

Collegedunia NCERT Formula Sheet

The Ultimate Formula Reference for Class 12 Physics

Chapter 5: Magnetism and Matter

Constant / Unit	Value
Permeability of free space, μ_0	$4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}$
Tesla (T)	$1 \text{ T} = 10^4 \text{ G}$
Earth's B at surface (typical)	$\sim 25\text{--}65 \mu\text{T}$
Bohr magneton, μ_B	$9.27 \times 10^{-24} \text{ J/T}$
Susceptibility χ (typical)	dia: $\sim -10^{-5}$; para: $\sim +10^{-5}$; ferro: $\sim 10^3\text{--}10^5$

1 The Bar Magnet

A bar magnet behaves like a magnetic dipole; its field at large distances mirrors the structure of an electric dipole's field (NCERT 5.2). Magnetic monopoles do not exist — field lines always close on themselves.

Bar magnet as a dipole

A bar magnet has two poles, North and South, that always come in pairs — cutting the magnet **never** isolates a single pole. The magnet behaves at large distances exactly like a magnetic dipole with moment \vec{m} along its axis from S to N.

Magnetic moment of a bar magnet

$\vec{m} = m\hat{n}$ where $m = q_m \cdot 2l$
 For a current loop: $\vec{m} = NIA\hat{n}$
 Direction: from S to N pole. Unit: $\text{A}\cdot\text{m}^2$ or

J/T. Both pictures (poles and current loop) give the same external field.

Field on axial line ($r \gg l$)

$$B_{\text{axial}} = \frac{\mu_0 2m}{4\pi r^3}$$

Parallel to \vec{m} . Same form as the electric dipole's E along axis. Falls as $1/r^3$.

Field on equatorial line ($r \gg l$)

$$B_{\text{eq}} = \frac{\mu_0 m}{4\pi r^3}$$

Anti-parallel to \vec{m} . **Half the magnitude** of the axial field at the same distance, and opposite in direction.

2 Magnetic Dipole in a Field

A bar magnet (or current loop) in a uniform \vec{B} feels a torque and stores potential energy depending on its orientation (NCERT 5.2 cont.).

Torque & potential energy

$$\vec{\tau} = \vec{m} \times \vec{B} \quad (\tau = mB \sin \theta)$$

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

Stable at $\theta = 0$ ($U_{\min} = -mB$); **unstable** at $\theta = 180^\circ$ ($U_{\max} = +mB$). Identical structure to the electric dipole equations.

Time period of oscillation

$$T = 2\pi \sqrt{\frac{I}{mB}}$$

where I = moment of inertia of the magnet about its suspension axis.

A bar magnet displaced from alignment with \vec{B} executes simple harmonic motion (small angle). Used to measure B if m is known, or vice versa.

3 Earth's Magnetic Field

Earth itself behaves like a giant bar magnet tilted relative to its rotation axis (NCERT 5.4). Three quantities — declination, dip, and horizontal component — specify the field at any location.

Magnetic elements

Declination (D): angle between geographic north and magnetic north.

Dip / inclination (I): angle between \vec{B} and the horizontal.

Horizontal component (B_H): the part of \vec{B} parallel to ground.

At magnetic equator: $I = 0$, \vec{B} is fully horizontal. At magnetic poles: $I = 90^\circ$, \vec{B} vertical.

Components of Earth's field

$$B_H = B \cos I$$

$$B_V = B \sin I$$

$$\tan I = \frac{B_V}{B_H}$$

B is the total magnitude; B_H acts on a horizontally-suspended magnet, B_V on a vertical one. Both are needed to fully specify direction.

4 Magnetisation & Magnetic Intensity

Inside a magnetisable material, the field has contributions from both free (real) currents and bound (atomic) currents. Two related vectors — \vec{M} and \vec{H} — separate these (NCERT 5.5).

Magnetisation \vec{M}

$$\vec{M} = \frac{\vec{m}_{\text{net}}}{V} \quad (\text{A/m})$$

Net magnetic moment per unit volume of the material. Zero for an unmagnetised sample; aligned with applied \vec{B} for paramagnets.

Magnetic intensity \vec{H}

$$\vec{B} = \mu_0(\vec{H} + \vec{M})$$

$$\vec{H} = \frac{\vec{B}_0}{\mu_0} \quad (\text{A/m})$$

\vec{H} is the part of \vec{B} from **free** currents; \vec{M} adds the contribution from atomic currents inside the material. SI units of both: A/m.

Susceptibility & permeability

$$\vec{M} = \chi \vec{H}$$

$$\mu_r = 1 + \chi$$

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

where χ = magnetic susceptibility (dimensionless); μ_r = relative permeability.

$\chi > 0$: paramagnet/ferromagnet. $\chi < 0$ (small): diamagnet. μ_r measures how much more (or less) field develops inside the material compared to vacuum.

5 Diamagnetism, Paramagnetism, Ferromagnetism

Materials respond to applied \vec{B} in three qualitatively different ways, depending on their atomic-scale magnetic structure (NCERT 5.6).

Diamagnetism

Weakly repelled by a magnet ($\chi < 0$, very small). All materials are diamagnetic to some degree, but the effect is dominant only when atoms have **no permanent magnetic moment** (e.g., Bi, Cu, H₂O, lead). χ is **independent of temperature**.

Paramagnetism

Weakly attracted by a magnet ($\chi > 0$, small). Atoms have permanent moments that align with \vec{B} but are randomised by thermal motion. Examples: Al, Na, O₂, Pt. χ **decreases** with T (Curie's law).

Curie's law (paramagnets)

$$\chi = \frac{C}{T}$$

where C = Curie constant (material-specific); T = absolute temperature (K). Susceptibility falls as temperature rises: thermal motion fights against alignment with \vec{B} .

Ferromagnetism

Strongly attracted by a magnet (χ very large). Atoms in ferromagnets (Fe, Co, Ni) form **domains** of aligned moments. Above the **Curie temperature** T_C , thermal energy destroys domain structure and the material becomes paramagnetic. Examples of T_C : Fe \approx 1043 K; Ni \approx 631 K.

Curie-Weiss law (ferromagnets above T_C)

$$\chi = \frac{C}{T - T_C}$$

Diverges at $T = T_C$: this is the ferromagnetic-paramagnetic phase transi-

tion. Below T_C , the material has spontaneous magnetisation even without an external field.

JEE/NEET Extension: Hysteresis

A ferromagnet's B - H curve forms a closed **hysteresis loop**: the present B depends on past history. Loop area = energy lost per cycle (heat). Soft ferromagnets (transformer cores) have **narrow** loops; hard ferromagnets (permanent magnets, audio tape) have **wide** loops.

Three M's of magnetism

Dia: weakly **minus** ($\chi < 0$). **Para**: weakly **plus**. **Ferro**: massively **plus**, with **memory** (hysteresis). Temperature kills paramagnetism (Curie); ferromagnetism dies above the Curie point.

Magnetic monopoles

Cutting a bar magnet does **not** produce isolated N and S poles — it produces two smaller bar magnets, each with its own pair of N and S. **No magnetic monopole has ever been observed**; magnetic field lines always form closed loops.

Quick Reference — Magnetism & Matter

Quantity / Configuration	Expression	Notes
Magnetic moment (loop)	$NI\vec{A}$	Right-hand rule
Bar magnet axial B	$\frac{\mu_0}{4\pi} \frac{2m}{r^3}$	Parallel to \vec{m}
Bar magnet equatorial B	$\frac{\mu_0}{4\pi} \frac{m}{r^3}$	Anti-parallel
Torque on dipole	$\vec{m} \times \vec{B}$	Aligns \vec{m} with \vec{B}
PE of dipole	$-\vec{m} \cdot \vec{B}$	Min when aligned
SHM period of bar magnet	$2\pi\sqrt{I/(mB)}$	Suspended in \vec{B}
Earth's B_H	$B \cos I$	Horizontal component
Earth's B_V	$B \sin I$	Vertical
Dip angle	$\tan^{-1}(B_V/B_H)$	0 at equator, 90° at pole
\vec{B} in matter	$\mu_0(\vec{H} + \vec{M})$	Free + bound
Susceptibility relation	$\vec{M} = \chi\vec{H}$	Dimensionless
Permeability	$\mu_r = 1 + \chi$	Relative
Curie's law (para)	$\chi = C/T$	Falls with T
Curie-Weiss (ferro)	$\chi = C/(T - T_C)$	Above T_C