}{4\pi}\frac{M}{r^B} = 0.36 \times 10^{-4} = \frac{\mu_0}{4\pi}\frac{2M}{r^3}$$

or, $$(r')^3 = \frac{r^3}{2}$$

or, $$r' = \frac{r}{.2^{1/3}} = 14\ (2)^{-1/3} = 11.1 \text{ cm}$$

It is on the normal bisector.

5.15. *A short bar magnet of magnetic moment 5.25 × 10⁻² JT⁻¹ is placed with its axis perpendicular to earth's field direction. At what distance from the centre of the magnet, is the resultant field inclined at 45° with earth's field on (i) its normal bisector, (ii) its axis? Magnitude of earth's field at the place 0.42 G. Ignore the length of the magnet in comparison to the distances involved.*

Sol. Here, $M = 5.25 \times 10^{-2}\ JT^{-1}$

$r = ?$

Earth's field $\vec{B}_e = 0.42\ G = 0.42 \times 10^{-4}\ T$

(*i*) At a point *P* distant *r* on normal bisector, fig. (*a*), field due to the magnet is

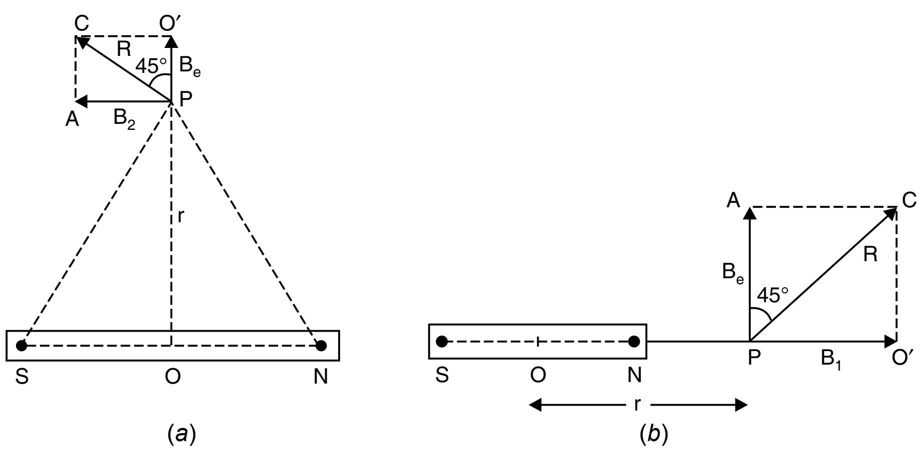

Fig. 5.23

Magnetic field B_2 due to magnet at equitorial line

$$\vec{B}_2 = \frac{\mu_0}{4\pi}\frac{M}{r^3} \text{ along } PA \parallel NS$$

The resultant field $\vec{R}$ will be inclined at 45° to the earth's field along PQ', only when

$$\left|\vec{B}_2\right| = \left|\vec{B}_e\right|$$

$$\frac{\mu_0}{4\pi}\frac{M}{r^3} = 0.42 \times 10^{-4}$$

$$\frac{10^{-7} \times 5.25 \times 10^{-2}}{r^3} = 0.42 \times 10^{-4}$$

which gives, $r = 0.05 \text{ m} = 5 \text{ cm}.$

(*ii*) When the point P lies on axis of the magnet such that $OP = r$, field due to magnet [Fig. (*b*),] is

$$\vec{B}_1 = \frac{\mu_0}{4\pi}\frac{2M}{r^3}, \text{ along } PO,$$

Earth's field $\vec{B}_e$ is along $\overrightarrow{PA}$.

The resultant field $\vec{R}$ will be inclined at 45° to earth's field only when

$$\left|\vec{B}_1\right| = \left|\vec{B}_e\right|$$

$$\therefore \qquad \frac{\mu_0}{4\pi}\frac{2M}{r^3} = 0.42 \times 10^{-4}$$

which gives $r = 6.3 \times 10^{-2} \text{ m} = 6.3 \text{ cm}.$

5.16. *Answer the following questions:*

(a) Why does a paramagnetic sample display greater magnetisation (for the same magnetising field) when cooled?

(b) Why is diamagnetism, in contrast, almost independent of temperature?

(c) If a toroid uses bismuth for its core, will the field in the core be (slightly) greater or (slightly) less than when the core is empty?

(d) Is the permeability of a ferromagnetic material independent of the magnetic field? If not, is it more for lower or higher fields?

(e) Magnetic field lines are always nearly normal to the surface of a ferromagnet at every point. (This fact is analogous to the static electric field lines being normal to the surface of a conductor at every point). Why?

(f) Would the maximum possible magnetisation of a paramagnetic sample be of the same order of magnitude as the magnetisation of a ferromagnet?

Sol. (*a*) The tendency to disrupt the alignment of dipoles (with the magnetising field) arising from random thermal motion is reduced at lower temperatures.

(*b*) The induced dipole moment in a diamagnetic sample is always opposite to the magnetising field, no matter what the internal motion of the atoms is.

(*c*) Slightly less, since bismuth is diamagnetic.

(*d*) No, as is evident from the magnetisation curve. From the slope of magnetisation curve, it is clear that μ is greater for lower fields.

(*e*) Proof of this important fact (of much practical use) is based on boundary conditions of magnetic field ($\vec{B}$ and $\vec{H}$) at the interface of two media. (When one of the media has $\mu >> 1$, the field lines meet this medium nearly normally).

(*f*) Yes. Apart from minor differences in strength of the individual atomic dipoles of two different materials, a paramagnetic sample with saturated magnetisation will have the same order of magnetisation. But of course, saturation requires impractically high magnetising fields.

5.17. *Answer the following questions:*

(a) Explain qualitatively on the basis of domain picture the irreversibility in the magnetisation curve of a ferromagnet.

(b) The hysteresis loop of a soft iron piece has a much smaller area than that of a carbon steel piece. If the material is to go through repeated cycles of magnetisation, which piece will dissipate greater heat energy?

(c) 'A system displaying a hysteresis loop such as a ferromagnet, is a device for storing memory ?' Explain the meaning of this statement.

(d) What kind of ferromagnetic material is used for coating magnetic tapes in a cassette player, or for building 'memory stores' in a modern computer?

(e) A certain region of space is to be shielded from magnetic fields. Suggest a method.

Sol. (*a*) The atomic dipoles are grouped together in domains in a ferromagnetic substance. All the dipoles of a domain are aligned in the same direction and have net magnetic moment. In an unmagnetised substance these domains are randomly distributed so that the resultant magnetisation is zero.

These domains align themselves in the direction of the field when the substance is placed in an external magnetic field. Some energy is spent in the process of alignment. These domains do not come back into their original random positions completely when the external field is removed.

Some magnetisation is retained by the substance. The energy spent in the process of magnetisation is not fully recovered. The balance of energy is lost as heat. This is the basic cause for irreversibility of the magnetisation curve of a ferromagnetic substance.

(*b*) Carbon steel piece, because heat lost per cycle is proportional to the area of hysteresis loop.

(*c*) Magnetisation of a ferromagnet is not a single-valued function of the magnetising field. Its value for a particular field depends both on the field and also on history of magnetisation (*i.e.,* how many cycles of magnetisation it has gone through etc.). In other words, the value of magnetisation is a record or 'memory' of its cycles of magnetisation. If information bits can be made to correspond to these cycles, the system displaying such a hysteresis loop can act as a device for storing information.

(*d*) Ceramics. (specially treated barium iron oxides, also called ferrites.)

(*e*) Surround the region by soft iron rings. Magnetic field lines will be drawn into the rings, and the enclosed space will be free of magnetic field. But this shielding is only approximate, unlike the perfect electric shielding of a cavity in a conductor placed in an external electric field.

5.18. *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 geographic meridian. The earth's 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)?*

Sol. Here,

$$I = 2.5 \text{ amp.}$$

$$R = 0.33G = 0.33 \times 10^{-4} \text{ T}$$

$$\delta = 0°$$

Horizontal component of earth's field

$$H = R \cos \delta = 0.33 \times 10^{-4} \cos 0°$$
$$= 0.33 \times 10^{-4} \text{ tesla}$$

Let the neutral points lie at a distance r from the cable.

Strength of magnetic field on this line due to

current in the cable $= \dfrac{\mu_0 I}{2\pi r}$

At neutral point,

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

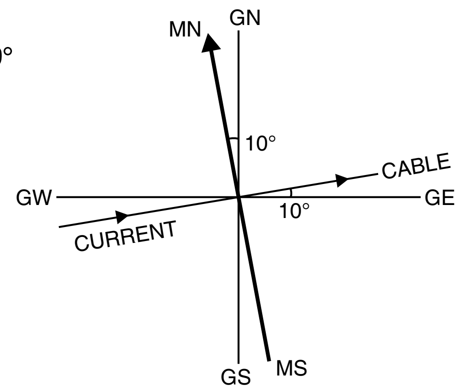

Fig. 5.24

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

Hence neutral points lie on a straight line parallel to the cable at a perpendicular distance of 1.5 cm above the plane of the paper.

5.19. *A telephonic cable at a place has four long straight horizontal wires carrying a current of 1.0 amp. in the same direction east to west. The earth's magnetic field at the place is 0.39 G and the angle of dip is 35°. The magnetic declination is almost zero. What are the resultant magnetic fields at points 4.0 cm below and above the cable?*

Sol. Given, earth's magnetic field,

$$B_e = 0.39 \text{ G}$$

and $\delta = 35°$

$\therefore$ Horizontal component of earth's magnetic field,

$$B_H = B_e \cos \delta$$

or, $B_H = 0.39 \cos 35° = 0.3195$ G

Vertical component of earth's magnetic field,

$$B_V = B_e \sin \delta$$

or, $B_V = 0.39 \sin 35° = 0.224$ G

Magnetic field produced by telephone cable having 4 wires

$$B = \left(\frac{\mu_0 I \,.\, 2}{4\pi r}\right) \times 4$$

$$\boxed{B = \frac{\mu_0 F}{2\pi r}}$$

where, $I = 1.0$ A, $a = 4.0$ cm $= 4 \times 10^{-2}$ m

$$\therefore \quad B' = 10^{-7} \times \frac{2 \times 1.0 \times 4}{4 \times 10^{-2}} = 0.2 \times 10^{-4} \text{ T} = 0.2 \text{ G}$$

Resultant field below the cable. As per the right hand thumb rule, the direction of B' will be opposite to B_H at a point below the cable.

Therefore at a point 4 cm *below* the cable, resultant horizontal component of earth's field

$$R_H = B_H - B' = 0.3195 - 0.2$$
$$= 0.1195 \text{ G}$$

Resultant vertical component of earth's field

$$R_v = B_v = 0.224 \text{ G (unchanged)}$$

∴ Resultant of earth's field

$$R = \sqrt{R_H^2 + R_V^2} = \sqrt{(0.1195)^2 + (0.224)^2}$$

$$= \sqrt{0.0143 + 0.0500} = \sqrt{0.0643}$$

$$= 0.254 \text{ G}$$

Resultant field above the cable. As per right hand thumb rule, at a point above the cable, B' will be in the same direction as B_H. Hence, at a point 4 cm above the cable.

$$R_H = B_H + B' = 0.3195 + 0.2 = 0.5195 \text{ G}$$

$$R_V = B_V = 0.224 \text{ G}$$

$$\therefore \quad R = \sqrt{R_H^2 + R_V^2}$$

$$= \sqrt{(0.5195)^2 + (0.224)^2}$$

or, $$R = 0.566 \text{ G.}$$

5.20. *A compass needle free to turn in a horizontal plane is placed at the centre of circular coil of 30 turns and radius 12 cm. The coil is in a vertical plane making an angle of 45° with the magnetic meridian. When the current in the coil is 0.35 A, the needle points west to east.*

(a) Determine the horizontal component of the earth's magnetic field at the location.

(b) The current in the coil is reversed, and the coil is rotated about its vertical axis by an angle of 90° in the anticlockwise sense looking from above. Predict the direction of the needle. Take the magnetic declination at the places to be zero.

Sol. (*a*) $$N = 30, \quad I = 0.35 \text{ A}, \quad r = 12 \text{ cm} = 0.12 \text{ m}$$

The magnetic field at the centre of the coil is $B = \dfrac{\mu_0 NI}{2r}$. It acts in a direction perpendicular to the plane of the coil. Its component parallel to the magnetic meridian is $\dfrac{\mu_0 NI}{2r}$ cos 45°. The component perpendicular to the magnetic meridian is $\dfrac{\mu_0 NI}{2r}$ sin 45°.

As the needle points in the west-east direction,

∴ Horizontal component of earth's magnetic field is given by

$$B_H = \frac{\mu_0 NI}{2r} \cos 45°$$

$$= \frac{4\pi \times 10^{-7} \times 30 \times 0.35}{2 \times 0.12 \times \sqrt{2}} = 0.39 \times 10^{-4} \text{ T}$$

or, $$B_H = 0.39 \text{ G}$$

(*b*) In this case, the plane of the coil makes an angle of 45° with the magnetic meridian on the other side. The needle will rotate and will set in east to west direction.

5.21. *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} tesla. If the dipole comes to stable equilibrium at an angle of 15° with this field, what is the magnitude of the other field ?*

Sol. Here,

$$\theta = 60°; \quad B_1 = 1.2 \times 10^{-2} \text{ tesla}$$
$$\theta_1 = 15°; \quad \theta_2 = 60° - 15° = 45°.$$

In equilibrium, torques due to two fields must balance

i.e., $\tau_1 = \tau_2$

$M B_1 \sin \theta_1 = MB_2 \sin \theta_2$

$$B_2 = \frac{B_1 \sin \theta_1}{\sin \theta_2} = \frac{1.2 \times 10^{-2} \sin 15°}{\sin 45°}$$

$$B_2 = \frac{1.2 \times 10^{-2} \times 0.2588}{0.7071}$$

$$= 4.4 \times 10^{-3} \text{ tesla}$$

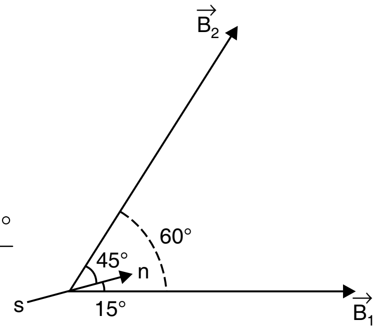

Fig. 5.25

5.22. *A monoenergetic (18 keV) electron beam initially in the horizontal direction is subjected to a horizontal magnetic field of 0.40 G normal to the initial direction. Estimate the up or down deflection of the beam over a distance of 30 cm. Given mass of electron 9.11 × 10^{-31} kg and charge on electron = 1.6 × 10^{-19} C.*

*[**Note:** Data in this exercise are so chosen that the answer will give you an idea of the effect of earth's magnetic field on the motion of electron beam from electron gun to the screen in a T.V. set.]*

Sol. Here,

energy $E = 18 \text{ keV} = 18 \times 1.6 \times 10^{-16}$ J

$B = 0.40 \text{ G} = 0.40 \times 10^{-4}$ T

$x = 30 \text{ cm} = 0.3$ m

As $E = \frac{1}{2} m v^2 \quad \therefore \quad v = \sqrt{2E/m}$

In a magnetic field, electron beam is deflected along a circular arc of radius r, such that

$$Bev = \frac{mv^2}{r} \quad \text{or} \quad r = \frac{mv}{Be}$$

$$r = \frac{m}{Be}\sqrt{\frac{2E}{m}} = \frac{1}{Be}\sqrt{2E\,m} = 11.3 \text{ m}$$

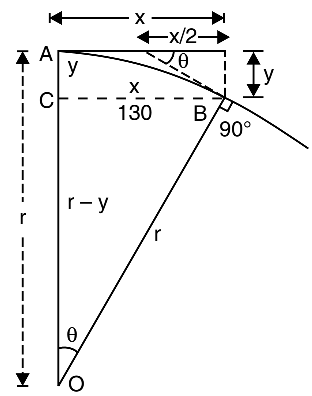

Fig. 5.26

$$\sin \theta = \frac{x}{r}$$

$$\sin \theta = \frac{0.3}{11.3} = \frac{3}{113}$$

$$y = r - OC$$
$$= r - r \cos \theta$$
$$= r (1 - \cos \theta)$$
$$= r [1 - \sqrt{1 - \sin^2 \theta}]$$

By x sin g binomial

$$y = r\left[1 - \left(1 - \frac{1}{2}\sin^2 \theta\right)\right.$$

$$y = \frac{r}{2} . \sin^2 \theta$$

$$y = \frac{11.3}{2} \times \frac{3 \times 3}{113 \times 113 \times 10} = \frac{9}{2260} = 3.98 \times 10^{-3} \cong 4 \text{ mm.}$$

5.23. *A sample of paramagnetic salt contains 2.0 × 10^{24} atomic dipoles each of dipole moment 1.5 × 10^{-23} J T^{-1}. The sample is placed under a homogeneous magnetic field of 0.64 T, and cooled to a temperature of 4.2 K. The degree of magnetic saturation achieved is equal to 15%. What is the total dipole moment of the sample for a magnetic field of 0.98 T and a temperature of 2.8 K? (Assume Curie's law)*

Sol. Magnetic dipole moment of each dipole = 1.5 × 10^{-23} J T^{-1}

Number of atomic dipoles = 2.0 × 10^{24}

∴ Possible magnetic dipole moment of the sample

$$M = 1.5 \times 10^{-23} \times 2.0 \times 10^{24} = 30 \text{ J T}^{-1}$$

At temperature of 4.2 K, the magnetic saturation is 15%.

∴ Dipole moment achieved at 4.2 K = 15% of M

$$M_1 = 30 \times \frac{15}{100} = 4.5 \text{ J T}^{-1}$$

According to Curie's law $\boxed{M \propto \frac{B}{T}}$

or $$\frac{M_1}{M_2} = \frac{B_1}{T_1} \times \frac{T_2}{B_2}$$

or, $$M_2 = M_1 \times \frac{T_1}{T_2} \times \frac{B_1}{B_2}$$

Here, $M_1 = 4.5 \text{ JT}^{-1}$, $T_1 = 4.2$ K, $T_2 = 2.8$ K

$B_1 = 0.84$ T and $B_2 = 0.98$ K

$$M_2 = \frac{4.5 \times 4.2 \times 0.98}{2.8 \times 0.84} = 7.875 \text{ JT}^{-1}$$

5.24. *A Rowland ring of mean radius 15 cm has 3500 turns of wire wound on a ferromagnetic core of relative permeability 800. What is the magnetic field B in the core for a magnetising current of 1.2 A?*

Sol. Rowland ring is toroid with core of magnetic material

∴ $$B = \mu_0 n I$$

$$n = \frac{N}{l}$$

But $\mu = \mu_0 \mu_r$ and $l = 2\pi r$

∴ $$B = \frac{\mu_r \mu_0 NI}{2\pi r}$$

∴ $$B = \frac{\mu_r \mu_0 NI}{2\pi r}$$

or, $$B = \frac{4\pi \times 10^{-7} \times 800 \times 3500 \times 1.2}{2\pi \times 0.15}$$

or, $B = 4.48$ tesla.

5.25. *The magnetic moment vectors μ_s and μ_l associated with the intrinsic spin angular momentum S and orbital angular momentum l, respectively, of an electron are predicted by quantum theory (and verified experimentally to a high accuracy) to be given by:*

$$\mu_s = -(e/m)\, S,$$
$$\mu_l = -(e/2m)\, 1$$

Which of these relations is in accordance with the result expected classically? Outline the derivation of the classical result.

Sol. The relation $\mu_1 = -\left(\frac{e}{2m}\right) l$ is in accordance with the result expected from classical physics. It can be derived as follows:

Magnetic moment associated with the orbital motion of the electron is

$$\mu_l = \text{current} \times \text{area of the orbit}$$
$$= IA = \frac{-e}{T} \cdot \pi r^2$$

and angular momentum of the orbiting electron is given by

$$l = mvr = m \cdot \frac{2\pi r}{T} \cdot r = \frac{2\pi\, mr^2}{T}$$

Here r is the radius of the circular orbit which the electron of mass m and charge $(-e)$ completes in time T.

$$\therefore \qquad \vec{\mu}_l = \frac{-e\pi r^2 l}{2\pi m r^2} = \frac{-e}{2m}\vec{l}$$

As charge of the electron is negative $(= -e)$ it is easily seen that μ_1 and l are antiparallel, both normal to the plane of the orbit.

Therefore, $\mu_1 = -\frac{e}{2ml}$ which is same result as predicted by quantum theory in contrast, $\mu_s/s = \frac{e}{m}$ is twice the classically expected value. This latter result (verified experimentally) is an outstanding consequence of modern quantum theory.

MORE QUESTIONS SOLVED

I. VERY SHORT ANSWER TYPE QUESTIONS

Q. 1. *The ratio of the horizontal component to the resultant magnetic field of earth at a given place is $\frac{1}{\sqrt{2}}$. What is the angle of dip at that place?*

Ans.

$$\boxed{\cos\delta = \frac{B_H}{B}} = \frac{1}{\sqrt{2}}$$

$$\cos\delta = \frac{1}{\sqrt{2}}$$

or $\qquad \delta = 45°.$

Q. 2. *The vertical component of earth's magnetic field at a place is $\sqrt{3}$ times the horizontal component. What is the value of angle of dip at this place?*

Ans. $\boxed{\tan\delta = \frac{B_V}{B_H}} = \frac{\sqrt{3}\,B_H}{B_H} = \sqrt{3}$

$\tan\delta = \sqrt{3}$

$\delta = 60° \rightarrow$ (angle of dip)

Q. 3. *Write the mathematical form of tangent law in magnetism.*

Ans. $\boxed{F = H\tan\theta}$

where θ is the angle made by the magnetic dipole with uniform magnetic field *H*.

Q. 4. *Steel is preferred for making permanent magnets whereas soft iron is preferred for making electromagnets. Give one reason.*

Ans. Since steel is of high coercivity, it is preferred for making permanent magnets.
Soft iron is used for making electromagnets because of its high *permeability* and low hysteresis loss.

Q. 5. *Write the relation between relative permeability (μ_r) and susceptibility (χ_m).*

Ans. $\boxed{\mu_r = 1 + \chi_m.}$

Q. 6. *What is the value of the horizontal component of the earth's magnetic field at magnetic poles?*

Ans. Zero.

Q. 7. *Horizontal and vertical components of earth's magnetic field at a place are 0.22 T and 0.38 T respectively. Find the resultant intensity of earth's magnetic field.*

Ans. $B_H = 0.22\text{ T}, \quad B_V = 0.38\text{ T}$

Resultant, $\boxed{B = \sqrt{B_H^2 + B_V^2}} = \sqrt{(0.22)^2 + (0.38)^2}$

or, $B = \sqrt{0.0484 + 0.1444}$

or, $B = \sqrt{0.1928} = 0.44\text{ T}.$

Q. 8. *What should be the orientation of a magnetic dipole in a uniform magnetic field so that its potential energy is maximum?*

Ans. When the magnetic moment of the magnetic dipole is antiparallel to the magnetic field (θ = 180°), its potential energy is maximum.

Q. 9. *What is the angle of dip at a place where horizontal and vertical components of earth's field are equal?*

Ans. Here $B_V = B_H$

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

$\tan\delta = \frac{B_H}{B_H} = 1$

$\tan\delta = \tan 45°$

$\delta = 45°$

Q. 10. *A magnetic needle free to rotate in a vertical plane, orients itself with its axis vertical at a certain place on the earth. What are the values of (a) horizontal component of earth's field? (b) angle of dip at this place?*

Ans. The place is clearly the magnetic pole of earth as nidde rotates in vertical plane not in horizontal plane $B_H = 0$

(*a*) $B_H = 0$ (horizontal component)

(*b*) $\delta = 90°$ (angle of dip).

Q. 11. *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 along its length?*

Ans. Each piece is a magnet with reduced pole strength and reduced magnetic moment.

(*i*) Pole strength becomes half of original.

(*ii*) Magnetic moment ($M = M \cdot 2l$) becomes t_1 times of original

Q. 12. *A short bar magnet placed with its axis making an angle θ with a uniform external field B experiences a torque. What is the magnetic moment of the magnet?*

Ans.

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

$$M = \frac{\tau}{B \sin \theta}$$

Q. 13. *What are S.I. units of susceptibility?*

Ans.

$$\boxed{\chi_m = \frac{I}{H}} = \frac{Am^{-1}}{Am^{-1}} = 1$$

$\therefore \chi_m$ has no units

here I is intensity of magnetisation and H is magnetising field.

Q. 14. *Which materials have negative value of magnetic susceptibility?*

Ans. Diamagnetic materials have negative susceptibility.

Q. 15. *Magnetic moment of atoms of certain materials is zero. Name such materials.*

Ans. Diamagnetic materials, like copper, bismuth etc.

Q. 16. *How does the magnetic susceptibility of a paramagnetic material change with temperature?*

Ans. The magnetic susceptibility of a paramagnetic material varies inversely with temperature.

Q. 17. *Name the parameters needed to completely specify the earth's magnetic field at a point on the earth's surface.*

Ans. Declination, Dip and Horizontal component of earth's field.

Q. 18. *Is the product of magnetic susceptibility and absolute temperature constant for a paramagnetic substance?*

Ans. Yes.

Q. 19. *Which materials have permeability > 1?*

Ans. Para and ferromagnetic materials.

Q. 20. *Classify the following into dia and para magnetic substances: aluminium, copper, water, mercury, oxygen, hydrogen.*

Ans. Dia: copper, water, mercury and hydrogen

Para: aluminium and Oxygen.

Q. 21. *Does the earth's magnetic field at a point vary with time? Is this variation appreciable ?*

Ans. Yes. The variation may be appreciable over a very large interval of time.

Q. 22. *Give an example of magnetic dipole.*

Ans. Bar magnet.

Q. 23. *What happens when a diamagnetic substance is placed in a varying magnetic field ?*

Ans. It moves from stronger to weaker part of the magnetic field.

Q. 24. *Can there be a material, which is non-magnetic?*

Ans. No, every substance is at least diamagnetic.

Q. 25. *What is the effect on the magnetisation of a diamagnetic substance when it is cooled ?*

Ans. The magnetisation of a diamagnetic substance is independent of temperature.

Q. 26. *Why electromagnets are made of soft iron?*

Ans. Electromagnets are made of soft iron because coercivity of soft iron is small high permeability and low hysteresis loss.

II. SHORT ANSWER TYPE QUESTIONS

Q. 1. *A magnet having a magnetic moment of 1.0 × 104 J/T is free to rotate in a horizontal plane where a magnetic field 4×10^{-5} T exists. Find the work done in rotating the magnet slowly from a direction parallel to the field to a direction 60° from the field.*

Ans. Here,

$$M = 1.0 \times 10^4 \text{ J/T}, \quad \theta_1 = 0°, \quad \theta_2 = 60°$$

$$B = 4 \times 10^{-5} \text{ T}$$

$$\boxed{W = -MB(\cos\theta_2 - \cos\theta_1)}$$

$$= -1.0 \times 10^4 \times 4 \times 10^{-5} (\cos 60° - \cos 0°)$$

$$= -0.4\left(\frac{1}{2} - 1\right) = 0.2 \text{ J.}$$

Q. 2. *Define magnetic susceptibility of a material. Name two elements, one having positive susceptibility and the other having negative susceptibility. What does negative susceptibility signify?*

Ans. Magnetic susceptibility of a material is defined as the ratio of the intensity of magnetisation (I) induced in the material to the magnetisation force (H) applied on it.

Magnetic susceptibility is given by

$$\boxed{\chi_m = \frac{I}{H}}$$

- ★ Diamagnetic substances like copper, lead etc., has negative susceptibility.
- ★ Paramagnetic substances like aluminium, calcium etc., has positive susceptibility.

Negative susceptibility of diamagnetic substance does not change with temperature.

Q. 3. *A magnet 10 cm long has a pole strength of 12 Am. Find the magnitude of magnetic field strength B at a point on its at a distance of 20 cm from it's mid point on axial line. What would be the value of B, if the point were to lie at the same distance on equatorial line of magnet ?*

Ans. Here,

$$2l = 10 \text{ cm} = 0.1 \text{ m}, \; m = 12 \text{ Am}$$

$$B = ? \; d = 20 \text{ cm} = 0.2 \text{ m}$$

As

$$\boxed{B_{ax} = \frac{\mu_0}{4\pi} = \frac{2\,md}{(d^2 - l^2)^2}} \quad B_{eq} = \frac{\mu_0 2.2\,mld}{4\pi\,(d^2 - l^2)^2} = \frac{\mu_0 4mld}{4\pi\,(d^2 - l^2)^2}$$

$$= \frac{4\pi \times 10^{-7} \times 4 \times 12 \times 0.05 \times 0.2}{4\pi\left[(0.2)^2 - (0.05)^2\right]^2}$$

$\therefore$

$$B_1 = 3.4 \times 10^{-5} \text{ T}$$

At the same distance, on equatorial line,

$$\boxed{B_{eq} = \frac{1}{2} B_{ax}}$$

assuming the magnet to be short

$\therefore$ $$B_2 = \frac{1}{2} \times 3.4 \times 10^{-5}\ \text{T} = 1.7 \times 10^{-5}\ \text{T}$$

Q. 4. *If χ stands for the magnetic susceptibility of a given material, identify the class of materials for which:*

(i) $-1 \geq \chi < 0$

(ii) $0 < \chi < \varepsilon$, (ε stands for a small positive number).

(a) Write the range of relative magnetic permeability of these materials.

(b) Draw the pattern of the magnetic field lines when these materials are placed in an external magnetic field.

Ans. (*i*) For $-1 \geq \chi < 0$, material is diamagnetic,

(*ii*) For $0 < \chi < \varepsilon$, material is paramagnetic,

(*a*) Range of relative magnetic permeability of diamagnetic material is

$$0 \leq \mu_r < 1$$

Range of relative magnetic permeability of paramagnetic material is

$$0 < \mu_r < 1 + \varepsilon$$

(*b*) Behaviour of magnetic field lines when diamagnetic material is placed in an external field.

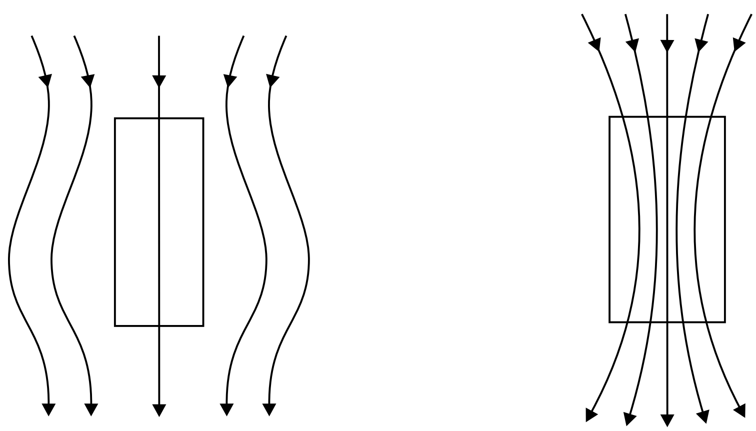

Fig. 5.27

Behaviour of magnetic field lines when paramagnetic material is placed in an external field.

Q. 5. *The horizontal component of earth's magnetic field at a place is 0.4×10^{-4} T. If angle of dip is 45°, what are the values of vertical component and total intensity of earth's field?*

Ans. Here, $$B_H = 0.4 \times 10^{-4}\ \text{T}, \quad \delta = 45°$$

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

$$B_V = B_H \tan \delta$$

Putting values,

$$B_V = 0.4 \times 10^{-4} \tan 45°$$
$$B_V = 0.4 \times 10^{-4} \text{ T}$$

Using formula

$$\boxed{B_H = B_E \cos \delta}$$
$$B_E = \frac{B_H}{\cos \delta}$$

or,
$$B_E = \frac{0.4 \times 10^{-4}}{\cos 45°} = 0.4\sqrt{2} \times 10^{-4} \text{T}$$

or,
$$B_E = 0.5656 \times 10^{-4} \text{ T.}$$

Q. 6. *Explain with the help of diagram the terms (i) magnetic declination and (ii) angle of dip at a given place.*

Ans. (*i*) Magnetic declination at a place may be defined as the angle between its magnetic meridian and the earth geographic meridian at the place.

(*ii*) Angle of dip at a place is defined as the angle between the direction of intensity of earth's magnetic field (B_E) and the horizontal direction in magnetic meridian at that place.

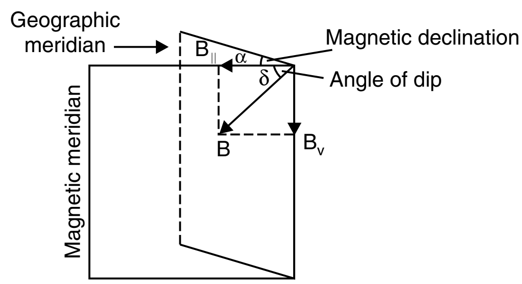

Fig. 5.28

Q. 7. *A uniform magnetic field gets modified as shown below, when two specimens X and Y are placed in it.*

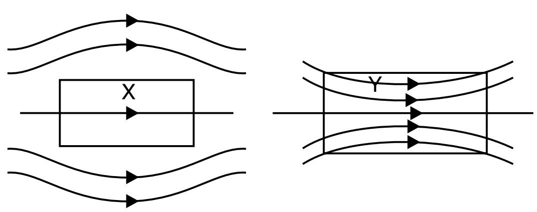

Fig. 5.29

(*i*) *Identify the two specimens X and Y.*

(*ii*) *State the reason for the behaviour of the field lines in X and Y.*

Ans. (*i*) X is a diamagnetic substance.

Y is a paramagnetic substance.

(*ii*) The field lines are repelled or expelled and the field inside the material is reduced when a diamagnetic bar is placed in an external field.

The field lines get concentrated inside the material and the field is increased when a paramagnetic bar is placed in an external field.

Q. 8. *Does an iron bar magnet retain its magnetism when melted? Give reason for your answer.*

Ans. Iron melts at a temperature which is higher than the Curie temperature of iron. So, the iron bar magnet cannot retain its magnetism when melted.

Q. 9. *What is the susceptibility and permeability of a perfectly diamagnetic substance?*

Ans. For a perfectly diamagnetic substance,

$$B = \mu_0 (H + I) = 0$$

$\therefore$ $$I = -H$$

Therefore, $$\chi_m = \frac{-H}{H} = -1$$

also, $$\mu_r = 1 + \chi_m = 1 - 1 = 0$$

$\therefore$ $$\mu = \mu_0 \mu_r = \text{zero.}$$

Q. 10. *Why does a paramagnetic substance display greater magnetisation for the same magnetising field when cooled? How does a diamagnetic substance respond to similar temperature changes?*

Ans. The atomic dipoles of paramagnetic substance tend to get aligned with the magnetisation of field as it is cooled. So it displays a greater magnetisation when cooled. The magnetisation of a diamagnetic substance is independent of temperature.

Q. 11. *Two substances A and B have their relative permeabilities slightly greater and less than unity respectively. What do you conclude about A and B?*

Ans. $$\chi_m = \mu_r - 1$$

Relative permeability of A is slightly greater than 1.

So, χ_m is small and positive. So, substance is paramagnetic.

Relative permeability of B is slightly less 1.

So, χ_m is small and negative. Clearly, substance is diamagnetic.

Q. 12. *Define magnetic dipole moment of a magnet and write its unit by taking into consideration the torque acting on it, when placed in magnetic field. Is it a vector or a scalar?*

Ans. We know that $$\boxed{\tau = MB \sin \theta}$$

If $B = 1$ and $\theta = 90°$, then $M = \tau$

Magnetic dipole moment is numerically equal to the torque experienced by the magnet when placed perpendicular to a uniform magnetic field of unit strength.

Now, $M = \dfrac{\tau}{B \sin \theta}$. So, SI unit of M is $N\ m\ T^{-1}$.

Magnetic dipole moment is a vector.

Q. 13. *Write two characteristic properties to distinguish between diamagnetic and paramagnetic materials.*

Ans. 1. Diamagnetic materials:

(*i*) They are feebly repelled by magnets.

(*ii*) χ is negative and very small.

2. Paramagnetic materials:

(*i*) They are feebly attracted by magnets

(*ii*) χ is positive and small.

Q. 14. *Distinguish between diamagnetic and ferromagnetic materials in respect of their (i) intensity of magnetisation, (ii) behaviour in a non-uniform magnetic field and (iii) susceptibility.*

Ans. (*i*) Intensity of magnetisation is small negative for a diamagnetic substance and large positive for a ferromagnetic substance.

(*ii*) In a non-uniform magnetic field, a diamagnetic substance tends to move from stronger to weaker part while the ferromagnetic substance tends to move from weaker to stronger part of the field.

(*iii*) For a diamagnetic substance, susceptibility is smaller negative while for a ferromagnetic substance, susceptibility is large positive.

Q. 15. *What do you understand by the terms 'magnetic length and geometric length' of the magnet? How are the two related to each other?*

Ans. The actual length of a magnet is called the geometric length of the magnet. The distance between the poles of a magnet is called the magnetic length of the magnet.

The geometric length of the magnet is nearly 8/7 times the magnetic length of the magnet.

Q. 16. *A short bar magnet placed with its axis inclined at 30° to the external magnetic field of 800 G acting horizontally experiences a torque of 0.016 Nm. Calculate (i) the magnetic moment of the magnet, (ii) the work done by an external force in moving it from most stable to most unstable position, (iii) what is the work done by the force due to the external magnetic field in the process mentioned in (ii)?*

Ans. (*i*) Since, $$\boxed{\tau = MB \sin \theta}$$

∴ $$M = \frac{\tau}{B \sin \theta}$$

or, $$M = \frac{0.016}{800 \times 10^{-4} \times \sin 30°}$$

or, $$M = 0.40 \text{ Am}^2 \qquad [\because 1 \text{ G} = 10^{-4} \text{ T}]$$

(*ii*) $$W = -MB [\cos \theta_2 - \cos \theta_1]$$

$$\boxed{W = -MB (\cos 180° - \cos 0°)}$$

$$= -MB(-1-1) = 2 \text{ MB}$$

or, $$W = 2 \times 0.40 \times 800 \times 10^{-4} = 0.064 \text{ J.}$$

(*iii*) The displacement and the torque due to the magnetic field are in opposite direction. So work done by the force due to the external magnetic field is

$$W_B = -0.064 \text{ J.}$$

III. LONG ANSWER TYPE QUESTIONS

Q. 1. *A small magnet of magnetic moment $\pi \times 10^{-10}$ Am^2 is placed on the Y-axis at a distance of 0.1 m from the origin with its axis parallel to the X-axis. A coil having 169 turns and radius 0.05 m is placed on the X-axis at a distance of 0.12 m from the origin with the axis of the coil coinciding with X-axis. Find the magnitude and direction of the current in the coil for a compass needle placed at the origin to point in the north-south direction.*

Ans. The compass needle placed at the origin will point in the north-south direction if the magnetic field, at the origin, produced by the magnet and the coil are equal in magnitude and opposite in direction. Magnetic field, at the origin, due to the magnet is given by

$$\boxed{B_m = \frac{\mu_0}{4\pi} \frac{M}{r^3}} \qquad \text{(equitorial line)}$$

or, $$B_m = \frac{10^{-7} \times \pi \times 10^{-10}}{0.1 \times 0.1 \times 0.1} \text{T}$$

or, $$B_m = \pi \times 10^{-14} \text{ T}$$

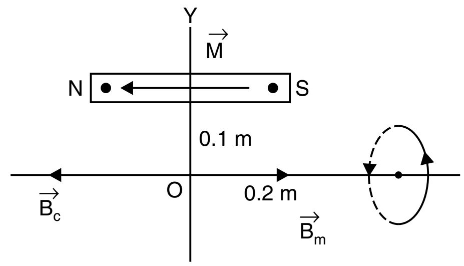

Fig. 5.30

The magnetic field B_C due to the circular coil should be opposite to $\vec{B}_m$. For this, the current through the coil should flow anticlockwise as seen from the origin. Now, radius of coil, $r = 0.05$ m, $x = 0.2$ m.

Hence, $$B_C = \frac{\mu_0 NIr^2}{2\left(r^2 + x^2\right)^{3/2}}$$ (axial line)

or, $$B_C = \frac{4\pi \times 10^{-7} \times 169 \times I \times (0.05)^2}{2\left[(0.05)^2 + (0.12)^2\right]^{3/2}} \text{ T}$$

or, $$B_C = \frac{0.845\pi \times 10^{-7} \times I}{[0.0025 + 0.0144]^{3/2}}$$

or, $$B_C = \frac{0.845\pi \times 10^{-7} \times I}{\left[\sqrt{0.0169}\right]^3}$$

or, $$B_C = \frac{0.845\pi \times 10^{-7} \times I}{0.13 \times 0.13 \times 0.13}$$

$$= 3.84\pi \times 10^{-5} \times I$$

For needle to point in north-south direction

$$3.846\pi \times 10^{-5} \times I = \pi \times 10^{-14}$$

or, $$I = \frac{10^{-14}}{3.846 \times 10^{-5}} \text{ A}$$

$$= 2.6 \times 10^{-10} \text{ A}$$

when viewed from origin, the current flows anti-clockwise.

Q. 2. *The magnetic moment of a short bar magnet is 1.6 m². It is placed in the magnetic meridian with north pole pointing south. The neutral point is obtained at 20 cm from the centre of the magnet. Calculate the horizontal component H of earth's field. If magnet be reversed i.e., north pole pointing north, find the position of the neutral point.*

Ans. Here, $M = 1.6 \text{ A } m^2$,

$$d_1 = 20 \text{ cm} = \frac{1}{5} m,\ H = ?$$

When north pole of magnet is pointing south, neutral points lie on axial line of magnet. At neutral point,

$$\boxed{B_{ax} = \frac{\mu_0}{4\pi} \frac{2M}{d_1^3}} = H$$

or, $$H = \frac{10^{-7} \times 2 \times 1.6}{(1/5)^3} = 4 \times 10^{-5} \text{ tesla.}$$

When magnet is reversed *i.e.,* north pole is pointing north, neutral points lie on equatorial line of the magnet. We have to calculate d_2.

As $$\boxed{B_{eq} = \frac{\mu_0}{4\pi} \frac{M}{d_2^3}} = H$$

$\therefore$ $$d_2^3 = \frac{\mu_0}{4\pi} \frac{M}{H}$$

$$d_2^3 = \frac{10^{-7} \times 1.6}{4 \times 10^{-5}} = 0.4 \times 10^{-2} \text{ m}^3$$

$$= 0.4 \times 10^{-2} \times 10^6 \text{ cm}^3$$

$$= 4000 \text{ cm}^3$$

$$d_2 = (4000)^{1/3} = 15.87 \text{ cm.}$$

Q. 3. *A short bar magnet is placed in a horizontal plane with its axis in the magnetic meridian. Null points are found on its equatorial line (i.e., its normal bisector) at 12.5 cm from the centre of the magnet. The earth's magnetic field at the place is 0.38 gauss, and the angle of dip is zero. (a) What is the total magnetic field at points on the axis of the magnet located at the same distance (12.5 cm) as the null points from the centre? (b) Locate the null points when the bar is turned around by 180°. Assume that the length of the magnet is negligible compared to the distance of the null points from the centre of the magnet.*

Ans. (*a*) From fig. (*a*), it is clear that null points are obtained on the normal bisector when the magnet's north and south poles face magnetic north and south respectively.

Magnetic field on the normal bisector at a distance r from the centre is given by $\vec{B}_e = -\frac{\mu_0}{4\pi}\frac{\vec{M}}{r^3}$, provided r is much greater than the length of the magnet. [*The above equation is strictly true only for a point dipole.*]

At a null point, this field is balanced by the earth's field.

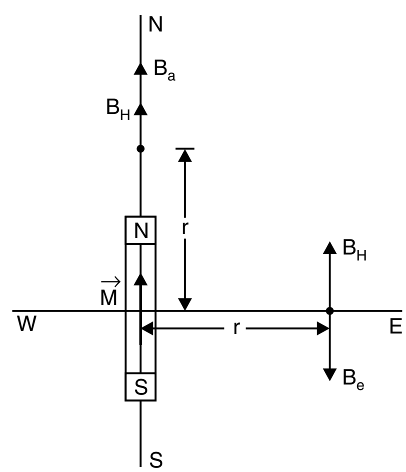

Fig. 5.31 (*a*)

So, $B_e = B_H$

$$\frac{\mu_0}{4\pi}\frac{M}{r^3} = 0.38 \times 10^{-4} \quad ...(1)$$

(*Since the dip angle (s) is zero, therefore, $B_v = 0$ and the horizontal component of the earth's field equals the field itself.*)

Next, magnetic field due to a magnet on its axis at point distant r from the centre is given by

$$B_a = \frac{\mu_0}{4\pi}\frac{2M}{r^3} \quad ...(2)$$

provided r is much greater than the length of the magnet. (*The above equation is strictly true only for a point dipole*). From fig. (*a*), it is clear that on the axis, this field adds up to the earth's field.

Thus, the total field at a point on the axis has a magnitude equal to $B_a + B_H$

i.e., $$\frac{\mu_0}{4\pi}\frac{2M}{r^3} + 0.38 \times 10^{-4} \quad ...(3)$$

and direction along $\vec{M}$ [which is parallel to the earth's field in case (*a*)].

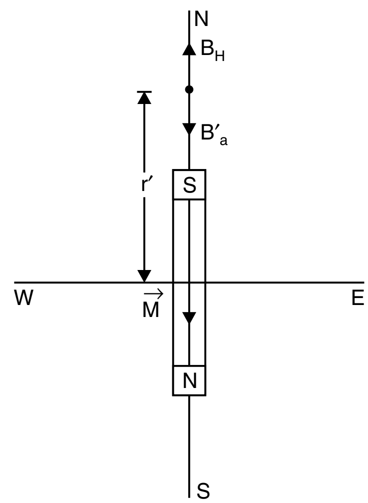

Fig. 5.31(*b*)

Thus, for the same distance on the axis as the distance of the null point, the total field, using equations (1) and (3) is

$$2 \times 0.38 \times 10^{-4} + 0.38 \times 10^{-4}$$

i.e., $3 \times 0.38 \times 10^{-4}$

i.e., 1.14 × 10–4 tesla

This field is directed along $\vec{M}$.

Note. *We did not require the given value of 12.5 cm for the nullpoint distance, except in so far that this was assumed to be much greater than the length of the magnet.*

(*b*) When the bar is turned around by 180°, the magnet's north and south poles face magnetic south and north respectively *i.e.,* in this case, $\vec{M}$ is antiparallel to the earth's field. From fig. (*b*), it is clear that the nullpoints now lie on the axis of the magnet at a distance r' given by $B_a' = B_H$

or $$\frac{\mu_0}{4\pi}\frac{2M}{r'^3} = 0.38 \times 10^{-4} \quad ...(4)$$

Comparing equations (4) and (1), we get

$$\frac{2}{r'^3} = \frac{1}{r^3} \quad \text{or} \quad r'^3 = 2r^3 \quad \text{or} \quad r' = (2)^{1/3}\, r$$

For $r = 12.5$ cm, $r' = 15.7$ cm

Q. 4. *A solenoid of 500 turns per metre is carrying a current of 3A. Its core is made of iron, which has a ralative permeability of 5000. Determine the magnitudes of magnetic intensity, magnetisation and magnetic field inside the core.*

Ans. Given, $n = 500$ turns/m

$i = 3A, \quad \mu_r = 5000$

Magnetic intensity,

$$\boxed{H = ni} = 500 \times 3 = 1500 \text{ Am}^{-1}$$

Since, $$\boxed{\mu_r = 1 + \chi \text{ cm}}$$

$\therefore$ $$\chi_m = \mu_r - 1 = 5000 - 1$$
$$= 4999 \approx 5000$$

Also, $$\boxed{\mu_r = \frac{\mu}{\mu_0}} = 5000$$

$\therefore$ $$\mu_r = 5000\ \mu_0$$

Magnetisation, $$\boxed{I = \chi_m \text{ H}}$$
$$= 5000 \times 1500 = 7.5 \times 10^6 \text{ Am}^{-1}$$

Magnetic field inside the core,

$$\boxed{B = \mu H} = 5000\ \mu_0\ H \qquad \boxed{\because \quad \mu = \mu_0 H}$$
$$= 5000\ (4\pi \times 10^{-7}) \times 1500$$

or, $$B = 3\pi = 3 \times \frac{22}{7} = 9.4 \text{ T.}$$

Q. 5. *If δ_1 and δ_2 be the angles of dip observed in two planes at right angles to each other and δ is the true angle of dip, then prove that*

$$cot^2\ \delta_1 + cot^2\ \delta_2 = cot^2\ \delta$$

Ans. If horizontal and vertical components of earth's magnetic field are represented by B_H and B_V respectively, then

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

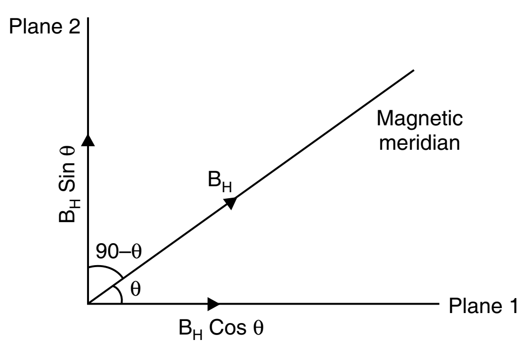

Fig. 5.32

Let δ_1 be the (apparent) dip in a plane which makes angle θ with the magnetic meridian. In this plane, the vertical component will be B_V only but the effective horizontal component will be $B_H \cos \theta$.

$$\tan \delta_1 = \frac{B_V}{B_H \cos \theta}$$

or, $$\tan \delta_1 = \frac{\tan \delta}{\cos \theta} \qquad \because \; B_V = B_H \tan \delta$$

or, $$\cos \theta = \frac{\tan \delta}{\tan \delta_1} = \tan \delta \cot \delta_1 \qquad ...(i)$$

Let δ_2 be the (apparent) dip in the second plane. The angle made by this plane with the magnetic meridian will be $(90° - \theta)$.

Effective horizontal component in this plane is $B_H \cos (90° - \theta)$ *i.e.,* $B_H \sin \theta$. The vertical component will be B_V only.

$$\tan \delta_2 = \frac{B_V}{B_H \sin \theta} = \frac{\tan \delta}{\sin \theta}$$

or, $$\sin \theta = \frac{\tan \delta}{\tan \delta_2} = \tan \delta \cot \delta_2 \qquad ...(ii)$$

Squaring and adding equation (*i*) and (*ii*), we get

$$\cos^2 \theta + \sin^2 \theta = \tan^2 \delta \cot^2 \delta_1 + \tan^2 \delta \cot^2 \delta_2$$

or, $$1 = \tan^2 \delta (\cot^2 \delta_1 + \cot^2 \delta_2)$$

or, $$\cot^2 \delta = \cot^2 \delta_1 + \cot^2 \delta_2$$ **Proved**

Q. 6. (*a*) *Draw diagrams to depict the behaviour of magnetic field lines near a 'bar' of:*

(i) copper

(ii) aluminium

(iii) mercury, cooled to a very low temperature (4.2 K)

(*b*) *The vertical component of the earth's magnetic field at a given place is* $\sqrt{3}$ *times its horizontal component. If total intensity of earth's magnetic field at the place is 0.4 G find the value of:*

(i) angle of dip

(ii) the horizontal component of earth's magnetic field.

Ans. (*a*) (*i*) Copper is a diamagnetic material. When a specimen of a diamagnetic material is placed in a magnetising field, the field lines are repelled and the field inside the material is reduced.

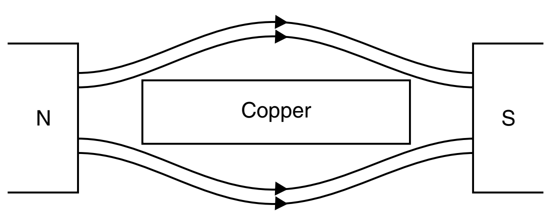

Fig. 5.33

(*ii*) Aluminium is a paramagnetic material. When a specimen of a paramagnetic material is placed in a magnetising field, the magnetic field lines prefer to pass through the specimen rather than through air.

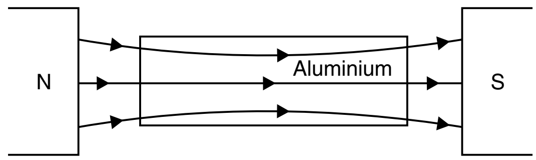

Fig. 5.34

(*iii*) Mercury at a very low temperature (4.2 K) is diamagnetic material. The magnetic field lines are shown as

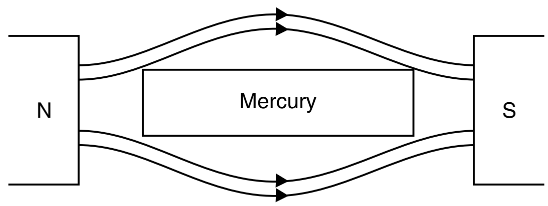

Fig. 5.35

(*b*) Here, $B_V = \sqrt{3}\, B_H$ and $B = 0.4$ G

(*i*)
$$\tan\delta = \frac{B_V}{B_H}$$
$$\tan\delta = \frac{\sqrt{3}\, B_H}{B_H} = \sqrt{3}$$
$$\tan\delta = \tan 60° \Rightarrow \delta = 60°$$

∴ Angle of dip = 60°

(*ii*) Horizontal component of earth's magnetic field
$$B_H = B\cos\delta$$
or,
$$H = 0.4\cos 60°$$
$$= 0.4 \times \frac{1}{2} = 0.2 \text{ G}$$

QUESTIONS ON HIGH ORDER THINKING SKILLS (HOTS)

Q. 1. *At a certain place, the angle between the geographic meridian and the magnetic meridian is 58 minutes. At the same place, the vertical and the horizontal components of earth's magnetic field are* $\left(\frac{0.3}{\sqrt{3}}\right) \times 10–4$ *Wb* m^{-2} *and* 0.3×10^{-4} *Wb* m^{-2} *respectively. Find the angle of declination and angle of dip at the place.*

Ans. Declination = Angle between geographic meridian and magnetic meridian.

Also, angle of dip (δ) is given by
$$\tan\delta = \frac{B_V}{B_H} = \frac{0.3}{\sqrt{3}} \times \frac{10^{-4}}{0.3 \times 10^{-4}}$$
$$= \frac{1}{\sqrt{3}}$$

Thus, $\delta = 30°$.

Q. 2. *The following figure shows the variation of intensity of magnetisation versus the applied magnetic field intensity, H, for two magnetic materials A and B:*

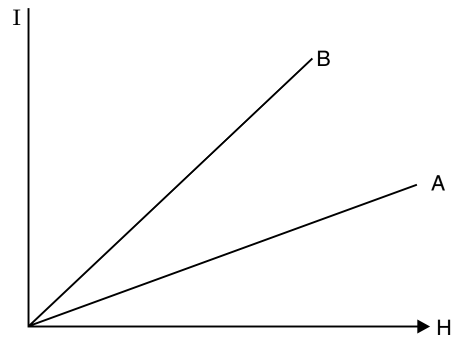

Fig. 5.36

(a) *Identify the materials A and B.*

(b) *Why does the material B, have a larger susceptibility than A, for a given field at constant temperature?*

Ans. (*a*) Material A is diamagnetic.

Material B is paramagnetic.

(*b*) Because paramagnetic substances have a tendency to pull in magnetic field lines when placed in a magnetic field or

$$\because \quad \chi = \frac{I}{H}$$

$$I_B > I_A \text{ for } H$$

Q. 3. *A circular coil of 100 turns and having a radius of 0.05 m carries a current of 0.1 A. Calculate the work required to turn the coil in an external magnetic field of 1.5 T through 180° about an axis perpendicular to the magnetic field. The plane of the coil is initially at right angles to the magnetic field.*

Ans. Here, $N = 100$, $r = 0.05$ m, $I = 0.1$A, θ = Angle between $\vec{B}$ and $\vec{A}$ of coil.

$W = ?$, $B = 1.5$ T, $\theta_1 = 0°$, $\theta_2 = 180°$

$$\boxed{M = N\,IA} = n\,I\,(\pi r^2) = 100 \times 0.1\,(3.14)\,(0.05)^2 = 7.85 \times 10^{-2} \text{ Am}^2$$

$$\boxed{W = -MB\,(\cos\theta_2 - \cos\theta_1)} = -7.85 \times 10^{-2} \times 1.5\,(\cos 180° - \cos 0°)$$

$$W = 0.24 \text{ J}$$

Q. 4. *Each atom of an iron bar (5 cm × 1 cm × 1 cm) has a magnetic moment 1.8×10^{-23} Am².*

(a) *What will be the magnetic moment of the bar in the state of magnetic saturation.*

(b) *What will be the torque required to place this magnetised bar perpendicular to magnetic field of 15000 gauss?*

Density of iron = 7.8×10^3 kg/m³

Atomic weight of iron = 56

Avagadro's number = 6.023×10^{23} gm/mole

Ans. Here, volume of specimen

$$V = 5 \times 1 \times 1 = 5 \times 10^{-6} \text{ m}^3$$

Number of atoms per unit volume

$$n = \frac{N}{A/\rho} = \frac{\rho N}{A}$$

For iron, $A = 56, \quad \rho = 7.8 \times 10^3 \text{ kg/m}^3$

$$N = 6.026 \times 10^{26} \text{ kg/mole}$$

$$\therefore \quad n = \frac{7.8 \times 10^3 \times 6.02 \times 10^{26}}{56} = 8.38 \times 10^{28} \text{ m}^{-3}$$

∴ Total number of atoms in the iron bar

$$N = n\,V = 8.38 \times 10^{28} \times 5 \times 10^{-6}$$

$$N = 4.19 \times 10^{23}$$

∴ Saturated magnetic moment of the bar

$$M = 4.19 \times 10^{23} \times 1.8 \times 10^{-23} = 7.54 \text{ Am}^2$$

$$\tau = MB \sin\theta = 7.54 \times (15000 \times 10^{-4}) \sin 90°$$

or, $\tau = 11.31$ Nm.

Q. 5. *The core of a toroid having 3000 turns has inner and outer radii of 11 cm and 12 cm respectively. The magnetic field in the core for a current of 0.70 A is 2.5 T. What is the relative permeability of the core? Take $\pi = 3.14$.*

Ans. The magnetic field in the empty space enclosed by the windings of the toroid is given by

$$\boxed{B = \mu_0 n I} \quad ...(1)$$

where n is the number of turns per unit length and I is the current.

If the space is filled by a core of permeability μ, then equation (1) is rewritten as under:

$$\boxed{B = \mu n I}$$

Now, B = 2.5 tesla, I = 0.70 ampere, mean radius = 11.5 cm = 11.5×10^{-2} m

Number of turns per unit length,

$$n = \frac{3000}{2\pi \times 11.5 \times 10^{-2}} \text{ m}^{-1}$$

Here, we have ignored the variation of B across the cross-section of the toroid and taken the radius of the toroid to be the mean of inner and outer radii.

$$\therefore \quad \mu = \frac{B}{nI} = \frac{2.5 \times 2\pi \times 11.5 \times 10^{-2}}{3000 \times 0.7}$$

$$\mu = 8.6 \times 10^{-4} \text{ T m A}^{-1}$$

Relative permeability of core, $\mu_r = \frac{\mu}{\mu_0} = 684.7$

Q. 6. *A tangent galvanometer is set with its plane making an angle of 30° with the magnetic meridian. When a current is passed through 2 turns coil of radius 0.10 m, in the anti-clockwise direction, the compass needle shows a deflection of 30°. Calculate the strength of current passed. Take $H = 0.32 \times 10^{-4}$ T.*

Ans. Before passing current, compass needle was along H. On passing current, the needle shows a deflection of 30° (with H) under the combined effect of H and B, magnetic field due to current (in a direction perpendicular to the plane of the coil).

As compass needle is inclined equally to H and B, figure therefore,

$$B = H$$

$$\frac{\mu_0 N I}{2r} = H$$

$$I = \frac{2r H}{\mu_0 N} = \frac{2 \times 0.1 \times 0.32 \times 10^{-4}}{4\pi \times 10^{-7} \times 2}$$

or, $$I = 2.54 \text{ A}$$

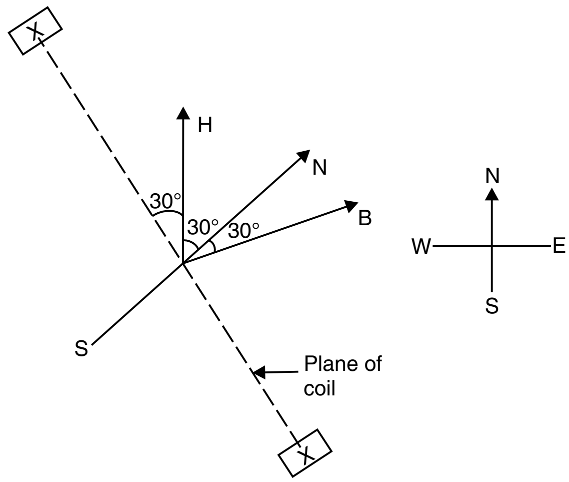

Fig. 5.37

Q. 7. *Two bar magnets placed together in a vibration magnetometer take 3 second for 1 vibration. If one magnet is reversed, the combination takes 4 second for 1 vibration. Find the ratio of their magnetic moments.*

Ans. $$T_1 = 3 \text{ s}, \quad T_2 = 4 \text{ s}$$

$$\frac{M_1}{M_2} = \frac{T_2^2 + T_1^2}{T_2^2 - T_1^2} = \frac{4^2 + 3^2}{4^2 - 3^2}$$

$$= \frac{16+9}{16-9} = \frac{25}{7} \quad \text{or} \quad \frac{M_1}{M_2} = 3.57$$

Q. 8. *A magnet is suspended so that it may oscillate in the horizontal plane. It performs 20 oscillations per minute at a place where the angle of dip is 30° and 15 oscillations per minute, where the angle of dip is 60°. Compare the earth's total magnetic field at these two places.*

Ans. $$v = \frac{1}{2\pi}\sqrt{\frac{MB_H}{I}} \quad \text{or} \quad v \propto \sqrt{B_H} \quad w^2 = \frac{MB}{I}$$

$$4\pi^2 v^2 = \frac{MB}{I}$$

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

or, $$v \propto \sqrt{B \cos \delta}$$

or, $$B \cos \delta \propto v^2 \quad \text{or} \quad B \propto \frac{v^2}{\cos \delta}$$

$$\frac{B_1}{B_2} = \frac{v_1^2}{\cos\delta_1} \times \frac{\cos\delta_2}{v_2^2} = \frac{20 \times 20 \times \cos 60°}{\cos 30° \times 15 \times 15}$$

$$= \frac{200 \times 2}{\sqrt{3} \times 225} = \frac{400}{225\sqrt{3}} = \frac{16}{9\sqrt{3}}$$

Q. 9. *The true value of dip at a place is 30°. The vertical plane carrying the needle is turned through 45° from the magnetic meridian. Calculate the apparent value of dip.*

Ans. Given, $\delta = 30°, \quad \theta = 45°, \quad \delta' = ?$

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

$$\tan\delta' = \frac{B_V}{B_H'} = \frac{B_V}{H\cos 45°}$$

$$\tan\delta' = \frac{\tan\delta}{\cos 45°} = \frac{\tan 30°}{\cos 45°}$$

or $$\tan\delta' = \frac{\sqrt{2}}{\sqrt{3}} = 0.8164.$$

$\therefore$ $$\delta' = 39°14'.$$

Q. 10. *If a compass is taken to magnetic north pole of earth, what will be the direction of the needle?*

Ans. Earth's magnetic field at the poles is exactly vertical with *S* pole of compass down side. A compass needle moves freely in a horizontal plane. Therefore, the compass needle will not necessarily rest along N-S direction, at the pole of earth. It may rest in any arbitrary direction in horizontal plane.

MULTIPLE CHOICE QUESTIONS

1. A magnet of magnetic moment *M* is suspended in a uniform magnetic field *B*. The maximum value of torque acting on the magnet is

(*a*) MB (*b*) $\frac{1}{2}MB$ (*c*) $2MB$ (*d*) zero

2. Magnetic field due to a bar magnet 2 cm long having a pole strength of 100 Am at a point 10 cm from each pole is

(*a*) 2×10^{-4} T (*b*) $8\pi \times 10^{-4}$ T (*c*) 2×10^{-5} T (*d*) 4×10^{-4} T

3. The vertical component of earth's magnetic field is zero at a place where angle of dip is

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

4. A magnetic component *M* is kept in a uniform magnetic field of strength *B*, making angle θ with its direction. The torque acting on it is

(*a*) MB (*b*) $MB\cos\theta$ (*c*) $MB(1 - \cos\theta)$ (*d*) $MB\sin\theta$

5. A bar magnet of magnetic moment *M*, is placed in a magnetic field of induction *B*. The torque exerted on it is

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

6. A bar magnet of magnetic moment *M* and length *L* is cut into two equal parts each of length *L*/2. The magnetic moment of each part will be

(*a*) M (*b*) $M/4$ (*c*) $\sqrt{2}M$ (*d*) $M/2$

7. At a certain place, the horizontal component of the earth's magnetic field is B_0 and the angle of dip is 45°. The total intensity of the field at that place will be

(*a*) B_0 (*b*) $\sqrt{2}B_0$ (*c*) $2B_0$ (*d*) B_0^2

8. At a given place on the earth's surface, horizontal component of earth's magnetic field is 3×10^{-5} T and resultant magnetic field is 6×10^{-5} T. The angle of dip at the place is

(*a*) 30° (*b*) 40° (*c*) 50° (*d*) 60°

9. Magnetic dipole moment is a vector quantity directed from

(*a*) south to north (*b*) north to south (*c*) east to west (*d*) west to east.

10. A dimagnetic substance is

(*a*) repelled when south pole of magnet is brought near it
(*b*) repelled when north pole of magnet is brought near it
(*c*) repelled by both the poles of magnet
(*d*) attracted by both the poles of magnet

11. The radius of the coil of a T.G. which has 10 turns is 0.1 m. The current required to produce a deflection of 60° ($B_H = 4 \times 10^{-5}$ T) is

(*a*) 3A (*b*) 1.1 A (*c*) 2.1 A (*d*) 2.6 A

12. The force between two magnetic poles is F. If the distance between the poles and pole strengths of each pole are doubled, then the force experienced is

(*a*) $2F$ (*b*) $F/2$ (*c*) $F/4$ (*d*) F.

13. Relative permeability of iron is 5500. Its magnetic susceptibility is

(*a*) 5500×10^7 (*b*) 5499 (*c*) 5501 (*d*) 5500×10^{-7}

14. A current is flowing north along a power line. The direction of the magnetic field above it neglecting the earth's field is towards.

(*a*) north (*b*) east (*c*) south (*d*) west
(*e*) none of these

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

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

Answers

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

TEST YOUR SKILLS

1. Why should the material used for making permanent magnets have high corecivity?
2. Mention two properties of the alloy from which permanent magnets are made.
3. You are given two identically looking bars A and B. One of these is a bar magnet and other an ordinary piece of iron. Give an experiment to identify which one of the two is a bar magnet. You are not to use any additional material for the experiment.
4. Define angle of dip. Deduce the relation connecting angle of dip and horizontal component of Earth's magnetic field at a place.
5. What is the angle of dip at a place where the horizontal and vertical components of earth's field are equal to each other?
6. Give main properties of dia, para, and ferromagnetic materials.

7. A short bar magnet of magnetic moment 0.9 JT^{-1}, placed with its axis at 45° with a uniform external magnetic field, experiences a torque of magnitude 0.063 J. Find the strength of the magnetic field.

8. Horizontal component of earth's magnetic field at a place is $\sqrt{3}$ times the vertical component. What is the value of angle of dip at this place?

9. Define magnetic susceptibility of a material. Name two elements, one having positive susceptibility and the other having negative susceptibility. What does negative susceptibility signify?

10. If χ stands for the magnetic susceptibility of a given material, identify the class of materials for which

    (*i*) $-1 \leq \chi < 0$

    (*ii*) $-1 < \chi < \varepsilon$, (ε stands for a small positive number)

    (*a*) Write the range of relative magnetic permeability of these materials

    (*b*) Draw the pattern of magnetic field lines when these materials are placed in an external magnetic field.

11. Name three elements required to specify the earth's magnetic field at a given place. Draw a labelled diagram to define these elements. Explain briefly how these elements are determined to find out the magnetic field at a given place on the surface of earth.

12. The following figure 5.38 shows the variation of intensity of magnetisation versus the applied magnetic field intensity, *H*, for two magnetic materials *A* and *B*.

    (*a*) Identity the materials *A* and *B*

    (*b*) Why does the material *B*, have a larger susceptibility than *A*, for a given field at constant temperature?

    (*c*) For the material *A*, plot the variation of intensity of magnetisation versus temperature.

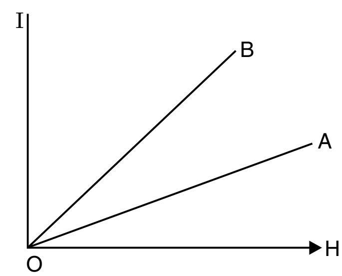

Fig. 5.38

13. The following figure shows the variation of intensity of magnetisation versus the applied magnetic field intensity, *H*, for two magnetic material *A* and *B*.

    (*a*) Identity the materials *A* and *B*

    (*b*) Draw the variation of susceptibility with temperature for *B*?

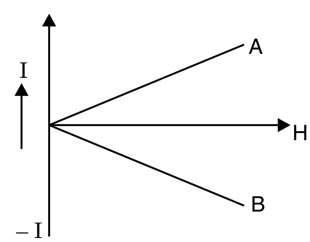

Fig. 5.39

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

15. When two materials are placed in an external magnetic field, the behaviour of magnetic field lines is as shown in the figure. Identify the magnetic nature of each of these materials.

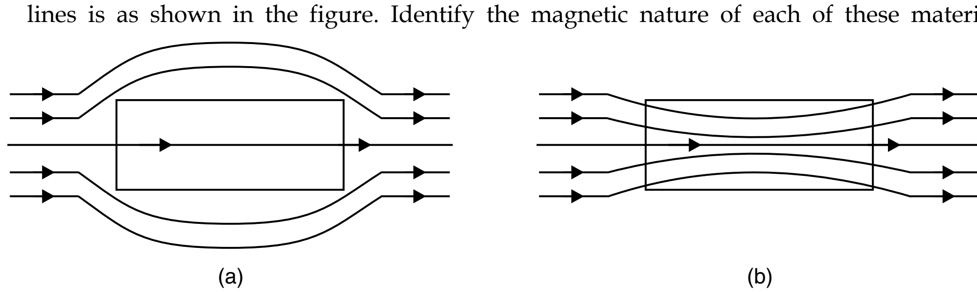

Fig. 5.40

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