FREE NOTES · NCERT + JEE/NEET LEVEL

Magnetism & Matter

The bar magnet, magnetic field lines, the magnetic dipole, Gauss's law for magnetism, Earth's magnetism, magnetisation and dia-, para- and ferromagnetic materials. With tables and solved numericals.

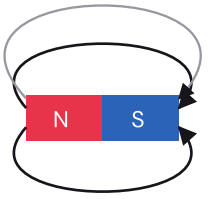
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01 Bar magnet

- Suspended freely, its North pole points to geographic north.
- Like poles repel, unlike poles attract.
- **There are no isolated poles (monopoles)**: break a magnet and each piece is a complete magnet (both N and S).
- The field of a bar magnet is just like that of a current-carrying solenoid.

02 Magnetic field lines

- Outside from N to S, inside the magnet from S to N: **closed loops** (unlike electric field lines, which end on - charges).
- Two lines never cross.
- Crowded lines = strong field.
- The tangent gives the field direction (compass needle).



Outside N → S, inside S → N

03 Bar magnet as a magnetic dipole

Magnetic moment $m = q_m \times 2l$ (from S to N), unit $A \cdot m^2$

Axial line: $B = (\mu_0/4\pi)\, 2m/r^3$

Equatorial line: $B = (\mu_0/4\pi)\, m/r^3$ (opposite to m)

Just like the electric dipole, with $\mu_0/4\pi$ in place of k and m in place of p.

Electrostatics	Magnetism
$1/\varepsilon_0$	μ_0
Dipole moment p	Magnetic moment m
E (axial) = $2kp/r^3$	B (axial) = $(\mu_0/4\pi)2m/r^3$
$\tau = p \times E$, $U = -p \cdot E$	$\tau = m \times B$, $U = -m \cdot B$
Monopoles (single charges) exist	No monopoles

04 Dipole in a uniform field

Torque $\tau = mB \sin\theta$, $U = -mB \cos\theta$

$$\text{Oscillation: } T = 2\pi \sqrt{(I / (mB))}$$

Disturb a compass needle slightly and it performs SHM. This can be used to measure B (I = moment of inertia of the needle). Work to rotate from 0° to 180° = 2mB.

05 Gauss's law for magnetism

STATEMENT

$\oint B \cdot dA = 0$

The net magnetic flux through any closed surface is zero, because as many lines leave as enter. In other words, **magnetic monopoles don't exist**.

06 Earth's magnetism

The Earth behaves like a huge bar magnet, but its magnetic **South pole is near the geographic North** (that's why a compass's N points there). The field comes from currents of molten metal in the Earth's core (dynamo effect).

Element	Meaning
Declination (D)	Angle between the geographic and magnetic meridians
Dip / inclination (I)	Angle of the total field with the horizontal. 0° at the equator, 90° at the poles
Horizontal component	$B_H = B\cos I$, $B_V = B\sin I$, $\tan I = B_V/B_H$

At the poles $B_H = 0$, so a compass needle can rest in any direction there.

07 Magnetisation & magnetic intensity

Magnetisation $M = m_{net}/V$ (A/m)

Magnetic intensity $H = B_0/\mu_0$ (A/m)

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

Susceptibility $\chi = M/H$, $\mu_r = 1 + \chi$, $\mu = \mu_0\mu_r$

08 Magnetic materials

	Diamagnetic	Paramagnetic	Ferromagnetic
χ	Small negative	Small positive	Very large positive
μ_r	< 1	> 1 (slightly)	$\gg 1$ (thousands)
Near a magnet	Weakly repelled (moves from strong to weak field)	Weakly attracted	Strongly attracted
Field lines	Pushed out	Pulled in slightly	Pulled in strongly
Temperature	No effect	$\chi \propto 1/T$ (Curie law)	Paramagnetic above the Curie temperature
Examples	Bismuth, copper, water, superconductors	Aluminium, sodium, O_2	Iron, cobalt, nickel

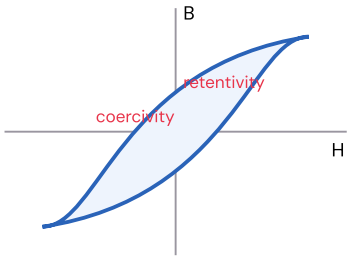
REMEMBER

A superconductor is a **perfect diamagnet** ($\chi = -1$): it expels the field completely (Meissner effect), so a magnet can float above it. Ferromagnets contain **domains** that line up in a field.

09 Hysteresis

When a ferromagnet is magnetised and demagnetised, B lags behind H: the **hysteresis loop**.

- **Retentivity:** B remaining when H = 0.
- **Coercivity:** reverse H needed to make B = 0.
- Area of the loop = energy lost (as heat) per cycle.



Hysteresis loop

Use	Material needed	Example
Permanent magnet	High retentivity and high coercivity	Steel, alnico
Electromagnet, transformer core	Low coercivity, narrow loop (low loss), high permeability	Soft iron

10 JEE Extra + Tricks

JEE LEVEL

- Susceptibility: diamagnetic small negative; paramagnetic small positive (Curie law $\chi \propto 1/T$); ferromagnetic large positive (becomes paramagnetic above Curie temperature).
- Soft iron: narrow hysteresis loop, low retentivity and coercivity ⇒ electromagnets, transformer cores. Steel: wide loop ⇒ permanent magnets.
- Bar magnet: axial $B = 2kM/r^3$, equatorial $B = kM/r^3$ ($k = \mu_0/4\pi$).
- Earth's field: $B_H = B\cos\delta$, $B_V = B\sin\delta$, $\tan\delta = B_V/B_H$ (δ = dip). At magnetic poles dip = 90°, at equator 0°.
- Superconductors are perfect diamagnets (Meissner effect).

11 Solved numericals ($\mu_0/4\pi = 10^{-7}$)

Q1. A bar magnet with m = 0.4 A·m². B on its axial line at 20 cm?
B = $10^{-7} \times 2 \times 0.4/0.008 = 10^{-5}$ T. **Ans: 10^{-5} T**

Q2. A magnet (m = 2 A·m²) is at 30° to a 0.2 T field. Torque and PE?
$\tau = 2 \times 0.2 \times 0.5 = 0.2$ N·m. $U = -2 \times 0.2 \times 0.866 \approx -0.35$ J. **Ans: 0.2 N·m, −0.35 J**

Q3. At a place B_H = 0.3 G and dip is 60°. Total field?
$B = B_H/\cos 60° = 0.6$ G. **Ans: 0.6 G**

Q4. A paramagnetic material has $\chi = 2 \times 10^{-4}$ at 300 K. At 150 K?
$\chi \propto 1/T \Rightarrow 4 \times 10^{-4}$. **Ans: 4×10^{-4}**

12 Common mistakes

- Treating magnetic field lines as open (starting at N and ending). They are closed loops.
- Thinking the Earth's magnetic North is at the geographic North (it's the magnetic South).
- Calling diamagnetic materials "non-magnetic": they are weakly repelled.
- Applying Curie's law to ferromagnets (it's for paramagnets).
- Choosing steel for a transformer core (soft iron is correct).

13 Formula sheet

Dipole field	axial $(\mu_0/4\pi)2m/r^3$, equatorial $(\mu_0/4\pi)m/r^3$
Torque, PE	$\tau = mB\sin\theta$, $U = -mB\cos\theta$
Oscillation	$T = 2\pi\sqrt{(I/mB)}$
Gauss (magnetism)	$\oint B\cdot dA = 0$
Earth	$B_H = B\cos I$, $\tan I = B_V/B_H$
B, H, M	$B = \mu_0(H + M)$
Susceptibility	$\chi = M/H$, $\mu_r = 1 + \chi$
Curie law	$\chi = C/T$

14 Practice questions

1. A bar magnet is cut into two equal halves across its length. Magnetic moment of each piece?
2. Dip angle at the equator?
3. Which kind of material is weakly repelled by a magnet?
4. Work to rotate a magnet in a field from 0° to 180°?

ANSWERS

1) m/2 (same pole strength, half the length) · 2) 0° · 3) Diamagnetic (e.g. bismuth) · 4) 2mB

15 Quick revision: 5 minutes before the exam

MAGNET

- No monopoles; lines are closed loops.
- Axial field = 2 × equatorial.
- $\tau = mB \sin\theta$, $T = 2\pi\sqrt{(I/mB)}$.

EARTH

- Magnetic S near geographic N.
- Dip: 0° at equator, 90° at poles.
- $B_H = B \cos I$.

MATERIALS

- Dia χ −, para χ + (small), ferro $\chi \gg$.
- Para: $\chi \propto 1/T$.
- Superconductor: $\chi = -1$.

HYSTERESIS

- Permanent: high retentivity + coercivity.
- Electromagnet: soft iron, narrow loop.

Have a doubt? Ask the AI Doubt Solver at padhaiadda.netlify.app, or take the mock test on this chapter.