# (Chapter 5)(Magnetism and Matter)

XII

## Additional Exercises

**Question 5.16:**

Answer the following questions:

**(a)** Why does a paramagnetic sample display greater magnetisation (for the same magnetising field) when cooled?

**(b)** Why is diamagnetism, in contrast, almost independent of temperature?

**(c)** If a toroid uses bismuth for its core, will the field in the core be (slightly) greater or (slightly) less than when the core is empty?

**(d)** Is the permeability of a ferromagnetic material independent of the magnetic field? If not, is it more for lower or higher fields?

**(e)** Magnetic field lines are always nearly normal to the surface of a ferromagnet at every point. (This fact is analogous to the static electric field lines being normal to the surface of a conductor at every point.) Why?

**(f)** Would the maximum possible magnetisation of a paramagnetic sample be of the same order of magnitude as the magnetization of a ferromagnet?

**Answer 5.16:**

**(a)** Owing to the random thermal motion of molecules, the alignments of dipoles get disrupted at high temperatures. On cooling, this disruption is reduced. Hence, a paramagnetic sample displays greater magnetisation when cooled.

**(b)** The induced dipole moment in a diamagnetic substance is always opposite to the magnetising field. Hence, the internal motion of the atoms (which is related to the temperature) does not affect the diamagnetism of a material.

**(c)** Bismuth is a diamagnetic substance. Hence, a toroid with a bismuth core has a magnetic field slightly greater than a toroid whose core is empty.

**(d)** The permeability of ferromagnetic materials is not independent of the applied magnetic field. It is greater for a lower field and vice versa.

**(e)** The permeability of a ferromagnetic material is not less than one. It is always greater than one. Hence, magnetic field lines are always nearly normal to the surface of such materials at every point.

**(f)** The maximum possible magnetisation of a paramagnetic sample can be of the same order of magnitude as the magnetisation of a ferromagnet. This requires high magnetising fields for saturation.

**Question 5.17:**

Answer the following questions:

**(a)** Explain qualitatively on the basis of domain picture the irreversibility in the magnetisation curve of a ferromagnet.

**(b)** The hysteresis loop of a soft iron piece has a much smaller area than that of a carbon steel piece. If the material is to go through repeated cycles of magnetisation, which piece will dissipate greater heat energy?

**(c)** 'A system displaying a hysteresis loop such as a ferromagnet, is a device for storing memory?' Explain the meaning of this statement.

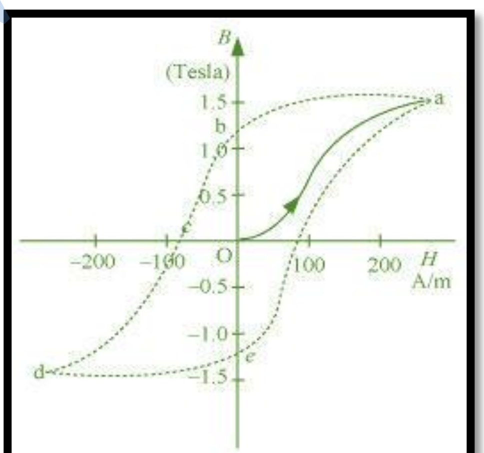
**(d)** What kind of ferromagnetic material is used for coating magnetic tapes in a cassette player, or for building 'memory stores' in a modern computer?

**(e)** A certain region of space is to be shielded from magnetic fields.

Suggest a method.

**Answer 5.17:**

The hysteresis curve (B-H curve) of a ferromagnetic material is shown in the following figure.



**(a)** It can be observed from the given curve that magnetisation persists even when the external field is removed. This reflects the irreversibility of a ferromagnet.

**(b)** The dissipated heat energy is directly proportional to the area of a hysteresis loop. A carbon steel piece has a greater hysteresis curve area. Hence, it dissipates greater heat energy.

**(c)** The value of magnetisation is memory or record of hysteresis loop cycles of magnetisation. These bits of information correspond to the cycle of magnetisation. Hysteresis loops can be used for storing information.

**(d)** Ceramic is used for coating magnetic tapes in cassette players and for building memory stores in modern computers.

**(e)** A certain region of space can be shielded from magnetic fields if it is surrounded by soft iron rings. In such arrangements, the magnetic lines are drawn out of the region.



**Question 5.18:**

A long straight horizontal cable carries a current of 2.5 A in the direction 10º south of west to 10° north of east. The magnetic meridian of the place happens to be 10º west of the geographic meridian. The earth's magnetic field at the location is 0.33 G, and the angle of dip is zero. Locate the line of neutral points (ignore the thickness of the cable). (At neutral points, magnetic field due to a current-carrying cable is equal and opposite to the horizontal component of earth's magnetic field.)

**Answer 5.18:**

Current in the wire, I = 2.5 A

Angle of dip at the given location on earth, $\delta$ = 0°

Earth's magnetic field, H = 0.33 G = 0.33 × $10^{-4}$ T

The horizontal component of earth's magnetic field is given as:

$H_H$ = H cos $\delta$

$= 0.33 \times 10^{-4} \times \cos 0° = 0.33 \times 10^{-4}$ T

The magnetic field at the neutral point at a distance R from the cable is given by the relation:

$$H_H = \frac{\mu_0 I}{2\pi R}$$

Where,

$\mu_0$ = Permeability of free space = $4\pi \times 10^{-7} \mathrm{Tm\,A^{-1}}$

$$\therefore R = \frac{\mu_0 I}{2\pi H_H}$$

$$= \frac{4\pi \times 10^{-7} \times 2.5}{2\pi \times 0.33 \times 10^{-4}} = 15.15 \times 10^{-3} \text{ m} = 1.51 \text{ cm}$$

Hence, a set of neutral points parallel to and above the cable are located at a normal distance of 1.51 cm.

**Question 5.19:**

A telephone cable at a place has four long straight horizontal wires carrying a current of 1.0 A in the same direction east to west. The earth's magnetic field at the place is 0.39 G, and the angle of dip is 35º. The magnetic declination is nearly zero. What are the resultant magnetic fields at points 4.0 cm below the cable?

**Answer 5.19:**

Number of horizontal wires in the telephone cable, n = 4

Current in each wire, I = 1.0 A

Earth's magnetic field at a location, H = 0.39 G = $0.39 \times 10^{-4}$ T

Angle of dip at the location, δ = 35°

Angle of declination, θ ~ 0°

For a point 4 cm below the cable:

Distance, r = 4 cm = 0.04 m

The horizontal component of earth's magnetic field can be written as:

$H_h = H\cos\delta - B$

Where,

B = Magnetic field at 4 cm due to current I in the four wires

$$= 4 \times \frac{\mu_0 I}{2\pi r}$$

$\mu_0$ = Permeability of free space = $4\pi \times 10^{-7}$ Tm $A^{-1}$

$$\therefore B = 4 \times \frac{4\pi \times 10^{-7} \times 1}{2\pi \times 0.04}$$

= $0.2 \times 10^{-4}$ T = 0.2 G

∴ $H_h$ = 0.39 cos 35° − 0.2

= 0.39 × 0.819 − 0.2 ≈ 0.12 G

The vertical component of earth's magnetic field is given as:

$H_v$ = Hsinδ

= 0.39 sin 35° = 0.22 G

The angle made by the field with its horizontal component is given as:

$$\theta = \tan^{-1}\frac{H_v}{H_h}$$

$$= \tan^{-1}\frac{0.22}{0.12} = 61.39°$$

The resultant field at the point is given as:

$$H_1 = \sqrt{(H_v)^2 + (H_h)^2}$$

$$= \sqrt{(0.22)^2 + (0.12)^2} = 0.25 \text{ G}$$

<u>For a point 4 cm above the cable:</u>

Horizontal component of earth's magnetic field:

$H_h$ = Hcosδ + B

= 0.39 cos 35° + 0.2 = 0.52 G

Vertical component of earth's magnetic field:

$H_v$ = Hsinδ

= 0.39 sin 35° = 0.22 G

Angle, θ $= \tan^{-1}\frac{H_v}{H_h} = \tan^{-1}\frac{0.22}{0.52}$ = 22.9°

And resultant field:

$$H_2 = \sqrt{(H_v)^2 + (H_h)^2}$$
$$= \sqrt{(0.22)^2 + (0.52)^2} = 0.56 \text{ T}$$

**Question 5.20:**

A compass needle free to turn in a horizontal plane is placed at the centre of circular coil of 30 turns and radius 12 cm. The coil is in a vertical plane making an angle of 45º with the magnetic meridian. When the current in the coil is 0.35 A, the needle points west to east.

**(a)** Determine the horizontal component of the earth's magnetic field at the location.

**(b)** The current in the coil is reversed, and the coil is rotated about its vertical axis by an angle of 90º in the anticlockwise sense looking from above. Predict the direction of the needle. Take the magnetic declination at the places to be zero.

**Answer 5.20:**

Number of turns in the circular coil, N = 30

Radius of the circular coil, r = 12 cm = 0.12 m

Current in the coil, I = 0.35 A

Angle of dip, $\delta = 45°$

**(a)** The magnetic field due to current I, at a distance r, is given as:

$$B = \frac{\mu_0 2\pi NI}{4\pi r}$$

Where,

$\mu_0$ = Permeability of free space = 4π × 10

$$\therefore B = \frac{4\pi \times 10^{-7} \times 2\pi \times 30 \times 0.35}{4\pi \times 0.12}$$

$= 5.49 \times 10^{-5}$ T

The compass needle points from West to East. Hence, the horizontal component of earth's magnetic field is given as:

$B_H = B\sin\delta$

$= 5.49 \times 10^{-5} \sin 45° = 3.88 \times 10^{-5}$ T = 0.388 G

**(b)** When the current in the coil is reversed and the coil is rotated about its vertical axis by an angle of 90 º, the needle will reverse its original direction. In this case, the needle will point from East to West.

**Question 5.21**:

A magnetic dipole is under the influence of two magnetic fields. The angle between the field directions is 60º, and one of the fields has a magnitude of $1.2 \times 10^{-2}$ T. If the dipole comes to stable equilibrium at an angle of 15º with this field, what is the magnitude of the other field?

**Answer 5.21:**

Magnitude of one of the magnetic fields, $B_1 = 1.2 \times 10^{-2}$ T

Magnitude of the other magnetic field = $B_2$

Angle between the two fields, $\theta = 60°$

At stable equilibrium, the angle between the dipole and field $B_1$, $\theta_1 = 15°$

Angle between the dipole and field $B_2$, $\theta_2 = \theta - \theta_1 = 60° - 15° = 45°$

At rotational equilibrium, the torques between both the fields must balance each other.

$\therefore$ Torque due to field $B_1$ = Torque due to field $B_2$

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

Where,

M = Magnetic moment of the dipole

$$\therefore B_2 = \frac{B_1 \sin\theta_1}{\sin\theta_2}$$

$$= \frac{1.2 \times 10^{-2} \times \sin 15°}{\sin 45°} = 4.39 \times 10^{-3} \text{ T}$$

Hence, the magnitude of the other magnetic field is $4.39 \times 10^{-3}$ T.

**Question 5.22:**

A monoenergetic (18 keV) electron beam initially in the horizontal direction is subjected to a horizontal magnetic field of 0.04 G normal to the initial direction. Estimate the up or down deflection of the beam over a distance of 30 cm ($m_e$= $9.11 \times 10^{-19}$ C). [Note: Data in this exercise are so chosen that the answer will give you an idea of the effect of earth's magnetic field on the motion of the electron beam from the electron gun to the screen in a TV set.]

**Answer 5.22:**

Energy of an electron beam, E = 18 keV = 18 × $10^3$ eV

Charge on an electron, e = 1.6 × $10^{-19}$ C

E = 18 × $10^3$ × 1.6 × $10^{-19}$ J

Magnetic field, B = 0.04 G

Mass of an electron, $m_e$ = 9.11 × $10^{-19}$ kg

Distance up to which the electron beam travels, d = 30 cm = 0.3 m

We can write the kinetic energy of the electron beam as:

$$E = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2E}{m}}$$

$$= \sqrt{\frac{2 \times 18 \times 10^3 \times 1.6 \times 10^{-19} \times 10^{-15}}{9.11 \times 10^{-31}}} = 0.795 \times 10^8 \text{ m/s}$$

The electron beam deflects along a circular path of radius, r.

The force due to the magnetic field balances the centripetal force of the path.

$$BeV = \frac{mv^2}{r}$$

$$\therefore r = \frac{mv}{Be}$$

$$= \frac{9.11 \times 10^{-31} \times 0.795 \times 10^8}{0.4 \times 10^{-4} \times 1.6 \times 10^{-19}} = 11.3 \text{ m}$$

Let the up and down deflection of the electron beam be $x = r(1 - \cos\theta)$

Where, θ = Angle of declination

$$\sin\theta = \frac{d}{r}$$

$$= \frac{0.3}{11.3}$$

$$\theta = \sin^{-1}\frac{0.3}{11.3} = 1.521°$$

$$\text{And } x = 11.3(1 - \cos 1.521°)$$

$$= 0.0039 \text{ m} = 3.9 \text{ mm}$$

Therefore, the up and down deflection of the beam is 3.9 mm.

**Question 5.23:**

A sample of paramagnetic salt contains $2.0 \times 10^{24}$ atomic dipoles each of dipole moment $1.5 \times 10^{-23}$ J T$^{-1}$. The sample is placed under a homogeneous magnetic field of 0.64 T, and cooled to a temperature of 4.2 K. The degree of magnetic saturation achieved is equal to 15%. What is the total dipole moment of the sample for a magnetic field of 0.98 T and a temperature of 2.8 K? (Assume Curie's law)

**Answer 5.23:**

Number of atomic dipoles, $n = 2.0 \times 10^{24}$

Dipole moment of each atomic dipole, $M = 1.5 \times 10^{-23}$ J T$^{-1}$

When the magnetic field, $B_1 = 0.64$ T

The sample is cooled to a temperature, $T_1 = 4.2°$K

Total dipole moment of the atomic dipole, $M_{tot} = n \times M$

$= 2 \times 10^{24} \times 1.5 \times 10^{-23}$

$= 30$ J T$^{-1}$

Magnetic saturation is achieved at 15%.

Hence, effective dipole moment, $M_1 = \frac{15}{100} \times 30 = 4.5 \text{ J T}^{-1}$

When the magnetic field, $B_2 = 0.98$ T

Temperature, $T_2 = 2.8°$K

Its total dipole moment $= M_2$

According to Curie's law, we have the ratio of two magnetic dipoles as:

$$\frac{M_2}{M_1} = \frac{B_2}{B_1} \times \frac{T_1}{T_2}$$

$$\therefore M_2 = \frac{B_2 T_1 M_1}{B_1 T_2}$$

$$= \frac{0.98 \times 4.2 \times 4.5}{2.8 \times 0.64} = 10.336 \text{ J T}^{-1}$$

Therefore, $10.336 \text{ J T}^{-1}$ is the total dipole moment of the sample for a magnetic field of 0.98 T and a temperature of 2.8 K.

**Question 5.24:**

A Rowland ring of mean radius 15 cm has 3500 turns of wire wound on a ferromagnetic core of relative permeability 800. What is the magnetic field B in the core for a magnetising current of 1.2 A?

**Answer 5.24:**

Mean radius of a Rowland ring, r = 15 cm = 0.15 m

Number of turns on a ferromagnetic core, N = 3500

Relative permeability of the core material, $\mu_r = 800$

Magnetising current, I = 1.2 A

The magnetic field is given by the relation:

A $= \dfrac{\mu_r \mu_0 IN}{2\pi r}$

Where,

$\mu_0$ = Permeability of free space = $4\pi \times 10^{-7}$ Tm $A^{-1}$

$$B = \frac{800 \times 4\pi \times 10^{-7} \times 1.2 \times 3500}{2\pi \times 0.15} = 4.48 \text{ T}$$

Therefore, the magnetic field in the core is 4.48 T.

**Question 5.25:**

The magnetic moment vectors $\mu_s$ and $\mu_l$ associated with the intrinsic spin angular momentum S and orbital angular momentum l, respectively, of an electron are predicted by quantum theory (and verified experimentally to a high accuracy) to be given by:

$\mu_s = -(e/m)\,S$,

$\mu_l = -(e/2m)\,l$

Which of these relations is in accordance with the result expected classically? Outline the derivation of the classical result.

**Answer 5.25:**

The magnetic moment associated with the intrinsic spin angular momentum and the orbital angular momentum.