CHAPTER

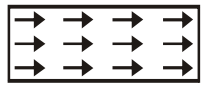
7 Magnetism

Magnetism

*The phenomenon of attracting magnetic substances like iron, cobalt, nickel etc. is called **magnetism**. A body possessing the property of magnetism is called **magnet**.*

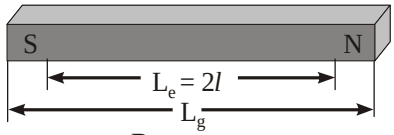
Lodestone or **magnetite** is natural magnet. Earth is also a natural magnet.

In magnetised substance all the atomic magnets are aligned in same direction and thus resultant magnetism is non-zero.



Bar Magnet

A bar magnet consists of two equal and opposite magnetic poles separated by a small distance. Poles are not exactly at the ends. The shortest distance between two poles is called effective length (L_e) and is less than its geometric length (L_g). For bar magnet $L_e = 2l$ and $L_e = (5/6)\, L_g$.



Bar magnet

Properties of Magnet

(i) Attractive property : When a magnet is dipped into iron fillings it is found that the concentration of iron filings, i.e., attracting power of the magnet is maximum at two points near the ends and minimum at the centre. The places where its attracting power is maximum are called **poles**.

(ii) Directive property : When a magnet is suspended its length becomes parallel to N-S direction. The pole pointing north is called the north pole while the other pointing in the geographical south is called the south pole of the magnet. 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**.

(iii) Poles of a magnet always exist in pairs : In a magnet the two poles are found to be equal in strength and opposite in nature. If a magnet is broken into number of pieces, each piece becomes a magnet with two equal and opposite poles. This shows that monopole do not exist.

(iv) Repulsive property : A pole of a magnet attracts the opposite pole while repels similar pole.

Demagnetisation of Magnet

A magnet gets demagnetised, i.e., loses its power of attraction if it is *heated, hammered* or *alternating current is passed through a wire wound over it*.

Permanent and Temporary Magnets (Electromagnets)

The **permanent artificial magnets** are made of some metals and alloys like Carbon-steel, Alnico, Platinum-cobalt, Alcomax, Ticonal etc. The permanent magnets are made of ferromagnetic substances with large coercivity and retentivity

The **temporary artificial magnets** like electromagnets are prepared by passing current through coil wound on soft iron core. These cannot retain its strength for a long time. These are made from soft iron, non-metal and alloy. Electromagnets are stronger than permanent magnet.

Some Applications of Electromagnets

(i) Electric motors
(ii) Doorbells
(iii) In scrapyards to separate iron from other metals

Coulomb's Law in Magnetism

If two magnetic poles of strengths m_1 and m_2 are kept at a distance r apart then force of attraction or repulsion between the two poles is directly proportional to the product of their pole strengths and inversely proportional to the square of the distance between them

$$i.e.,\ F \propto \frac{m_1 m_2}{r^2} \qquad \text{or} \qquad F = \frac{\mu_0}{4\pi}\,\frac{m_1 m_2}{r^2}$$

where $F = \dfrac{\mu_0}{4\pi} = 10^{-7}$ Wb A^{-1} $m^{-1} = 10^{-7}$ henry/m

μ_0 is permeability of free space or absolute permeability

Magnetic Field

The space around a magnet (or a current carrying conductor) in which its magnetic effect can be experienced is called the magnetic field.

If a magnet is cut into two equal parts along the length then pole strength is reduced to half and length remains unchanged.

New magnetic dipole moment $M' = m'(2\ell) = \dfrac{m}{2} \times 2\ell = \dfrac{M}{2}$

If a magnet is cut into two equal parts transverse to the length then pole strength remains unchanged and length is reduced to half.

New magnetic dipole moment $M' = m\left(\dfrac{2\ell}{2}\right) = \dfrac{M}{2}$

Magnetic Lines of Force

Magnetic line of force is an imaginary curve tangent to which at a point gives the direction of magnetic field at that point or the magnetic field line is the imaginary path along which an isolated north pole will tend to move if it is free to do so.

Magnetic lines of force do not intersect each other. Because if they do, there will be two directions of magnetic field which is not possible.

Gauss's Law in Magnetism

The surface integral of magnetic field $\vec{B}$ over a closed surface S is always zero.

Mathematically, $\oint_S \vec{B} \cdot \vec{da} = 0$

The Earth's Magnetism

The branch of Physics which deals with the study of earth's magnetic field is called **terrestrial magnetism**.

William Gilbert suggested that earth itself behaves like a huge magnet.

(a) A freely suspended magnet always comes to rest in N-S direction.

(b) A piece of soft iron buried in N-S direction inside the earth acquires magnetism.

Geographic meridian : It is a vertical plane passing through geographic north and south pole of the earth.

Geographic equator : A great circle on the surface of the earth in a plane perpendicular to geographical axis is called geographic equator. All places on geographic equator are at equal distances from geographical poles.

Magnetic meridian : It is a vertical plane passing through the magnetic north and south pole of the earth.

Magnetic equator : A great circle on the surface of the earth in a plane perpendicular to magnetic axis is called magnetic equator. All places on magnetic euqator are at equal distance from magnetic poles.

Magnetic Elements

The physical quantities which determine the intensity of earth's total magnetic field completely both in magnitude and direction are called magnetic elements.

Angle of declination (ϕ) : *The angle between the magnetic meridian and geographical meridian at a place is called angle of declination.*

Angle of dip or inclination (θ) : *The angle through which the N pole dips down with reference to horizontal is called the angle of dip.* At magnetic north and south pole angle of dip is 90°. At magnetic equator the angle of dip is 0°.

Horizontal component of earth's magnetic field : The total intensity of the earth's magnetic field makes an angle θ with horizontal. It has

(i) component in horizontal plane called **horizontal component B_H**.

(ii) component in vertical plane called **vertical component B_V**.

$B_V = B \sin\theta$ $\qquad$ $B_H = B\cos\theta$

so, $\frac{B_V}{B_H} = \tan\theta$ and $\qquad B = \sqrt{B_H^2 + B_V^2}$

Intensity of Magnetisation

It is defined as the magnetic dipole moment developed per unit volume when a magnetic material is subjected to magnetising field.

Intensity of magnetisation,

$$I = \frac{Magnetic\ \ dipole\ \ moment}{Volume} = \frac{M}{V}$$

Magnetic Susceptibility

The magnetic susceptibility of a magnetic substance is defined as the ratio of the intensity of magnetisation to magnetic intensity.

i.e., $\chi_m = \frac{I}{H}$

The value of χ_m **depends on nature of material and temperature.**

Magnetic Permeability

The magnetic permeability of a magnetic substance is defined as the ratio of the magnetic induction to the magnetic intensity.

i.e., $\mu = \frac{B}{H}$

Hysteresis

The lagging of intensity of magnetisation (I) or magnetic induction (B) behind the magnetising field (H) during the process of magnetisation and demagnetisation of a ferromagnetic material is called hysteresis.

Retentivity : *The value of I (or B) of a material when the magnetising field is reduced to zero is called retentivity or residual magnetism of the material.*

Coercivity : *The value of reverse magnetising field required to reduce residual magnetism to zero is called coercivity of the material.*

Comparison of properties of soft iron and steel :

(1) The area of hysteresis loop for soft iron is much smaller than for steel, so energy loss per unit volume per cycle for soft iron is smaller than steel.

(2) The retentivity of soft iron is greater than that of steel.

(3) The coercivity of steel is much larger than that of soft iron.

(4) The magnetisation and demagnetisation is easier in soft iron than steel.

(5) Soft iron acquires saturation magnetisation for quite low value of magnetising field than in case of steel or soft iron is much strongly magnetised than steel.

Diamagnetic Substances : *The substances which when placed in a magnetic field are feebly magnetised in a direction opposite to that of the magnetising field are called diamagnetic substances.*

Some diamagnetic substances are Cu, Zn, Bi, Ag, Au, Pb, He, Ar, NaCl, H_2O, marble, glass, etc.

Paramagnetic Substances : *The substances which when placed in a magnetic field are feebly magnetised in the direction of magnetising field are called paramagnetic substances.*

Some paramagnetic substances are Al, Na, Sb, Pt, $CuCl_2$, Mn, Cr, liquid oxygen, etc.

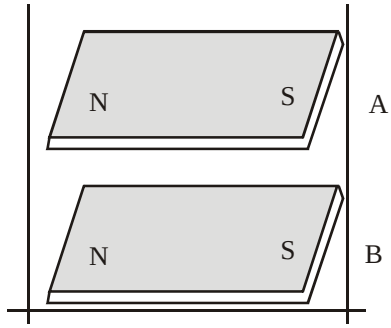
Ferromagnetic Substances : *The substances which when placed in a magnetic field are strongly magnetised in the direction of the magnetising field are called ferromagnetic substances.*

Iron, cobalt, nickel, etc. are some examples of ferromagnetic substance.

EXERCISE

1. The magnetism of magnet is due to
   (a) the spin motion of electron
   (b) earth
   (c) pressure of big magnet inside the earth
   (d) cosmic rays
2. Which of the following is the most suitable material for making permanent magnet ?
   (a) Steel (b) Soft iron
   (c) Copper (d) Nickel
3. The permanent magnet is made from which one of the following substances?
   (a) Diamagnetic (b) Paramagnetic
   (c) Ferromagnetic (d) Electromagnetic
4. Demagnetisation of magnets can be done by
   (a) rough handling
   (b) heating
   (c) magnetising in the opposite direction
   (d) All of the above
5. Which of the following is most suitable for the core of electromagnets?
   (a) Soft iron (b) Steel
   (c) Copper-nickel alloy (d) Air
6. 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
7. Out of the following, diamagnetic substance is
   (a) iron (b) copper
   (c) lead (d) silver
8. The magnetic compass is not useful for navigation near the magnetic poles. Since
   (a) $R = 0$ (b) $V = 0$
   (c) $H = 0$ (d) $\theta = 0^\circ$
9. Metals getting magnetised by orientation of atomic magnetic moments in external magnetic field are called
   (a) diamagnetics (b) paramagnetics
   (c) ferromagnetics (d) antimagnetics
10. At magnetic poles, the angle of dip is
    (a) 45° (b) 30°
    (c) zero (d) 90°
11. Curie temperature is the temperature above which
    (a) a ferromagnetic material becomes paramagenetic
    (b) a paramagnetic material becomes diamagnetic
    (c) a ferromagnetic material becomes diamagnetic
    (d) a paramagnetic m aterial becomes ferromagnetic
12. Electromagnets are made of soft iron because soft iron has
    (a) low retentivity and high coercive force
    (b) high retentivity and high coercive force
    (c) low retentivity and low coercive force
    (d) high retentivity and low coercive force
13. To shield an instrument from external magnetic field, it is placed inside a cabin made from
    (a) wood (b) ebonite
    (c) iron (d) diamagnetic substance
14. The force which makes maglev move
    (a) gravitational field (b) magnetic field
    (c) nuclear forces (d) air drag
15. A conducting wire can give magnetic poles when it
    (a) bent into the form of a circular ring
    (b) placed in an external magnetic field
    (c) suspended freely in air
    (d) All of the above
16. Which of the following is an artificial magnet?
    (a) Bar magnet
    (b) Horse-shoe magnet
    (c) Magnetic needle
    (d) All of the above
17. The distance between two magnetic poles is doubled and their pole-strength is also doubled. The force between them
    (a) increases to four times
    (b) decreases by half
    (c) remains unchanged
    (d) increases to two times
18. Earth's magnetic field always has a horizontal component except at
    (a) magnetic equator
    (b) magnetic pole
    (c) geographical north pole
    (d) at an altitude of 45°
19. When an iron bar is moved over a bar magnet along its length the attractive force
    (a) increases first and then decreases
    (b) decreases first and then increases
    (c) remains same
    (d) cannot say
20. When the S–pole of a magnet is placed near an unknown pole of another magnet, the two magnets
    (a) repel each other because the unknown pole is N–pole
    (b) repel each other because the unknown pole is S–pole
    (c) attract each other because the unknown pole is S–pole
    (d) can either attract or repel

21 Two magnets A and B are placed with like poles having one above another. What will happen?



(a) A will stuck to B
(b) A will remain as in figure
(c) A will move side ways
(d) Can't say

22. A compass which is allowed to move in a horizontal plane is taken to a geomagnetic pole. It
(a) will stay in north-south direction only
(b) will stay in east-west direction only
(c) will stay in any position
(d) None of these

23. Magnetic meridian is a
(a) point (b) horizontal plane
(c) vertical plane (d) line along N-S

24. Due to the earth's magnetic field, charged cosmic ray particles
(a) require greater kinetic energy to reach the equator than the poles
(b) require less kinetic energy to reach the equator than the poles
(c) can never reach the equator
(d) can never reach the poles

25. Which one of the following is a non-magnetic substance?
(a) Iron (b) Cobalt
(c) Nickel (d) Brass

26. The universal properties of all substances is
(a) diamagnetism (b) ferromagnetism
(c) paramagnetism (d) All of these

ANSWER KEY											
1	(a)	**6**	(d)	**11**	(a)	**16**	(d)	**21**	(b)	**26**	(a)
2	(a)	**7**	(b)	**12**	(d)	**17**	(b)	**22**	(c)		
3	(c)	**8**	(c)	**13**	(c)	**18**	(b)	**23**	(c)		
4	(d)	**9**	(b)	**14**	(b)	**19**	(b)	**24**	(c)		
5	(a)	**10**	(d)	**15**	(a)	**20**	(b)	**25**	(d)		

HINTS AND SOLUTIONS

5. (a) Soft iron is highly ferromagnetic.
6. (d) A magnetic needle kept in non uniform magnetic field experience a force and torque due to unequal forces acting on poles.
7. (b) Copper has negative susceptibility (*i.e.* $\chi = -0.96$). Hence, it is diamagnetic.
8. (c) Near the magnetic poles, $H = 0$, therefore, magnetic compass will not work.
9. (b) In paramagnetic metals, magnetism is acquired by orientation of atomic dipoles.
10. (d) At poles, $\delta = 90^{\circ}$.
12. (d) Soft iron has high retentivity and low coercive force.
13. (c) The cabin is made up of iron because maximum magnetic lines of forces pass through it.
14. (b) The magnetic force will pull the vehicle.
21. (b) Unlike poles repel. The repulsive magnetic force will not allow the like poles to get stuck.
22. (c) At geomagnetic poles, there is no horizontal component of earth field and so compass needle may stay at any position.