Exercise Solutions

**Question 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$^{-1}$. Find the number of turns per centimeter of the solenoid.

**Solution:**

Current in the solenoid = $I = 2A$ (given)

Magnetic intensity $H$ at the centre = 1500 A m$^{-1}$ (Given)

We know, Magnetic field produced by solenoid = $B = \mu_0 n i$ ..(1)

Where,
- $i =$ current in the solenoid
- $n =$ number of turns per unit length
- $\mu_0 =$ absolute permeability of vacuum

And, magnetizing field intensity ($H$) in the absence of any material:

$H = B/\mu_0$ ...(2)

Where $B$ is net magnetic field

From (1) and (2),

$H = ni$

$1500 = n \times 2$

$\Rightarrow n = 750$ turns/m or 7.5 turns/cm

Number of turns per cm of the solenoid is 7.5 turn/cm.

**Question 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$^{-1}$, find the susceptibility of the material of the rod.

(c) Is the material paramagnetic, diamagnetic or ferromagnetic?

**Solution:**

(a) Since the magnet and rod are long and we are interested in the magnetic intensity at the center, the end effects can be neglected. There is no effect of the rod on the magnetic intensity in the middle. So, magnetization intensity remains the same.

Therefore, magnetic intensity $H$ at the centre = $H = 1500$ A m$^{-1}$ (using from previous problem as given)
(b) Magnetization of the core = \( I = 0.12 \, \text{Am}^{-1} \)

We know, \( I = \chi H \)

\( \chi = \text{susceptibility of material of the rod.} \)

\( \chi = \frac{0.12}{1500} \)

\( \Rightarrow \chi = 8 \times 10^{-5} \)

(c) The material is paramagnetic.

**Question 3:** The magnetic field inside a long solenoid having 50 turns cm\(^{-1}\) 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.

**Solution:**
Number of turns per cm = 50
Magnetic field inside solenoid with iron core = 2.5 T
Magnetic field inside without iron core = \( 2.5 \times 10^{-3} \) T
Cross-sectional area = 4 cm\(^2\)

Magnetic field inside the solenoid without iron core:

\[ B = \mu_0 n i \]

Or \( i = \frac{B}{\mu_0} \)

\[ i = \frac{2.5 \times 10^{-3}}{4\pi \times 10^{-7} \times 5000} = 0.4 \, \text{A} \]

(b)

\[ I = \frac{B}{\mu_0} - H \]

\[ B = 2.5 \, \text{T} \, \text{(Known)} \]

Where, \( I = \text{Magnetization of the core} \) and \( H = \text{magnetization intensity} \)

The difference between two magnetic fields strengths, say \( B_1 \) and \( B_2 \) is
Question 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} \text{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.

Solution:
(a) Magnetic field at a point in the axis of magnet:
\[
B = \frac{\mu_0}{4\pi} \times \frac{2Md}{(d^2 - l^2)^2}
\]
Substituting given values,
\[
1.5 \times 10^{-4} = \frac{3 \times 10^{-6} \times M}{[5.01 \times 10^{-4}]}
\]
Or \(M = 2.5 \text{ A}\)

(b) Intensity of magnetization:
\[
I = \frac{M}{V} = \frac{2.5}{[10^{-4} \times 10^{-2}]} = 2.5 \times 10^6 \text{ A/m}
\]

(c) We know, \(H = \frac{M}{4\pi l d^2}\)

Total magnetic field intensity (H) is the sum of magnetic field intensities due to north pole and south pole, which are equal in magnitude.
\[ H = \frac{M}{4\pi l d^2} + \frac{M}{4\pi l d^2} = \frac{M}{2\pi l d^2} \]

\[ H = \frac{2.5}{2 \times 3.14 \times 0.01 \times (0.15)^2} \]

\[ \Rightarrow H = 2 \times 884.6 \text{ Am}^{-1} \]

Now net magnetic at the centre B:

\[ B = \mu_0 (H + I) \]

\[ I = \text{Intensity of magnetization} \]

\[ \Rightarrow B = 4\pi \times 10^{-7} \times [(2 \times 884.6) + (2.5 \times 10^6)] = 3.14 \text{ T} \]

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

**Solution:**

Susceptibility of iron at saturation = \( \chi = 5500 \)

We know,

\[ \mu = \mu_0 (1 + \chi) \]

\[ \mu = 4\pi \times 10^{-7} (1 + 5500) = 6.9 \times 10^{-3} \]

\[ \mu = 6.9 \times 10^{-3} \text{ Henry/m} \]

**Question 6:** The magnetic field \( B \) and the magnetic intensity \( H \) in a material are found to be 1.6 T and 1000 A m\(^{-1}\) respectively. Calculate the relative permeability \( \mu_r \) and the susceptibility \( \chi \) of the material.

**Solution:**

Magnetic field in the material = 1.6 T

Magnetic intensity = \( H = 1000 \text{ Am}^{-1} \)

We know, \( \mu = \frac{B}{H} \) and \( \mu_r = \frac{\mu}{\mu_0} \)

\[ \Rightarrow \mu_r = \frac{B}{H\mu_0} = 1.6/[1000 \times 4\pi \times 10^{-7}] = 1.3 \times 10^3 \]

Relation between \( \chi \) and \( \mu_r \) is
μᵣ = 1 + χ

or χ = 1.3 x 10³ − 1 = 1299

or χ = 1.3 x 10³ (approx.)

**Question 7:** The susceptibility of magnesium at 300 K is 1.2 x 10⁻⁵. At what temperature will the susceptibility increase to 1.8 x 10⁻⁵?

**Solution:**

Susceptibility at temperature T₁, χ₁ = 1.2 x 10⁻⁵

Susceptibility at temperature T₂, χ₂ = 1.8 x 10⁻⁵

According to Curie’s law, χ = C/T

We have, χ₁/χ₂ = T₁/T₂

=> [1.2 x 10⁻⁵]/[1.8 x 10⁻⁵] = T₁/300

=> T₂ = 200 K

**Question 8:** Assume that each iron atom has a permanent magnetic moment equal to 2 Bohr magnetons (1 Bohr magneton equals 9.27 x 10⁻²⁴ A m²). The density of atoms in iron is 8.52 x 10²⁸ 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.

**Solution:**

We know, Intensity of magnetization = I = M/V  ...(1)

For 1m³ volume, the number of atoms will be 8.52 x 10²⁸

So, total magnetic moment = M = 8.52 x 10²⁸ x 2 x 9.27 x 10⁻²⁴ Am²

=> M = 1.58 x 10⁶ Am²

(1)=> I = 1.58 x 10⁶ Am⁻¹ : maximum magnetization

Now,

The net magnetic field: B = μ₀(I + H)

Magnetizing field intensity (H) = 0, as we have to find the maximum magnetic field on the axis of cylinder.
So, \( B = \mu_0 I \)

\[
B = 4\pi \times 10^{-7} \times 1.58 \times 10^{-6} = 2 \text{ T (approx.)}
\]

**Question 9:** The coercive force for a certain permanent magnet is \( 4.0 \times 10^4 \text{ A m}^{-1} \). This magnet is placed inside a long solenoid of 40 turns/cm and a current is passed in the solenoid to demagnetize it completely. Find the current.

**Solution:**

Coercive force for magnet = Magnetic intensity = \( H = 4.0 \times 10^4 \text{ Am}^{-1} \)

Number of turns per cm inside solenoid = 40

Number of turns per m inside the solenoid = 4000 turns/m

Magnetic field produced by solenoid at the centre:

\[
B = \mu_0 n I
\]

And magnetizing field intensity in the absence of any material:

\[
H = \frac{B}{\mu_0}
\]

\[
\Rightarrow H = n I \text{ (From above equations)}
\]

Or \( I = \frac{H}{n} = \frac{4 \times 10^4}{4000} = 10 \text{ A} \), which is the required current.