Collegedunia NCERT Formula Sheet

The Ultimate Formula Reference for Class 12 Physics

Chapter 4: Moving Charges and Magnetism

Constant / Unit	Value
Permeability of free space, μ_0	$4\pi \times 10^{-7}$ T·m/A
$\frac{\mu_0}{4\pi}$	10^{-7} T·m/A
Tesla (T)	1 T = 1 N/(A·m) = 1 V·s/m^2
Gauss (G)	1 G = 10^{-4} T
Elementary charge, e	1.6×10^{-19} C
Electron mass, m_e	9.11×10^{-31} kg

1 Magnetic Force

A magnetic field exerts a velocity-dependent force on moving charges and on current-carrying wires (NCERT 4.2–4.3). Always perpendicular to velocity — it does **no work**.

Lorentz force

A charge q moving with velocity $\vec{v}$ in fields $\vec{E}$ and $\vec{B}$ feels the **total Lorentz force** $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$. The magnetic part is always **perpendicular** to $\vec{v}$, so it changes direction but **never** the speed of the particle.

Force on a moving charge

$\vec{F} = q\,\vec{v} \times \vec{B}$

Magnitude: $F = qvB \sin\theta$

where θ = angle between $\vec{v}$ and $\vec{B}$. Unit of $\vec{B}$: tesla (T).

Force is **zero** when $\vec{v} \parallel \vec{B}$, **maximum** when $\vec{v} \perp \vec{B}$. Magnetic force does **no work** on the charge.

Force on a current-carrying conductor

$\vec{F} = I\,\vec{L} \times \vec{B}$

Magnitude: $F = BIL \sin\theta$

where $\vec{L}$ points along current direction; L = length of conductor in field.

Direction by right-hand rule: **fingers I to B**, thumb gives F. This is the basis of motors.

2 Motion in a Magnetic Field

A charged particle in a uniform $\vec{B}$ moves on a circle (when $\vec{v} \perp \vec{B}$) or a helix (with parallel component) (NCERT 4.4).

Circular motion in $\vec{B}$

Radius: $r = \dfrac{mv}{qB}$

Period: $T = \dfrac{2\pi m}{qB}$

Frequency: $f = \dfrac{qB}{2\pi m}$

Period and frequency are **independent of speed** and radius — this is what makes the cyclotron work. Faster particles trace bigger circles in the same time.

Helical motion

Pitch: $p = v_{\parallel} T = \dfrac{2\pi m\, v_{\parallel}}{qB}$

where $v_{\parallel} = v \cos\theta$ is the component along $\vec{B}$.

Component along $\vec{B}$ is **unchanged**; perpendicular component spirals in a circle. Result: helix of radius $r = mv_{\perp}/qB$ and pitch p.

Velocity selector

$$qE = qvB \;\Rightarrow\; v = \frac{E}{B}$$

Crossed $\vec{E}$ and $\vec{B}$ fields with charged particles: only those with the right speed pass undeflected. Used in mass spectrometers.

JEE/NEET Extension: Cyclotron

Maximum kinetic energy at radius R: $K_{\text{max}} = \dfrac{q^2B^2R^2}{2m}$.

Frequency of dee oscillation matches cyclotron frequency $f = qB/(2\pi m)$. Limits: **cannot accelerate electrons** (relativistic) or neutral particles.

3 Biot–Savart Law

The magnetic field set up by a steady current is given by the Biot–Savart integral, the magnetic analogue of Coulomb's law (NCERT 4.5).

Biot–Savart law

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\, d\vec{l} \times \hat{r}}{r^2}$$

where $d\vec{l}$ = current element; $\hat{r}$ = unit vector from element to field point; r = distance.

Integrate $d\vec{B}$ over the entire current loop to get $\vec{B}$. Direction by right-hand rule. Inverse-square in r, like Coulomb's law.

Long straight wire

$$B = \frac{\mu_0 I}{2\pi r}$$

where r = perpendicular distance from wire.

Field circles the wire (right-hand rule: thumb I, fingers curl in $\vec{B}$ direction). Falls as $1/r$.

Centre of a circular loop

$$B = \frac{\mu_0 I}{2R}$$

For N turns: $B = \dfrac{\mu_0 NI}{2R}$

Direction along the loop's axis (right-hand rule: fingers I, thumb $\vec{B}$). N turns scale up the field linearly.

On the axis of a circular loop

$$B = \frac{\mu_0 NIR^2}{2(R^2 + x^2)^{3/2}}$$

where x = distance from centre along axis.

Reduces to $\mu_0 NI/(2R)$ at $x = 0$. Far away ($x \gg R$): $B \approx \mu_0 NIR^2/(2x^3)$ — like a magnetic dipole.

4 Ampere's Law & Force Between Currents

Ampere's law gives $\vec{B}$ for high-symmetry current distributions in one line (NCERT 4.6). Two parallel currents experience a mutual magnetic force — the basis of the SI definition of the ampere (NCERT 4.7).

Ampere's circuital law

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{enc}}$$

Line integral of $\vec{B}$ around any closed loop equals μ_0 times the current passing through it. Magnetic analogue of Gauss's law for $\vec{E}$.

Long solenoid (interior)

$$B = \mu_0 n I$$

where n = turns per unit length (m^{-1}).

Uniform inside, near zero outside (idealised). Direction along the axis. Fundamental tool in physics labs.

Toroid (interior)

$$B = \frac{\mu_0 N I}{2\pi r}$$

where N = total turns; r = distance from axis.

Field is confined to inside the toroid; zero in the central hole and outside. Used in tokamaks and inductors.

Force between parallel wires

$$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi d}$$

where d = separation between wires.

Attractive for currents in the same direction; **repulsive** for opposite directions. (Opposite to the rule for charges.)

The ampere (legacy definition)

One ampere is the steady current that, when maintained in two parallel infinitely long thin wires placed **1 m apart** in vacuum, produces a force of 2×10^{-7} N per metre between them.

JEE/NEET Extension: Choosing an Amperian loop

For symmetric distributions, pick a loop where $\vec{B} \cdot d\vec{l}$ is either constant or zero on each segment:

Long wire / coaxial cable: circular loop, $\vec{B}$ tangent to loop.

Solenoid: rectangular loop, only one side inside contributes.

Toroid: circular loop concentric with toroid axis.

5 Torque on a Current Loop & Magnetic Dipole

A current loop in a uniform $\vec{B}$ feels a torque that tries to align its magnetic moment with the field (NCERT 4.8). This is the operating principle of the moving-coil galvanometer and of motors.

Magnetic moment of a loop

$$\vec{m} = N I \vec{A} \quad (\text{A·m}^2)$$

where $\vec{A}$ = area vector (right-hand rule: fingers I, thumb $\vec{A}$); N = turns.

Magnetic dipole moment is the magnetic analogue of $\vec{p}$ (electric dipole moment).

Torque on the loop

$$\vec{\tau} = \vec{m} \times \vec{B}$$

$$\tau = mB \sin\theta = NIAB \sin\theta$$

Maximum torque when loop's plane is parallel to $\vec{B}$ ($\theta = 90°$); zero when $\vec{m} \parallel \vec{B}$. Same form as electric dipole.

Potential energy of magnetic dipole

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

Stable equilibrium at $\theta = 0$ ($U = -mB$); unstable at $\theta = 180°$. Mirror image of the electric-dipole formula $U = -\vec{p} \cdot \vec{E}$.

6 Moving-Coil Galvanometer

A small coil suspended in a radial $\vec{B}$ field deflects in proportion to the current — the basis of analogue meters (NCERT 4.9).

Galvanometer current–deflection

$$I = \frac{k}{NAB}\phi$$

Sensitivity: $\dfrac{\phi}{I} = \dfrac{NAB}{k}$

where k = torsion constant of suspension wire; ϕ = angular deflection.

Higher N, A, B or lower $k \Rightarrow$ more sensitive. The radial field design ensures a linear scale.

Galvanometer to ammeter

Shunt: $S = \dfrac{I_g R_g}{I - I_g}$

A small resistor S in **parallel** bypasses most of the current. An ideal ammeter has **very low** resistance (so it doesn't disturb the circuit).

Galvanometer to voltmeter

Series resistor: $R = \dfrac{V}{I_g} - R_g$

A large resistor R in **series** ensures only I_g flows for full-scale at voltage V. An ideal voltmeter has **very high** resistance.

Right-hand rule snapshot

Force on charge: fingers $\vec{v}$ to $\vec{B}$, thumb gives $\vec{F}$ (for $+q$).
Field of a wire: thumb points along I, fingers curl in direction of $\vec{B}$.
Loop's magnetic moment: fingers curl with I, thumb gives $\vec{m}$.

Sign of charge

For a **negative** charge, the magnetic force direction is **reversed** from the right-hand-rule result. Apply the rule for $+q$ and then flip the answer for an electron, or use the left-hand rule directly.

Quick Reference — Magnetic Forces & Fields

Quantity / Source	Expression	Notes
Force on charge	$q\vec{v} \times \vec{B}$	Perpendicular to $\vec{v}$
Force on wire	$I\vec{L} \times \vec{B}$	Right-hand rule
Circular motion radius	$\frac{mv}{qB}$	Independent of position
Cyclotron period	$\frac{2\pi m}{qB}$	Speed-independent
Velocity selector	$\frac{E}{B}$	Crossed fields
B from straight wire	$\frac{\mu_0 I}{2\pi r}$	Falls as $1/r$
B at loop centre	$\frac{\mu_0 NI}{2R}$	Along axis
B on loop axis	$\frac{\mu_0 NIR^2}{2(R^2+x^2)^{3/2}}$	Dipole at large x
B inside solenoid	$\mu_0 nI$	Uniform
B inside toroid	$\frac{\mu_0 NI}{2\pi r}$	Confined inside
Force / length (parallel)	$\frac{\mu_0 I_1 I_2}{2\pi d}$	Same dir.: attract
Magnetic moment	$NI\vec{A}$	Right-hand rule
Torque on loop	$\vec{m} \times \vec{B}$	Aligns $\vec{m}$ with $\vec{B}$
PE of magnetic dipole	$-\vec{m} \cdot \vec{B}$	Min when aligned
Cyclotron K_{max}	$\frac{q^2B^2R^2}{2m}$	At max radius