Magnetism & Matter — JEE Mains Formula Sheet

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Class XII | Chapter: Magnetism & Matter | ★ = High JEE Mains Frequency

Magnetic Dipole Moment:

$$\vec{M} = m \cdot (2\ell)$$

m = pole strength, 2ℓ = magnetic length

Field on Axial Line (end-on position):

$$\boxed{B_{\text{axial}} = \frac{\mu_0}{4\pi} \cdot \frac{2Mr}{(r^2 - \ell^2)^2}}$$

For $r \gg \ell$:

$$B_{\text{axial}} \approx \frac{\mu_0}{4\pi} \cdot \frac{2M}{r^3}$$

Field on Equatorial Line (broad-side on):

$$\boxed{B_{\text{equat}} = \frac{\mu_0}{4\pi} \cdot \frac{M}{(r^2 + \ell^2)^{3/2}}}$$

For $r \gg \ell$:

$$B_{\text{equat}} \approx \frac{\mu_0}{4\pi} \cdot \frac{M}{r^3}$$

Key ratio: At equal distances,

$$B_{\text{axial}} = 2\, B_{\text{equat}}$$

Field at General Point (angle θ from axis):

$$B = \frac{\mu_0}{4\pi} \cdot \frac{M\sqrt{3\cos^2\theta + 1}}{r^3}$$

$$\tan\alpha = \frac{1}{2}\tan\theta \quad (\alpha = \text{angle of } B \text{ with } r)$$

2. Torque, PE and Oscillations

Torque on dipole in uniform field:

$$\boxed{\vec{\tau} = \vec{M} \times \vec{B} = MB\sin\theta}$$

Potential energy:

$$\boxed{U = -\vec{M} \cdot \vec{B} = -MB\cos\theta}$$

- Equilibrium (stable): $\theta = 0°$, $U = -MB$
- Equilibrium (unstable): $\theta = 180°$, $U = +MB$

Work done to rotate from θ_1 to θ_2:

$$W = MB(\cos\theta_1 - \cos\theta_2)$$

Time period of oscillation in field B:

$$\boxed{T = 2\pi\sqrt{\frac{I}{MB}}}$$

I = moment of inertia of magnet

Frequency:

$$f = \frac{1}{2\pi}\sqrt{\frac{MB}{I}}$$

Magnetic moment of current loop:

$$\boxed{M = NIA}$$

N = turns, I = current, A = area

For circular loop of radius r:

$$M = NI\pi r^2$$

Gyromagnetic ratio (electron):

$$\frac{M_l}{L} = \frac{e}{2m_e} = 8.8 \times 10^{10}\ \text{C kg}^{-1}$$

Bohr Magneton:

$$\mu_B = \frac{eh}{4\pi m_e} = 9.27 \times 10^{-24}\ \text{J T}^{-1}$$

$$\boxed{\oint \vec{B} \cdot d\vec{A} = 0}$$

- Magnetic monopoles **do not exist**
- Magnetic field lines are **closed loops**
- Contrast: Gauss's law for E gives $\frac{q}{\varepsilon_0}$

5. Earth's Magnetism

Three elements of Earth's magnetism:

Element	Definition
Declination (δ)	Angle between geographic north and magnetic north
Dip / Inclination (ϕ)	Angle between B_E and horizontal plane
Horizontal component	$H = B_E\cos\phi$
Vertical component	$V = B_E\sin\phi$

Key relations:

$$\boxed{V = H\tan\phi} \qquad \boxed{B_E = \sqrt{H^2 + V^2}}$$

$$\tan\phi = \frac{V}{H}$$

Apparent dip (when vertical plane turned by angle α):

$$\tan\phi' = \frac{\tan\phi}{\cos\alpha}$$

At magnetic poles: $\phi = 90°$, $H = 0$
At magnetic equator: $\phi = 0°$, $V = 0$

Magnetisation:

$$\vec{M} = \frac{\text{Net magnetic moment}}{\text{Volume}} \quad [\text{A m}^{-1}]$$

Magnetic intensity / field strength:

$$\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{M} \quad \Rightarrow \quad \vec{B} = \mu_0(\vec{H} + \vec{M})$$

Magnetic susceptibility:

$$\boxed{\chi_m = \frac{M}{H}}$$

Relative permeability:

$$\boxed{\mu_r = 1 + \chi_m} \qquad \mu = \mu_0\mu_r$$

Relation:

$$\vec{B} = \mu_0\mu_r\vec{H}$$

Property	Dia	Para
χ_m	Small, $-$ve	Small, $+$ve
μ_r	< 1	> 1 (slightly)
Behaviour in field	Weakly repelled	Weakly attracted
Examples	Cu, Bi, Au, Water	Al, Na, O_2

Ferromagnetic materials: Fe, Co, Ni
$\chi_m \gg 1$, $\mu_r \gg 1$, strongly attracted.

8. Curie's Law & Curie-Weiss Law

Curie's Law (paramagnetic):

$$\boxed{\chi_m = \frac{C}{T}}$$

C = Curie constant, T = absolute temperature
Curie-Weiss Law (ferromagnetic above T_C):

$$\boxed{\chi_m = \frac{C}{T - T_C}}$$

T_C = Curie temperature (ferromagnet becomes paramagnetic above T_C)
Key Curie temperatures:

- Fe: ≈ 1043 K
- Ni: ≈ 631 K
- Co: ≈ 1388 K

Effect of temperature on diamagnetics: Nearly **independent** of temperature.

1. $B_{\text{axial}} = \frac{\mu_0}{4\pi} \cdot \frac{2M}{r^3}$ (most tested)
2. $B_{\text{equat}} = \frac{\mu_0}{4\pi} \cdot \frac{M}{r^3}$ and $B_A = 2B_E$
3. $T = 2\pi\sqrt{I/MB}$ — *compare two magnets!*
4. $V = H\tan\phi$, $B_E = \sqrt{H^2 + V^2}$
5. $\chi_m = C/T$ and $\mu_r = 1 + \chi_m$
6. $\tau = MB\sin\theta$, $U = -MB\cos\theta$
7. $M = NIA$ (current loop analogy)

- **Axial vs Equatorial:** Axial field is *along* the axis (same direction as M); equatorial is *opposite* to M. Students often forget the direction reversal.
- **Magnetic length $\neq$ geometric length:** Effective magnetic length $= 0.84\times$ geometric length for a bar magnet.
- **H vs B:** H is magnetic field intensity (A/m); B is magnetic flux density (T). They differ inside a medium. $B = \mu_0 H$ only in vacuum.
- **Dip $\neq$ Declination:** Dip is measured in the vertical plane; declination is in the horizontal plane.
- **Curie vs Curie-Weiss:** Curie law applies to paramagnetics; Curie-Weiss law applies to ferromagnetics above T_C.
- **Diamagnetic susceptibility:** χ_m is negative (repelled), NOT zero. Students confuse it with vacuum ($\chi_m = 0$).
- **$\mu_r < 1$ for diamagnetics:** Since χ_m is small and negative, $\mu_r = 1 + \chi_m$ is slightly less than 1.
- **Gauss's law for magnetism:** Surface integral of B is zero; this does *not* mean $B = 0$ everywhere on the surface.
- **Apparent dip:** $\tan\phi' = \tan\phi/\cos\alpha$, NOT $\tan\phi\cdot\cos\alpha$.
- **Time period comparison:** When two magnets are placed N-N or N-S, use $M_{\text{eff}} = M_1 + M_2$ or $M_1 - M_2$ in T formula.

9. Hysteresis & Permanent Magnets

Hysteresis Loop terms:

- **Retentivity** (Remanence): Value of B when $H = 0$ (residual magnetism)
- **Coercivity**: Value of H needed to demagnetise

($B = 0$)

- **Hysteresis loss** $\propto$ area of B-H loop

Property	Perm. Magnet	Electromagnet
Retentivity	High	High
Coercivity	High	Low
Material	Steel, Alnico	Soft iron
Hysteresis area	Large	Small

$$\mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1}$$
$$\frac{\mu_0}{4\pi} = 10^{-7} \text{ T m A}^{-1}$$
$$\mu_B = 9.27 \times 10^{-24} \text{ J T}^{-1}$$
$$B_E \text{ (Earth)} \approx 4 \times 10^{-5} \text{ T (at equator)}$$

Prepared by: Let's Play With Physics • **letsplaywithphysics.in** • *Master the concept, not just the formula.*