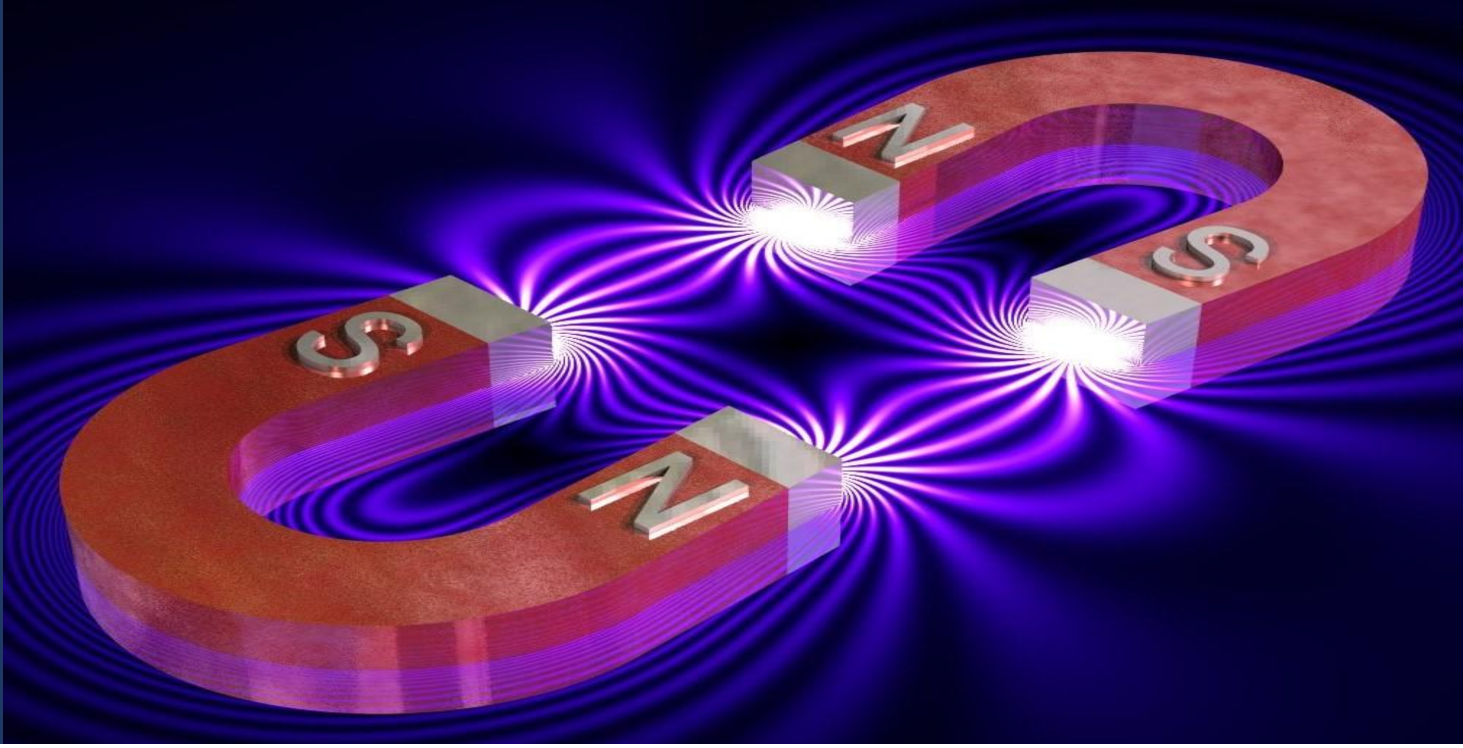
MAGNETISM AND MATTER

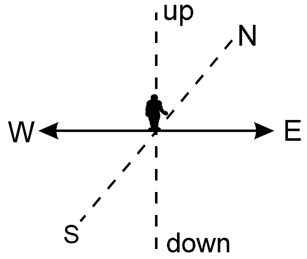


CHAPTER – 5

MAGNETISM AND MATTER

Two bodies even after being neutral (showing no electric interaction) may attract / repel strongly if they have a special property. This property is known as magnetism. This force is called magnetic force. Those bodies are called magnets. Later on, we will see that it is due to circulating currents inside the atoms. Magnets are found in different shape but for many experimental purposes, a bar magnet is frequently used. When a bar magnet is suspended at its middle, as shown, and it is free to rotate in the horizontal plane it always comes to equilibrium in a fixed direction.

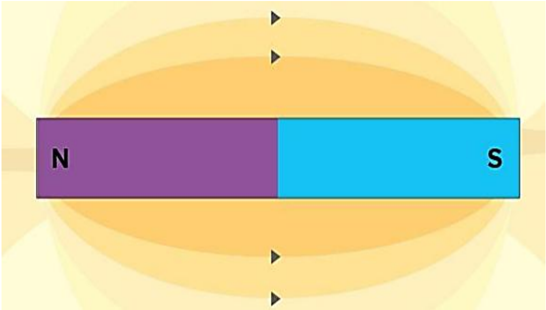
One end of the magnet (say A) is directed approximately towards north and the other end (say B) approximately towards south. This observation is made everywhere on the earth. Due to this reason the end A, which points towards north direction is called NORTH POLE and the other end which points towards south direction is called SOUTH POLE. They can be marked as 'N' and 'S' on the magnet. This property can be used to determine the north or south direction anywhere on the earth and indirectly east



and west also if they are not known by other method (like rising of sun and setting of the sun). This method is used by navigators of ships and aero planes. The directions are as shown in the figure. All directions E, W, N, S are in the horizontal plane.

The magnet rotates due to the earth's magnetic field about which we will discuss later in this chapter.

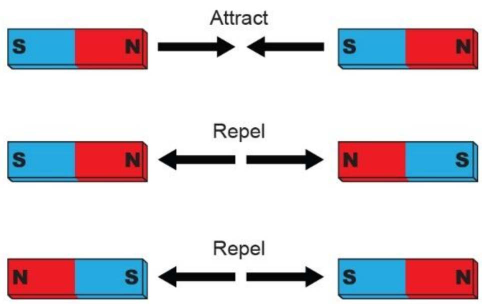
The Bar Magnet



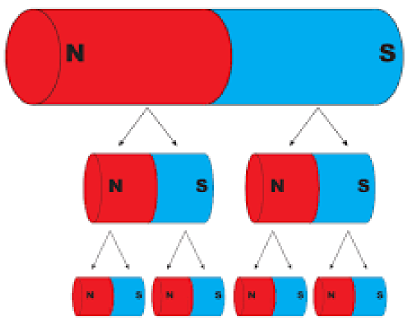
A bar magnet is a rectangular piece of an object, made up of iron, steel or any other ferromagnetic substance or ferromagnetic composite, that shows permanent magnetic properties. It has two poles, a north and a south pole such that when suspended freely, the magnet aligns itself so that the northern pole points towards the magnetic north pole of the earth.

Pole Strength Magnetic Dipole and Magnetic Dipole Moment

A magnet always has two poles 'N' and 'S' and like poles of two magnets repel each other and the unlike poles of two magnets attract each other they form action reaction pair.

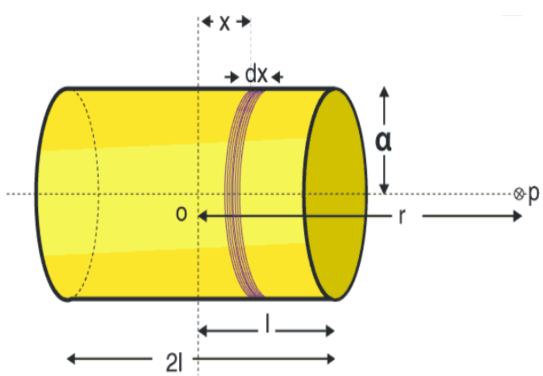


The poles of the same magnet do not come to meet each other due to attraction. They are maintained we cannot get two isolated poles by cutting the magnet from the middle. The other end becomes pole of opposite nature. So, 'N' and 'S' always exist together.



Bar Magnet as an Equivalent Solenoid

By calculating the axial field of a finite solenoid carrying current, a bar magnet can be demonstrated as a solenoid. Consider a solenoid of radius a and length 2l with n number of turns per unit length that has current I passing through the solenoid. Considering a small element of thickness dx of the solenoid at a distance x from O such that OP = r.



Bar magnet as an Equivalent Solenoid

Magnetic field due to n turns at the axis of the solenoid

$$dB = \frac{\mu_0 n dx I a^2}{2[(r-x)^2+a^2]^{3/2}}$$

Integrating x from -l to +l to get the magnitude of the total field

$$B=\frac{\mu_0 n I a^2}{2}\int_{-l}^{l}\frac{dx}{[(r-x)^2+a^2]^{\frac{3}{2}}}$$

$$[(r-x)^2+a^2]^{3/2}=r^3$$

And

$$B=\frac{\mu_0 n I a^2}{2}\int_{-l}^{l}dx$$

Therefore

$$B=\frac{\mu_0}{4\pi}\frac{2m}{r^3}$$

From the above expression, it is understood that the magnetic moment of a bar magnet is equal to the magnetic moment of a solenoid.

Difference between a Bar Magnet and a Solenoid

The bar magnet is a permanent magnet, whereas a solenoid is an electromagnet i.e., it acts as a magnet only when an electric current is passed through.

When a bar magnet is cut into two halves, both the pieces act as a magnet with the same magnetic properties, whereas when a solenoid is cut into two halves, it will have weaker fields.

The poles of the bar magnet are fixed, whereas, for a solenoid, the poles can be altered.

The strength of the magnetic field of a bar magnet is fixed, i.e., unaltered, whereas the strength of the magnetic field of a solenoid depends on the electric current that is passed through it.

The Dipole in a Uniform Magnetic Field

if we place iron filings around a bar magnet on a sheet of paper and tape the sheet, the fillings rearrange themselves to form a specific pattern. The pattern of iron filings here denotes the magnetic field lines generated due to the magnet. These magnetic field lines give us an approximate idea of the magnetic field B. But many times, we are required to determine the magnitude of the magnetic field B accurately. We accomplish this by placing a small compass needle of known magnetic moment m and moment of inertia and allowing it to oscillate in the magnetic field. The torque on the needle can be given as,

$$\vec{\tau} = \overrightarrow{m} \times \vec{B}$$

The magnitude of this torque is given by mB sinθ. Here τ is the restoring torque, and θ is the angle between the direction of the magnetic moment (m) and the direction of the magnetic field (B).

At equilibrium, we can say that,

$$\frac{Id^2\theta}{dt} \cong -mBsin\theta$$

The negative sign in the above expression mB sinθ brings us to the conclusion that the restoring torque acting here acts in the opposite direction to the deflecting torque. Also, as the value of θ is very small in radians, we can approximate sin θ ≈ θ. Thus, using this approximation, we can write

$$\frac{Id^2\theta}{dt} \cong -mB\theta$$

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

The above equation is a representation of a simple harmonic motion and the angular frequency can be given as,

$\omega = \frac{mB}{I}$ and thus, the time period can be stated as,

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

An expression for magnetic potential energy can also be obtained on lines similar to electrostatic potential energy. The magnetic potential energy Um is given by

$U_m = \int \tau(\theta) d\theta$

$= -\int mB \sin\theta \, d\theta \cos\theta = -m B \cos\theta$

$=-m.B$

Q. A 250-turn rectangular coil of length 2.1 cm and width 1.25 cm carries a current of 85 μA and subjected to a magnetic field of strength 0.85 T. find the Work done for rotating the coil by 180° against the torque.

Sol. Work done in a coil

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

When it is rotated by angle 180° then

$W = 2mb = 2\,(NIA)B$ ...(i)

Given: $N = 250, I = 85\ \mu A = 85 \times 10^{-6}$ A

$A = 1.25 \times 2.1 \times 10^{-4}\ m^2 \approx 2.6 \times 10^{-4}\ m^2$

$B = 0.85$ T

Putting these values in eqn. (i), we get

$W = 2 \times 250 \times 85 \times 10^{-6} \times 2.6 \times 10^{-4} \times 0.85$

$\approx 9.1 \times 10^{-6}\ J = 9.1\ \mu J$

Q. A closely wound solenoid of 2000 turns and area of cross-section $1.5 \times 10^{-4}\ m^2$ carries a current of 2.0 A. It is suspended through its centre and perpendicular to its length, allowing it to turn in a horizontal plane in a uniform magnetic field 5×10^{-2} tesla making an angle of 30° with the axis of the solenoid. Determine the torque on the solenoid

Sol. Magnetic moment of the loop

$M = NIA = 2000 \times 2 \times 1.5 \times 10^{-4} = 0.6\ J/T$ Torque $\tau = MB\sin 30°$

$= 0.6 \times 5 \times 10^{-2} \times \frac{1}{2} = 1.5 \times 10^{-2}$ Nm

The Electrostatic Analog

If we compare the equation derived above with the equations of electric dipole in an electric field, we conclude that the magnetic field due to a bar magnet at a large distance is analogous to that of an electric dipole in an electric field. The correspondence relation can be stated as given below,

$E \to B, p \to m, \frac{1}{4\pi\epsilon_0} \to \frac{\mu_0}{4\pi}$

If the value of r, that is, the distance of the point from the given magnet is very large as compared to the size of the magnet given by l, or r >> l, then we can write the equatorial field generated by a bar magnet as

$B_E = -\frac{\mu_0 m}{4\pi r^3}$

Similarly, the axial field of the bar magnet in the same condition can be given as,

$B_A = -\frac{\mu_0 2m}{4\pi r^3}$

Magnetism and Gauss's Law

The number of magnetic field lines leaving the surface is balanced by the number of lines entering it. The net magnetic flux is zero for both the surfaces. This is true for any closed surface.

Consider a small vector area element ΔS of a closed surface S as in Fig. 5.6. The magnetic flux through ÄS is defined as $\Delta\phi_B = B.\Delta S$, where B is the field at ΔS. We divide S into many small area elements and calculate the individual flux through each. Then, the net flux ϕ_B is,

$$\varphi_B = \sum_{all} \Delta\varphi_B = \sum_{all} B.\Delta s = 0$$

where 'all' stands for 'all area elements ΔS'

The flux through a closed surface in that case is given by

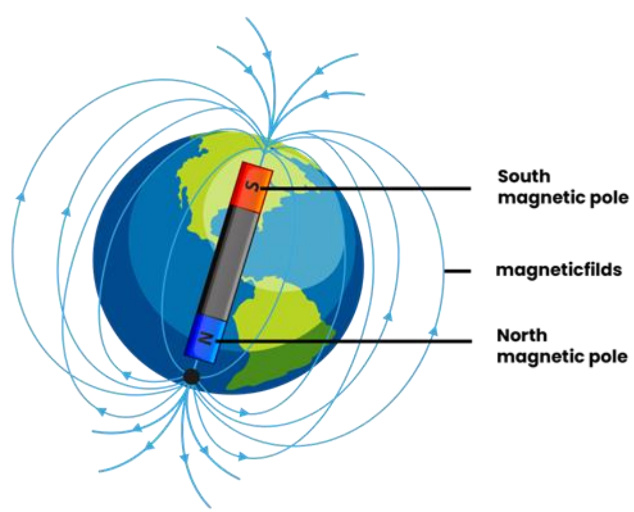
$$\sum_{all} E.\Delta s = \frac{q}{\varepsilon_0}$$

where q is the electric charge enclosed by the surface. The difference between the Gauss's law of magnetism and that for electrostatics is a reflection of the fact that isolated magnetic poles (also called monopoles) are not known to exist. There are no sources or sinks of B; the simplest magnetic element is a dipole or a current loop. All magnetic phenomena can be explained in terms of an arrangement of dipoles and/or current loops. Thus, Gauss's law for magnetism is:

The net magnetic flux through any closed surface is zero.

Earth's Magnetism

The idea that earth is magnetized was first suggested towards the end of the six-tenth century by Dr William Gilbert. The origin of earth's magnetism is still a matter of conjecture among scientists but it is agreed upon that the earth behaves as a magnetic dipole inclined at a small angle (11.5º) to the earth's axis of rotation with its south pole pointing north. The lines of force of earth's magnetic field are shown in figure which are parallel to the earth's surface near the equator and perpendicular to it near the poles. While discussing magnetism of the earth one should keep in mind that:



(a) The **magnetic meridian** at a place is not a line but a vertical plane passing through the axis of a freely suspended magnet, i.e., it is a plane which contains the place and the magnetic axis.

(b) The **geographical meridian** at a place is a vertical plane which passes through the line joining the geographical north and south, i.e., it is a plane
which contains the place and earth's axis of rotation, i.e., geographical axis.

(c) The **magnetic Equator** is a great circle (a circle with the center at earth's Centre) on earth's surface which is perpendicular to the magnetic axis. The magnetic equator passing through Trivandrum in South India divides the earth into two hemispheres. The hemisphere containing south polarity of earth's magnetism is called the northern hemisphere (NHS) while the other, the southern hemisphere (SHS).

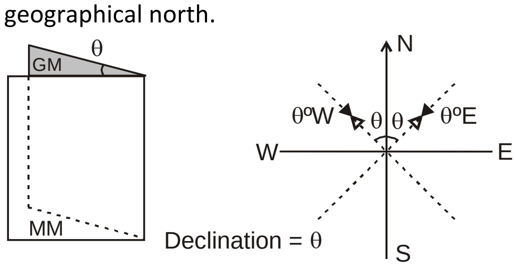
(d) The magnetic field of earth is not constant and changes irregularly from place to place on the surface of the earth and even at a given place it varies with time too.

Elements of earths magnetism

The magnetism of earth is completely specified by the following three parameters called elements of earth's magnetism

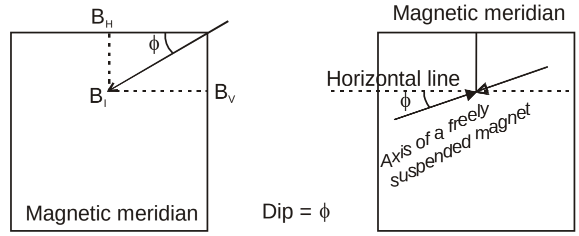
(a) Variation or Declination

At a given place the angle between the geographical meridian and the magnetic meridian is called declination, i.e., at a given place it is the angle between the geographical north-south direction and the direction indicated by a magnetic compass needle, Declination at a place is expressed at q° E or q°W depending upon whether the north pole of the compass needle lies to the east (right) or to the west (left) of the geographical north-south direction. The declination at London is 10ºW means that at London the north pole of a compass needle points 10°W, i.e., left of the geographical north.



(A) (B)

(b) Inclination or Angle of Dip f: It is the angle which the direction of resultant intensity of earth's magnetic field subtends with horizontal line in magnetic meridian at the given place. Actually, it is the angle which the axis of a freely suspended magnet (up or down) subtends with the horizontal in magnetic meridian at a given place. Here, it is worthy to note that as the northern hemisphere contains south polarity of earth's magnetism, in it the north pole of a freely suspended magnet (or pivoted compass needle) will dip downwards, i.e., towards the earth while the opposite will take place in the southern hemisphere.



(A) (B)

Angle of dip at a place is measured by the instrument called Dip-Circle in which a magnetic needle is free to rotate in a vertical plane which can be set in any vertical direction. Angle of dip at Delhi is 42°.

(c) Horizontal Component of Earth's Magnetic Field B_H:

At a given place it is defined as the component of earth's magnetic field along the horizontal in the magnetic meridian. It is represented by BH and is measured with the help of a vibration or deflection magnetometer. At Delhi the horizontal component of the earth's magnetic field is 35 MT, i.e., 0.35 G. If at a place magnetic field of earth is BI and angle of dip f, then in accordance with figure (a).

$B_H = B_I \cos f$

and $B_v = B_I \sin f$ .... (1)

so that, $\tan f = \frac{B_v}{B_H}$

and $I = \sqrt{B_H^2 + B_v^2}$ ....(2)

Magnetization and Magnetic Intensity

The earth abounds with a bewildering variety of elements and compounds. In addition, we have been synthesizing new alloys, compounds and even elements. One would like to classify the magnetic properties of these substances. In the present section, we define and explain certain terms which will help us to carry out this exercise.

We have seen that a circulating electron in an atom has a magnetic moment. In a bulk material, these moments add up vectorially and they can give a net magnetic moment which is non-zero.

Magnetization

Magnetization M of a sample to be equal to its net magnetic moment per unit volume:

$M = \frac{m_{net}}{V}$

M is a vector with dimensions L^{-1} A and is measured in units of A m^{-1}. Consider a long solenoid of n turns per unit length and carrying a current I. The magnetic field in the interior of the solenoid was shown to be given by $B_0 = \mu_0 nI$

If the interior of the solenoid is filled with a material with non-zero magnetization, the field inside the solenoid will be greater than B_0. The net B field in the interior of the solenoid may be expressed as

$B = B_0 + B_m$

where B_m is the field contributed by the material core. It turns out that this additional field B_m is proportional to the magnetization M of the material and is expressed as $B_m = \mu_0 M$

where μ_0 is the same constant (permeability of vacuum) that appears in Biot-Savart's law.

Magnetic Intensity

It is convenient to introduce another vector field H, called the magnetic intensity, which is defined by

$\Rightarrow \quad H = \frac{B}{\mu} \qquad \Rightarrow \quad H = \frac{B_0 + B_m}{\mu}$

where H has the same dimensions as M and is measured in units of A m^{-1}. Thus, the total magnetic field B is written as: $B = B_0 + B_m$

We repeat our defining procedure. We have partitioned the contribute onto the total magnetic field inside the sample into two parts: one, due to external factors such as the current in the solenoid. This is represented by H. The other is due to the specific nature of the magnetic material, namely M.

$\Rightarrow \quad H = \frac{\mu_0 H + \mu_0 M}{\mu} \qquad \Rightarrow H = \frac{H}{\mu_r} + \frac{M}{\mu_r}$

$\Rightarrow \quad (\mu_r - 1) H = M \quad \Rightarrow \quad M = \chi H$

The latter quantity can be influenced by external factors. This influence is mathematically expressed as

$M = \chi H$

where χ, a dimensionless quantity, is appropriately called the **magnetic susceptibility.** It is a measure of how a magnetic material responds to an external field. Table lists χ for some elements. It is small and positive for materials, which are called paramagnetic. It is small and negative for materials, which are termed diamagnetic.

$\mu_r - 1 = \chi$,

$\mu_r = 1 + \chi$

is a dimensionless quantity called the relative magnetic permeability of the substance? It is the analog of the dielectric constant in electrostatics. The magnetic permeability of the substance is μ and it has the same dimensions and units as μ_0;

$\mu = \mu_0 \mu_r = \mu_0 (1 + \chi)$.

$\mu_r = (1 + \chi)$.

The three quantities χ, μ_r and μ are interrelated and only one of them is independent. Given one, the other two may be easily determined.

Table- Magnetic Susceptibility of Some Element At 300K

Diamagnetic substance	χ	Paramagnetic substance	χ
Bismuth	-1.66×10^{-5}	Aluminium	2.3×10^{-5}
Copper	-9.8×10^{-6}	Calcium	1.9×10^{-5}
Diamond	-2.2×10^{-5}	Chromium	2.7×10^{-4}
Gold	-3.6×10^{-5}	Lithium	2.1×10^{-5}
Lead	-1.7×10^{-5}	Magnesium	1.2×10^{-5}
Mercury	-2.9×10^{-5}	Niobium	2.6×10^{-5}
Nitrogen (STP)	-5.0×10^{-9}	Oxygen (STP)	2.1×10^{-6}
Silver	-2.6×10^{-5}	Platinum	2.9×10^{-4}
Silicon	-4.2×10^{-6}	Tungsten	6.8×10^{-5}

Q. An iron rod of susceptibility 599 is subjected to a magnetizing field of 1200 A m^{-1}. Find the permeability of the material of the rod. $(\mu_0 = 4\pi \times 10^{-7}\ \text{T m A}^{-1})$

Sol. Given, $X_m = 599$

Relative permeability of the material, $\mu_r = 1 + X_m$

or $\quad \mu_r = 1 + 599 = 600$

$\therefore \quad \mu = \mu_r \mu_0 = 600 \times (4\pi \times 10^{-7}) = 24\pi \times 10^{-5}\ \text{T m A}^{-1}$

Magnetic Properties of Materials

The discussion in the previous section helps us to classify materials as diamagnetic, paramagnetic or ferromagnetic. In terms of the susceptibility c, a material is diamagnetic if c is negative, para- if c is positive and small, and ferro- if c is large and positive.

A glance at Table 5.3 gives one a better feeling for these materials. Here e is a small positive number introduced to quantify paramagnetic materials. Next, we describe these materials in some detail.

Table: 2

Diamagnetic	Paramagnetic	Ferromagnetic
$-1 \leq \chi < 0$	$0 < \chi < \varepsilon$	$\chi >> 1$
$0 \leq \mu_r < 1$	$1 < \mu_r < 1 + \varepsilon$	$\mu_r >> 1$
$\mu < \mu_0$	$\mu > \mu_0$	$\mu >> \mu_0$

Diamagnetism:

Diamagnetic substances are those which have tendency to move from stronger to the weaker part of the external magnetic field. In other words, unlike the way a magnet attracts metals like iron, it would repel diamagnetic substance.

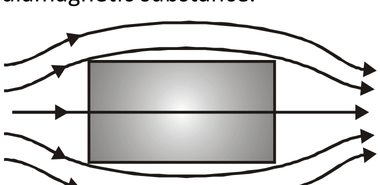


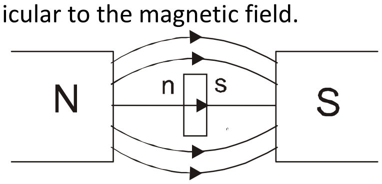
Figure shows a bar of diamagnetic material placed in an external magnetic field. The field lines are repelled or expelled and the field inside the material is reduced. In most cases, as is evident from Table 1, this reduction is slight, being one part in 10^5. When placed in a non-uniform magnetic field, the bar will tend to move from high to low field. The simplest explanation for diamagnetism is as follows. Electrons in an atom orbiting around nucleus possess orbital angular momentum. These orbiting electrons are equivalent to current-carrying loop and thus possess orbital magnetic moment. Diamagnetic substances are the ones in which resultant magnetic moment in an atom is zero. When magnetic field is applied, those electrons having orbital magnetic moment in

opposite direction speed up. This happens due to induced current in accordance with Lenz's law which you will study in Electro Magnetic Induction. Thus, the substance develops a net magnetic moment in direction opposite to that of the applied field and hence repulsion. Some diamagnetic materials are bismuth, copper, lead, silicon, nitrogen (at STP), water and sodium chloride. Diamagnetism is present in all the substances. However, the effect is so weak in most cases that it gets shifted by other effects like Para magnetism, ferromagnetism, etc. The most exotic diamagnetic materials are superconductors. These are metals, cooled to very low temperatures which exhibits both perfect conductivity and perfect diamagnetism. Here the field lines are completely expelled! $c = -1$ and $\mu_r = 0$. A superconductor repels a magnet and (by Newton's third law) is repelled by the magnet. The phenomenon of perfect diamagnetism in superconductors is called the Meissner effect, after the name of its discoverer. Superconducting magnets can be gainfully exploited in variety of situations, for example, for running magnetically levitated superfast trains.

Properties of diamagnetic substance

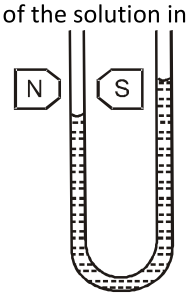
Diamagnetic substance shows following properties.

(i) When a rod of diamagnetic material is suspended freely between two magnetic poles, then its axis becomes perpendicular to the magnetic field.



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

(iii) If a diamagnetic solution is poured into a U-tube and one arm of this U-tube is placed between the poles of a strong magnet, the level of the solution in that arm is depressed.

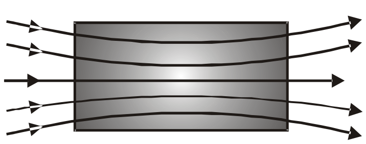


(iv) A diamagnetic gas when allowed to ascend in between the poles of a magnet spreads across the field.

(v) The susceptibility of a diamagnetic substance is independent of temperature.

Paramagnetism

Paramagnetic substances are those which get weakly magnetized when placed in an external magnetic field. They have tendency to move from a region of weak magnetic field to strong magnetic field, i.e., they get weakly attracted to a magnet.



The individual atoms (or ions or molecules) of a paramagnetic material possess a permanent magnetic dipole moment of their own. On account of the ceaseless random thermal motion of the atoms, no net magnetization is seen. In the presence of an external field B_0, which is strong enough, and at low temperatures, the individual atomic dipole moment can be made to align and point in the same direction as B_0. Figure shows a bar of paramagnetic material placed in an external field. The field lines get concentrated inside the material, and the field inside is enhanced. In most cases, as is evident from Table 1, this enhancement is slight, being one part in 10^5. When placed in a non-uniform magnetic field, the bar will tend to move from weak field to strong. Some paramagnetic materials are aluminum, sodium, calcium, oxygen (at STP) and copper chloride. Experimentally, one finds that the magnetization of a paramagnetic material is inversely proportional to the absolute temperature T,

$$M = C\frac{B_0}{T}$$

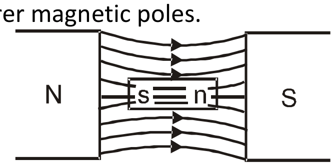
or equivalently, using Eqs $M = c\,H$ and $B_0 = m_0H$

$$c = \frac{\mu_0}{T}$$

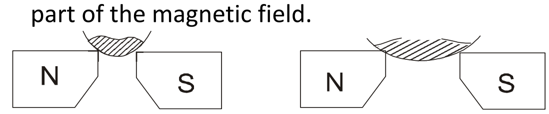
This is known as Curie's law, after its discoverer Pierre Curie (1859-1906). The constant C is called Curie's constant. Thus, for a paramagnetic material both c and μ_r depend not only on the material, but also (in a simple fashion) on the sample temperature. As the field is increased or the temperature is lowered, the magnetization increases until it reaches the saturation value M_s, at which point all the dipoles are perfectly aligned with the field. Beyond this, Curie's law is no longer valid.

Properties of Paramagnetic Substance

(i) When a rod of paramagnetic material is suspended freely between two magnetic poles, then its axis becomes parallel to the magnetic field The poles produced at the ends of the rod are opposite to the nearer magnetic poles.

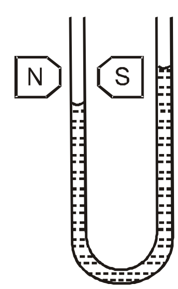


(ii) In a non-uniform magnetic field, the paramagnetic substances tend to move from weaker to stronger part of the magnetic field.



(a) **(b)**

(iii) If a paramagnetic solution is poured in a U-tube and one arm of the U-tube is placed between two strong poles, the level of the solution in that arm rises.



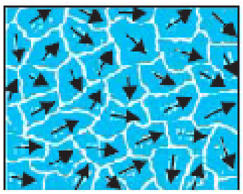
(iv) A paramagnetic gas when allowed to ascend between the pole-pieces of a magnet, spreads along the field.

(v) The susceptibility of a paramagnetic substance varies inversely as the kelvin temperature of the substance, that is,

χ_m μ $\frac{1}{T}$. This known as curie's law.

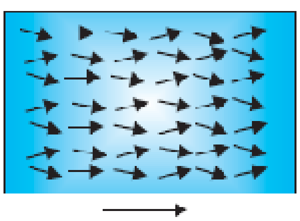
Ferromagnetism

Ferromagnetic substances are those which gets strongly magnetized when placed in an external magnetic field. They have strong tendency to move from a region of weak magnetic field to strong magnetic field, i.e., they get strongly attracted to a magnet. The individual atoms (or ions or molecules) in a ferromagnetic material possess a dipole moment as in a paramagnetic material. However, they interact with one another in such a way that they spontaneously align themselves in a common direction over a macroscopic volume called domain. The explanation of this cooperative effect requires quantum mechanics and is beyond the scope of this textbook. Each domain has a net magnetization. Typical domain size is 1mm and the domain contains about 10^{11} atoms. In the first instant, the magnetization varies randomly from domain to domain and there is no bulk magnetization. This is shown in Figure.



Randomly oriented domains,

When we apply an external magnetic field B_0, the domains orient themselves in the direction of B_0 and simultaneously the domain oriented in the direction of B_0 grow in size. This existence of domains and their motion in B_0 are not speculations. One may observe this under a microscope after sprinkling a liquid suspension of powdered ferromagnetic substance of samples. This motion of suspension can be observed. Figure (b) shows the situation when the domains have aligned and amalgamated to form a single 'giant' domain.



Aligned domains.

Thus, in a ferromagnetic material the field lines are highly concentrated. In non-uniform magnetic field, the sample tends to move towards the region of high field. We may wonder as to what happens when the external field is removed. In some ferromagnetic materials the magnetization persists. Such materials are called hard magnetic materials or hard ferromagnets. Alnico, an alloy of iron, aluminum, nickel, cobalt and copper, is one such material. The naturally occurring lodestone is another. Such materials form permanent magnets to be used among other things as a compass needle. On the other hand, there is a class of ferromagnetic materials in which the magnetizations disappears on removal of the external field. Soft iron is one such material. Appropriately enough, such materials are called soft ferromagnetic materials. There are a number of elements, which are ferromagnetic: iron, cobalt, nickel, gadolinium, etc. The relative magnetic permeability is >1000!

The ferromagnetic property depends on temperature. At high enough temperature, a ferromagnet becomes a paramagnet. The domain structure disintegrates with temperature. This disappearance of magnetization with temperature is gradual. It is a phase transition reminding us of the melting of a solid crystal. The temperature of transition from ferromagnetic to Para magnetism is called the Curie Temperature T_c. Table lists the Curie temperature of certain ferromagnets. The susceptibility above the Curie temperature, i.e., in the paramagnetic phase is described by,

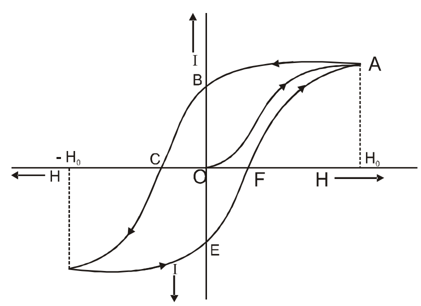
$\chi = \frac{C}{T - T_c}$ $(T > T_c)$

Ferromagnetic substances

These substances which are strongly attracted by a magnet, show all the properties of a paramagnetic substance to a much higher degree. For example, they are strongly magnetized in relatively weak magnetizing field in the same direction as the field. They have relative permeabilities of the order of hundreds and thousands. Similarly, the susceptibilities of ferromagnetic have large positive values.

Curie temperature: Ferromagnetism decreases with rise in temperature. If we heat a ferromagnetic substance, then at a definite temperature the ferromagnetic property of the substance "suddenly" disappears and the substance becomes paramagnetic. The temperature above which a ferromagnetic substance becomes paramagnetic is called the' Curie temperature' of the substance. The curie temperature of iron is 770°C and that of nickel is 358°C.

Hysteresis



Consider that a specimen of ferromagnetic material is placed in a magnetizing field, whose strength and direction can be changed. Suppose that the specimen is unmagnetized initially. When the magnetizing field (H) is increased, the intensity of magnetization (I) of the material of the specimen also increases. It is found that when the magnetizing field is made zero, the intensity of magnetization does not become zero but still has some finite value. It becomes zero only, when magnetizing field is increased in reversed direction. In other words, intensity of magnetization does not become zero on making magnetizing field zero but does so a little late and this effect is called hysteresis.

The lag of intensity of magnetizations behind the magnetizing field during the process of magnetizations and

demagnetization of a ferromagnetic material is called hysteresis.

Fig shows the magnetizations curve of a ferromagnetic material, when it is taken over a complete cycle of magnetization (I) is also zero. As magnetizing field is increased, intensity of a magnetization also increases along OA. Corresponding to point A, the intensity of magnetization becomes maximum. The increase in value of the magnetizing field beyond H_0 does not produce any increase in the intensity of magnetization. In other words, corresponding to point A, the specimen of the ferromagnetic material acquires a state of magnetic saturation. If magnetizing field is now decreased slowly, intensity of magnetization decreases but not a along the path AO. It decreases along the path AB. Corresponding to point B, magnetizing field becomes zero but some magnetization equal to OB is still left in the specimen. Here, OB gives the measure of retentivity of the material of the specimen.

The value of the intensity of magnetization of a material, when the magnetizing field is reduced to zero, is called retentivity of the material. It is also known residual magnetism.

To reduce intensity of magnetization to zero, the magnetizing field has to be increased in reverse direction. As it is done so, the intensity of magnetization decreases along BC, till it become zero corresponding to point C. Thus, to make intensity of magnetization zero, magnetizing field equal OC has to be applied in reverse direction. Here, OC gives the measure of coercivity of the material of the specimen.

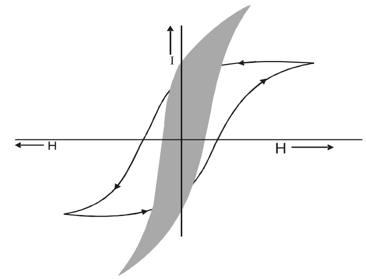
The value of reverse magnetizing field required so as to reduce residual magnetism to zero, is called coercivity of the material.

When the magnetizing field is further increased in reverse direction, intensity of magnetization increases along CD with the increase in magnetizing field. Corresponding to point D (when the magnetizing field becomes-H_0) it again acquires a saturation value, which is symmetrical to that corresponding to point A. If the magnetizing field is decreased from–H_0 to zero, the intensity of magnetization follows the path DE. Finally, when magnetizing field is increased field in original direction, the point A is reached via EFA. If the magnetizing field is repeatedly changed between H_0 and – H_0 , the curve ABCDEFA is retraced. The curve ABCDEFA is called the hysteresis loop. It is found that the area of the hysteresis loop (I – H curve) is proportional to the net energy absorbed per unit volume by the specimen, as it taken over a complete cycle of magnetization and demagnetization. The energy so absorbed by the specimen appears as the heat energy.

Note

If hysteresis loop is drawn by plotting a graph between magnetic induction (B) and intensity of magnetization, then area of the hysteresis loop is numerically equal to the work done per unit volume (or energy absorbed per unit volume) in taking the magnetic specimen over a complete cycle of magnetization

Comparison Of Hysteresis Loops For Soft Iron And Steel: -



The shape of the hysteresis loop is a characteristic of a ferromagnetic substance. It gives the idea about many important magnetic properties of the substance.

Figure Shown hysteresis loops for soft iron and steel. Whereas the hysteresis loop for soft iron is narrow, the hysteresis loop for steel is quite wide. The following conclusion can be drawn from the study of the hysteresis loops of soft iron and steel:

1. The area of hysteresis loop for soft iron is much smaller then that for steel. Therefore, loss of energy per unit volume in case of soft iron will be very small as compared to that in case of steel, when they are taken over a complete cycle of magnetization and demagnetization.
2. Soft iron acquires maximum intensity of magnetization for comparatively much lesser value of magnetizing field than in case of steel. In other words, soft iron is much strongly magnetized (or more susceptible to magnetization) than steel.
3. The retentivity of soft iron is greater than that of steel. On removing magnetizing field, quite a large amount of magnetization is retained by soft iron.
4. The coercivity of steel is much larger than that of soft iron. Therefore, the residula magnetism in steel cannot be destroyed that easily as in case of soft iron.

Section of magnetic materials:

The choice of a magnetic material for making permanent magnet, electromagnet, core of transformer or diaphragm of telephone ear-piece can be decided from the hysteresis curve of the material.

(i) **Permanent magnets:** The material for a permanent magnet should have high retentivity so that the magnet is strong, and high coercivity so that the magnetization is not wiped out by stray external fields, mechanical ill treatment and temperature changes. The hysteresis loss is immaterial because the material in this case is never put to cyclic changes of magnetization. From these considerations permanent magnets are made of steel. The fact that the retentivity of soft iron is a little greater than that of steel is outweighed by its much smaller coercivity, which makes it very easy to demagnetize.

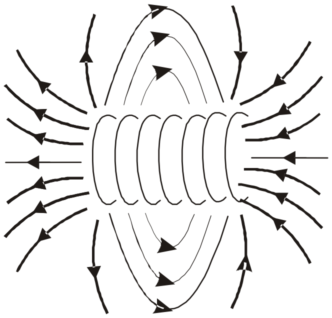
(ii) **Electromagnets:** The material for the cores of electromagnets should have high permeability (or high susceptibility), specially at low magnetizing fields, and a low retentivity. Soft iron is suitable material for electromagnets).

(iii) Transformer cores and telephone diaphragms: In these cases, the material goes through complete cycles of magnetization continuously. The material must therefore have a low hysteresis loss to have less dissipation of energy and hence a small heating of the material (otherwise the insulation of windings may break), a high permeability (to obtain a large flux density at low field) and a high specific resistance (to reduce eddy current loses).

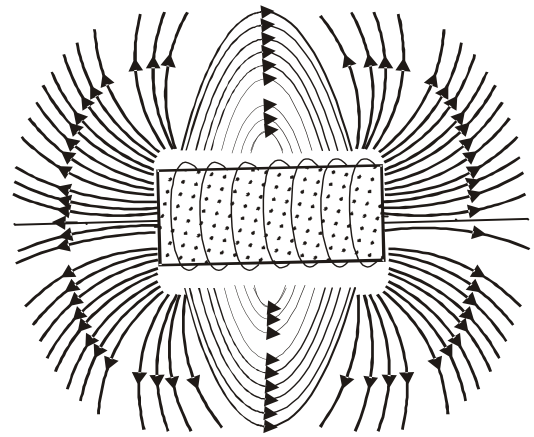
Soft -iron is used for making transformer cores and telephone diaphragms: More effective alloys have now been developed for transformer cores. They are permalloys, metals etc.

Electromagnet

If we place a soft-iron rod in the solenoid, the magnetism of solenoid increases hundreds of times. Then the solenoid is called an 'electromagnet'. It is a temporary magnet.

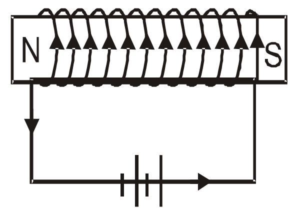


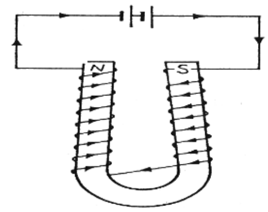
(a)



(b)

An electromagnet is made by winding closely a number of turns of insulated copper wire over a soft-iron straight rod or a horse-shoe rod. On passing current through this solenoid, a magnetic field is produced in the space within the solenoid.

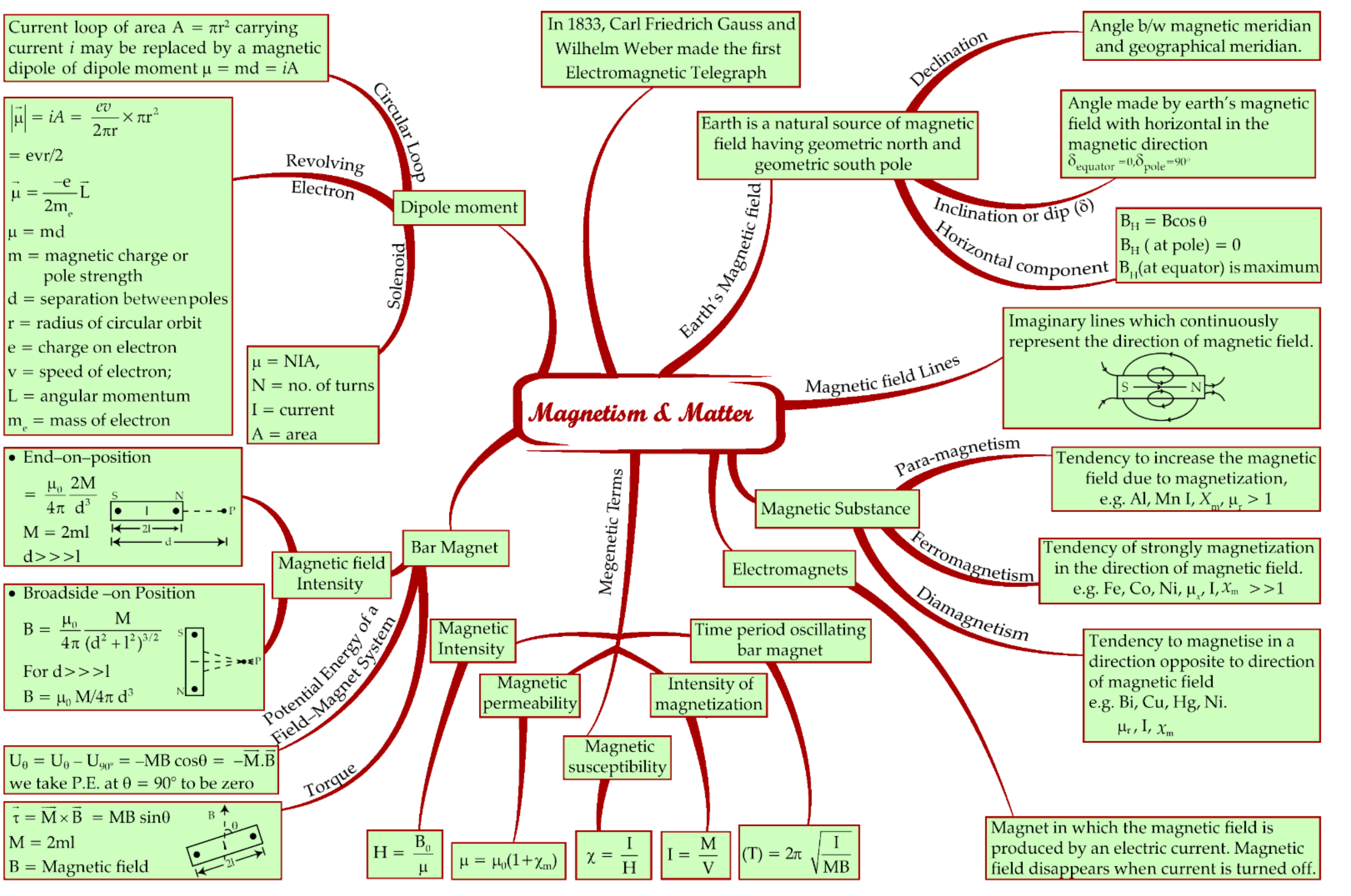




SUMMARY

- Magnetic materials tend to point in the north – south direction.
- Like magnetic poles repel and unlike ones attract.
- Magnetic poles cannot be isolated.
- When a bar magnet of dipole moment $\vec{m}$ is placed in a uniform magnetic field $\vec{B}$, then,
  a) The force on it is zero
  b) The torque on it is $\vec{m} x \vec{B}$
  c) Its potential energy is $-\vec{m}.\vec{B}$
  where we choose the zero of energy at the orientation when $\vec{m}$ is perpendicular to $\vec{B}$.
- Consider a bar magnet of size l and magnetic moment $\vec{m}$, at a distance r from its mid – point, where r >>l, the magnetic field $\vec{B}$ due to this bar is,
  $\vec{B} = \frac{\mu_0 \vec{m}}{2\prod r^3}$ (along axis)
  $= \frac{\mu_0 \vec{m}}{4\prod r^3}$ (along equator)
- **Gauss's Law for Magnetism:**
  It states that the net magnet flux through any closed surface is zero
  $$\phi_B = \sum_{\substack{all\ \text{area} \\ elements \Delta \vec{S}}} \vec{B}.\Delta\vec{S} = 0$$
- **Poles:**
  (a) The pole near the geographic north pole of the earth is called the north magnetic pole.
  (b) The pole near the geographic south – pole is called the south magnetic pole.
  (c) The magnitude of the magnetic field on the earth's surface = 4 x 10^{-5} T.
- **Elements of the Earth's Magnetic Field:**
  Three quantities are needed to specify the magnetic field of the earth on its surface,
  (a) The horizontal component
  (b) The magnetic declination
  (c) The magnetic dip.
  These are known as the elements of the earth's magnetic field.
- **Magnetic Intensity:**
  Consider a material placed in an external magnetic field $\vec{B}_0$. The magnetic intensity is,
  $$\vec{H} = \frac{\vec{B}_0}{\mu_0}$$
  If the magnetization $\vec{M}$ of the material is its dipole moment per unit volume, then the magnetic field $\vec{B}$ in the material will be,
  $\vec{B} = \mu_0(\vec{H} + \vec{M})$
  For a linear material,
  $\vec{M} = \chi\vec{H}$
  So that,
  $\vec{B} = \mu\,\vec{H}$
  Where χ is the magnetic susceptibility of the material and μ, is the relative magnetic permeability.
- **Relationship between** $\mu, \mu_0\ and\ \mu_2$:
  The magnetic permeability area, μ is related as,
  $\mu = \mu_0\mu_r$
  $\mu_r = 1 + \chi$
- **Classification of Magnetic Materials:**
  Magnetic materials area broadly classified as,
  (a) Diamagnetic
  (b) Paramagnetic
  (c) Ferromagnetic
- **Magnetic Susceptibility of the Material for Magnetic Materials:**
  (a) For diamagnetic materials χ is negative and small.
  (b) For paramagnetic materials χ is positive ad small.
  (c) For ferromagnetic materials χ lies between $\vec{B}$ and $\vec{H}$
- **Permanent Magnets:**
  Substances which retain their ferromagnetic property for a long period of time at room temperature are called permanent magnets.

MIND MAP



Magnetism & Matter
Current loop of area A = πr² carrying current i may be replaced by a magnetic dipole of dipole moment μ = md = iA
Circular Loop
|μ| = iA = ev/2πr × πr²
= evr/2
μ = −e/2mₑ L
μ = md
m = magnetic charge or pole strength
d = separation between poles
r = radius of circular orbit
e = charge on electron
v = speed of electron;
L = angular momentum
mₑ = mass of electron
Revolving Electron
Dipole moment
Solenoid
μ = NIA,
N = no. of turns
I = current
A = area
In 1833, Carl Friedrich Gauss and Wilhelm Weber made the first Electromagnetic Telegraph
Earth's Magnetic field
Earth is a natural source of magnetic field having geometric north and geometric south pole
Declination
Angle b/w magnetic meridian and geographical meridian.
Inclination or dip (δ)
Angle made by earth's magnetic field with horizontal in the magnetic direction
δequator = 0, δpole = 90°
Horizontal component
B_H = Bcos θ
B_H (at pole) = 0
B_H(at equator) is maximum
Magnetic field Lines
Imaginary lines which continuously represent the direction of magnetic field.
S N
• End–on–position
= μ0/4π 2M/d³
M = 2ml
d>>l
S N P
l 2l d
Magnetic field Intensity
• Broadside –on Position
B = μ0/4π M/(d² + l²)^3/2
For d>>l
B = μ0 M/4π d³
S N P
Bar Magnet
Potential Energy of a Field–Magnet System
Uθ = Uθ – U90° = –MB cosθ = –M.B
we take P.E. at θ = 90° to be zero
Torque
τ = M × B = MB sinθ
M = 2ml
B = Magnetic field
B θ l 2l
Megenetic Terms
Magnetic Intensity
H = B0/μ
Magnetic permeability
μ = μ0(1+χm)
Magnetic susceptibility
χ = I/H
Intensity of magnetization
I = M/V
Time period oscillating bar magnet
(T) = 2π √(I/MB)
Magnetic Substance
Para-magnetism
Tendency to increase the magnetic field due to magnetization, e.g. Al, Mn I, Xm, μr > 1
Ferromagnetism
Tendency of strongly magnetization in the direction of magnetic field. e.g. Fe, Co, Ni, μr, I, Xm >>1
Diamagnetism
Tendency to magnetise in a direction opposite to direction of magnetic field e.g. Bi, Cu, Hg, Ni.
μr, I, Xm
Electromagnets
Magnet in which the magnetic field is produced by an electric current. Magnetic field disappears when current is turned off.

PRACTICE EXERCISE

MCQ

Q1. Two identical magnetic dipoles of magnetic moments 1.0 A-m^2 each, placed at a separation of 2 m with their axis perpendicular to each other. The resultant magnetic field at point midway between the dipole is

(a) $5 \times 10^{-7}\ T$ (b) $\sqrt{5} \times 10^{-7}\ T$
(c) $10^{-1}\ T$ (d) $2 \times 10^{-7}\ T$

Q2. Two identical thin bar magnets each of length ℓ and pole strength m are placed at right angles to each other, with north pole of one touching south pole of the other, then the magnetic moment of the system is

(a) $1\ m\ell$ (b) $2m\ell$
(c) $\sqrt{2}\ m\ell$ (d) $\frac{m\ell}{2}$

Q3. The magnetic lines of force inside a bar magnet

(a) are from north-pole to south pole of the magnet
(b) do not exit
(c) depend upon the area of cross-section of the bar magnet
(d) are from south-pole to north-pole of the magnet

Q4. If the period of oscillation of freely suspended bar magnet in earth's horizontal field H is 4 sec. When another magnet is brought near it, the period of oscillation is reduced to 2s. The magnetic field of second bar magnet is

(a) $4H$ (b) $3H$
(c) $2H$ (d) $\sqrt{2}\ H$

Q5. Curie temperature is the temperature above which

(a) a ferromagnetic material becomes paramagnetic
(b) a paramagnetic material becomes diamagnetic
(c) a ferromagnetic material becomes diamagnetic
(d) a paramagnetic material becomes ferromagnetic

Q6. A watch glass containing some powdered substance is placed between the pole pieces of a magnet. Deep concavity is observed at the center. The substance in the watch glass is

(a) Iron (b) chromium
(c) carbon (d) wood

Q7. A compass needle whose magnetic moment is 60 Am^2, is directed towards geographical north at any place experiencing moment of force of 1.2×10^{-3} Nm. At that place the horizontal component of earth field is 40 micro W/m^2. What is the value of dip angle at that place?

(a) 30^0 (b) 60^0
(c) 45^0 (d) 15^0

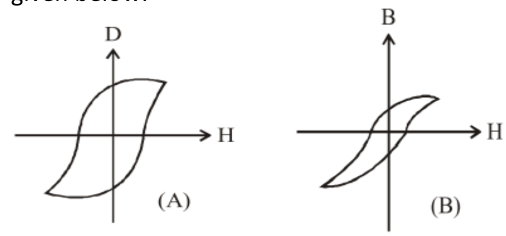
Q8. The materials suitable for making electromagnets should have

(a) high retentivity and low coercivity
(b) low retentivity and low coercivity
(c) high retentivity and high coercivity
(d) low retentivity and high coercivity

Q9. The length of a magnet is large compared to its width and breadth. The time period of its oscillation in a vibration magnetometer is 2s. The magnet is cut along its length into three equal parts and these parts are then placed on each other with their like poles together. The time period of this combination will be

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

Q10. Hysteresis loops for two magnetic materials A and B are given below:



These materials are used to make magnets for electric generators, transformer core and electromagnet core. Then it is proper to use:

(a) A for transformers and B for electric generators.
(b) B for electromagnets and transformers.
(c) A for electric generators and transformers.
(d) A for electromagnets and B for electric generators.

Q11. Which of the following is responsible for the earth's magnetic field?

(a) Convective currents in earth's core.
(b) Divertive current in earth's core.
(c) Rotational motion of earth.
(d) Translational motion of earth.

Q12. In a vibration magnetometer, the time period of a bar magnet oscillating in horizontal component of earth's magnetic field is 2 sec. When a magnet is brought neqar and parallel to it, the time period reduces to 1 sec. The ratio H/F of the horizontal component H and the field F due to magnet will be

(a) 3 (b) 1/3
(c) $\sqrt{3}$ (d) $\frac{1}{\sqrt{3}}$

Q13. A thin circular wire carrying a current I has a magnetic moment M. The shape of the wire is changed to a square and it carries the same current. It will have a magnetic moment

(a) M (b) $\frac{4}{\pi^2}M$
(c) $\frac{4}{\pi}\ M$ (d) $\frac{\pi}{4}M$

Q14. A bar magnet of magnetic moment M is placed at right angles to a magnetic induction B. If a force F is experienced by each pole of the magnet. The length of the magnet will be

(a) F/MB (b) MB/F
(c) BF/M (d) MF/B

Q15. A magnetic needle suspended by a silk thread is vibrating in the earth's magnetic field. If the temperature of the needle is increased by $700°C$, then
(a) time period decreases
(b) time period increases
(c) time period remains unchanged
(d) the needle stops vibrating

Q16. Torques τ_1 and τ_2 are required for a magnetic needle to remain perpendicular to the magnetic fields at two different places. The magnetic fields at those places are B_1 and B_2 respectively; then ratio $\frac{B_1}{B_2}$ is
(a) $\frac{\tau_2}{\tau_1}$ (b) $\frac{\tau_1}{\tau_2}$
(c) $\frac{\tau_1+\tau_2}{\tau_1-\tau_2}$ (d) $\frac{\tau_1-\tau_2}{\tau_1+\tau_2}$

Q17. A bar magnet has a length 8 cm. The magnetic field at a point at a distance 3 cm from the center in the broad side-on position is found to be $4 \times 10^{-6}\ T$. The pole strength of the magnet is.
(a) $6 \times 10^{-5}\ Am$ (b) $5 \times 10^{-5}\ Am$
(c) $2 \times 10^{-4}\ Am$ (d) $3 \times 10^{-4} Am$

Q18. A magnetic needle is kept in a non-uniform magnetic field. It experiences
(a) neither a force nor a torque
(b) a torque but not a force
(c) a force but not a torque
(d) a force and a torque

Q19. The angle of dip at a place is 37^0 and the vertical component of the earth's magnetic field is $6 \times 10^{-5}\ T$. The earth's magnetic field at this place is $(\tan 37^0 = \frac{3}{4})$
(a) $7 \times 10^{-5} T$ (b) $6 \times 10^{-5} T$
(c) $5 \times 10^{-5}\ T$ (d) $10^{-4}\ T$

Q20. Needles N_1, N_2 and N_3 are made of a ferromagnetic, a paramagnetic and a diamagnetic substance respectively. A magnet when brought close to them will
(a) attract N_1 and N_2 strongly but repel N_3
(b) $attract$ N_1 and N_2 strongly but repel N_3
(c) attract N_1 strongly, but repel N_2 and N_3 weakly
(d) attract all three of them

Q21. If a conducting wire carries a direct current through it, the magnetic field associated with the current will be __________ .
(a) both inside and outside the conductor
(b) neither inside nor outside the conductor
(c) only outside the conductor
(d) only inside the conductor

Q22. A compass needle is placed above a straight conducting wire. If current passes through the conducting wire from South to North. Then the deflection of the compass __________ .
(a) is towards West
(b) is towards East
(c) keeps oscillating in East-West direction
(d) no deflection

Q23. In a cyclotron, a charged particle
(a) undergoes acceleration all the time
(b) speeds up between the dees because of the magnetic field
(c) speeds up in a dee
(d) slows down within a dee and speeds up between dees

Q24. Susceptibility is small and positive for
(a) paramagnetic substances
(b) ferromagnetic substances
(c) non-magnetic substances
(d) diamagnetic substances

Q25. A permanent magnet attracts
(a) all substances
(b) only ferromagnetic substances
(c) some substances and repels others
(d) ferromagnetic substances and repels all others

ASSERTION AND REASONING

Directions: These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses.
(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.
(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.
(c) If the Assertion is correct but Reason is incorrect.
(d) If both the Assertion and Reason are incorrect.

Q1. Assertion: The susceptibility of diamagnetic materials does not depend upon temperature.
Reason: Every atom of a diamagnetic material is not a complete magnet in itself.

Q2. Assertion: If a compass needle be kept at magnetic north pole of Earth, the compass needle may stay in any direction.
Reason: Dip needle will stay vertical at the north pole of Earth.

Q3. Assertion: Soft iron is used a transformer core.
Reason: Soft iron has a narrow hysteresis loop.

Q4. Assertion: Earth's magnetic field does not affect the working of a moving coil galvanometer. Reason (R): Earth's magnetic field is very weak.

Q5. Assertion: Diamagnetic materials can exhibit magnetism.
Reason: Diamagnetic materials have permanent magnetic dipole moment.

VERY SHORT ANSWER QUESTIONS

Q1. Where on the earth's surface is the value of vertical component of earth's magnetic field zero?

Q2. The horizontal component of the earth's magnetic field at a place is B and angle of dip is 60°. What is the value of vertical component of earth's magnetic field at equator?

Q3. A small magnet is pivoted to move freely in the magnetic meridian. At what place on earth's surface will the magnet be vertical?

Q4. Which of the following substances are diamagnetic?
Bi, Al, Na, Cu, Ca and Ni

Q5. What are permanent magnets? Give one example.

SHORT ANSWER QUESTIONS

Q1. What is the basic difference between the atom and molecule of a diamagnetic and a paramagnetic material? Why are elements with even atomic number more likely to be diamagnetic?

Q2. From molecular view point, discuss the temperature dependence of susceptibility for diamagnetism, paramagnetism and ferromagnetism.

Q3. Write two properties of a material suitable for making
(a) a permanent magnet, and
(b) an electromagnet.

Q4. The susceptibility of a magnetic material is –2.6 × 10–5. Identify the type of magnetic material and state its two properties.

Q5. Explain the following:
(i) Why do magnetic field lines form continuous closed loops?
(ii) Why are the field lines repelled (expelled) when a diamagnetic material is placed in an external uniform magnetic field?

NUMERICAL TYPE QUESTIONS

Q1. A short bar magnet placed with its axis at 30° with a uniform external magnetic field of $0.25\ \mathrm{T}$ experiences a torque of magnitude equal to $4.5 \times 10^{-2}\ \mathrm{N-m}$. What is the magnitude of magnetic moment of the magnet?

Q2. A short bar magnet of magnetic moment $m = 0.32 \mathrm{JT}^{-1}$ is placed in a uniform magnetic field of $0.15\ \mathrm{T}$. If the bar is free to rotate in the plane of the field, which orientation would correspond to its (i) stable and (ii) unstable equilibrium? What is the potential energy of the magnet in each case?

Q3. (a) Closely wound solenoid of 800 turns and area of cross-section $2.5 \times 10^{-4}\ \mathrm{m}^2$ carries a current of 3.0 A. Explain the sense in which solenoid acts like a bar magnet. What is the associated magnetic moment?
(b) If the solenoid is free to turn about the vertical direction in an external uniform horizontal magnetic field at $0.25\ \mathrm{T}$, what is the magnitude of the torque on the solenoid when its axis makes an angle of 30° with the direction of the external field.

Q4. A magnetic needle free to rotate in a vertical plane parallel to the magnetic meridian has its north tip pointing down at 22° with the horizontal. The horizontal component of the earth's magnetic field at a place is known to be $0.35\mathrm{G}$. Determine the magnitude of the earth's magnetic field at the place. (Given $\cos 22^\circ = 0.927, \sin 22^\circ = 0.375$).

Q5. At a certain location in Africa, compass points 12° west of geographical north. The north top of magnetic needle of a dip circle placed in the plane of the magnetic meridian points 60° above the horizontal. The horizontal component of earth's magnetic field is measured to be 0.16 gauss. Specify the direction and magnitude of earth's magnetic field at the location.

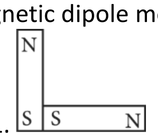
Q6. At a certain place, horizontal component is $\sqrt{3}$ times the vertical component. Then determine the angle of dip at this place.

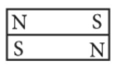
MCQ

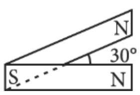
Q1. A bar magnet is hung by a thin cotton thread in a uniform horizontal magnetic field and is in equilibrium state. The energy required to rotate it by 60° is W. Now the torque required to keep the magnet in this new position is

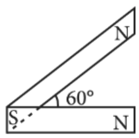
(a) $\frac{W}{\sqrt{3}}$ (b) $\sqrt{3}W$
(c) $\frac{\sqrt{3}W}{2}$ (d) $\frac{2W}{\sqrt{3}}$

Q2. Following figures show the arrangement of bar magnets in different configurations. Each magnet has magnetic dipole moment $\vec{m}$. Which configuration has highest net magnetic dipole moment?

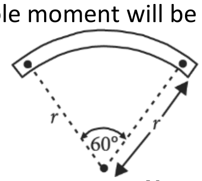
(a) 1. 

(b) 2. 

(c) 3. 

(d) 4. 

Q3. A bar magnet of length 'l' and magnetic dipole moment 'M' is bent in the form of an arc as shown in figure. The new magnetic dipole moment will be



(a) $\frac{2}{\pi}M$ (b) $\frac{M}{2}$
(c) M (d) $\frac{3}{\pi}M$

Q4. A bar magnet of magnetic moment M is placed at right angles to a magnetic induction B. If a force F is experienced by each pole of the magnet, the length of the magnet will be

(a) MB/F (b) BF/M
(c) MF/B (d) F/MB

Q5. A magnetic needle suspended parallel to a magnetic field requires $\sqrt{3}$ J of work to turn it through 60°. The torque needed to maintain the needle in this position will be

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

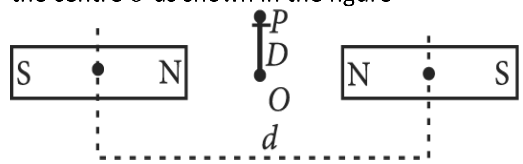
Q6. A short bar magnet of magnetic moment 0.4 J T^{-1} is placed in a uniform magnetic field of 0.16 T. The magnet is in stable equilibrium when the potential energy is

(a) 0.064 J (b) –0.064 J
(c) zero (d) –0.082 J

Q7. A vibration magnetometer placed in magnetic meridian has a small bar magnet. The magnet executes oscillations with a time period of 2 sec in earth's horizontal magnetic field of 24 micro-Tesla. When a horizontal field of 18 micro-Tesla is produced opposite to the earth's field by placing a current carrying wire, the new time period of magnet will be

(a) 1 s (b) 2 s
(c) 3 s (d) 4 s

Q8. Two identical bar magnets are fixed with their centres at a distance d apart. A stationary charge Q is placed at P in between the gap of the two magnets at a distance D from the centre O as shown in the figure



The force on the charge Q is

(a) zero
(b) directed along OP
(c) directed along PO
(d) directed perpendicular to the plane of paper

Q9. A closely wound solenoid of 2000 turns and area of cross-section 1.5×10^{-4} m^2 carries a current of 2.0 A. It is suspended through its centre and perpendicular to its length, allowing it to turn in a horizontal plane in a uniform magnetic field 5×10^{-2} tesla making an angle of 30° with the axis of the solenoid. The torque on the solenoid will be

(a) 3×10^{-3} N m
(b) 1.5×10^{-3} N m
(c) 1.5×10^{-2} N m
(d) 3×10^{-2} N m

Q10. A bar magnet having a magnetic moment of 2×10^4 J T^{-1} is free to rotate in a horizontal plane. A horizontal magnetic field $B = 6 \times 10^{-4}$ T exists in the space. The work done in taking the magnet slowly from a direction parallel to the field to a direction 60° from the field is

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

Q11. A bar magnet is oscillating in the Earth's magnetic field with a period T. What happens to its period and motion if its mass is quadrupled?

(a) Motion remains simple harmonic with time period = $T/2$
(b) Motion remains S.H.M with time period = $2T$
(c) Motion remains S.H.M with time period = $4T$
(d) Motion remains S.H.M and period remains nearly constant

Q12. Two bar magnets having same geometry with magnetic moments M and $2M$, are firstly placed in such a way that their similar poles are in same side then its time period of oscillation is T_1. Now the polarity of one of the magnets is reversed then time period of oscillation is T_2, then

(a) $T_1 < T_2$ (b) $T_1 = T_2$

(c) $T_1 > T_2$ (d) $T_2 = \infty$

Q13. At a point A on the earth's surface the angle of dip, δ = +25°. At a point B on the earth's surface the angle of dip, δ = –25°. We can interpret that
(a) A and B are both located in the southern hemisphere.
(b) A and B are both located in the northern hemisphere.
(c) A is located in the southern hemisphere and B is located in the northern hemisphere.
(d) A is located in the northern hemisphere and B is located in the southern hemisphere.

Q14. A bar magnet of magnetic moment M is cut into two parts of equal length. The magnetic moment of each part will be
(a) M (b) $2M$
(c) zero (d) $0.5M$ *(1997)*

Q15. The work done in turning a magnet of magnetic moment M by an angle of 90° from the meridian, is n times the corresponding work done to turn it through an angle of 60°. The value of n is given by
(a) ½ (b) ¼
(c) 2 (d) 1

ASSERTION AND REASONING

Directions: These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses.
(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.
(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.
(c) If the Assertion is correct but Reason is incorrect.
(d) If both the Assertion and Reason are incorrect.

Q1. Assertion: For making permanent magnets, steel is preferred over soft iron.
Reason: As retentivity of steel is smaller

Q2. Assertion: Gauss's theorem is not applicable in magnetism.
Reason: Magnetic monopoles do not exist.

Q3. Assertion: The magnetic poles of a magnet can never be separated.
Reason: Every atom of a magnetic substance is a complete dipole.

Q4. Assertion: The poles of a magnet cannot be separated by breaking into two pieces.
Reason: The magnetic moment will be reduced to half when a magnet is broken into two equal pieces.

Q5. Assertion: The ferromagnetic substances do not obey Curie's law.
Reason: At Curie point a ferromagnetic substance start behaving as a paramagnetic substance.

VERY SHORT ANSWER QUESTIONS

Q1. Mention two characteristics of a material that can be used for making permanent magnets.

Q2. Why is the core of an electromagnet made of ferromagnetic materials?

Q3. The susceptibility of a magnetic materials is -4.2×10^{-6}. Name the type of magnetic materials it represents.

Q4. In what way is the behavior of a diamagnetic material different from that of a paramagnetic, when kept in an external magnetic field?

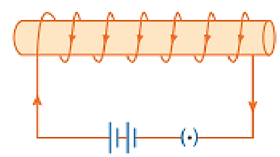
Q5. Write one important property of a paramagnetic material.

SHORT ANSWER QUESTIONS

Q1. (a) State Gauss's law for magnetism. Explain its significance
(b) Write the four important properties of the magnetic field lines due to a bar magnet.

Q2. Write three points of differences between para-, dia- and ferro- magnetic materials, giving one example for each.

Q3. Draw the magnetic field lines for a current carrying solenoid when a rod made of
(a) copper,
(b) aluminum and
(c) iron is inserted within the solenoid as shown.



NUMERICAL TYPE QUESTIONS

Q1. The horizontal component of the earth's magnetic field at any place is 0.36×10^{-4} Wb/m^2. If the angle of dip at that place is 60°, then find the value of vertical component of the earth's magnetic field. (in Wb/m^2)

Q2. Determine the angle of dip at a certain place where the horizontal and vertical components of the earth's magnetic field are equal.

Q3. Obtain the earth's magnetization assuming that the earth's field can be approximated by a giant bar magnet of magnetic moment 8.0×10^{22} $\mathrm{A-m^2}$. The earth's radius is 6400 km.

Q4. The horizontal component of flux density of earth's magnetic field is 1.7×10^{-6} T. Then find the value of horizontal component of intensity of earth's magnetic field.

Q5. A paramagnetic substance in the form of a cube with sides 1 cm has a magnetic dipole moment of 20×10^{-6} J/T when a magnetic intensity of 60×10^3 A/m is applied. Find its magnetic susceptibility.

PRACTICE QUESTIONS SOLUTION

MCQ

S1. (b) As the axes are perpendicular, mid-point lies on axial line of one magnet and on equatorial line of another magnet.

$\therefore B_1 = \frac{\mu_0}{4\pi}\frac{2M}{d^3} = \frac{10^{-7}\times 2\times 1}{1^3} = 2\times 10^{-7}$

and $B_2 = \frac{\mu_0}{4\pi}\frac{M}{d^3} = 10^{-7}$

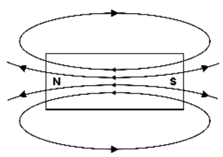
$\therefore$ Resultantfield $= \sqrt{G_1^2 + B_2^2} = \sqrt{5}\times 10^{-7} T$

S2. (c) Initial magnetic moment of each magnet = m $\times \ell$. As is clear from Fig., S_1 and N_2 neutralize each other. Effective distance between

$$N_1 \text{ and } S_2 = \sqrt{\ell^2 + \ell^2} = \ell\sqrt{2}$$

$$\therefore M' = m\ell\sqrt{2}.$$

S3. (d) As shown in the figure, the magnetics lines of force are directed from south to north inside a bar magnet.



S4. (a) The time period of oscillation of a freely suspended magnet is given by

$$T = 2\pi\sqrt{\frac{1}{MH}}$$

$$\text{Thus, } \frac{T}{T'} = \frac{2\pi\sqrt{\frac{I}{MH}}}{2\pi\sqrt{\frac{I}{MH'}}}$$

Given, T = 4 sec, T' = 2 sec,

So, $\frac{4}{2} = \sqrt{\frac{H'}{H}}$

or $\sqrt{\frac{H'}{H}} = 0$

or $H' = 4H$

S5. (a) The temperature above which a ferromagnetic substance becomes paramagnetic is called Curie's temperature.

S6. (a) Iron is ferromagnetic.

S7. (a) M=60 Am^2

$\vec{\tau} = 1.2\times 10^{-3}\text{Nm}, B_H = 40\times 10^{-6}\text{Wb/m}^2$

$\vec{\tau} = \vec{M}\times\vec{B}_H \Rightarrow \tau = MB_H \sin\theta$

$\Rightarrow 1.2\times 10^{-3} = 60\times 40\times 10^{-6} \sin\theta$

$\Rightarrow \sin\theta = \frac{1.2\times 10^{-3}}{60\times 40\times 16^{-6}} = \frac{1}{2} = \sin 30°$

$\Rightarrow \theta = 30°$

S8. (b) Electro magnet should be amenable to magnetization and demagnetization.

☐ Retentivity and coercivity should below.

S9. (b) $T = 2\pi\sqrt{\frac{I}{M\times B}} = 2\pi\sqrt{\frac{I}{MB}}$ where $I = \frac{1}{12}m\ell^2$

When the magnet is cut into three pieces the pole strength will remain the same and

$$\text{M.I.}(I') = \frac{1}{12}\left(\frac{m}{3}\right)\left(\frac{\ell}{3}\right)^2\times 3 = \frac{I}{9}$$

We have, Magnetic moment (*M*)

= Pole strength (*m*) $\times \ell$

$\therefore$ New magnetic moment,

$$M' = m\times\left(\frac{\ell}{3}\right)\times 3 = m\ell = M$$

$$\therefore T' = \frac{T}{\sqrt{9}} = \frac{2}{3} s.$$

S10. (b) Graph [A] is for material used for making permanent magnets (high coercivity) Graph [B] is for making electromagnets and transformers.

S11. (a) The earth's core is hot and molten. Hence, convective current in earth's core is responsible for it's magnetic field.

S12. (b) $T \propto \frac{1}{\sqrt{H}} \Rightarrow \frac{T_1}{T_2} = \sqrt{\frac{H_2}{H_1}} \Rightarrow \frac{2}{1} = \sqrt{\frac{H+F}{H}}$

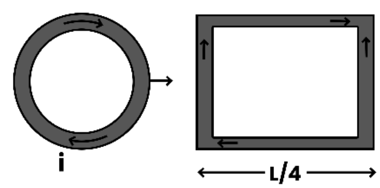
$\Rightarrow F = 3H \text{ or } \frac{H}{F} = \frac{1}{3}$

S13. (d) Initially for circular coil $L = 2\pi r$ and $M = i\times\pi r^2$

$$= i\times\pi\left(\frac{L}{2\pi}\right)^2 = \frac{iL^2}{4\pi}$$

Finally for square coil side $a = \frac{L}{4}$ and

$M' = i\times\left(\frac{L}{4}\right)^2 = \frac{iL^2}{16}$



Solving equation (i) and (ii) $M' = \frac{\pi M}{4}$

S14. (b) *FL* = MB (=Torque) $\Rightarrow L = \frac{MB}{F}$

S15. (b) On increasing the temperature by 700°C, the magnetic needle is demagnetized. Therefore, the needle stops vibrating.

S16. (b) τ = MB sin θ (θ = 90°)

$$\tau = MB \Rightarrow \frac{B_1}{B_2} = \frac{\tau_1}{\tau_2}$$

(Since magnetic moment is same)

S17. (a) Magnetic field due to a bar magnet in the broad-side on position is given by

$B = \frac{\mu_0}{4\pi}\frac{M}{\left[r^2 + \frac{\ell^2}{4}\right]^{3/2}}; M = m\ell.$

After substituting the values and simplifying we get $B = 6 \times 1^{-5}$ A -m

18. (d) A magnetic needle kept in non-uniform magnetic field experience a force and torque due to unequal forces acting on poles.

19. (d) $tan\,\delta = \frac{V}{H} = \frac{3}{4}\left[\because tan\,37° = \frac{3}{4}\right]$

$$\therefore V = \frac{3}{4}H$$

$$V = 6 \times 10^{-5}T$$

$$H = \frac{4}{3} \times 6 \times 10^{-5}T = 8 \times 10^{-5}T$$

$$\therefore B_{\text{total}} = \sqrt{V^2 + H^2} = \sqrt{(36+64)} \times 10^{-5}$$

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

20. (b) Ferromagnetic substance has magnetic domains whereas paramagnetic substances have magnetic dipoles which get attracted to a magnetic field. Diamagnetic substances do not have magnetic dipole but in the presence of external magnetic field due to their orbital motion of electrons these substances are repelled.

S21. (c) Ampere's law –
$\phi B.dl = \mu_\circ I$
$B.\phi dl = \mu \times 0$
$B = 0$
The magnetic field lines will be concentric circles and the magnetic field around the conductor will be circular around the wire. Therefore, the magnetic field associated with the current will only be outside the conductor.

S22. (a) If a compass needle is placed above a straight conducting wire and the current passes through the conducting wire from South to North. Then the deflection of the compass will be towards the west direction as the compass needle is parallel to the conducting wire.

S23. (a) In a cyclotron, charged particles experience force due to electric field between the Dees and magnetic force (force due to magnetic field) while circulating inside the Dees. That is, it always experiences a centripetal force.
Therefore, it always accelerates.

S24. (a) For a paramagnetic material, magnetic susceptibility is greater than 0 and less than 1. Hence for paramagnetic material, magnetic susceptibility is always positive.

Q25. (c) A permanent magnet attracts all magnetic substances.

ASSERTION AND REASONING

S1. (c) Diamagnetism is non-cooperative behavior of orbiting electrons when exposed to an applied magnetic field. Diamagnetic substance is composed of atom which have no net magnetic moment (i.e., all the orbital shells are filled and there are no unpaired electrons). When exposed to a field, a negative magnetization is produced and thus the susceptibility is negative Behavior of diamagnetic material is that the susceptibility is temperature independent.

S2. (b) The earth has only vertical component of its magnetic field at the magnetic poles. Since compass needle is only free to rotate in horizontal plane where H = 0, hence the compass needle may stay in any direction. The dip needle rotates in a vertical plane and angle of dip at poles is 90°. So, it will stand vertical.

S3. (a) The core of a transformer undergoes cycles of magnetization again and again. During each cycle of magnetization, energy numerically equal to the area of the hysteresis loop is spent per unit volume of the core. Therefore, for high efficiency of transformer, the energy loss will be lesser if the hysteresis loop is of lesser area, i.e. narrow. That's why the soft iron is used as core, which has narrow hysteresis loop (or area of B−H curve is very small). Also, soft iron (ferromagnetic substance) has high permeability, high retentivity, low coercivity and low hysteresis loss.

S4. (a) The field magnet used in a moving coil galvanometer is very strong. The earth's magnetic field is quite weak as compared to the magnetic field produced by the field magnet. Practically the coil rotates under the effect of the strong magnetic field due to the earth does not affect the working of the moving coil galvanometer.

S5. (c) Diamagnetic material exhibits magnetism in reverse direction. Reason is a wrong statement. Because due to absence of unpaired electron in diamagnetic material it does not exhibit permanent magnet dipole moment.

VERY SHORT ANSWER QUESTIONS

S1. Vertical component of earth's magnetic field is zero at magnetic equator

S2. Zero

S3. Magnet will be vertical at the either magnetic pole of earth.

S4. Diamagnetic substances are (i) Bi (ii) Cu

S5. Substances that retain their attractive property for a long period of time at room temperature are called permanent magnets. Examples: Those pieces which are made up of steel, alnico, cobalt and ticonal.

SHORT ANSWER QUESTIONS

S1. Atoms/molecules of a diamagnetic substance contain even number of electrons and these electrons form the pairs of opposite spin; while the atoms/molecules of a paramagnetic substance have excess of electrons spinning in the same direction. The elements with even atomic number Z has even number of electrons in its atoms/molecules, so they are more likely to form electrons pairs of opposite spin and hence more likely to be diamagnetic.

S2. Diamagnetism is due to orbital motion of electrons developing magnetic moments opposite to applied field and hence is not much affected by temperature. Paramagentism and ferromagnestism is due to alignments of atomic magnetic moments in the direction of the applied field. As temperature increases, this alignment is disturbed and hence susceptibilities of both decrease as temperature increases.

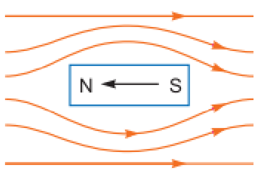
S3. (a) Two properties of material used for making permanent magnets are
(i) High coercivity (ii) High retentivity (iii) High permeability

(b) Two properties of material used for making electromagnets are
(i) High permeability (ii) Low coercivity (iii) Low retentivity

S4. The magnetic material having negative susceptibility is diamagnetic in nature.

Properties:

(i) This material has + ve but low relative permeability.
(ii) They have the tendency to move from stronger to weaker part of the external magnetic field.



(i) Magnetic lines of force form continuous closed loops because a magnet is always a dipole and as a result, the net magnetic flux of a magnet is always zero.
(ii) When a diamagnetic substance is placed in an external magnetic field, a feeble magnetism is induced in opposite direction. So, magnetic lines of force are repelled.

NUMERICAL TYPE QUESTIONS

S1. Given, $B = 0.25\ \mathrm{T}, \tau = 4.5 \times 10^{-2}\ \mathrm{N-m}, \theta = 30^\circ$
We have $\tau = mB\sin\theta$

$$\Rightarrow \text{Magnetic moment } m = \frac{\tau}{B\sin\theta} = \frac{4.5 \times 10^{-2}}{0.25 \times \sin 30^\circ}$$
$$= \frac{4.5 \times 10^{-2}}{0.25 \times 0.5} = 0.36\mathrm{A-m^2}$$

S2. Given $m = 0.32\mathrm{JT^{-1}}, B = 0.15\ \mathrm{T}$
Potential energy of magnet in magnetic field
$U = -mB\cos\theta$

(i) In stable equilibrium the potential energy of magnet is the minimum; so
$\cos\theta = 1$ or $\theta = 0^\circ$
Thus, in stable equilibrium position, the bar magnet is so aligned that its magnetic moment is along the direction of magnetic field ($\theta = 0^\circ$).
$U_m = -mB = -0.32 \times 0.15 = -4.8 \times 10^{-2}\ \mathrm{J}$
(ii) In unstable equilibrium, the potential energy of magnet is the maximum.
Thus, in unstable equilibrium position, the bar magnetic is so aligned that its magnetic moment is opposite to the direction of the magnetic field, i.e., $\cos\theta = -1$ or $\theta = 180^\circ$.
In this orientation potential energy, $U_{\max} = +mB = +4.8 \times 10^{-2}\ \mathrm{J}$.

S3. (a) If solenoid is suspended freely, it stays in N-S direction. The polarity of solenoid depends on the sense of flow of current. If to an observer looking towards an end of a solenoid, the current appears anticlockwise, the end of solenoid will be N-pole and other end will be S-pole.
Magnetic moment, $m = NIA = 800 \times 3.0 \times 2.5 \times 10^{-4} = 0.60\mathrm{A\cdot m^2}$

(b) Torque on solenoid $\tau = mB\sin\theta$
$= 0.60 \times 0.25\sin 30^\circ$
$= 0.60 \times 0.25 \times 0.5 = 7.5 \times 10^{-2}\ \mathrm{N-m}$

S4. By definition, angle of dip $\theta = 22^\circ$
Given $H = 0.35\mathrm{G}$
We have $H = B_e\cos\theta$ or $B_e = \frac{H}{\cos\theta} = \frac{0.35}{\cos 22^\circ}\mathrm{G}$
or $B_e = \frac{0.35}{0.927} = 0.38\mathrm{G}$

S5. This problem illustrates how the three elements of earth's field: angle of declination (α) angle of dip(θ) and horizontal component H; determine the earth's magnetic field completely.
Here angle of declination $(\alpha) = 12^\circ$
Angle of dip $\theta = 60^\circ$
and horizontal component, $H = 0.16$ gauss
$= 0.16 \times 10^{-4}\ \mathrm{T}$
If B_e is the total earth's magnetic field, then the relation between B_e and H is $H = B_e\cos\theta$ gauss
$$\Rightarrow B_e = \frac{H}{\cos\theta} = \frac{0.16 \times 10^{-4}}{\cos 60^\circ} = \frac{0.16 \times 10^{-4}}{0.5}$$
$$= \mathbf{0.32} \times \mathbf{10^{-4}T}$$

S6. Given that, $H_E = \sqrt{3}\,V_E$, where $H_E =$ horizontal component of earth's magnetic field and V_E = vertical component of earth's magnetic field.
Angle of dip, $\tan\delta = \frac{V_E}{H_E}$
$\tan\delta = \frac{V_E}{H_E} = \frac{V}{\sqrt{3}V_E} = \frac{1}{\sqrt{3}}$
∴ Angle of dip, $\delta = 30^\circ = (\pi/6)\mathrm{rad}$

HOMEWORK SOLUTIONS

MCQ

S1. (b) $\sqrt{3}W$

At equilibrium, potential energy of dipole

$U_i = -MB_H$

Final potential energy of dipole,

$U_f = -MB_H \cos 60° = -\frac{MB_H}{2}$

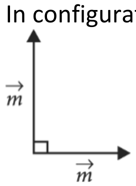
$W = U_f - U_i = -\frac{MB_H}{2} - (-MB_H) = \frac{MB_H}{2}$ ....(i)

$\tau = MB_H \sin 60° = 2W \times \frac{\sqrt{3}}{2}$ [Using eqn. (i)]

$= \sqrt{3}W$

S2. (c) The direction of magnetic dipole moment is from south to north pole of the magnet.

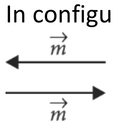
In configuration (1),



$m_{\text{net}} = \sqrt{m^2 + m^2 + 2mm \cos 90°}$

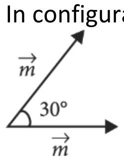
$= \sqrt{m^2 + m^2} = m\sqrt{2}$

In configuration (2)



$m_{\text{net}} = m - m = 0$

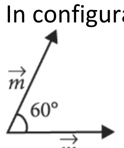
In configuration (3),



$m_{\text{net}} = \sqrt{m^2 + m^2 + 2mm \cos 30°}$

$= \sqrt{2m^2 + 2m^2 \left(\frac{\sqrt{3}}{2}\right)} = m\sqrt{2 + \sqrt{3}}$

In configuration (4),



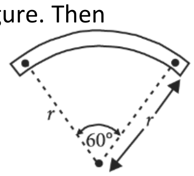
$m_{\text{net}} = \sqrt{m^2 + m^2 + 2mm \cos 60°}$

$= \sqrt{2m^2 + 2m^2 \left(\frac{1}{2}\right)} = m\sqrt{3}$

S3. (d) Let m be strength of each pole of bar magnet of length l. Then

$M = m \times l$

When the bar magnet is bent in the form of an arc as shown in figure. Then



$l = \frac{\pi}{3} \times r = \frac{\pi r}{3}$ or $r = \frac{3l}{\pi}$

New magnetic dipole moment

$M' = m \times 2r \sin 30°$

$= m \times 2 \times \frac{3l}{\pi} \times \frac{1}{2} = \frac{3ml}{\pi} = \frac{3M}{\pi}$ (Using (i))

S4. (a) As we know, torque experienced by bar magnet kept in magnetic field B of magnetic moment m is given by,

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

$= MB\sin\theta$

Since, the magnetic moment is at the right angle with a magnetic field,

so $\theta = 90°$

As, $\sin 90° = 1$

So, $\tau = MB$ .... eq(1)

Also, torque experienced by bar magnet is given by,

$\tau = \vec{r} \times \vec{F}$

As, $\theta = 90°$, So, $\tau = rF$ As, $r = L$,

where L is the length of bar magnet.

Therefore, $\tau = LF$ ....eq (2)

From (1) and (2) we get, $L = MB/F$

S5. (b) Work done in changing the orientation of a magnetic needle of magnetic moment M in a magnetic field B from position θ_1 to θ_2 is given by

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

Here, $\theta_1 = 0°, \theta_2 = 60°$

$= MB\left(1 - \frac{1}{2}\right) = \frac{MB}{2}$ ...(i)

The torque on the needle is $\vec{\tau} = \vec{M} \times \vec{B}$

In magnitude,

$\tau = MB \sin\theta = MB \sin 60° = \frac{\sqrt{3}}{2} MB$ ...(ii)

Dividing (ii) by (i), we get

$\frac{\tau}{W} = \sqrt{3}$ or $\tau = \sqrt{3}W = \sqrt{3} \times \sqrt{3}\ \text{J} = 3\ \text{J}$

S6. (b) Here, Magnetic moment, $M = 0.4\ \text{J T}^{-1}$

Magnetic field, $B = 0.16$ T

When a bar magnet of magnetic moment is placed in a uniform magnetic field, its potential energy is

$U = -\vec{M} \cdot \vec{B} = -MB\cos\theta$

For stable equilibrium, $\theta = 0°$

$\therefore \quad U = -MB = -(0.4\ \text{J T}^{-1})(0.16\ \text{T}) = -0.064\ \text{J}$

S7. (d) The time period T of oscillation of a magnet is given by

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

where, I = Moment of inertia of the magnet about the axis of rotation

M = Magnetic moment of the magnet

B = Uniform magnetic field

As I and M remain the same

$\therefore T \propto \frac{1}{\sqrt{B}}$ or $\frac{T_2}{T_1} = \sqrt{\frac{B_1}{B_2}}$

According to given problem,

$B_1 = 24\ \mu\text{T}, B_2 = 24\ \mu\text{T} - 18\ \mu\text{T} = 6\ \mu\text{T}, T_1 = 2\ \text{s}$

$\therefore \quad T_2 = (2\text{ s})\sqrt{\frac{(24\ \mu\text{T})}{(6\ \mu\text{T})}} = 4\text{ s}$

S8. (a) Magnetic field due to bar magnets exerts force on moving charges only. Since the charge is at rest, no force acts on it.

S9. (c) Magnetic moment of the loop

$M = NIA = 2000 \times 2 \times 1.5 \times 10^{-4} = 0.6\text{ J/T}$

Torque τ $= MB\sin 30°$

$= 0.6 \times 5 \times 10^{-2} \times \frac{1}{2} = 1.5 \times 10^{-2}$ Nm

S10. (b) Here, $M = 2 \times 10^4\text{ J T}^{-1}$

$B = 6 \times 10^{-4}\text{ T}, \theta_1 = 0°, \theta_2 = 60°$

$W = MB(\cos\theta_1 - \cos\theta_2) = MB(1 - \cos 60°)$

$W = 2 \times 10^4 \times 6 \times 10^{-4}\left(1 - \frac{1}{2}\right) = 6\text{ J}$

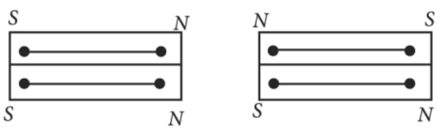
S11. (b) Initial mass of the magnet $(m_1) = m$ and final mass of the magnet $(m_2) = 4m$.

The time period, $T = 2\pi\sqrt{\frac{I}{MB}} = 2\pi\sqrt{\frac{mk^2}{MB}} \propto \sqrt{m}$

Therefore $\frac{T_1}{T_2} = \frac{\sqrt{m_1}}{\sqrt{m_2}} = \frac{\sqrt{m}}{\sqrt{4m}} = \frac{1}{2}$

Or $T_2 = 2T_1 = 2T$

S12. (a)



(i) $M = M_1 + M_2$

$I = I_1 + I_2$

(ii) $M = M_1 - M_2$

$I = I_1 + I_2$

(i) Similar poles are placed at the same side (sum position)

(ii) Opposite poles are placed at the same side (difference position)

I_1 and I_2 are the moments of inertia of the magnets and M_1 and M_2 are the moments of the magnets.

Here $M_1 = M$ and $M_2 = 2M$, $I_1 = I_2 = I$ (say), for same geometry.

For sum position

$T_1 = 2\pi\sqrt{\frac{I_1+I_2}{(M_1+M_2)H}} = 2\pi\sqrt{\frac{2I}{(M+2M)H}}$

For difference position.

$T_2 = 2\pi\sqrt{\frac{I_1+I_2}{(M_2-M_1)H}} = 2\pi\sqrt{\frac{2I}{(2M-M)H}}$

$\therefore \frac{T_1}{T_2} = \sqrt{\frac{M}{3M}} = \frac{1}{\sqrt{3}} < 1$ or $T_1 < T_2$

S13. (d)

At a point A, the angle of dip is positive and the earth's magnetic north pole is in northern hemisphere. So, point A is located in the northern hemisphere and B is located in the southern hemisphere.

S14. (d) Magnetic moment = pole strength × length

$\therefore \quad M' = M/2 = 0.5M$

S15. (c) Angle of magnet (θ) = 90° and 60°.

Work done in turning the magnet through 90°

$W_1 = MB(\cos 0° - \cos 90°) = MB(1 - 0) = MB$.

Similarly

$W_2 = MB(\cos 0° - \cos 60°) = MB\left(1 - \frac{1}{2}\right) = \frac{MB}{2}$

Therefore, $W_1 = 2W_2$ or $n = 2$

ASSERTION AND REASONING

S1. (b) Steel is preferred over soft iron for making permanent magnets, because coercivity of steel is larger

S2. (a) Gauss's law of magnetism is different from that for electrostatic because electric charges do not necessarily exist in pairs but magnetic monopoles do not exist

S3. (a) Pole of magnet can never be separated because every atom of a magnet is itself a magnet

S4. (b) As we know every atom of a magnet acts as dipole, So poles cannot be separated. When magnet is broken into two equal pieces, magnetic moment of each part will be half of the original magnet.

S5. (b) The susceptibility of ferromagnetic substance decreases with the rise of temperature in a complicated manner. After Curies point the susceptibility of ferromagnetic substance varies inversely with its absolute temperature. Ferromagnetic substance obeys curie's law only above its Curie point.

VERY SHORT ANSWER QUESTIONS

S1. For making for making permanent magnet, the material must have high retentivity and high coercivity (e.g., steel).

S2. Ferromagnetic material has a high permeability. So on passing current through windings, it gains sufficient magnetism immediately.

S3. Susceptibility of material is negative, so given material is diamagnetic.

S4. A diamagnetic specimen would move towards the weaker region of the field while a paramagnetic specimen would move towards the stronger region.

S5. It moves from weaker magnetic field towards stronger magnetic field.

SHORT ANSWER QUESTIONS

S1. (a) Gauss's law for magnetism states that "The total flux of the magnetic field, through any closed surface, is always zero."

Alternatively,

$\int_s \vec{B}.\vec{d}\,s = 0$

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

(b) Four properties of magnetic field lines

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

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

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

(iv) Magnetic field lines do not intersect.

S2.

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

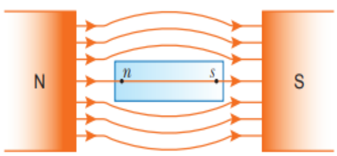
Where e is any positive constant.

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

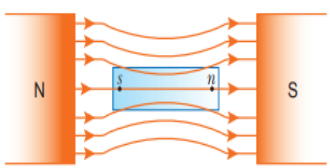
Paramagnetic materials: Al, Na, Ca, Oxygen (at STP), Copper chloride

Ferromagnetic materials: Fe, Ni, Co, Alnico

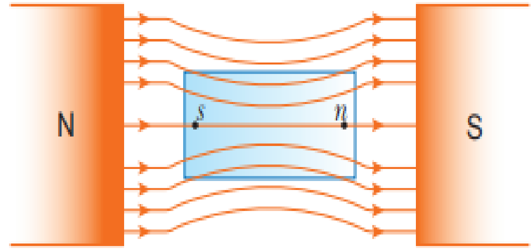
S3. (a) When a bar of diamagnetic material (copper) is placed in an external magnetic field, the field lines are repelled or expelled and the field inside the material is reduced.



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



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



NUMERICAL TYPE QUESTIONS

S1. Given, $H_E = 0.36 \times 10^{-4}$ Wb/m^2 and $\delta = 60°$

Vertical component of earth's magnetic field,

$V_E = H_E \tan\delta = 0.36 \times 10^{-4} \times \tan 60°$

$= 0.36 \times 10^{-4} \times \sqrt{3}$

$\therefore \quad V_E = 0.622 \times 10^{-4} \frac{\text{Wb}}{\text{m}^2}$

S2. Given that, $V_E = H_E$

Angle of dip, $\tan\delta = \frac{V_E}{H_E} = \frac{H_E}{H_E} = 1 = \tan 45°$

Angle of dip, $\delta = 45°$

S2. Given, $m = 8.0 \times 10^{22}$ A $-$ m^2 and R = 6400 km.

Magnetization, $M = \frac{m_{net}}{V} = \frac{8.0 \times 10^{22}}{\left(\frac{4}{3}\right)\pi R^3}$

$$\left[\because V = \frac{4}{3}\pi R^3\right]$$

$= \frac{8.0\times10^{22}}{(4/3)(3.14)(6.4\times10^6)^3} = 73 \text{ Am}^{-1}$

Hence, the earth's magnetization is 73 Am^{-1}.

S4. Given, $B = 1.7 \times 10^{-6}$ T

Horizontal component of intensity of earth is magnetic field,

$H = \frac{B}{\mu_0} = \frac{1.7\times10^{-6}}{4\pi\times10^{-7}} = 1.35 \text{ Am}^{-1}$

S5. Given, side of cube = 1cm = 10^{-2} m

$\therefore$ Volume, $V = 10^{-6}$ m^3

Dipole moment, M = 20×10^{-6} J/T

Applied magnetics intensity, H = 60×10^3 A/m

Intensity of magnetization

$I = \frac{M}{V} = \frac{20\times10^{-6}}{10^{-6}} = 20$ A/m

Now, magnetic susceptibility χ is

$\chi = \frac{\text{Intensity of magnetisation}}{\text{Applied magnetic intensity}} = \frac{I}{H}$

$= \frac{20}{60\times10^3}$

$\Rightarrow \quad \chi = \frac{1}{3} \times 10^{-3} = 3.33 \times 10^{-4}$