

Class 12 Physics



Chapter 5 – Magnetism and Matter

Notes By- The Conclusion Daily

5.1 Introduction

- Magnetic phenomena exist **everywhere** — from subatomic particles to galaxies.
- The Earth itself behaves like a **giant magnet**, with field lines roughly from **geographic south** → **north**.
- When a bar magnet is suspended freely:
 - The end pointing north = **North pole (N)**
 - The end pointing south = **South pole (S)**
- Like poles repel; unlike poles attract.
- **Magnetic monopoles do not exist** – cutting a magnet gives two smaller magnets.

5.2 The Bar Magnet

5.2.1 Magnetic Field Lines

- Magnetic field lines are **continuous closed loops**, unlike electric field lines.
- Tangent to a field line → direction of $\vec{B}$.
- Field strength $\propto$ number of lines per unit area.
- Field lines never intersect.
- Can be traced using a small **magnetic compass**.

5.2.2 Bar Magnet as an Equivalent Solenoid

- The magnetic field of a **bar magnet** is similar to that of a **current-carrying solenoid**.
- The magnet can be imagined as composed of **many microscopic current loops** (Ampere's hypothesis).

- Axial magnetic field at a point far from magnet:

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

where m = magnetic dipole moment, r = distance.

- Hence, a **bar magnet** $\approx$ **solenoid** in behaviour and field pattern.

5.2.3 Magnetic Dipole in a Uniform Magnetic Field

- A magnetic dipole $\vec{m}$ placed in field $\vec{B}$ experiences:

- **Torque:** $\vec{\tau} = \vec{m} \times \vec{B}$

- **Magnitude:** $\tau = mB \sin\theta$

- **Potential Energy:**

$$U = -\vec{m} \cdot \vec{B} = mB \cos\theta$$

- Minimum at $\theta = 0^\circ$ (stable equilibrium)

- Maximum at $\theta = 180^\circ$ (unstable equilibrium)

5.2.4 Electrostatic Analogy

Magnetic dipole $\leftrightarrow$ Electric dipole

Concept	Electric Dipole	Magnetic Dipole
Dipole moment	$\vec{p}$	$\vec{m}$
Medium constant	$\frac{1}{4\pi\epsilon_0}$	$\frac{\mu_0}{4\pi}$
Axial field	$E_A = \frac{1}{4\pi\epsilon_0} \frac{2p}{r^3}$	$B_A = \frac{\mu_0}{4\pi} \frac{2m}{r^3}$
Equatorial field	$E_E = -\frac{1}{4\pi\epsilon_0} \frac{p}{r^3}$	$B_E = -\frac{\mu_0}{4\pi} \frac{m}{r^3}$
Torque	$\vec{p} = \vec{E}$	$\vec{m} \times \vec{B}$

Potential energy

$$- \vec{p} \cdot \vec{E}$$

$$- m \vec{\omega} \times \vec{B}$$

5.3 Gauss's Law for Magnetism

- Magnetic field lines form **closed loops**, no “start” or “end”.
- Hence, net magnetic flux through a closed surface is **zero**:

$$\oint_S \vec{B} \cdot d\vec{S} = 0$$

- This implies:
 - **No magnetic monopoles** exist.
 - Magnetic field lines that leave a surface always re-enter it elsewhere.

5.4 Magnetisation and Magnetic Intensity

Definitions:

1. **Magnetisation (M):**

$$m = \frac{m_{net}}{V}$$

2. **Magnetic Field due to Solenoid (no core):**

$$B_0 = \mu_0 n I$$

where n = turns/m, I = current.

3. **With Magnetic Material:**

$$B = B_0 + B_m = \mu_0 (H + M)$$

4. **Magnetic Intensity (H):**

$$\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{M}$$

5. **Magnetic Susceptibility (χ):**

$$M = \chi H$$

→ χ = measure of how easily a material magnetises.

6. **Relative Permeability (μ_r):**

$$\mu_r = 1 + \chi$$

7. **Absolute Permeability (μ):**

$$\mu = \mu_0 \mu_r = \mu_0 (1 + \chi)$$

5.5 Magnetic Properties of Materials

Materials are classified as:

1. **Diamagnetic**
2. **Paramagnetic**
3. **Ferromagnetic**

Property	Diamagnetic	Paramagnetic	Ferromagnetic
χ (susceptibility)	Negative ($\approx -10^{-5}$)	Small positive ($\approx +10^{-5}$)	Large positive (>1)
μ_r	< 1	Slightly > 1	$\gg 1$
Response to field	Weakly repelled	Weakly attracted	Strongly attracted
Example	Bi, Cu, H ₂ O	Al, Na, O ₂	Fe, Co, Ni
Cause	Induced magnetic moment opposite to field	Random atomic dipoles align slightly	Domains align spontaneously
Behaviour	Moves to weak field region	Moves to strong field region	Retains magnetisation (permanent)

5.5.1 Diamagnetism

- **Reason:** Orbital motion of electrons changes slightly under external fields (Lenz's law).
- **Result:** Induced magnetic moment opposite to applied field.
- **Key Examples:** Bismuth, copper, lead, water.
- **Special case: Superconductors** → Perfect diamagnets ($\chi = -1$, $\mu_r = 0$).
→ Exhibit **Meissner effect** (complete expulsion of magnetic field).

5.5.2 Paramagnetism

- **Reason:** Atoms have permanent magnetic moments, but random orientation cancels them.
- When placed in magnetic field:

- Dipoles align partially along B.
- Magnetisation increases slightly.
- **Examples:** Aluminium, platinum, sodium, oxygen.
- **Effect of Temperature:** Magnetisation decreases with increasing temperature.

5.5.3 Ferromagnetism

- **Reason:** Strong interaction between atomic dipoles causes **spontaneous alignment** forming **domains**.
- Domains → large regions with uniform magnetisation.
- When external B applied → domains align & grow → strong magnetisation.
- **After removing field:**
 - **Soft ferromagnets:** Magnetisation disappears (e.g., soft iron).
 - **Hard ferromagnets:** Magnetisation retained → permanent magnets (e.g., Alnico).
- **Curie Temperature:** Above this, ferromagnet → paramagnet.
- **Typical μ_r :** > 1000.

5.6 Summary of Key Equations

Concept	Formula	Description
Torque on dipole	$\tau = mB \sin \theta$	Rotational effect on magnet
Potential energy	$U = -mB \cos \theta$	Minimum when aligned
Axial field	$B_A = \frac{\mu_0}{4\pi} \frac{2m}{r^3}$	Along magnet's axis
Equatorial field	$B_E = -\frac{\mu_0}{4\pi} \frac{m}{r^3}$	Along perpendicular bisector
Gauss's law	$\oint \mathbf{B} \cdot d\mathbf{S} = 0$	No monopoles
Magnetisation	$M = \frac{m_{net}}{V}$	Moment per volume

B–H relation	$B = \mu_0 (H + M)$	Total field in material
Susceptibility	$M = \chi H$	Linear relation
Permeability	$\mu = \mu_0 (1 + \chi)$	Relation between constants

5.7 Quick Concept Recap

- Magnetic field lines form **closed loops** → monopoles don't exist.
- **Bar magnet** $\approx$ **magnetic dipole** with moment m .
- **Gauss's law for magnetism**: Net flux = 0.
- $M = \chi H$ links magnetisation & external field.
- **Ferromagnetism** arises from domain alignment.
- **Superconductors** show **perfect diamagnetism** (Meissner effect).