Fields

IB SL Study Guide

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Aligned to IB Physics 2025 syllabus — Theme D: Fields (first assessment 2025)

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Section 1: D.1 Gravitational Fields

Quick Recall — Gravitational Fields

Q: What is gravitational field strength? A: $g = F/m$ — the gravitational force per unit mass at a point in the field. Units: N kg^{-1} (equivalent to m s^{-2}).

Q: What does the negative sign in $V = -GM/r$ mean? A: Gravitational potential is zero at infinity; it becomes more negative as you move closer to a mass. The field is attractive — work must be done against the field to move away from the mass.

Q: What is Kepler's Third Law? A: $T^2 \propto r^3$ — the square of the orbital period is proportional to the cube of the orbital radius.

Gravitational Field Strength

A **gravitational field** is a region of space in which a mass experiences a gravitational force. Field strength g at a point is defined as the force per unit mass experienced by a small test mass placed at that point:

$$g = \frac{F}{m} \qquad \text{units: N kg}^{-1}$$

For a point mass M (or outside a uniform sphere of mass M), the field strength at distance r from the centre is:

$$g = \frac{GM}{r^2}$$

where $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}.

MEMORISE THIS

Gravitational field patterns:

- Around a point mass or uniform sphere: radial field — field lines point inward toward the mass, equally spaced around the sphere (not a SL diagram requirement, but useful context)
- Near Earth's surface: approximately uniform — field lines are parallel and equally spaced, $g \approx 9.81\ \mathrm{m\ s^{-2}}$ downward

EXAM ALERT

g **is both a field strength and an acceleration.** The gravitational field strength at Earth's surface ($9.81\ \mathrm{N\ kg^{-1}}$) is numerically identical to the free-fall acceleration ($9.81\ \mathrm{m\ s^{-2}}$). IB questions sometimes describe one or the other — recognise they are the same quantity in two different roles.

Newton's Law of Gravitation

$F = \frac{GMm}{r^2}$

EXAM ALERT

r **is always centre-to-centre.** For a satellite orbiting at height h above a planet of radius R, use $r = R + h$. Using surface-to-surface distance instead is one of the most common Paper 2 errors.

Gravitational Potential

The **gravitational potential** V at a point is the work done per unit mass in bringing a small test mass from infinity to that point:

$V = -\frac{GM}{r}$ units: $\mathrm{J\ kg^{-1}}$

The negative sign reflects the attractive nature of the field — the potential decreases (becomes more negative) as you approach the mass. At $r \to \infty, V = 0$.

The **gravitational potential energy** of mass m at distance r from mass M:

$E_p = mV = -\frac{GMm}{r}$

MEMORISE THIS

Summary of gravitational quantities:

Quantity	Symbol	Formula	Unit
Gravitational field strength	g	GM/r^2	$\mathrm{N\ kg^{-1}}$
Gravitational potential	V	$-GM/r$	$\mathrm{J\ kg^{-1}}$
Gravitational potential energy	E_p	$-GMm/r$	J
Gravitational force	F	GMm/r^2	N

All four are in the IB data booklet.

WORKED EXAMPLE

Worked Example D1.1 — Gravitational potential:

Calculate the gravitational potential at the surface of the Earth.

Given: $M_E = 5.97 \times 10^{24}$ kg, $R_E = 6.37 \times 10^6$ m, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}

$V = -\frac{GM}{r} = -\frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{6.37 \times 10^6}$

$V = -\frac{3.98 \times 10^{14}}{6.37 \times 10^6} \approx -6.25 \times 10^7$ J kg^{-1}

The negative value confirms that Earth's surface is a bound location — energy must be supplied to move a mass from here to infinity.

Orbital Mechanics

For a satellite in a **circular orbit** of radius r around a planet of mass M, the gravitational force provides the centripetal force:

$$\frac{GMm}{r^2} = \frac{mv^2}{r}$$

Solving for **orbital speed**:

$$v = \sqrt{\frac{GM}{r}}$$

Using $v = 2\pi r/T$, the **orbital period** follows:

$$T^2 = \frac{4\pi^2 r^3}{GM}$$

This is **Kepler's Third Law** for circular orbits: $T^2 \propto r^3$.

EXAM ALERT

Kepler's Third Law comparisons. If a question asks you to compare two orbiting objects around the same planet, take the ratio: $\frac{T_1^2}{T_2^2} = \frac{r_1^3}{r_2^3}$. This cancels G and M, making the calculation much simpler than using absolute values.

MEMORISE THIS

Geostationary orbit conditions:

1. Orbital period = 24 hours (Earth's rotation period)
2. Orbit is in the **equatorial plane**
3. Direction of orbit is the **same** as Earth's rotation (west to east)
4. Altitude $\approx$ 36,000 km above the equator
5. Appears **stationary** from the ground

Applications: telecommunications satellites, weather satellites.

Escape Velocity

The minimum launch speed for an object to escape a planet's gravitational field (reaching $r \to \infty$ with zero kinetic energy remaining):

Setting total energy = 0:

$$\frac{1}{2}mv_{\text{esc}}^2 + \left(-\frac{GMm}{R}\right) = 0$$

$$v_{\text{esc}} = \sqrt{\frac{2GM}{R}}$$

where R is the planet's radius. Note that escape velocity depends on the planet's mass and radius — not on the mass of the escaping object.

WORKED EXAMPLE

Worked Example D1.2 — Orbital speed and period:

A satellite orbits the Earth at a height of 600 km. Calculate (a) its orbital speed and (b) its orbital period.

Data: $G = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$, $M_E = 5.97 \times 10^{24}$ kg, $R_E = 6.37 \times 10^6$ m, orbital height $h = 600$ km

$$r = R_E + h = 6.37 \times 10^6 + 6.00 \times 10^5 = 6.97 \times 10^6\ \text{m}$$

(a) Orbital speed:

$$v = \sqrt{\frac{GM}{r}} = \sqrt{\frac{6.67\times10^{-11}\times5.97\times10^{24}}{6.97\times10^6}} = \sqrt{5.71 \times 10^7} \approx 7560\ \text{m s}^{-1}$$

(b) Orbital period:

$$T = \frac{2\pi r}{v} = \frac{2\pi\times6.97\times10^6}{7560} \approx 5800\ \text{s} \approx 97\ \text{min}$$

IB TIP

Data booklet reference: $g = GM/r^2, V = -GM/r, E_p = -GMm/r, T^2 = 4\pi^2 r^3/(GM), v = \sqrt{GM/r}$, and $v_{\text{esc}} = \sqrt{2GM/R}$ are all in the data booklet. Know which formula to reach for and always check r is centre-to-centre.

▸Watch: Gravitational Fields and Orbits VIDEO

Section 2: D.2 Electric and Magnetic Fields

Quick Recall — Electric and Magnetic Fields

Q: What is the direction of an electric field line? A: From positive to negative — the direction a positive test charge would move. Field lines never cross.

Q: What direction is the magnetic force on a current-carrying wire? A: Use the left-hand rule (for conventional current): thumb = force, index finger = field B, middle finger = current I.

Q: What is the Hall effect used for? A: To determine the sign of charge carriers in a conductor and to measure magnetic field strength.

Electric Field Strength

The **electric field strength** E at a point is the force per unit positive charge experienced by a small test charge:

$$E = \frac{F}{q} \qquad \text{units: N C}^{-1} \text{ (equivalent to V m}^{-1}\text{)}$$

⚠ **EXAM ALERT**

Electric field strength is a vector. Its direction is the direction of force on a **positive** test charge. The force on a negative charge is opposite to the field direction. Forgetting to reverse the direction for negative charges is a common error.

Coulomb's Law

The electrostatic force between two point charges q_1 and q_2 separated by distance r:

$$F = \frac{kq_1q_2}{r^2} = \frac{q_1q_2}{4\pi\varepsilon_0 r^2}$$

where $k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$ and $\varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$.

The electric field of a **point charge** q at distance r:

$$E = \frac{kq}{r^2}$$

MEMORISE THIS

Comparing gravitational and electric fields:

Property	Gravitational	Electric
Source	Mass m	Charge q
Force law	$F = GMm/r^2$	$F = kq_1q_2/r^2$
Field strength	$g = GM/r^2$	$E = kq/r^2$
Potential	$V = -GM/r$	$V = kq/r$
Always attractive?	Yes	No (like charges repel)

Notice the mathematical structure is identical — this analogy is a useful memory tool.

Electric Potential

The **electric potential** V at a point is the work done per unit positive charge in bringing a small test charge from infinity to that point:

$V = \frac{kq}{r}$ units: $\text{J C}^{-1} = \text{V (volt)}$

Note: unlike gravitational potential, electric potential can be positive (near positive charge) or negative (near negative charge).

The relationship between electric field and potential:

$$E = -\frac{\Delta V}{\Delta r}$$

The field points in the direction of **decreasing** potential.

The **electric potential energy** of charge q at a point with potential V:

$$E_p = qV = \frac{kq_1q_2}{r}$$

Uniform Electric Field Between Parallel Plates

For two parallel plates separated by distance d with potential difference V between them:

$E = \frac{V}{d}$ units: V m^{-1}

The field is uniform (constant magnitude and direction) between the plates, directed from the positive plate to the negative plate.

WORKED EXAMPLE

Worked Example D2.1 — Electric field between plates:

Two parallel plates are separated by $d = 4.0$ mm and connected to a 120 V supply. Calculate (a) the electric field strength between the plates, and (b) the force on an electron between the plates.

(a) Field strength:

$$E = \frac{V}{d} = \frac{120}{4.0 \times 10^{-3}} = 3.0 \times 10^4 \text{ V m}^{-1}$$

(b) Force on electron ($q = 1.60 \times 10^{-19}$ C):

$$F = qE = 1.60 \times 10^{-19} \times 3.0 \times 10^4 = 4.8 \times 10^{-15} \text{ N}$$

The force is directed toward the positive plate (opposite to E because the electron is negatively charged).

Magnetic Field and Flux Density

The **magnetic flux density** B (also called the magnetic field strength) is measured in **tesla** (T). It characterises the strength of a magnetic field.

Field patterns (qualitative knowledge required for IB SL):

- **Straight current-carrying wire:** concentric circular field lines around the wire. Direction given by the right-hand rule: curl the fingers in the direction of field, thumb points in the direction of current.
- **Solenoid:** uniform field inside, similar to a bar magnet outside. Inside, field lines are parallel to the axis. Direction: use the right-hand rule with the coil current.

Force on a Current-Carrying Conductor

A straight conductor of length L carrying current I in a magnetic field B:

$$F = BIL\sin\theta$$

where θ is the angle between the current direction and the field direction. Maximum force when $\theta = 90^\circ$ (perpendicular); zero force when the current is parallel to the field.

MEMORISE THIS

Fleming's Left-Hand Rule (for conventional current):

- **Thumb:** direction of Force (thrust)
- **Index finger:** direction of field B
- **Middle finger:** direction of conventional Current

Keep the three fingers mutually perpendicular.

Force on a Moving Charge

A charge q moving with velocity v in a magnetic field B:

$$F = qvB\sin\theta$$

where θ is the angle between the velocity and the field. This force is always perpendicular to both v and B.

EXAM ALERT

The magnetic force does no work. Because the magnetic force $F = qvB$ is always perpendicular to the velocity, it cannot change the kinetic energy of the charged particle — only its direction. This is why a charged particle in a magnetic field moves in a circle (uniform circular motion), not a spiral.

The Hall Effect

When a current-carrying conductor is placed in a magnetic field perpendicular to the current, charge carriers are deflected sideways, building up a potential difference across the conductor known as the **Hall voltage**:

$V_H = \frac{BI}{nqt}$

where:

- B = magnetic flux density (T)
- I = current through the conductor (A)
- n = number density of charge carriers (m^{-3})
- q = charge on each carrier (C)
- t = thickness of the conductor in the direction of B (m)

MEMORISE THIS

Hall effect applications:

1. **Determining the sign of charge carriers:** the polarity of V_H depends on whether positive or negative charges are the majority carriers. If the polarity is reversed when the same current flows in the same direction, the carriers are holes (positive) rather than electrons.
2. **Measuring magnetic field strength:** rearranging gives $B = V_H nqt/I$. Hall probes are widely used in magnetometers and contactless current measurement.

WORKED EXAMPLE

Worked Example D2.2 — Hall voltage:

A copper strip of thickness $t = 0.20$ mm carries a current of 5.0 A in a magnetic field of $B = 0.15$ T perpendicular to the strip. The charge carrier density for copper is $n = 8.5 \times 10^{28}\ \text{m}^{-3}$. Calculate the Hall voltage.

$V_H = \frac{BI}{nqt} = \frac{0.15 \times 5.0}{8.5 \times 10^{28} \times 1.60 \times 10^{-19} \times 0.20 \times 10^{-3}}$

$V_H = \frac{0.75}{2.72 \times 10^{6}} \approx 2.8 \times 10^{-7}\ \text{V} = 0.28\ \mu\text{V}$

This extremely small voltage explains why Hall probes use semiconductor materials (small n) rather than metals — a smaller n gives a larger, more measurable V_H.

IB TIP

Data booklet reference: $F = kq_1q_2/r^2$, $E = kq/r^2$, $V = kq/r$, $E = V/d$, $E_p = qV$, $F = BIL\sin\theta$, $F = qvB\sin\theta$, and $V_H = BI/(nqt)$ are all in the data booklet.

▸**Watch: Electric Fields and Coulomb's Law** VIDEO

Section 3: D.3 Motion in Electromagnetic Fields

Quick Recall — Motion in EM Fields

Q: What shape is the path of a charged particle in a uniform electric field (perpendicular entry)? A: Parabolic — the same shape as projectile motion under gravity, because the electric force is constant and perpendicular to the initial velocity.

Q: What determines the radius of circular motion in a magnetic field? A: $r = mv/(qB)$. Greater momentum or smaller charge/field gives a larger radius.

Q: How does a velocity selector work? A: Electric force and magnetic force are balanced for one particular speed: $qE = qvB$, so $v = E/B$. Only particles with that speed travel in a straight line.

Charged Particle in a Uniform Electric Field

A charged particle entering a uniform electric field perpendicular to the field lines (e.g., horizontally between vertical plates) behaves exactly like a projectile:

- **Along the field direction:** constant acceleration $a = qE/m$, parabolic displacement
- **Perpendicular to the field:** constant velocity (no force component)

MEMORISE THIS

Parallel plate particle motion (entering horizontally):

- Horizontal: $x = v_0 t$ (constant velocity)
- Vertical: $y = \frac{1}{2}at^2$ where $a = \frac{qE}{m} = \frac{qV}{md}$
- Time of flight inside plates: $t = L/v_0$ where L is the plate length
- Vertical deflection: $y = \frac{qVL^2}{2mdv_0^2}$

WORKED EXAMPLE

Worked Example D3.1 — Deflection between plates:

A proton ($m = 1.67 \times 10^{-27}$ kg, $q = 1.60 \times 10^{-19}$ C) enters horizontally between parallel plates of length $L = 8.0$ cm with initial speed $v_0 = 2.0 \times 10^6$ m s^{-1}. The electric field between the plates is $E = 5.0 \times 10^4$ V m^{-1}, directed upward.

Acceleration:

$$a = \frac{qE}{m} = \frac{1.60\times10^{-19}\times5.0\times10^4}{1.67\times10^{-27}} = \frac{8.0\times10^{-15}}{1.67\times10^{-27}} \approx 4.79 \times 10^{12} \text{ m s}^{-2}$$

Time inside the plates:

$$t = \frac{L}{v_0} = \frac{0.080}{2.0\times10^6} = 4.0 \times 10^{-8} \text{ s}$$

Vertical deflection:

$$y = \frac{1}{2}at^2 = \frac{1}{2} \times 4.79 \times 10^{12} \times (4.0 \times 10^{-8})^2 = \frac{1}{2} \times 4.79 \times 10^{12} \times 1.6 \times 10^{-15} \approx 3.8 \times 10^{-3} \text{ m} = 3.8 \text{ mm}$$

Charged Particle in a Uniform Magnetic Field

A charged particle moving **perpendicular** to a uniform magnetic field experiences a force $F = qvB$ that is always perpendicular to its velocity. Since the force never does work (no component along v), the speed remains constant and the path is a **circle**.

Setting magnetic force equal to centripetal force:

$qvB = \frac{mv^2}{r}$

$r = \frac{mv}{qB}$

MEMORISE THIS

Key facts about circular motion in a B field:

- Radius $r = mv/(qB)$ — increases with momentum mv, decreases with charge or field strength
- The period $T = 2\pi m/(qB)$ — independent of speed (this is why cyclotrons work)
- If the particle enters at an angle to B, the path is a helix (SL does not require helical motion calculations)

EXAM ALERT

More massive or faster particles curve less. In a magnetic field, a proton curves less than an electron (same charge, much greater mass, so larger r). A faster particle also curves less. IB Paper 1 frequently shows two curved tracks and asks which corresponds to a higher momentum particle — it is always the track with the larger radius.

WORKED EXAMPLE

Worked Example D3.2 — Circular motion in a magnetic field:

An electron ($m = 9.11 \times 10^{-31}$ kg, $q = 1.60 \times 10^{-19}$ C) moves at 3.0×10^7 m s^{-1} perpendicular to a magnetic field of $B = 0.040$ T. Find the radius of its circular path.

$r = \frac{mv}{qB} = \frac{9.11\times10^{-31}\times3.0\times10^{7}}{1.60\times10^{-19}\times0.040}$

$r = \frac{2.73\times10^{-23}}{6.40\times10^{-21}} \approx 4.3 \times 10^{-3}\ \text{m} = 4.3\ \text{mm}$

Velocity Selector

A **velocity selector** uses crossed electric and magnetic fields to select particles of one specific speed, regardless of their mass or charge.

Setup: $\vec{E}$ and $\vec{B}$ are perpendicular to each other and both perpendicular to the particle's velocity. The electric force qE and magnetic force qvB act in opposite directions.

For straight-line (undeflected) travel, the forces must be equal:

$$qE = qvB \implies v = \frac{E}{B}$$

Only particles with speed $v = E/B$ pass through undeflected. Faster particles are deflected in the magnetic force direction; slower particles in the electric force direction.

IB TIP

The charge q cancels in the velocity selector equation. This means the selector works for any charge value — it selects by speed alone, not by charge-to-mass ratio. IB questions sometimes ask students to show this derivation — write it out step by step.

The Cyclotron

A **cyclotron** is a particle accelerator that uses a combination of:

1. A uniform magnetic field (perpendicular to the plane of motion) to curve the particles in semicircles
2. An alternating electric field across the gap between two D-shaped hollow electrodes (called **dees**) to accelerate particles each time they cross the gap

MEMORISE THIS

How a cyclotron works (step by step for IB):

1. Protons (or ions) start at the centre between the dees
2. The magnetic field causes them to travel in a semicircle inside a dee
3. As they cross the gap, the alternating voltage accelerates them (gains kinetic energy)
4. In the next dee, they travel in a larger semicircle (greater $r = mv/qB$ because v has increased)
5. They spiral outward, gaining energy each time they cross the gap
6. The period of revolution $T = 2\pi m/(qB)$ is constant regardless of speed, so the alternating field frequency stays fixed at $f = qB/(2\pi m)$ — this is the key reason the cyclotron design works
7. The maximum kinetic energy is achieved when the radius equals the dee radius

EXAM ALERT

Cyclotron vs linear accelerator. The cyclotron's advantage over a simple linear accelerator is that the magnetic field makes the particle travel in circles, so a small number of accelerating electrodes can be used many times over. The fixed-frequency condition (T independent of v) breaks down at relativistic speeds — this is why synchrotrons (which vary the field frequency) are needed for very high-energy physics.

Combined Fields: Mass Spectrometry Principles

In a **mass spectrometer**, ions pass through a velocity selector (ensuring known speed $v = E/B_1$), then enter a region of different magnetic field B_2 where they travel in semicircles. The radius of curvature is:

$r = \frac{mv}{qB_2}$

Since v, q, and B_2 are known, measuring r gives the mass m of the ion. Different isotopes (same q, different m) have different radii and land at different positions on a detector.

WORKED EXAMPLE

Worked Example D3.3 — Velocity selector and mass spectrometer:

Ions of charge $q = 1.60 \times 10^{-19}$ C pass through a velocity selector where $E = 2.4 \times 10^4$ V m^{-1} and $B_1 = 0.080$ T.

(a) Find the speed selected.

(b) The ions then enter a region with $B_2 = 0.15$ T and travel in a semicircle of radius $r = 0.21$ m. Find the mass of the ions.

(a) $v = E/B_1 = (2.4 \times 10^4)/(0.080) = 3.0 \times 10^5$ m s^{-1}

(b) Rearranging $r = mv/(qB_2)$:

$m = \frac{qB_2 r}{v} = \frac{1.60\times10^{-19}\times0.15\times0.21}{3.0\times10^5} = \frac{5.04\times10^{-21}}{3.0\times10^5} \approx 1.68 \times 10^{-26}$ kg

This corresponds to approximately 10 atomic mass units (1 u $= 1.66 \times 10^{-27}$ kg), consistent with a boron-10 ion ($^{10}_{5}$B).

IB TIP

Data booklet reference: $F = qvB\sin\theta, r = mv/(qB)$ (derivable from setting $qvB = mv^2/r$). The cyclotron frequency formula can be derived: $f = v/(2\pi r) = v/(2\pi \cdot mv/(qB)) = qB/(2\pi m)$.

Watch: Motion in Magnetic Fields — Circular Motion, Velocity Selector, and Cyclotron VIDEO

May 2026 Exam Predictions — Theme D

Paper 1 MCQ — Likely Topics

D.1 Gravitational Fields

- Given two planets with different masses and radii, calculate the ratio of surface gravitational field strengths ($g \propto M/R^2$)

- Use $T^2 \propto r^3$ to find the period or radius of a second orbit when the first is known
- State which of four statements about geostationary satellites is correct
- Identify the sign and shape of a gravitational potential graph ($V = -GM/r$, negative and asymptotically approaching zero from below)

D.2 Electric and Magnetic Fields

- Coulomb's law: if one charge is doubled and separation is halved, find the factor change in force
- Identify the direction of force on a charge moving in a magnetic field (left-hand rule / $\vec{v} \times \vec{B}$)
- Which statement about the Hall effect is correct — expect one option about carrier sign determination
- Compare field lines of a uniform electric field vs a point charge field

D.3 Motion in EM Fields

- Given a diagram of two particle tracks in a magnetic field, identify which has greater momentum (larger radius = greater momentum)
- A proton and an electron enter a magnetic field with the same speed — compare their radii (proton has larger r because greater mass)
- Velocity selector: show that the selected speed is independent of charge — expect a derivation-style MCQ

Paper 2 Multi-Part — Likely Questions

Question type 1 (D.1): Satellite orbit calculation

Typical structure: given a planet's mass and radius, calculate orbital speed and period at a specified altitude. Then state what happens to orbital speed if the satellite moves to a higher orbit (speed decreases — counter-intuitive but follows from $v = \sqrt{GM/r}$). May ask to explain why a geostationary orbit must be equatorial.

Question type 2 (D.2): Parallel plate deflection

Given plate separation, voltage, and particle initial speed, calculate: (a) electric field between plates; (b) acceleration of particle; (c) vertical deflection after travelling the length of the plates. Expect 5–7 marks total with a follow-up asking about the shape of the trajectory.

Question type 3 (D.3): Cyclotron or mass spectrometer

Describe how a cyclotron accelerates protons — IB mark schemes want at minimum: role of the dees, role of the alternating electric field at the gap, role of the magnetic field causing circular motion, and why the radius increases. Alternatively, a mass spectrometer calculation: select speed, find radius, determine mass.

⚠ **EXAM ALERT**

Theme D most-dropped marks (from past IB mark schemes):

1. Using surface radius instead of $r = R + h$ for satellite problems
2. Stating that the magnetic force does work on a moving charge — it does NOT
3. Forgetting to square r in Kepler's Third Law ratio comparisons
4. Confusing electric field strength E (force per charge) with electric potential V (energy per charge)
5. Stating the cyclotron frequency changes as the particle speeds up — it does NOT (that is the whole point of the cyclotron design)

Exam-Style Practice Questions

Paper 1 Style (MCQ)

Q1. A satellite orbits a planet in a circular orbit of radius r. The gravitational field strength at radius r is g. Which expression gives the orbital speed of the satellite?

A. $\sqrt{gr}$

B. $\sqrt{g/r}$

C. gr

D. g/r

▶ Answer

Q2. A proton and an electron enter a region of uniform magnetic field with the same speed, both moving perpendicular to the field. How do their radii of curvature compare?

A. The proton has a smaller radius because it has greater charge.

B. The radii are equal because the charges are equal in magnitude.

C. The electron has a larger radius because the magnetic force on it is directed opposite to the field.

D. The proton has a larger radius because it has greater mass.

▶ Answer

Q3. An electric field E and magnetic field B are perpendicular to each other in a velocity selector. A particle of charge q and mass m travels undeflected through the selector. The speed of the particle is:

A. qB/E

B. E/B

C. qE/mB

D. B/E

▶ Answer

Q4. Two identical point charges, each of charge $+Q$, are separated by distance d. The electric force between them is F. The separation is increased to $3d$ and one charge is changed to $-2Q$. What is the new force?

A. $\frac{2F}{9}$

B. $\frac{F}{9}$

C. $\frac{2F}{3}$

D. $2F$

▶ Answer

Paper 2 Style (Structured Response)

Q5. A satellite of mass m orbits Earth (mass M, radius R) at an altitude h above the surface.

(a) Show that the orbital speed is given by $v = \sqrt{GM/(R+h)}$. [2]

(b) The satellite is at altitude $h = 200$ km. Given $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}, $M = 5.97 \times 10^{24}$ kg, $R = 6.37 \times 10^6$ m, calculate the orbital period in minutes. [3]

(c) State two conditions that a geostationary satellite must satisfy in addition to having the correct orbital period. [2]

(d) Explain why a geostationary orbit must be at one specific altitude and no other. [2]

▶ Mark-scheme answers

Q6. A student investigates the motion of electrons in a magnetic field. Electrons are accelerated through a potential difference $V_a = 2.5$ V from rest, then enter a uniform magnetic field of $B = 8.0 \times 10^{-3}$ T perpendicular to their velocity.

Data: $m_e = 9.11 \times 10^{-31}$ kg, $e = 1.60 \times 10^{-19}$ C

(a) Calculate the speed of the electrons as they enter the magnetic field. [2]

(b) Calculate the radius of the circular path. [2]

(c) Explain why the magnetic field does no work on the electron as it moves in the circle. [2]

(d) The electron beam is adjusted so that the same electrons also pass through a region of uniform electric field directed perpendicular to both the electron velocity and B. State the value of E required so that the electrons travel in a straight line, and state which direction E must point. [2]

▶ Mark-scheme answers

⚠ **EXAM ALERT**

Theme D final checklist before the exam:

- Know all four gravitational field formulas and when to use each
- Remember $r = R + h$ for satellite orbit problems
- Understand the negative sign in $V = -GM/r$ and $E_p = -GMm/r$
- Know that the magnetic force does NO work on a charged particle
- Know $r = mv/(qB)$ and be able to derive it from $qvB = mv^2/r$
- Be able to explain the velocity selector using force balance $qE = qvB$
- Be able to describe the cyclotron: dees, alternating field, why radius increases, why frequency is constant