CHAPTER 4

Moving Charges and Magnetism

CBSE · Physics · Class 12

WHAT THIS CHAPTER DOES

Boards prep that builds confidence, not anxiety.

TODAY'S MISSION

Today's Mission

WHY THIS MATTERS

The Big Picture

TOPIC

Before You Start, You Should Know

TOPIC

A

Part A — Force on a Moving Charge

THEOREM · LOAD-BEARING RESULT

Magnetic Force and the Lorentz Force

> "A charge q moving with velocity v in a magnetic field B feels F = q v x B, with magnitude qvB sin(theta). With an electric field also present, the total Lorentz force is F = q(E + v x B).

STATEMENT

A charge q moving with velocity v in a magnetic field B feels F = q v x B, with magnitude qvB sin(theta). With an electric field also present, the total Lorentz force is F = q(E + v x B).

WHY THIS MATTERS

- Because F is perpendicular to v, the magnetic force does no work (F.v = 0)
- It changes the direction of motion but never the speed or kinetic energy.

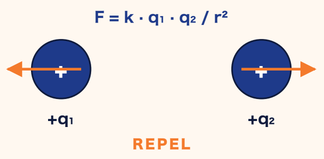
WATCH OUT FOR

NOTE A charge AT REST (v = 0) feels NO magnetic force. The force is maximum when v is perpendicular to B and zero when v is parallel to B.

WORKED EXAMPLE

Charge in a Uniform Field — Circular Motion

1. Magnetic force qvB is perpendicular to v -> it acts as the centripetal force
2. Set qvB = mv^2/r
3. Solve for radius: r = mv/(qB)
4. Time period T = 2*pi*r/v = 2*pi*m/(qB) -> independent of v and r



TOPIC

Why the Magnetic Force Does No Work

WORKED EXAMPLE

Cyclotron — Radius and Frequency

1. Ion is accelerated across the dee-gap by an alternating voltage; B bends it in a semicircle inside each dee
2. Force balance in each dee: $qvB = mv^2/r \rightarrow r = mv/(qB)$
3. Period $T = 2\pi m/(qB)$ is independent of $v \rightarrow f = qB/(2\pi m)$
4. At maximum radius R, $v_{max} = qBR/m$, so $KE_{max} = (1/2)m\, v_{max}^2 = q^2 B^2 R^2/(2m)$

TOPIC

Velocity Selector and Lorentz Balance

POINT 1	POINT 2

TOPIC

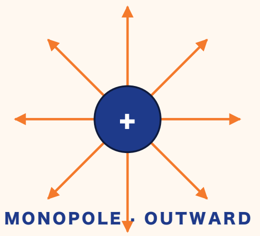
B

Part B — Fields Produced by Currents

WORKED EXAMPLE

Biot-Savart — B on the Axis of a Loop

1. Element field dB = (mu_0/4*pi) I dL/r^2 with r = sqrt(R^2+x^2) and sin(theta)=1 (dL perpendicular to r)
2. By symmetry, perpendicular components cancel; axial components dB cos(alpha) add, cos(alpha)=R/sqrt(R^2+x^2)
3. Integrate over the loop (total length 2*pi*R): B = mu_0 I R^2/[2 (R^2+x^2)^(3/2)]
4. At the centre x = 0: B = mu_0 I/(2R)



THEOREM · LOAD-BEARING RESULT

Ampere's Circuital Law

> "The line integral of B around any closed loop equals mu_0 times the net current enclosed: closed integral of B.dL = mu_0 I_enc.

STATEMENT

The line integral of B around any closed loop equals mu_0 times the net current enclosed: closed integral of B.dL = mu_0 I_enc.

WHY THIS MATTERS

- It is equivalent to the Biot-Savart law but far quicker when symmetry lets B come outside the integral (long straight wire, solenoid, toroid).

WATCH OUT FOR

NOTE I_enc is only the current THREADING the chosen Amperian loop. Currents outside the loop contribute to B but NOT to the closed line integral.

TOPIC

Standard Ampere's-Law Results

POINT 1

POINT 2

POINT 3

POINT 4

TRY IT · SOLVE BEFORE YOU PEEK

Quick Test — 60 Seconds

Work it out before you flip the answer.

SOLUTION

TOPIC

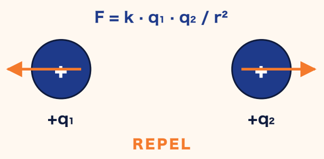
C

Part C — Forces, Torque and Meters

WORKED EXAMPLE

Force Between Two Parallel Wires

1. Field of wire 1 at wire 2: B1 = mu_0 I1/(2*pi*d)
2. Force per unit length on wire 2: F/L = I2 B1 = mu_0 I1 I2/(2*pi*d)
3. Same-direction currents attract; opposite-direction currents repel
4. Define ampere: currents giving F/L = 2 x 10^-7 N/m when d = 1 m in vacuum



TOPPER TEMPLATE · MARK-BY-MARK

Topper Template — Torque on a Loop and the Galvanometer

1. **TORQUE EXPRESSION**
   1 m
2. **RADIAL FIELD**
   1 m
3. **LINEAR SCALE + SENSITIVITY**
   1 m

PYQ PATTERNS

5 PYQ Patterns You Must Recognise

MARKS DISTRIBUTION

Where the 8-10 Marks Come From

TRY IT · SOLVE BEFORE YOU PEEK

Mid-Chapter Pulse Check

Work it out before you flip the answer.

SOLUTION

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** A magnetic field can change the speed of a moving charge

✓ **CORRECT** Force F = qv x B is always PERPENDICULAR to v, so it does ZERO work. A magnetic field changes only the DIRECTION of velocity, never the speed or kinetic energy.

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** A charge at rest experiences a magnetic force in a magnetic field

✓ **CORRECT** F = qv x B. If v = 0, the force is zero. Magnetic force acts only on MOVING charges (or currents).

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** Cyclotron frequency depends on the speed of the particle

✓ **CORRECT** f = qB/2*pi*m is INDEPENDENT of speed and radius. As the particle speeds up its radius grows but it still takes the same time per revolution — that is why a fixed-frequency oscillator works.

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** Biot-Savart law and Ampere's law give different magnetic fields

✓ **CORRECT** They are equivalent — both come from the same physics. Biot-Savart suits any geometry by integration; Ampere's law is a shortcut that works only when there is high symmetry (long wire, solenoid, toroid).

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** The magnetic field is uniform everywhere inside a finite solenoid

✓ **CORRECT** B = mu_0 n I is the field deep inside a LONG (ideal) solenoid. Near the ends the field is weaker (about half at the very end) and it fringes outward.

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** Parallel wires carrying currents in the same direction repel

✓ **CORRECT** Like (parallel, same-direction) currents ATTRACT; opposite-direction currents repel. This is the OPPOSITE of the rule for static charges.

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** Magnetic moment of a loop depends on its shape

✓ **CORRECT** $m = N I A$ depends only on the number of turns, current and the AREA enclosed — not the shape of the boundary. A circular and a square loop of equal area have equal moment.

TOPIC

Trap

TRAP → TRUTH

× **MISTAKE** A galvanometer can be used directly to measure large currents

✓ **CORRECT** A galvanometer is a sensitive, low-range device. To measure large currents it is converted to an ammeter by a LOW shunt in parallel; for voltage, to a voltmeter by a HIGH resistance in series.

TOPPER TEMPLATE · MARK-BY-MARK

Derive B on the axis of a circular current loop using Biot-Savart (3 marks)

1	**STATE BIOT-SAVART + ELEMENT FIELD** 1 m	For a current element I dL, dB = (mu_0/4*pi) I dL sin(theta)/r^2, directed by dL x r. For a loop of radius R, a point at axial distance x has r = sqrt(R^2 + x^2) and dL is perpendicular to r so sin(theta) = 1.
2	**RESOLVE AND USE SYMMETRY** 1 m	Each dB has an axial component dB cos(alpha) and a perpendicular component. By symmetry, perpendicular components from diametrically opposite elements cancel. Only axial components add, where cos(alpha) = R/sqrt(R^2 + x^2).
3	**INTEGRATE AROUND THE LOOP** 1 m	B = integral dB cos(alpha) = (mu_0 I)/(4*pi) * (1/(R^2+x^2)) * (R/sqrt(R^2+x^2)) * (2*pi*R) = mu_0 I R^2 / [2 (R^2 + x^2)^(3/2)]. At centre x = 0: B = mu_0 I/(2R).

TOPPER TEMPLATE · MARK-BY-MARK

Cyclotron — working, radius and frequency (3 marks)

1	**PRINCIPLE + WORKING** 1 m	A positive ion is accelerated across the gap between two D-shaped electrodes (dees) by an alternating voltage. A uniform magnetic field perpendicular to the plane bends it into a semicircle inside each dee. Each crossing of the gap adds energy.
2	**RADIUS FROM FORCE BALANCE** 1 m	Magnetic force provides the centripetal force: qvB = mv^2/r, so r = mv/qB. The radius grows as the ion speeds up.
3	**FREQUENCY INDEPENDENT OF V** 1 m	Time for one semicircle = pi*m/qB; full period T = 2*pi*m/qB is independent of v and r. Cyclotron frequency f = qB/(2*pi*m). The oscillator is tuned to this f (resonance). Limitation: relativistic mass increase at high speed breaks resonance.

TOPPER TEMPLATE · MARK-BY-MARK

Force between two parallel wires; define the ampere (3 marks)

1	**FIELD OF WIRE 1 AT WIRE 2** 1 m	An infinite straight wire carrying I1 produces, at perpendicular distance d, a field B1 = mu_0 I1/(2*pi*d), directed by the right-hand rule.
2	**FORCE PER UNIT LENGTH** 1 m	Wire 2 (current I2) in this field feels force per unit length F/L = I2 B1 = mu_0 I1 I2/(2*pi*d). Same-direction currents attract; opposite-direction repel.
3	**DEFINITION OF AMPERE** 1 m	One ampere is that steady current which, flowing in each of two infinitely long parallel wires 1 m apart in vacuum, produces a force of 2 x 10^-7 N per metre of length between them.

PYQ PATTERNS

Top PYQ patterns to drill

#1	State Biot-Savart law and derive B at the centre / on the axis of a circular current loop (3 marks)	88%
#2	Cyclotron	explain working and derive radius r = mv/qB and frequency f = qB/2*pi*m (3 marks) — 80%
#3	Force between two parallel current-carrying conductors; define the ampere (3 marks)	78%
#4	Torque on a current loop; magnetic moment m = NIA; moving-coil galvanometer (3 marks)	75%
#5	Convert a galvanometer to an ammeter (shunt) / voltmeter (series R); numerical (3 marks)	70%

RECAP · MEMORISE THESE

Chapter Summary

WHAT'S NEXT

Next Class

→

Your Move Tonight

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Boards prep that builds confidence, not anxiety.