5 Magnetism and Matter

Fastrack Revision

- **Magnetism:** A material that has both attractive and directive properties and attracts some elements such as iron, nickel, cobalt etc., is called magnet. The property of attraction of small bits of iron, steel, cobalt, nickel etc., towards the ore (magnetite) is called magnetism.
- **Some Basics of Magnetism**
  - The Earth behaves as a magnet.
  - Every magnet attracts small pieces of magnetic substance like iron, steel, cobalt and nickel towards it.
  - When a magnet is suspended freely with the help of a thread, it comes to rest along the North-South direction.
  - The poles always exist in pairs.
  - Like poles repel each other and unlike poles attract each other.
  - The force of attraction or repulsion between two magnetic poles of strength m_1 and m_2 separated by a distance r is directly proportional to the product of pole strengths and inversely proportional to the square of the distance between their centres.

$$F = \frac{\mu_0 m_1 m_2}{4\pi r^2}$$

- **Magnetic Field Lines**
  - The magnetic field lines of a magnet form closed continuous loops (from South pole to North pole).
  - Outside the body of the magnet, the direction of magnetic field lines is from north pole to south pole.
  - At any given point, tangent to the magnetic field lines represents the direction of net magnetic field at that point.
  - The magnitude of magnetic field at any point is represented by the number of magnetic field lines passing around that point.
  - No two magnetic field lines can intersect each other.
- **Magnetic Dipole Moment:** It is the product of strength of either pole (m) and the magnetic length ($2l$) of the magnet.

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

SI unit of M is J/ Tesla or Am^2.

- **Magnetic Field due to a Magnetic Dipole (Bar Magnet)**
  - Magnetic field due to a magnetic dipole (bar magnet) along its axis is given by

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

where, M = magnetic dipole moment

μ_0 = permeability of free space

r = distance from the centre of magnet

  - Magnetic field due to a magnetic dipole (bar magnet) perpendicular to its axis is given by

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

- **Torque on Magnetic Dipole (Bar Magnet) in a Uniform Magnetic Field:** A uniform magnetic field B is represented by equidistant parallel lines due to a bar magnet of length $2l$ and strength of each pole is M.

Torque, $$\tau = MB\sin\theta = \vec{M} \times \vec{B}$$

where, θ is the angle between $\vec{M}$ and $\vec{B}$. Its SI unit is Joule per Tesla (JT^{-1}).

- **Magnetic Properties of Materials:** In terms of susceptibility χ, a material is diamagnetic, if χ is negative; paramagnetic, if χ is positive and small and ferromagnetic, if χ is large and positive.

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

- **Bar Magnet:** A bar magnet is a rectangular piece of an object, made up of iron, steel or any other ferromagnetic substances or ferromagnetic composite, that shows permanent magnetic properties.

  It has two poles, a north pole and south pole such that when suspended freely, the magnetic aligns itself so that the northern pole points towards the magnetic north pole of the earth.
- **Bar Magnet as an Equivalent Solenoid:** A bar magnet and a solenoid produce similar magnetic field. The magnetic moment of a bar magnet is equal to the magnetic moment of an equivalent solenoid that produces the same magnetic field.

  The magnetic moment of solenoid , $M = NIA$

$$= (n \cdot 2l) I \times \pi a^2$$

Thus, the magnetic field of solenoid is given by,

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

This is also the far axial magnetic field of a bar magnet.

- **Potential Energy of a Magnetic Dipole in a Magnetic Field:** Potential energy of a magnetic dipole *i.e.*, bar magnet in a magnetic field is given by

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

where, θ is the angle between $\vec{M}$ and $\vec{B}$.

- **Oscillation of a Freely Suspended Magnet:** The oscillations of a freely suspended magnet in a uniform magnetic field are in SHM.

  The time period of oscillation, $T = 2\pi\sqrt{\frac{I}{MB}}$

- **The Electrostatic Analogy**

Electrostatics	Magnetism
$\vec{E}$	$\vec{B}$
$\vec{p}$	$\vec{M}$
$\frac{1}{4\pi\varepsilon_0}$	$\frac{\mu_0}{4\pi}$

- **Magnetism and Gauss's Law:** According to Gauss's law for magnetism, the net magnetic flux (ϕ_B) through any closed surface is also zero.

$$\phi_B = \sum_{all} \Delta\phi_B = 0$$

or $$\phi_B = \oint \vec{B} \cdot d\vec{S} = 0$$

- **Magnetisation of Material:** It is defined as the magnetic moment per unit volume of the material.

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

Its SI unit is Am^{-1}.

- **Magnetic Field Strength/Magnetic Induction/Flux Density:** It is the force experienced by a unit positive charge moving with unit velocity in a direction perpendicular to the magnetic field.
- **Magnetising Field Intensity $(\vec{H})$:** The capability of magnetic field to magnetise the substance is measured in terms of magnetic intensity of the field.

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

- **Magnetic Susceptibility (χ_m):** It is defined as the ratio of the intensity of magnetisation (M) to the magnetising field intensity (H).

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

It has no unit.

- **Magnetic Permeability:** The magnetic permeability of a material may be defined as the ratio of its magnetic induction (B) to the magnetic intensity (H).

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

Its SI unit is TmA^{-1} or H/m or NA^{-2}.

- **Relative Permeability:** It is defined as the ratio of the permeability of the medium to the permeability of free space.

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

It has no unit.

- **Relation between Magnetic Permeability and Magnetic Susceptibility**

$$\mu = \mu_0 \mu_r = \mu_0 (1 + \chi_m) \text{ or } \mu_r = 1 + \chi_m$$

- **Magnetic Substances:** Magnetic substances are those substances that can be either attracted or repelled when placed in an external magnetic field and can be magnetised themselves.
- **Classification of Magnetic Substances**
  - **Diamagnetic Substances:** Substance that are partially magnetised on the opposite side of the field when placed in a magnetic field of strong intensity and are slightly repulsed when brought near the tip of a powerful magnet, are called diamagnetic substances. This property of substances is called diamagnetism. For example, Silver (Ag), Gold (Au), Copper (Cu), Bismuth (Bi), Zinc (Zn), Diamond (C), Salt (NaCl), Water (H_2O), Air, Hydrogen (H_2), Nitrogen (N_2), Helium (He), Krypton (Kr) and most inorganic compounds and almost all organic compounds are found in category of diamagnetic substances.
  - **Paramagnetic Substances:** Substances that, when placed in a magnetic field of strong intensity, receive low magnetisation in the direction of the field and are slightly attracted towards the end when brought near the end of the powerful magnet, are called paramagnetic material. This property of substances is called paramagnetism. For example, Sodium (Na), Aluminium (Al), Platinum (Pt), Manganese (Mn), Copper chloride ($CuCl_2$), solution of Nickel and Iron salts, Oxygen (O_2) etc., are categorised as paramagnetic substances.
  - **Ferromagnetic Substances:** Some materials gain strong magnetism in the direction of the field even when they are in a weak magnetic field and when the magnet is brought close to it, these materials are strongly attracted towards the end of the magnet. These substances are called ferromagnetic materials and this property of substances is called ferromagnetism. For example, Iron (Fe), Cobalt (Co), Nickel (Ni), Tungsten (W), Steel, Gadolinium (Gd) etc., are ferromagnetic substances.

Practice Exercise

Multiple Choice Questions

Q 1. Which of the following is correct about magnetic monopole?

a. Magnetic monopole exists.
b. Magnetic monopole does not exist.
c. Magnetic monopole have constant value of monopole momentum.
d. The monopole momentum increases due to increase at its distance from the field.

Q 2. Magnetic moment for a solenoid and corresponding bar magnet is:

a. equal for both
b. more for solenoid
c. more for bar magnet
d. None of these

Q 3. A bar magnet has magnetic dipole moment $\vec{M}$. Its initial position is parallel to the direction of uniform magnetic field $\vec{B}$. In this position, the magnitudes of torque and force acting on it respectively are: *(CBSE 2021 Term-1)*

a. 0 and MB b. MB and MB

c. 0 and 0 d. $|\vec{M} \times \vec{B}|$ and 0

Q 4. A circular coil of 300 turns and diameter 14 cm carries a current of 15 A. The magnitude of magnetic moment associated with the loop is:

a. 51.7 JT^{-1} b. 69.2 JT^{-1}

c. 38.6 JT^{-1} d. 19.5 JT^{-1}

Q 5. A natural bar magnet:

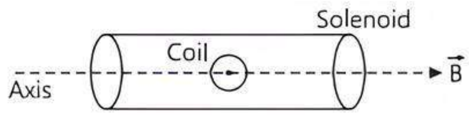
a. has always two poles

b. is made of iron and its alloys

c. is always suspended in North-South direction

d. All of the above

Q 6. The torque required to hold a small circular coil of 10 turns, area 1 mm^2 and carrying a current of $\left(\frac{21}{44}\right)$A in the middle of a long solenoid of 10^3 turns/m carrying a current of 2.5 A, with its axis perpendicular to the axis of the solenoid, is:



a. 1.5×10^{-6} Nm b. 1.5×10^{-8} Nm

c. 1.5×10^{6} Nm d. 1.5×10^{8} Nm

Q 7. A circular coil of 100 turns, radius 10 cm carries a current of 5A. It is suspended vertically in a uniform horizontal magnetic field of 0.5 T and the field lines make an angle of 60° with the plane of the coil. The magnitude of the torque that must be applied on it to prevent it from turning is:

a. 2.93 Nm b. 3.43 Nm

c. 3.93 Nm d. 4.93 Nm

Q 8. A uniform horizontal magnetic field of 7.5×10^{-2} T is set up at an angle of 30° with the axis of an solenoid and the magnetic moment associated with it is 1.28 JT^{-1}. Then the torque on it is:

a. 4.8×10^{-2} Nm b. 1.6×10^{-2} Nm

c. 1.2×10^{-2} Nm d. 4.8×10^{-4} Nm

Q 9. A magnetic dipole is under the influence of two magnetic fields. The angle between the field directions is 60° and one of the fields has a magnitude of 1.2×10^{-2} T. If the dipole comes to stable equilibrium at an angle of 30° with this field, then the magnitude of the field is:

a. 1.2×10^{-4} T b. 2.4×10^{-4} T

c. 1.2×10^{-2} T d. 2.4×10^{-2} T

Q 10. If the magnetising field on a ferromagnetic material is increased, its permeability: *(CBSE SQP 2022-23)*

a. decreases

b. increases

c. remains unchanged

d. first decreases and then increases

Q 11. The domain formation is a necessary feature of:

a. diamagnetism b. paramagnetism

c. ferromagnetism d. All of these

Q 12. Which of the following is weakly repelled by a magnetic field?

a. Iron b. Cobalt c. Steel d. Copper

Q 13. If a diamagnetic material is placed in a magnetic field, then the magnetic field inside the material compared to that outside will be:

a. slightly less b. slightly more

c. very high d. same

Q 14. Which of the following is an example for diamagnetic substance?

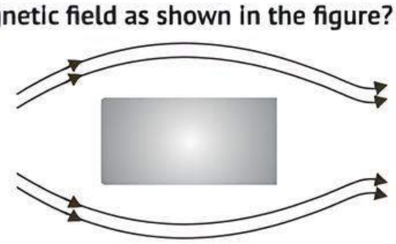
a. Copper b. Nickel

c. Aluminium d. Iron

Q 15. The susceptibility of a ferromagnetic material is χ at 27°C. At what temperature will its susceptibility be 0.5χ?

a. 54°C b. 327°C c. 600°C d. 237°C

Q 16. Which of the following cannot modify an external magnetic field as shown in the figure? *(CBSE 2023)*



a. Nickel b. Silicon

c. Sodium chloride d. Copper

Q 17. The relative permeability of a substance *X* is slightly less than unity and that of substance *Y* is slightly more than unity, then: *(CBSE SQP 2023-24)*

a. *X* is paramagnetic and *Y* is ferromagnetic

b. *X* is diamagnetic and *Y* is ferromagnetic

c. *X* and *Y* both are paramagnetic

d. *X* is diamagnetic and *Y* is paramagnetic

Q 18. A magnetising field of 1500 Am^{-1} produces flux of 2.4×10^{-5} weber in an iron bar of the cross-sectional area of 0.5 cm^2. The permeability of the iron bar is:

a. 245 b. 250 c. 252 d. 255

Q 19. A solenoid has a core of a substance with relative permeability 600. What is the magnetic permeability of the given substance?

a. $20\pi \times 10^{-5}$ NA^{-2} b. $21\pi \times 10^{-5}$ NA^{-2}

c. $22\pi \times 10^{-5}$ NA^{-2} d. $24\pi \times 10^{-5}$ NA^{-2}

Q 20. A domain in ferromagnetic iron in the form of cube is having 5×10^{10} atoms. If the side length of this domain is 1.5μm and each atom has a dipole moment of 8×10^{-24} Am^2, then magnetisation of domain is:

a. 11.8×10^{5} Am^{-1} b. 1.18×10^{4} Am^{-1}

c. 23.5×10^{4} Am^{-1} d. 1.18×10^{5} Am^{-1}

Q 21. A magnetising field of 2×10^3 Am^{-1} produces a magnetic flux density of 8π T in an iron rod. The relative permeability of the rod will be:

a. 10^2
b. 1
c. 10^4
d. 10^3

Q 22. A ring of mean radius 15 cm has 3500 turns of wire wound on a ferromagnetic core of relative permeability 800. The magnetic field in the core for a magnetising current of 1.2 A is:

a. 2.48 T
b. 3.48 T
c. 4.48 T
d. 5.48 T

Q 23. A solenoid has core of a material with relative permeability 500 and its windings carry a current of 1.2 A. The number of turns of the solenoid is 500 per metre. The magnetisation of the material is nearly:

a. $2.5 \times 10^3 Am^{-1}$
b. $3 \times 10^5 Am^{-1}$
c. $2.0 \times 10^3 Am^{-1}$
d. $2.0 \times 10^5 Am^{-1}$

Q 24. The relation connecting magnetic susceptibility χ_m and relative permeability μ_r is:

a. $\chi_m = \mu_r + 1$
b. $\chi_m = \mu_r - 1$
c. $\chi_m = \frac{1}{\mu_r}$
d. $\chi_m = 3(1 + \mu_r)$

Assertion & Reason Type Questions

Directions (Q.Nos. 25-28): *In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) and Reason (R) are false.

Q 25. Assertion (A): Gauss's law of magnetism is different from that for electrostatics.
Reason (R): Isolated magnetic poles are not known to exist.

Q 26. Assertion (A): The poles of magnet cannot be separated by breaking into two pieces.
Reason (R): The magnetic moment will be reduced to half when a magnet is broken into two equal pieces.

Q 27. Assertion (A): In water, value of magnetic field decreases.
Reason (R): Water is a diamagnetic substance.

Q 28. Assertion (A): The ability of a material to permit the passage of magnetic lines of force through it is called magnetic permeability.
Reason (R): For a perfect diamagnetic substance, permeability is always one.

Fill in the Blanks Type Questions

Q 29. You can determine the sense of magnetic field lines surrounding a straight current carrying conductor by applying .... rule.

Q 30. Inside the body of a magnet, the direction of magnetic field lines is from ....

Q 31. The magnetic field lines of a magnet form .... loop unlike electric field lines.

Q 32. The magnetic field strength at a point due to a short bar on its axis varies .... as cube of distance of the point from the centre of magnet.

Q 33. The magnetic field lines are .... by a paramagnetic substance. *(CBSE 2020)*

Q 34. The magnetic field lines are .... by a diamagnetic substance. *(CBSE 2020)*

Q 35. There is no effect of temperature on .... type of materials.

Q 36. Magnetic susceptibility is slightly negative for .... type substances.

Q 37. The ability of a material to retain magnetism after removal of magnetizing field is called as ....

Answers

1. (b) Magnetic monopole does not exist.
When a bar magnet is broken into two halves, we get two similar bar magnet with weaker properties. So, magnetic monopoles do not exist.

2. (a) equal for both
Since a bar magnet and a corresponding solenoid produce similar magnetic fields. Hence the magnetic moment of a bar magnet is equal to the magnetic moment of an equivalent solenoid that produces the same magnetic field.

TiP

Magnetic moment of a current loop is defined as the product of current (I) and the area (A) enclosed by the current loop i.e., M = IA.

3. (c) 0 and 0

4. (b) 69.2 $J T^{-1}$.
Here, $N = 300$, $I = 15$ A, $r = 7 cm = 7 \times 10^{-2} m$
$\therefore$ $M = NIA = NI \times \pi r^2$
$= 300 \times 15 \times 3.14 \times (7 \times 10^{-2})^2$
$= 69.2 JT^{-1}$

5. (d) All of the above

6. (b) 1.5×10^{-8} Nm
Here, for small circular coil,
Number of turns, $N = 10$,
Area $A = 1 mm^2 = 1 \times 10^{-6} m^2$
Current $I_1 = \frac{21}{44}$ A

For a long solenoid.

Number of turns per metre. $n = 10^3$

Current. $I_2 = 2.5$ A

Magnetic field due to a long solenoid on its axis is

$$B = \mu_0 n I_2 \quad ...(1)$$

Magnetic moment of a circular coil is

$$M = NAI_1 \quad ...(2)$$

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

$\tau = MB\sin\theta = MB$ $\quad$ [$\because \theta = 90°$ (Given)]

$\tau = (NAI_1)(\mu_0 n I_2)$ $\quad$ [Using eqs. (1) and (2)]

$$\tau = 10 \times 1 \times 10^{-6} \times \frac{21}{44} \times 4 \times \frac{22}{7} \times 10^{-7} \times 10^3 \times 2.5$$

$$= 1.5 \times 10^{-8} \text{ Nm}$$

7. (c) 3.93 Nm

Here, $N = 100$, $r = 10$ cm $= 0.10$ m, $I = 5$ A, $B = 0.5$ T,

$\theta = 90° - 60° = 30°$

Area of the coil, $A = \pi r^2 = 3.14 \times (0.1)^2$

$\therefore \quad \tau = NIBA\sin\theta$

$= 100 \times 5 \times 0.5 \times 3.14 \times (0.1)^2 \times \sin 30°$

$= 3.931$ Nm

8. (a) 4.8×10^{-2} Nm

Torque, $\quad \tau = MB\sin\theta$

Here, $\quad M = 1.28$ JT^{-1}, $B = 7.5 \times 10^{-2}$T, $\theta = 30°$

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

$$= 1.28 \times 7.5 \times 10^{-2} \times \frac{1}{2}$$

$= 0.64 \times 7.5 \times 10^{-2} = 4.8 \times 10^{-2}$ Nm

9. (c) 1.2×10^{-2} T

Here, $\theta = 60°$, $B_1 = 1.2 \times 10^{-2}$ T

$\theta_1 = 30°$ and $\theta_2 = 60° - 30° = 30°$

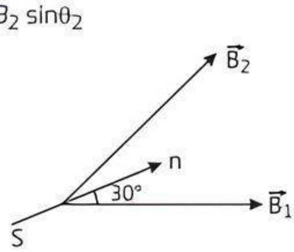
In stable equilibrium, torque due to two fields must be balanced *i.e.*, $\quad \tau_1 = \tau_2$

$\Rightarrow \quad MB_1\sin\theta_1 = MB_2\sin\theta_2$

or $\quad B_2 = B_1 \dfrac{\sin\theta_1}{\sin\theta_2}$

$$= B_1 \frac{\sin 30°}{\sin 30°} = B_1$$

$= 1.2 \times 10^{-2}$T



10. (a) decreases

In case of a ferromagnetic material, there is no constant relative permeability. As the magnetising field increases, the relative permeability increases, reaches its maximum and then decreases.

We know that permeability, $\mu = \dfrac{B}{H}$

where, B = magnetic field density

H = magnetic field strength

Thus, the magnetic field strength is inversely proportional to permeability *i.e.*, permeability decreases with increase in magnetising field.

11. (c) ferromagnetism

12. (d) Copper

Because copper is a diamagnetic material.

13. (a) slightly less

14. (a) Copper

15. (b) 327°C

$$\frac{\chi_1}{\chi_2} = \frac{T_2}{T_1} \Rightarrow \frac{\chi}{0.5\chi} = \frac{T}{300} \text{ or } T = 600 \text{ K or } 327°\text{C}$$

TiP

Try to remember direct relations.

16. (d) Copper

17. (d) X is diamagnetic and Y is paramagnetic

The relative permeability of a substance X is slightly less than unity and that of substance Y is slightly more than unity, then X is diamagnetic and Y is paramagnetic.

18. (d) 255

Here, $H = 1500$ Am^{-1}, $\phi = 2.4 \times 10^{-5}$ weber

$A = 0.5$ $cm^2 = 0.5 \times 10^{-4} m^2$

$$\therefore \quad B = \frac{\phi}{A} = \frac{2.4 \times 10^{-5}}{0.5 \times 10^{-4}} = 4.8 \times 10^{-1} \text{ T}$$

$$\text{and} \quad \mu = \frac{B}{H} = \frac{4.8 \times 10^{-1}}{1500} = 3.2 \times 10^{-4}$$

So, relative permeability

$$\mu_r = \frac{\mu}{\mu_0} = \frac{3.2 \times 10^{-4}}{4\pi \times 10^{-7}}$$

$$= 0.255 \times 10^3 = 255$$

19. (d) $24\pi \times 10^{-5}$ NA^{-2}

As $\quad \mu = \mu_r \times \mu_0$

Here, $\quad \mu_r = 600$ and $\mu_0 = 4\pi \times 10^{-7}$ NA^{-2}

$\therefore$ Magnetic permeability.

$\mu = 600 \times 4\pi \times 10^{-7}$

$= 24\pi \times 10^{-5}$ NA^{-2}

20. (d) $1.18 \times 10^5 Am^{-1}$.

The volume of the cubic domain is

$V = (1.5 \times 10^{-6} m)^3$

$= 3.38 \times 10^{-18}$ m^3

Number of atoms in domain $(N) = 5 \times 10^{10}$ atoms

Since, each iron atom has a dipole moment (M)

$= 8 \times 10^{-24} Am^2$

M_{max} = Total number of dipole moment for all atoms

$= N \times M = 5 \times 10^{10} \times 8 \times 10^{-24}$

$= 40 \times 10^{-14} = 4 \times 10^{-13} Am^2$

Now the consequent magnetisation,

$$M'_{max} = \frac{M_{max}}{\text{Domain volume}}$$

$$= \frac{4 \times 10^{-13} Am^2}{3.38 \times 10^{-18} m^3} = 1.18 \times 10^5 Am^{-1}$$

21. (c) 10^4

Here, $\quad H = 2 \times 10^3 Am^{-1}$,

$B = 8\pi$ T, $\mu_0 = 4\pi \times 10^{-7}$

Since $\mu_r = \frac{\mu}{\mu_0} = \frac{\mu H}{\mu_0 H} = \frac{B}{\mu_0 H}$

$$= \frac{8\pi}{4\pi \times 10^{-7} \times 2 \times 10^{3}} = 10^4$$

22. (c) 4.48 T

Here, $r = 15 \text{ cm} = 15 \times 10^{-2}$ m

$N = 3500$ turns, $I = 1.2$ A, $\mu_r = 800$

Then number of turns/length (n)

$$= \frac{N}{2\pi r} = \frac{3500}{2\pi \times 15 \times 10^{-2}} = 3715.5$$

$\because$ $B = \mu_0 \mu_r n I$

$\therefore$ $B = 4\pi \times 10^{-7} \times 800 \times 3715.5 \times 1.2 = 4.48$ T

23. (b) $3 \times 10^5 \text{Am}^{-1}$

Here, $n = 500$ turns/m

$I = 1.2\text{A}$, $\mu_r = 500$

Magnetic intensity,

$$H = nI = 500 \text{ m}^{-1} \times 1.2\text{A} = 600 \text{ Am}^{-1}$$

As $\mu_r = 1 + \chi$

where, χ is the magnetic susceptibility of the material

or $\chi = (\mu_r - 1)$

Magnetisation, $M = \chi H$

$$= (\mu_r - 1)H = (500 - 1) \times 600 \text{ Am}^{-1}$$
$$= 499 \times 600 \text{ Am}^{-1}$$
$$= 2.994 \times 10^5 \text{Am}^{-1}$$
$$\approx 3 \times 10^5 \text{Am}^{-1}$$

24. (b) $\chi_m = \mu_r - 1$

Relationship between magnetic susceptibility χ_m and relative permeability μ_r is $\mu_r = 1 + \chi_m$ or $\chi_m = \mu_r - 1$.

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

26. (b) As we know every atom of a magnet acts as a 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.

TiP

Poles of a magnet always exist in pair.

27. (a) Water is a diamagnetic substance. The relative permeability of water is less than 1.

Therefore, the magnetic field intensity decreases in water.

28. (c) For a perfectly diamagnetic substance,

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

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

Therefore relative permeability,

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

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

i.e., for a perfect diamagnetic material, permeability is zero.

29. the right hand thumb

30. South pole to North pole

31. closed

32. inversely

33. attracted

34. repelled

35. diamagnetic

36. diamagnetic

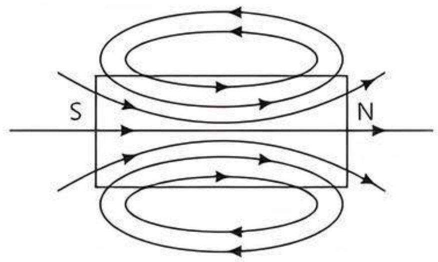
37. retentivity

Case Study Based Questions

Case Study 1

By analogy to Gauss's law of electrostatics, we can write Gauss's law of magnetism as $\oint \vec{B} \cdot d\vec{S} = \mu_0 m_{\text{inside}}$, where $\oint \vec{B} \cdot d\vec{S}$ is the magnetic flux and m_{inside} is the net pole strength inside the closed surface.

We do not have an isolated magnetic pole in nature. At least one has been found to exist till date. The smallest unit of the source of magnetic field is a magnetic dipole, where the net magnetic pole is zero. Hence, the net magnetic pole enclosed by any closed surface is always zero. Correspondingly, the flux of the magnetic field through any closed surface is zero.



Read the given passage carefully and give the answer of the following questions:

Q 1. Consider the two idealised systems:

(i) A parallel plate capacitor with large plates and small separation.

(ii) A long solenoid of length $L >> R$ radius of cross-section.

In (i), $\vec{E}$ is ideally treated as a constant between plates and zero outside. In (ii), magnetic field is constant inside the solenoid and zero outside. These idealised assumptions, however, contradict fundamental laws as below:

a. Case (i) contradicts Gauss's law for electrostatic fields.

b. Case (ii) contradicts Gauss's law for magnetic fields.

c. Case (i) agrees with $\oint \vec{E} \cdot d\vec{l} = 0$.

d. Case (ii) contradicts $\oint \vec{E} \cdot d\vec{l} = I_{en}$.

Q 2. The net magnetic flux through any closed surface, kept in a magnetic field is:

a. zero b. $\frac{\mu_0}{4\pi}$ c. $4\pi\mu_0$ d. $\frac{4\mu_0}{\pi}$

Q 3. A closed surface S encloses a magnetic dipole of magnetic moment $2ml$. The magnetic flux emerging from the surface is:

a. $\mu_0 m$ b. zero c. $2\mu_0 m$ d. $\frac{2m}{\mu_0}$

Q 4. Which of the following is not a consequence of Gauss's law?

a. The magnetic poles always exist as unlike pairs of equal strength
b. If several magnetic lines of force enter in a closed surface, then an equal number of lines of force must leave that surface
c. There are abundant sources or sinks of the magnetic field inside a closed surface
d. Isolated magnetic poles do not exist

Q 5. The surface integral of a magnetic field over a surface:

a. is proportional to mass enclosed
b. is proportional to charge enclosed
c. is zero
d. equal to its magnetic flux through that surface

Answers

1. (b) Case (ii) contradicts Gauss's law for magnetic fields.

   According to Gauss's law in magnetism $\oint \vec{B} \cdot d\vec{S} = 0$

   which implies that number of magnetic field lines entering the Gaussian surface is equal to the number of magnetic field lines leaving it. Therefore, Case (ii) is not possible.

2. (a) zero

   The net magnetic flux through a closed surface will be zero, *i.e.*, $\oint \vec{B} \cdot d\vec{S} = 0$ because there are no magnetic monopoles.

3. (b) zero

   According to Gauss's law in magnetism, net magnetic flux through any closed surface is always zero.

4. (c) There are abundant sources or sinks of the magnetic field inside a closed surface.

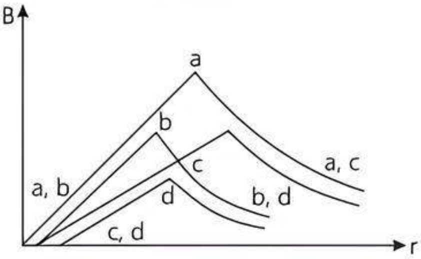
   Gauss' law indicates that there are no sources or sinks of the magnetic field inside a closed surface. In other words, there are no free magnetic charges

5. (d) equal to its magnetic flux through that surface.

   The surface integral of a magnetic field over a surface gives magnetic flux through that surface.

Case Study 2

The field of a hollow wire with constant current is homogeneous. Curves in the graph shown give, as functions of radius distance r, the magnitude B of the magnetic field inside and outside four long wires a, b, c and d carrying currents that are uniformly distributed across the cross-sections of the wires. Overlapping portions of the plots are indicated by double labels.



Read the given passage carefully and give the answer of the following questions:

Q 1. Which wire has the greatest magnitude of the magnetic field on the surface?

Q 2. What is the current density in a wire a ?

Q 3. Which wire has the greatest radius?

Q 4. A direct current I flows along the length of an infinitely long straight thin walled pipe, then what is the magnetic field?

Answers

1. It can be seen that slope of curve for wire a is greater than wire c.
2. Inside the wire,

   $$B(r) = \frac{\mu_0}{2\pi} \cdot \frac{I}{R^2} r \Rightarrow \frac{dB}{dr} = \frac{\mu_0}{2\pi} \cdot \frac{I}{R^2} r$$

   i.e., Slope $\propto \frac{I}{\pi R^2} \propto$ Current density

   So, current density in a wire a is less than in wire c.
3. Wire c has the greatest radius.
4. If a direct current I flows along the length of an infinitely long straight thin walled pipe, then the magnetic field is zero at any point inside the pipe.

Very Short Answer Type Questions

Q 1. Define magnetic dipole moment.

Ans. Magnetic dipole moment is the product of strength of either pole (m) and the magnetic length ($2l$) of the magnet.

i.e., $\vec{M} = m \times 2l$

Q 2. What is the magnitude of the equatorial and axial fields due to a bar magnet of length 5.0 cm at a distance of 50 cm from its mid-point? The magnetic moment of the bar magnet is 0.40 A-m^2.

Ans. $\because B_E = \frac{\mu_0 M}{4\pi r^3} = \frac{10^{-7} \times 0.4}{(0.5)^3} = \frac{10^{-7} \times 0.4}{0.125} = 3.2 \times 10^{-7}$ T

and $B_A = \frac{\mu_0 2M}{4\pi r^3} = 6.4 \times 10^{-7}$ T

Q 3. In what way is the behaviour of a diamagnetic material different from that of a paramagnetic material, when kept in an external magnetic field?

(CBSE 2016)

Ans. When paramagnetic materials are placed in external magnetic field, these are feebly magnetised in the direction of the applied external magnetic field whereas in case of diamagnetic materials, these are feebly magnetised opposite to that of applied external magnetic field.

Q 4. The magnetic susceptibility of magnesium at 300 K is 1.2×10^5. At what temperature will its magnetic susceptibility become 1.44×10^5? *(CBSE 2019)*

Sol. The susceptibility of magnetic material is inversely proportional to temperature,

i.e.,
$$\chi_m \propto \frac{1}{T}$$
$$T_1 = 300K$$
$$\chi_1 = 1.2 \times 10^5$$
and
$$\chi_2 = 1.44 \times 10^5$$
$$\therefore \frac{\chi_1}{\chi_2} = \frac{T_2}{T_1}$$
$$\Rightarrow T_2 = \frac{300 \times 1.2 \times 10^5}{1.44 \times 10^5} = 250 \text{ K}$$

Q 5. The magnetic susceptibility χ of a given material is − 0.5. Identify the magnetic material. *(CBSE 2019)*

Ans. Substance having small or negative value (−0.5) of magnetic susceptibility χ is diamagnetic.

Q 6. Relative permeability of a material $\mu_r = 0.5$. Identify the nature of the magnetic material and write its relation of magnetic susceptibility.

Ans. The nature of magnetic material is a diamagnetic. The relation between relative permeability and magnetic susceptibility is

$$\mu_r = 1 + \chi_m$$

Q 7. The permeability of a magnetic material is 0.9983. Name the type of magnetic material, it represents.

Ans. The magnetic material is diamagnetic substance for which $\mu_r < 1$.

Q 8. What is the characteristic property of a diamagnetic material?

Ans. Diamagnetic material acquires feeble magnetisation in the opposite direction of the magnetic field when they are placed in an external magnetic field.

Short Answer Type-I Questions

Q 1. The relative magnetic permeability of a magnetic material is 800. Identify the nature of magnetic material and state its two properties.

Ans. The substance is ferromagnetic substance have very high magnetic permeability.

Properties (i) High retentivity

(ii) High susceptibility $(\chi_m > 1000)$

Q 2. Explain the following:

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

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

Ans. (i) Magnetic lines of force come out from North pole and enter into the South pole outside the magnet and travels from South pole to North pole inside the magnet. So, magnetic lines of force form closed loop, magnetic monopoles do not exist.

(ii) The diamagnetic material gets slightly magnetised in a direction opposite to external field, therefore lines of force are repelled by diamagnetic material.

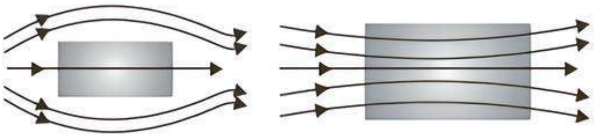
Q 3. (i) How does a diamagnetic material behave when it is cooled at very low temperature?

(ii) Why does a paramagnetic sample display greater magnetisation when cooled? Explain.

Ans. (i) For diamagnetic substances, the variation of susceptibility is very small $(0 < \chi_m < \varepsilon)$. i.e. diamagnetic materials are unaffected by the change in temperature (except bismuth).

(ii) Paramagnetic materials when cooled due to thermal agitation, the tendency to alignment of magnetic dipoles decreases. Hence, they shows greater magnetisation.

Q 4. A uniform magnetic field gets modified as shown in figure when two specimens A and B are placed in it.



(a) (b)

(i) Identify the specimen A and B.

(ii) How is the magnetic susceptibility of specimen A different from that of specimen B?

(CBSE SQP 2022-23)

Ans. (i) A − diamagnetic
D − paramagnetic

(ii) The magnetic susceptibility of specimen A is small negative and that of specimen B is small positive.

Q 5. Write any two points of difference between a diamagnetic and a paramagnetic substances. *(CBSE 2023)*

Ans. Difference between paramagnetic and diamagnetic substances:

S. No.	Paramagnetic Substance	Diamagnetic Substance
1.	A paramagnetic substance is feebly attracted by magnet.	A diamagnetic substance is feebly repelled by a magnet.
2.	For a paramagnetic substance, the intensity of magnetisation has a small positive value.	For a diamagnetic substance, the intensity of magnetism has a small negative value.

Short Answer Type-II Questions

Q 1. A bar magnet of magnetic moment 6 J/T is aligned at 60° with a uniform external magnetic field of 0.44 T. Calculate:
(i) the work done in turning the magnet to align its magnetic moment (a) normal to the magnetic field, (b) opposite to the magnetic field.
(ii) the torque on the magnet in the final orientation in case (b). *(CBSE 2018)*

Ans. (i) Given, magnetic moment, $M = 6$ J/T

Aligned angle, $\theta_1 = 60°$

External magnetic field, $B = 0.44$ T

(a) When the bar magnet is align normal to the magnetic field, *i.e.*, $\theta_2 = 90°$

∴ Amount of work done in turning the magnet,

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

$= -6 \times 0.44(\cos 90° - \cos 60°)$

$= -6 \times 0.44(0 - 1/2)$

$= 6 \times 0.44 \times 1/2$

$= 1.32$ J

TiP

Make a note of formula for amount of work done in turning the magnet.

(b) When the bar magnet align opposite to the magnetic field. *i.e.*, $\theta_2 = 180°$

∴ Amount of work done in turning the magnet,

$W = -MB(\cos 180° - \cos 60°)$

$= -6 \times 0.44(-1 - 1/2)$

$= 6 \times 0.44 \times 3/2 = 3.96$ J

(ii) We know that,

Torque, $\tau = \vec{M} \times \vec{B} = MB\sin\theta$

For case (b), $\theta = 180°$

∴ $\tau = MB\sin 180° = 0$

Thus, amount of torque is zero for case (b).

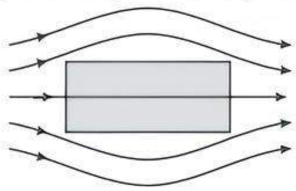
Q 2. Write three points of differences between paramagnetic, diamagnetic and ferromagnetic materials, giving one example for each. *(CBSE 2019)*

Ans. Difference between Paramagnetic, Diamagnetic and Ferromagnetic materials

S. No.	Basis of Difference	Paramagnetic	Diamagnetic	Ferromagnetic
1.	When placed in a uniform magnetic field	Feebly magnetised along applied field	Feebly magnetised opposite to magnetic field	Strongly magnetised along magnetic field
2.	When placed in a non-uniform magnetic field	Tends to move from weaker to stronger magnetic field	Tends to move from stronger to weaker magnetic field	Tends to move quickly from weaker to stronger magnetic field
3.	Effect of temperature	$\chi_m \propto \frac{1}{T}$	Independent with temperature	$\chi_m \propto \frac{1}{T - T_c}$ $(T > T_c)$
4.	Example	Lead	Sodium	Nickel

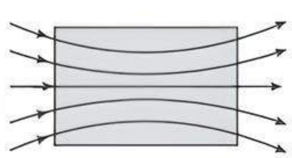
Q 3. Draw the magnetic field lines distinguishing between diamagnetic and paramagnetic materials. Give a simple explanation to account for the difference in the magnetic behaviour of these materials. *(CBSE 2017, 16, 15)*

Ans. Explanation: (i) When a diamagnetic material is placed in an external magnetic field, atoms acquire net magnetic moment opposite to field, and material acquires a slight magnetism in the opposite direction of field. Hence, magnetic field lines are repelled or expelled.



(i) Diamagnetic

(ii) When a paramagnetic material is placed in an external magnetic field, atomic magnets align themselves along the field direction and material acquires a slight magnetism in the direction of field. Hence, magnetic field lines are attracted.



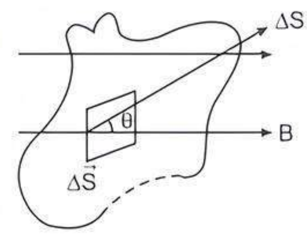
(ii) Paramagnetic

Q 4. (i) State Gauss's law for magnetism. Explain its significance.
(ii) Write the four important properties of the magnetic field lines due to a bar magnet. *(CBSE 2019)*

Ans. (i) **Gauss's law for magnetism:** The net magnetic flux (ϕ_B) through any closed surface is always zero.

$\phi_B = \Sigma \vec{B} \cdot \Delta\vec{S} = 0 = \oint_s B \cdot \Delta S = 0$

Significance: This law suggests that the number of magnetic field lines leaving any closed surface is always equal to the number of magnetic field lines entering it.



(ii) The important properties of the magnetic field lines due to a bar magnet are given below:

(a) These lines form continuous closed loops.

(b) The tangent to the field line at a particular point gives the direction of the field at that point.

(c) Larger the density of the lines, stronger will be the magnetic field.

(d) These lines do not intersect one another.

Q 5. (i) An iron ring of relative permeability μ_r has windings of insulated copper wire of n turns per metre. When the current in the windings is I, find the expression for the magnetic field in the ring.

(ii) The susceptibility of a magnetic material is 0.9853. Identify the type of magnetic material. Draw the modification of the field pattern on keeping a piece of this material in a uniform magnetic field. *(CBSE 2018)*

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

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \mu_r I_{enclosed} \quad ...(1)$$

For the field inside the ring, we can write

$$\oint \vec{B} \cdot d\vec{l} = \oint B \cdot dl = B \cdot 2\pi r$$

where, r is the radius of ring.

Also, $I_{enclosed} = (2\pi r n) I$ ($\because$ using eq. (1))

$\therefore$ $B \cdot 2\pi r = \mu_0 \mu_r (n \cdot 2\pi r) I$

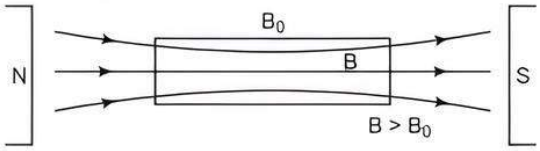
$\therefore$ $B = \mu_0 \mu_r n I$

(ii) Given, susceptibility, $\chi_m = 0.9853$

As the susceptibility of material is positive but small.

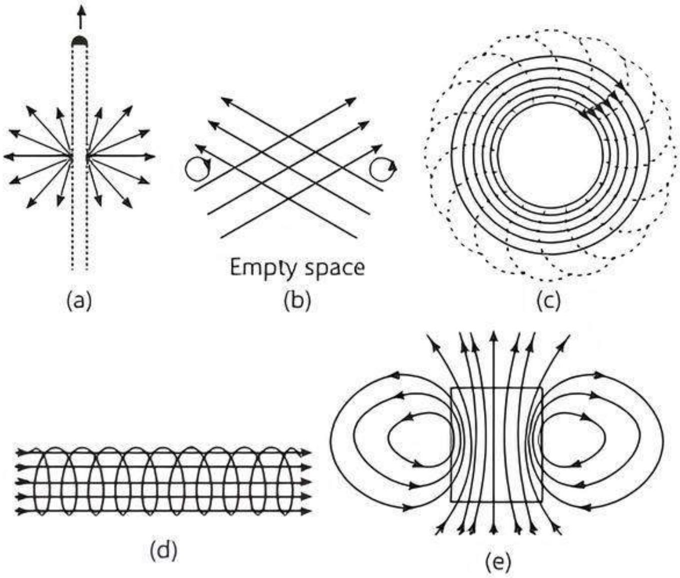
$\therefore$ The material is paramagnetic in nature. For paramagnetic material, magnetic lines of external magnetic field will passes through the material without much deviation, when it is placed in between magnetic poles.

The modification of the field pattern is shown in the following figure:



Long Answer Type Questions

Q 1. The following diagrams (see figures) show magnetic field lines (thick lines in the figure) wrongly. Point out what is wrong with them. Some of them may describe electrostatic field lines correctly. Point out which ones.



Ans. (a) Wrong. Magnetic field lines can never emanate from a point as shown in figure. Over any closed surface, the net flux of $\vec{B}$ must always be zero, *i.e.*, pictorially as many field lines should seem to enter the surface as the number of lines leaving it. The field lines shown, in fact, represent electric field of a long positively charged wire. The correct magnetic field lines are circling the straight conductor.

(b) Wrong. Magnetic field lines (like electric field lines) can never cross each other, because otherwise the direction of field at the point of intersection is ambiguous. There is further error in the figure. Magnetostatic field lines can never form closed loops around empty space. A closed loop of at static magnetic field line must enclose a region across which a current is passing. By contrast, electrostatic field lines can never form closed loops neither in empty space nor when the loop encloses charges.

(c) Right. Magnetic lines are completely confined within a toroid. Nothing wrong here in field lines forming closed loops, since each loop encloses a region across which a current passes. Note, for clarity of figure, only a few field lines within the toroid have been shown. Actually, the entire region enclosed by the windings contains magnetic field.

(d) Wrong. Field lines due to a solenoid at its ends and outside cannot be so completely straight and confined; such a thing violates Ampere's law. The lines should curve out at both ends and meet eventually to form closed loops.

(e) Right. These are field lines outside and inside a bar magnet. Note carefully the direction of field lines inside. Not all field lines emanate out of a North pole (or converge into a South pole). Around both the N-pole and the S-pole, the net flux of the field is zero.

Q 2. **(i) What happens if a bar magnet is cut into two pieces: (a) transverse to its length, (b) along its length?**

(ii) A magnetised needle in a uniform magnetic field experiences a torque but no net force. An iron nail near a bar magnet, however, experiences a force of attraction addition to a torque. Why?

(iii) Must every magnetic configuration have a North pole and a South pole? What about the field due to a toroid?

(iv) Two identical looking iron bars *A* and *B* are given, one of which is definitely known to be magnetised. (We do not know which one). [How would one ascertain whether or not both are magnetised? If only one is magnetised, how does one ascertain which one? Use nothing else but the bars *A* and *B*.]

Ans. (i) In either case, one gets two magnets each with a North and South pole.

(ii) No force if the field is uniform. The iron nail experiences a non-uniform field due to the bar magnet. There is induced magnetic moment in the nail. Therefore it experiences both force and torque. The net force is attractive because the induced South pole (say) in the nail is closer to the North pole of magnet than induced North pole.

(iii) Not necessarily. True only if the source of the field has a net non-zero magnetic moment. This is not so for a toroid or even for a straight infinite conductor.

(iv) Try to bring different ends of the bars closer *A* repulsive force in some situation establishes that both are magnetised. If it is always attractive, then one of them is not magnetised. In a bar magnet, the intensity of the magnetic field is the strongest at the two ends (poles) and weakest at the central region. This fact may be used to determine whether *A* or *B* is the magnet. In this case, to see which one of the two bars is a magnet, pick up one, (say, *A*) and lower one of its ends; first on one of the ends of the other (say *B*) and then on the middle of B. If you notice that in the middle of *B*, *A* experiences no force, then *B* is magnetised. If you do not notice any change from the end to the middle of *B*, then *A* is magnetised.

Chapter Test

Multiple Choice Questions

Q 1. A uniform horizontal magnetic field of 7.5×10^{-2} T is set up at an angle of 30° with the axis of an solenoid and the magnetic moment associated with it is 1.28 JT^{-1}. Then, the torque on it is:

a. 4.8×10^{-2} Nm
b. 1.6×10^{-2} Nm
c. 1.2×10^{-2} Nm
d. 4.8×10^{-4} Nm

Q 2. The area of *B-H* loop for soft iron, as compared to that for steel is:

a. more
b. less
c. equal
d. zero

Assertion and Reason Type Questions

Directions (Q.Nos. 3-4): *In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) and Reason (R) are false.

Q 3. Assertion (A): The poles of magnet cannot be separated by breaking into two pieces.

Reason (R): The magnetic moment will be reduced to half when a magnet is broken into two equal pieces.

Q 4. Assertion (A): In water, value of magnetic field decreases.

Reason (R): Water is a diamagnetic substance.

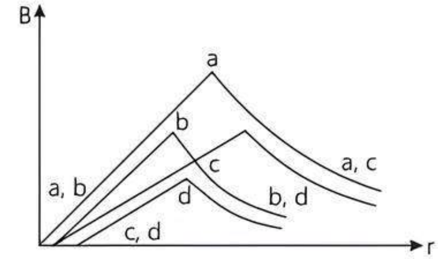
Fill in the blanks

Q 5. The ferromagnetic property depends on ....

Q 6. Substances which at room temperature retain their ferromagnetic property for a long period of time are called .... magnets.

Case Study Based Question

Q 7. The field of a hollow wire with constant current is homogeneous. Curves in the graph shown give, as functions of radius distance r, the magnitude B of the magnetic field inside and outside four long wires a, b, c and d carrying currents that are uniformly distributed across the cross-sections of the wires. Overlapping portions of the plots are indicated by double labels.



Read the given passage carefully and give the answer of the following questions:

(i) Which wire has the greatest magnitude of the magnetic field on the surface?

(ii) What is the current density in a wire *a*?

(iii) Which wire has the greatest radius?

(iv) A direct current *I* flows along the length of an infinitely long straight thin walled pipe, then what is the magnetic field?

Very Short Answer Type Questions

Q 8. If a solenoid is having magnetic moment of $0.65 JT^{-1}$ is free to turn about the vertical direction and has a uniform horizontal magnetic field of 0.25T applied. What is the magnitude of the torque on the solenoid when its axis makes an angle of 30° with the direction of applied field?

Q 9. What is the characteristic property of a diamagnetic material?

Q 10. The relative permeability of iron is 6200. Calculate its magnetic susceptibility.

Short Answer Type-I Questions

Q 11. What do you mean by:

(i) bar magnet?

(ii) magnetic field due to a magnetic dipole?

Q 12. A solenoid has core of a material with relative permeability of 500. The windings of the solenoid are insulated from the core and carry a current of 2 A. If the number of turns is 1000 per metre, then what will be the magnetisation?

Short Answer Type-II Questions

Q 13. (i) Explain torque on a bar magnet in a uniform magnetic field.

(ii) A circular coil of 25 turns and radius of 12 cm is placed in a uniform magnetic field of 0.5 T normal to the plane of coil. If the current in the coil is 5A, then what will be the total torque experienced by the coil?

Q 14. A solenoid has a core of a material with relative permeability 400. The windings of the solenoid are insulated from the core and carry a current of 2A. If the number of turns is 1000 per metre, calculate (i) *H*, (ii) *M*, (iii) *B* and (iv) the magnetising current I_m.

Long Answer Type Questions

Q 15. Explain the term magnetic dipole moment. Derive an expression for magnetic field intensity due to magnetic dipole (i) at a point on its axis and (ii) at a point on its equator.

Q 16. (i) Magnetic field lines show the direction (at every point) along which a small magnetised needle aligns (at the point). Do the magnetic field lines also represent the lines of force on a moving charged particle at every point?

(ii) Magnetic field lines can be entirely confined within the core of a toroid, but not within a straight solenoid. Why?

(iii) If magnetic monopoles existed, how would the Gauss's law of magnetism be modified?

(iv) Does a bar magnet exert a torque on itself due to its own field? Does one element of a current-carrying wire exert a force on another element of the same wire?