



## Chapter 5 : Magnetism and Matter (Solved Examples & Exercises)

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### Notes

Step-by-step solutions · NCERT Examples 5.1–5.5 and Exercises 5.1–5.7 · Class 12 Physics

### Part A — NCERT Solved Examples

#### Example 5.1

**Question:** (a) What happens if a bar magnet is cut into two pieces: (i) transverse to its length, (ii) along its length? (b) 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 in addition to a torque. Why? (c) Must every magnetic configuration have a north pole and a south pole? What about the field due to a toroid? (d) 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.]

**Solution:**

- (a) In either case, one gets **two magnets**, each with a north and a south pole.
- (b) There is no force if the field is uniform. The iron nail experiences a **non-uniform** field due to the bar magnet. A magnetic moment is induced in the nail, so 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 the magnet than the induced north pole.
- (c) **Not necessarily.** This is true only if the source of the field has a net non-zero magnetic moment. It is not so for a **toroid**, or even for a straight infinite conductor.
- (d) Bring different ends of the bars closer. A **repulsive** force in some situation shows that **both are magnetised**. If it is always attractive, only one is magnetised. To find which one: the field of a magnet is strongest at its ends (poles) and weakest in the middle. Pick up one bar (say A) and bring one of its ends first near an end of B, then near the middle of B. If A experiences no force at the middle of B, then **B is the magnet**. If there is no change from the end to the middle of B, then **A is the magnet**.

#### Example 5.2

**Question:** Figure 5.4 shows a small magnetised needle P placed at a point O. The arrow shows the direction of its magnetic moment. The other arrows show different positions (and orientations of the magnetic moment) of another identical magnetised needle Q. (a) In which configuration the system is not in equilibrium? (b) In which configuration is the system in (i) stable, and (ii) unstable equilibrium? (c) Which configuration corresponds to the lowest potential energy among all the configurations shown?

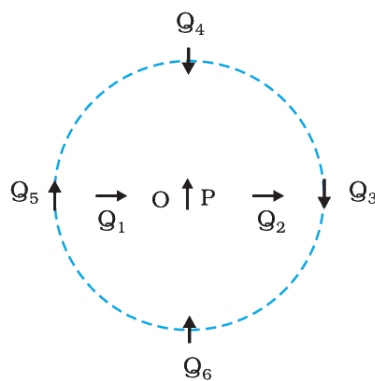


Fig. 5.4

**Solution:** The potential energy of the configuration is that of one dipole (Q) in the field of the other (P):

$$\vec{B}_P = -\frac{\mu_0}{4\pi} \frac{\vec{m}_P}{r^3} \text{ (on the normal bisector),} \quad \vec{B}_P = \frac{\mu_0}{4\pi} \frac{2\vec{m}_P}{r^3} \text{ (on the axis)}$$

Equilibrium is **stable** when  $\vec{m}_Q$  is parallel to  $\vec{B}_P$  and **unstable** when it is antiparallel. For example, in configuration  $Q_3$ , Q lies on the perpendicular bisector of P and its moment is parallel to the field there, so  $Q_3$  is stable.

**Answer:**

- (a)  $PQ_1$  and  $PQ_2$  (not in equilibrium)
- (b) (i) Stable:  $PQ_3, PQ_6$ ; (ii) unstable:  $PQ_5, PQ_4$
- (c)  $PQ_6$  (lowest potential energy)

### Example 5.3

**Question:** Many of the diagrams given in Fig. 5.6 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.

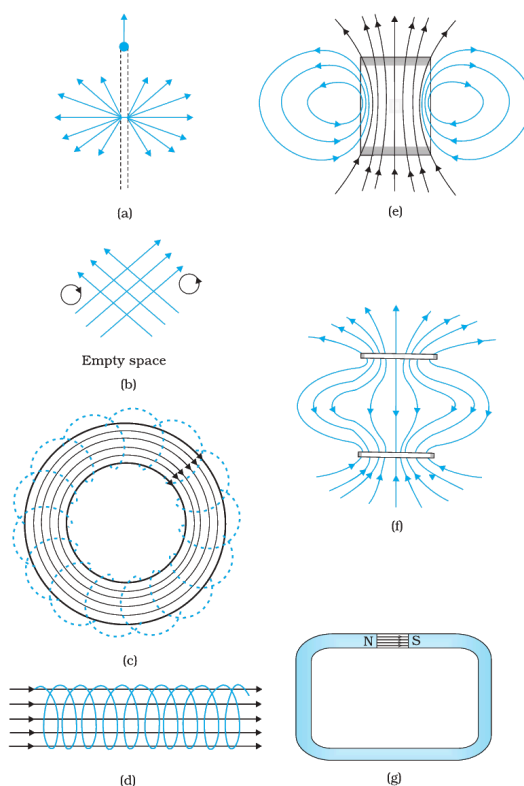


Fig. 5.6

**Solution:**

- **(a) Wrong.** Magnetic field lines can never emanate from a point. Over any closed surface, the net flux of  $\mathbf{B}$  must be zero. The lines shown actually represent the electric field of a long positively charged wire. The correct magnetic field lines circle the straight conductor.
- **(b) Wrong.** Field lines (magnetic or electric) can never cross each other. Also, magnetostatic field lines can never form closed loops around **empty space** — a closed loop of static field must enclose a region through which a current passes. Electrostatic field lines can never form closed loops at all.
- **(c) Right.** Magnetic lines are completely confined within a toroid. Each closed loop encloses a region through which current passes. (Only a few lines are drawn for clarity.)
- **(d) Wrong.** Field lines of a solenoid cannot be so completely straight and confined at its ends and outside — this violates Ampere's law. The lines should curve out at both ends and meet to form closed loops.
- **(e) Right.** These are field lines outside and inside a bar magnet. Note the direction inside: not all lines emanate from the north pole. The net flux around both the N-pole and the S-pole is zero.
- **(f) Wrong.** These cannot be magnetic field lines: in the upper region all lines seem to emanate from the shaded plate, so the net flux through a surface around it is not zero. They show the **electrostatic** field around a positively charged upper plate and a negatively charged lower plate.
- **(g) Wrong.** Field lines between two pole pieces cannot be precisely straight at the ends; some **fringing** is inevitable (otherwise Ampere's law is violated). This is also true for electric field lines.

**Example 5.4**

**Question:** (a) 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? (b) If magnetic monopoles existed, how would the Gauss's law of magnetism be modified? (c) 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? (d) Magnetic field arises due to charges in motion. Can a system have magnetic moments even though its net charge is zero?

**Solution:**

- **(a) No.** The magnetic force  $q\vec{v} \times \vec{B}$  is always normal to **B**. It is misleading to call magnetic field lines “lines of force”.
- **(b)** Gauss’s law of magnetism states that the flux of **B** through any closed surface is zero:  $\oint_S \vec{B} \cdot d\vec{s} = 0$ . If monopoles existed, the right-hand side would equal the monopole (magnetic) charge enclosed:  $\oint_S \vec{B} \cdot d\vec{s} = \mu_0 q_m$  — analogous to Gauss’s law of electrostatics.
- **(c) No.** There is no force or torque on an element due to the field produced by that element itself. But there is a force (or torque) on an element of the same wire due to other elements. (For a straight wire this force is zero.)
- **(d) Yes.** The average of the charge may be zero, yet the mean of the magnetic moments due to various current loops may not be zero. Example: paramagnetic atoms, which have a net dipole moment though their net charge is zero.

**Example 5.5**

**Question:** 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 2 A. If the number of turns is 1000 per metre, calculate (a) H, (b) M, (c) B and (d) the magnetising current  $I_m$ .

**Solution:**

**(a)** The field H depends only on the current in the windings, not on the core:

$$H = nI = 1000 \times 2.0 = 2 \times 10^3 \text{ A/m}$$

**(b) and (c)** The magnetic field B:

$$B = \mu_r \mu_0 H = 400 \times 4\pi \times 10^{-7} \times 2 \times 10^3 = 1.0 \text{ T}$$

Magnetisation:

$$M = \frac{B - \mu_0 H}{\mu_0} = (\mu_r - 1) H = 399 \times 2 \times 10^3 \approx 8 \times 10^5 \text{ A/m}$$

**(d)** The magnetising current  $I_M$  is the additional current needed in the windings, without the core, to give the same B:  $B = \mu_0 n (I + I_M)$ .

$$I + I_M = \frac{B}{\mu_0 n} = \frac{1}{4\pi \times 10^{-7} \times 1000} = 796 \text{ A} \Rightarrow I_M = 794 \text{ A}$$

**Answer:**  $H = 2 \times 10^3 \text{ A/m}$ ;  $M \approx 8 \times 10^5 \text{ A/m}$ ;  $B = 1.0 \text{ T}$ ;  $I_M = 794 \text{ A}$

**Part B — NCERT Exercises****Exercise 5.1**

**Question:** A short bar magnet placed with its axis at  $30^\circ$  with a uniform external magnetic field of 0.25 T experiences a torque of magnitude equal to  $4.5 \times 10^{-2} \text{ J}$ . What is the magnitude of magnetic moment of the magnet?

**Solution:**

$$\tau = mB \sin \theta \Rightarrow m = \frac{\tau}{B \sin \theta} = \frac{4.5 \times 10^{-2}}{0.25 \times \sin 30^\circ} = \frac{4.5 \times 10^{-2}}{0.125} = 0.36 \text{ J T}^{-1}$$

**Answer:**  $m = 0.36 \text{ J T}^{-1}$

## Exercise 5.2

**Question:** A short bar magnet of magnetic moment  $m = 0.32 \text{ J T}^{-1}$  is placed in a uniform magnetic field of  $0.15 \text{ T}$ . If the bar is free to rotate in the plane of the field, which orientation would correspond to its (a) stable, and (b) unstable equilibrium? What is the potential energy of the magnet in each case?

**Solution:**  $U = -mB \cos \theta$ , with  $mB = 0.32 \times 0.15 = 0.048 \text{ J}$ .

(a) **Stable equilibrium:**  $\vec{m}$  parallel to  $\vec{B}$  ( $\theta = 0^\circ$ ):

$$U = -mB = -4.8 \times 10^{-2} \text{ J}$$

(b) **Unstable equilibrium:**  $\vec{m}$  antiparallel to  $\vec{B}$  ( $\theta = 180^\circ$ ):

$$U = +mB = +4.8 \times 10^{-2} \text{ J}$$

**Answer:** (a)  $\theta = 0^\circ$ ,  $U = -4.8 \times 10^{-2} \text{ J}$  (b)  $\theta = 180^\circ$ ,  $U = +4.8 \times 10^{-2} \text{ J}$

## Exercise 5.3

**Question:** A closely wound solenoid of 800 turns and area of cross section  $2.5 \times 10^{-4} \text{ m}^2$  carries a current of  $3.0 \text{ A}$ . Explain the sense in which the solenoid acts like a bar magnet. What is its associated magnetic moment?

**Solution:** Each turn of the solenoid behaves as a small current loop (magnetic dipole). Together they produce a field like that of a bar magnet: field lines emerge from one end (N-pole) and enter the other (S-pole), and the far field along the axis is  $\frac{\mu_0 2m}{4\pi r^3}$ . The solenoid also aligns along an external field like a magnet.

$$m = NIA = 800 \times 3.0 \times 2.5 \times 10^{-4} = 0.60 \text{ J T}^{-1}$$

The moment is directed along the axis of the solenoid, given by the right-hand thumb rule.

**Answer:**  $m = 0.60 \text{ J T}^{-1}$  (A  $\text{m}^2$ ) along the axis

## Exercise 5.4

**Question:** If the solenoid in Exercise 5.3 is free to turn about the vertical direction and a uniform horizontal magnetic field of  $0.25 \text{ T}$  is applied, what is the magnitude of torque on the solenoid when its axis makes an angle of  $30^\circ$  with the direction of applied field?

(The textbook says “Exercise 5.5”, but the solenoid is the one in Exercise 5.3.)

**Solution:**  $m = 0.60 \text{ J T}^{-1}$ .

$$\tau = mB \sin \theta = 0.60 \times 0.25 \times \sin 30^\circ = 7.5 \times 10^{-2} \text{ N m}$$

**Answer:**  $\tau = 7.5 \times 10^{-2} \text{ N m}$

## Exercise 5.5

**Question:** A bar magnet of magnetic moment  $1.5 \text{ J T}^{-1}$  lies aligned with the direction of a uniform magnetic field of  $0.22 \text{ T}$ . (a) What is the amount of work required by an external torque to turn the magnet so as to align its magnetic moment: (i) normal to the field direction, (ii) opposite to the field direction? (b) What is the torque on the magnet in cases (i) and (ii)?

**Solution:**  $W = mB (\cos \theta_1 - \cos \theta_2)$  with  $\theta_1 = 0^\circ$ ;  $mB = 1.5 \times 0.22 = 0.33 \text{ J}$ .

(a)

- i.  $\theta_2 = 90^\circ$ :  $W = mB (1 - 0) = 0.33 \text{ J}$
- ii.  $\theta_2 = 180^\circ$ :  $W = mB (1 - (-1)) = 2mB = 0.66 \text{ J}$

(b)  $\tau = mB \sin \theta$ :

- i.  $\theta = 90^\circ$ :  $\tau = mB = 0.33 \text{ N m}$
- ii.  $\theta = 180^\circ$ :  $\tau = 0$  (but this is unstable equilibrium)

**Answer:** (a) 0.33 J, 0.66 J (b) 0.33 N m, 0

### Exercise 5.6

**Question:** A closely wound solenoid of 2000 turns and area of cross-section  $1.6 \times 10^{-4} \text{ m}^2$ , carrying a current of 4.0 A, is suspended through its centre allowing it to turn in a horizontal plane. (a) What is the magnetic moment associated with the solenoid? (b) What is the force and torque on the solenoid if a uniform horizontal magnetic field of  $7.5 \times 10^{-2} \text{ T}$  is set up at an angle of  $30^\circ$  with the axis of the solenoid?

**Solution:**

(a)

$$m = NIA = 2000 \times 4.0 \times 1.6 \times 10^{-4} = 1.28 \text{ A m}^2$$

directed along the axis of the solenoid (right-hand thumb rule).

(b) In a **uniform** field, the net force on a magnetic dipole is **zero**.

$$\tau = mB \sin \theta = 1.28 \times 7.5 \times 10^{-2} \times \sin 30^\circ = 4.8 \times 10^{-2} \text{ N m}$$

The torque tends to align the axis of the solenoid along the field.

**Answer:** (a)  $1.28 \text{ A m}^2$  (b) Force = 0; torque =  $4.8 \times 10^{-2} \text{ N m}$

### Exercise 5.7

**Question:** A short bar magnet has a magnetic moment of  $0.48 \text{ J T}^{-1}$ . Give the direction and magnitude of the magnetic field produced by the magnet at a distance of 10 cm from the centre of the magnet on (a) the axis, (b) the equatorial lines (normal bisector) of the magnet.

**Solution:**  $r = 0.1 \text{ m}$ , so  $r^3 = 10^{-3} \text{ m}^3$ .

(a) **Axial point:**

$$B_A = \frac{\mu_0}{4\pi} \frac{2m}{r^3} = 10^{-7} \times \frac{2 \times 0.48}{10^{-3}} = 9.6 \times 10^{-5} \text{ T} = 0.96 \text{ G}$$

directed along the magnetic moment, i.e. **from S-pole to N-pole** (along the axis, pointing away from the N-pole on that side).

(b) **Equatorial point:**

$$B_E = \frac{\mu_0}{4\pi} \frac{m}{r^3} = 10^{-7} \times \frac{0.48}{10^{-3}} = 4.8 \times 10^{-5} \text{ T} = 0.48 \text{ G}$$

directed **opposite** to the magnetic moment, i.e. **from N-pole to S-pole** (parallel to the axis).

**Answer:** (a) 0.96 G along S  $\rightarrow$  N (b) 0.48 G along N  $\rightarrow$  S