magnetic intensity is

$$H = H_n + H_s$$

$$= 159\cdot2 \text{ A/m towards the south pole.}$$

(c) The magnetic field $\vec{B}$ at the centre is

$$\vec{B} = \mu_0(\vec{H} + \vec{I})$$

or, $$B = \left(4\pi \times 10^{-7} \frac{\text{T-m}}{\text{A}}\right)(4 \times 10^{4} - 159\cdot2)\frac{\text{A}}{\text{m}}$$

$$= 5\cdot0 \times 10^{-2} \text{ T}$$

The field is towards the north pole.

5. *The maximum value of the permeability of μ-metal (77% Ni, 16% Fe, 5% Cu, 2% Cr) is 0·126 T–m/A. Find the maximum relative permeability and susceptibility.*

Solution : Relative permeability is

$$\mu_r = \frac{\mu}{\mu_0} = \frac{0\cdot126 \text{ T-m/A}}{4\pi \times 10^{-7} \text{ T-m/A}}$$

$$= 1\cdot00 \times 10^{5}.$$

Susceptibility $\chi = \mu_r - 1 \approx 1\cdot00 \times 10^{5}$.

6. *A toroid has a mean radius R equal to 20/π cm, and a total of 400 turns of wire carrying a current of 2·0 A. An aluminium ring at temperature 280 K inside the toroid provides the core. (a) If the magnetization I is* $4\cdot8 \times 10^{-2}$ A/m, *find the susceptibility of aluminium at* 280 K. *(b) If the temperature of the aluminium ring is raised to 320 K, what will be the magnetization?*

Solution : (a) The number of turns per unit length of the toroid is

$$n = \frac{400}{2\pi R}.$$

The magnetic intensity H in the core is

$$H = ni$$

$$= \frac{400 \times 2\cdot0 \text{ A}}{2\pi \times \frac{20}{\pi} \times 10^{-2} \text{ m}} = 2000 \text{ A/m}.$$

The susceptibility is

$$\chi = I/H$$

$$= \frac{4\cdot8 \times 10^{-2} \text{ A/m}}{2000 \text{ A/m}} = 2\cdot4 \times 10^{-5}.$$

(b) The susceptibility χ of a paramagnetic substance varies with absolute temperature as $\chi = c/T$.

Thus, $\chi_2/\chi_1 = T_1/T_2.$

The susceptibility of aluminium at temperature 320 K is, therefore,

$$\chi = \frac{280}{320} \times 2\cdot4 \times 10^{-5} = 2\cdot1 \times 10^{-5}.$$

Thus, the magnetization at 320 K is

$$I = \chi H$$

$$= 2\cdot1 \times 10^{-5} \times 2000 \text{ A/m}.$$

$$= 4\cdot2 \times 10^{-2} \text{ A/m}.$$

□

QUESTIONS FOR SHORT ANSWER

1. When a dielectric is placed in an electric field, it gets polarized. The electric field in a polarized material is less than the applied field. When a paramagnetic substance is kept in a magnetic field, the field in the substance is more than the applied field. Explain the reason of this opposite behaviour.
2. The property of diamagnetism is said to be present in all materials. Then, why are some materials paramagnetic or ferromagnetic?
3. Do permeability and relative permeability have the same dimensions?
4. A rod when suspended in a magnetic field stays in east-west direction. Can we be sure that the field is in the east-west direction? Can it be in the north-south direction?
5. Why cannot we make permanent magnets from paramagnetic materials?
6. Can we have magnetic hysteresis in paramagnetic or diamagnetic substances?
7. When a ferromagnetic material goes through a hysteresis loop, its thermal energy is increased. Where does this energy come from?
8. What are the advantages of using soft iron as a core, instead of steel, in the coils of galvanometers?
9. To keep valuable instruments away from the earth's magnetic field, they are enclosed in iron boxes. Explain.

OBJECTIVE I

1. A paramagnetic material is placed in a magnetic field. Consider the following statements:

(A) If the magnetic field is increased, the magnetization is increased.

(B) If the temperature is increased, the magnetization is increased.
(a) Both A and B are true.
(b) A is true but B is false.
(c) B is true but A is false.
(d) Both A and B are false.

2. A paramagnetic material is kept in a magnetic field. The field is increased till the magnetization becomes constant. If the temperature is now decreased, the magnetization
(a) will increase (b) decrease
(c) remain constant (d) may increase or decrease.

3. A ferromagnetic material is placed in an external magnetic field. The magnetic domains
(a) increase in size (b) decrease in size
(c) may increase or decrease in size
(d) have no relation with the field.

4. A long, straight wire carries a current i. The magnetizing field intensity H is measured at a point P close to the wire. A long, cylindrical iron rod is brought close to the wire so that the point P is at the centre of the rod. The value of H at P will
(a) increase many times (b) decrease many times
(c) remain almost constant (d) become zero.

5. The magnetic susceptibility is negative for
(a) paramagnetic materials only
(b) diamagnetic materials only
(c) ferromagnetic materials only
(d) paramagnetic and ferromagnetic materials.

6. The desirable properties for making permanent magnets are
(a) high retentivity and high coercive force
(b) high retentivity and low coercive force
(c) low retentivity and high coercive force
(d) low retentivity and low coercive force.

7. Electromagnets are made of soft iron because soft iron has
(a) high retentivity and high coercive force
(b) high retentivity and low coercive force
(c) low retentivity and high coercive force
(d) low retentivity and low coercive force.

OBJECTIVE II

1. Pick the correct options.
(a) All electrons have magnetic moment.
(b) All protons have magnetic moment.
(c) All nuclei have magnetic moment.
(d) All atoms have magnetic moment.

2. The permanent magnetic moment of the atoms of a material is not zero. The material
(a) must be paramagnetic (b) must be diamagnetic
(c) must be ferromagnetic (d) may be paramagnetic.

3. The permanent magnetic moment of the atoms of a material is zero. The material
(a) must be paramagnetic (b) must be diamagnetic
(c) must be ferromagnetic (d) may be paramagnetic.

4. Which of the following pairs has quantities of the same dimensions?
(a) magnetic field B and magnetizing field intensity H
(b) magnetic field B and intensity of magnetization I
(c) magnetizing field intensity H and intensity of magnetization I
(d) longitudinal strain and magnetic susceptibility.

5. When a ferromagnetic material goes through a hysteresis loop, the magnetic susceptibility
(a) has a fixed value (b) may be zero
(c) may be infinity (d) may be negative.

6. Mark out the correct options.
(a) Diamagnetism occurs in all materials.
(b) Diamagnetism results from the partial alignment of permanent magnetic moment.
(c) The magnetizing field intensity H is always zero in free space.
(d) The magnetic field of induced magnetic moment is opposite to the applied field.

EXERCISES

1. The magnetic intensity H at the centre of a long solenoid carrying a current of 2·0 A, is found to be 1500 A/m. Find the number of turns per centimetre of the solenoid.

2. A rod is inserted as the core in the current-carrying solenoid of the previous problem. (a) What is the magnetic intensity H at the centre? (b) If the magnetization I of the core is found to be 0·12 A/m, find the susceptibility of the material of the rod. (c) Is the material paramagnetic, diamagnetic or ferromagnetic?

3. The magnetic field inside a long solenoid having 50 turns/cm is increased from $2·5 \times 10^{-3}$ T to 2·5 T when an iron core of cross-sectional area 4 cm^2 is inserted into it. Find (a) the current in the solenoid, (b) the magnetization I of the core and (c) the pole strength developed in the core.

4. A bar magnet of length 1 cm and cross-sectional area 1·0 cm^2 produces a magnetic field of $1·5 \times 10^{-4}$ T at a point in end-on position at a distance 15 cm away from the centre. (a) Find the magnetic moment M of the magnet. (b) Find the magnetization I of the magnet. (c) Find the magnetic field B at the centre of the magnet.

5. The susceptibility of annealed iron at saturation is 5500. Find the permeability of annealed iron at saturation.

6. The magnetic field B and the magnetic intensity H in a material are found to be 1·6 T and 1000 A/m

respectively. Calculate the relative permeability μ_r and the susceptibility χ of the material.

7. The susceptibility of magnesium at 300 K is $1{\cdot}2 \times 10^{-5}$. At what temperature will the susceptibility increase to $1{\cdot}8 \times 10^{-5}$?

8. Assume that each iron atom has a permanent magnetic moment equal to 2 Bohr magnetons (1 Bohr magneton equals $9{\cdot}27 \times 10^{-24}$ A–m^2). The density of atoms in iron is $8{\cdot}52 \times 10^{28}$ atoms/m^3. (a) Find the maximum magnetization I in a long cylinder of iron. (b) Find the maximum magnetic field B on the axis inside the cylinder.

9. The coercive force for a certain permanent magnet is $4{\cdot}0 \times 10^4$ A/m. This magnet is placed inside a long solenoid of 40 turns/cm and a current is passed in the solenoid to demagnetise it completely. Find the current.

□

ANSWERS

OBJECTIVE I

1. (b) 2. (c) 3. (c) 4. (c) 5. (b) 6. (a)
7. (d)

OBJECTIVE II

1. (a), (b) 2. (d) 3. (b) 4. (c), (d)
5. (b), (c), (d) 6. (a), (d)

EXERCISES

1. 7·5
2. (a) 1500 A/m (b) $8{\cdot}0 \times 10^{-5}$ (c) paramagnetic
3. (a) 0·4 A (b) $2{\cdot}0 \times 10^{6}$ A/m (c) 800 A–m
4. (a) $2{\cdot}5$ A–m^2 (b) $2{\cdot}5 \times 10^{6}$ A/m (c) 1·2 T
5. $6{\cdot}9 \times 10^{-3}$
6. $1{\cdot}3 \times 10^{3}$ each
7. 200 K
8. (a) $1{\cdot}58 \times 10^{6}$ A/m (b) 2·0 T
9. 10 A

□

CHAPTER – 37
MAGNETIC PROPERTIES OF MATTER

1. $B = \mu_0 ni$, $H = \frac{B}{\mu_0}$

$\Rightarrow$ H = ni

$\Rightarrow$ 1500 A/m = n× 2

$\Rightarrow$ n = 750 turns/meter

$\Rightarrow$ n = 7.5 turns/cm

2. (a) H = 1500 A/m

As the solenoid and the rod are long and we are interested in the magnetic intensity at the centre, the end effects may be neglected. There is no effect of the rod on the magnetic intensity at the centre.

(b) I = 0.12 A/m

We know $\vec{I} = X\vec{H}$ X = Susceptibility

$\Rightarrow X = \frac{I}{H} = \frac{0.12}{1500} = 0.00008 = 8 \times 10^{-5}$

(c) The material is paramagnetic

3. $B_1 = 2.5 \times 10^{-3}$, $B_2 = 2.5$

$A = 4 \times 10^{-4}\ m^2$, n = 50 turns/cm = 5000 turns/m

(a) $B = \mu_0 ni$,

$\Rightarrow 2.5 \times 10^{-3} = 4\pi \times 10^{-7} \times 5000 \times i$

$\Rightarrow i = \frac{2.5 \times 10^{-3}}{4\pi \times 10^{-7} \times 5000} = 0.398\ A \approx 0.4\ A$

(b) $I = \frac{B_2}{\mu_0} - H = \frac{2.5}{4\pi \times 10^{-7}} - (B_2 - B_1) = \frac{2.5}{4\pi \times 10^{-7}} - 2.497 = 1.99 \times 10^6 \approx 2 \times 10^6$

(c) $I = \frac{M}{V} \Rightarrow I = \frac{m\ell}{A\ell} = \frac{m}{A}$

$\Rightarrow m = IA = 2 \times 10^6 \times 4 \times 10^{-4} = 800$ A-m

4. (a) Given d = 15 cm = 0.15 m

ℓ = 1 cm = 0.01 m

$A = 1.0\ cm^2 = 1 \times 10^{-4}\ m^2$

$B = 1.5 \times 10^{-4}$ T

M = ?

We Know $\vec{B} = \frac{\mu_0}{4\pi} \times \frac{2Md}{(d^2 - \ell^2)^2}$

$\Rightarrow 1.5 \times 10^{-4} = \frac{10^{-7} \times 2 \times M \times 0.15}{(0.0225 - 0.0001)^2} = \frac{3 \times 10^{-8} M}{5.01 \times 10^{-4}}$

$\Rightarrow M = \frac{1.5 \times 10^{-4} \times 5.01 \times 10^{-4}}{3 \times 10^{-8}} = 2.5$ A

(b) Magnetisation $I = \frac{M}{V} = \frac{2.5}{10^{-4} \times 10^{-2}} = 2.5 \times 10^6$ A/m

(c) $H = \frac{m}{4\pi d^2} = \frac{M}{4\pi I d^2} = \frac{2.5}{4 \times 3.14 \times 0.01 \times (0.15)^2}$

net $H = H_N + H_{'} = 2 \times 884.6 = 8.846 \times 10^2$

$\vec{B} = \mu_0 (-H + I) = 4\pi \times 10^{-7} (2.5 \times 10^6 - 2 \times 884.6) \approx 3,14$ T

5. Permiability (μ) = $\mu_0(1 + x)$
   Given susceptibility = 5500
   $\mu = 4 \times 10^{-7} (1 + 5500)$
   $= 4 \times 3.14 \times 10^{-7} \times 5501\ 6909.56 \times 10^{-7} \approx 6.9 \times 10^{-3}$
6. B = 1.6 T, H = 1000 A/m
   μ = Permeability of material
   $\mu = \frac{B}{H} = \frac{1.6}{1000} = 1.6 \times 10^{-3}$
   $\mu r = \frac{\mu}{\mu_0} = \frac{1.6 \times 10^{-3}}{4\pi \times 10^{-7}} = 0.127 \times 10^4 \approx 1.3 \times 10^3$
   $\mu = \mu_0 (1 + x)$
   $\Rightarrow x = \frac{\mu}{\mu_0} - 1$
   $= \mu_r - 1 = 1.3 \times 10^3 - 1 = 1300 - 1 = 1299 \approx 1.3 \times 10^3$
7. $x = \frac{C}{T} = \Rightarrow \frac{x_1}{x_2} = \frac{T_2}{T_1}$
   $\Rightarrow \frac{1.2 \times 10^{-5}}{1.8 \times 10^{-5}} = \frac{T_2}{300}$
   $\Rightarrow T_2 = \frac{12}{18} \times 300 = 200$ K.
8. $f = 8.52 \times 10^{28}$ atoms/m^3
   For maximum 'I', Let us consider the no. of atoms present in 1 m^3 of volume.
   Given: m per atom = $2 \times 9.27 \times 10^{-24}$ A–m^2
   $I = \frac{\text{net } m}{V} = 2 \times 9.27 \times 10^{-24} \times 8.52 \times 10^{28} \approx 1.58 \times 10^6$ A/m
   $B = \mu_0 (H + I) = \mu_0 I$ [$\therefore$ H = 0 in this case]
   $= 4\pi \times 10^{-7} \times 1.58 \times 10^6 = 1.98 \times 10^{-1} \approx 2.0$ T
9. $B = \mu_0 ni$, $H = \frac{B}{\mu_0}$
   Given n = 40 turn/cm = 4000 turns/m
   $\Rightarrow H = ni$
   $H = 4 \times 10^4$ A/m
   $\Rightarrow i = \frac{H}{n} = \frac{4 \times 10^4}{4000} = 10$ A.

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