IB DP PHYSICS

Theme D · Fields

MARK SCHEME

D.1 Gravitational Fields · D.2 Electric and Magnetic Fields
D.3 Motion in Electromagnetic Fields · D.4 Induction (HL)

Standard and Higher Level · Syllabus 2025

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Original exam-style questions written for the IB Diploma Programme Physics course (first assessment 2025)

Section A — Multiple Choice: Answer Key (15 marks)

1. Answer: **B** — $F = Gm_1m_2/r^2 = 6.67\times10^{-11}\cdot5.0\cdot3.0/0.20^2 = 2.50\times10^{-8}$ N.

2. Answer: **B** — Gravity is always attractive, so the gravitational field strength at any point is directed towards the mass producing the field.

3. Answer: **B** — Gravity provides centripetal force: $GMm/r^2 = mv^2/r \Rightarrow v = \sqrt{(GM/r)} = 7.54$ km s^{-1}.

4. Answer: **C** — $T \in r^{3/2}$, so if r increases by a factor of 4, T increases by a factor of $4^{3/2} = 8$.

5. Answer: **C** — $F = kq_1q_2/r^2 = 8.99\times10^9\cdot(2.0\times10^{-6})^2/0.30^2 = 0.40$ N.

6. Answer: **B** — Electric field lines point away from positive charges (and towards negative charges), radially outward for an isolated point charge.

7. Answer: **A** — $F = qvB = 1.6\times10^{-19}\cdot2.0\times10^6\cdot0.50 = 1.6\times10^{-13}$ N.

8. Answer: **C** — $F = BIL\sin\theta$ is maximised when $\sin\theta = 1$, i.e. when the current is perpendicular to the field ($\theta = 90°$).

9. Answer: **B** — $r = mv/(qB) = (9.11\times10^{-31}\cdot3.0\times10^6)/(1.6\times10^{-19}\cdot0.20) = 8.5\times10^{-5}$ m.

10. Answer: **C** — For straight-through motion, electric and magnetic forces balance: $qE = qvB \Rightarrow v = E/B = 1.0\times10^5/0.40 = 2.5\times10^5$ m s^{-1}.

11. Answer: **D** — $T = 2\pi m/(qB)$ contains no dependence on speed v: faster particles move in larger circles, but complete each revolution in the same time.

12. Answer: **D** — $EMF = N\Delta\Phi/\Delta t = 200\cdot0.050/0.20 = 50$ V.

13. Answer: **B** — $V_s/V_p = N_s/N_p \Rightarrow V_s = 230\cdot100/500 = 46$ V.

14. Answer: **B** — Lenz's law (a consequence of energy conservation) states that the induced current always flows in the direction that opposes the change in flux that caused it.

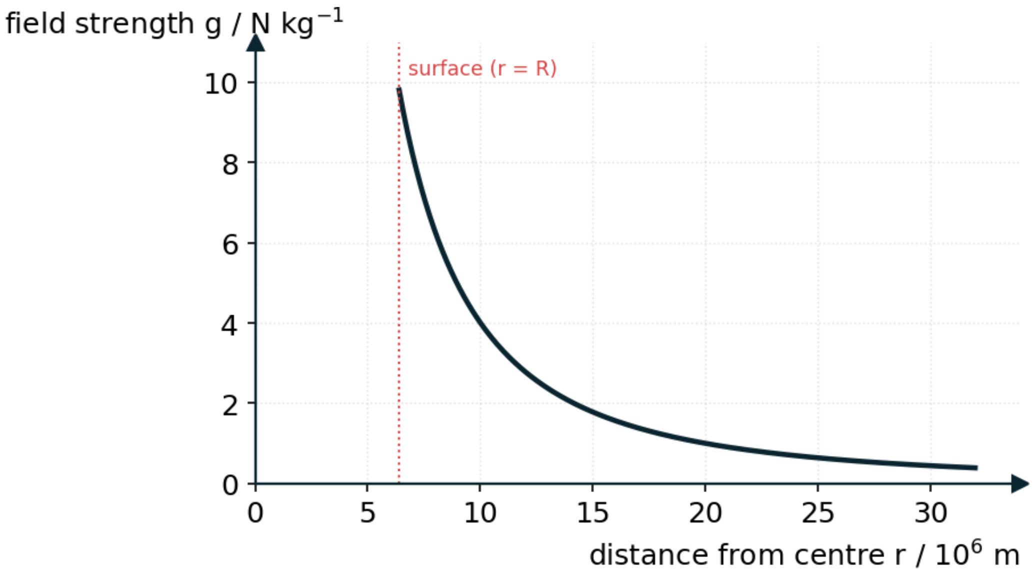
Section B — Structured Questions: Worked Solutions (65 marks)

Mark-scheme notation: M = method mark, A = accuracy mark (dependent on the preceding M mark), R = reasoning mark.

D.1 Gravitational Fields

Question 1 [7 marks]

The graph shows how the gravitational field strength g varies with distance r from the centre of a planet of radius R, for points on or above its surface.



Gravitational field strength g against distance from the planet's centre (surface value and radius are given data).

(a) Using the surface value $g = 9.8$ N kg^{-1} at $R = 6.4\times10^{6}$ m (marked on the graph), calculate the mass of the planet. **[3]**

$g = GM/R^2 \Rightarrow M = gR^2/G = (9.8\cdot(6.4\times10^6)^2)/6.67\times10^{-11} = \mathbf{6.018\times10^{24}}$ **kg**. **M1 M1 A1**

(b) Calculate the field strength at a distance of 2R from the centre of the planet. **[2]**

$g(2R) = GM/(2R)^2 = g(R)/4 = 9.8/4 =$ **2.45 N kg^{-1}**. **M1 A1**

(c) State how the gravitational field strength of a point (or spherical) mass varies with distance from its centre. **[2]**

The field strength obeys an inverse-square law: $g \in 1/r^2$, i.e. g is inversely proportional to the square of the distance from the centre of the mass. **A1 A1**

Question 2 [6 marks]

A planet has mass 6.0×10^{24} kg and radius 6.4×10^{6} m.

(a) Calculate the escape velocity from the surface of the planet. **[2]**

$v_{esc} = \sqrt{(2GM/R)} = \sqrt{((2\cdot6.67\times10^{-11}\cdot6.0\times10^{24})/6.4\times10^{6})} =$ **11183 m s^{-1}** (≈ 11.18 km s^{-1}). **M1 A1**

(b) Calculate the gravitational potential at the surface of the planet. **[2]**

$V = -GM/R = -(6.67\times10^{-11}\cdot6.0\times10^{24})/6.4\times10^{6} = \mathbf{-6.253\times10^{7}}$ **J kg^{-1}**. **M1 A1**

(c) A 500 kg satellite is launched from the surface to completely escape the planet's gravity. Calculate the minimum kinetic energy it must be given. **[2]**

$KE_{min} = \frac{1}{2}mv_{esc}^2 = 0.5 \cdot 500 \cdot 11183^2 = \mathbf{3.127 \times 10^{10}\ J}$. **M1 A1**

Question 3 [7 marks]

A satellite orbits Earth (mass 5.97×10^{24} kg) in a circular orbit of radius 7.20×10^6 m.

(a) By equating the gravitational force to the required centripetal force, show that the orbital speed is $v = \sqrt{(GM/r)}$, and calculate its value. **[3]**

$GMm/r^2 = mv^2/r \Rightarrow v = \sqrt{(GM/r)}$. **M1 M1 A1**
$v = \sqrt{((6.67 \times 10^{-11} \cdot 5.97 \times 10^{24})/7.20 \times 10^6)} = \mathbf{7437\ m\ s^{-1}}$.

(b) Calculate the orbital period of the satellite. **[2]**

$T = 2\pi r/v = (2\pi \cdot 7.20 \times 10^6)/7437 = \mathbf{6083\ s}$ ($\approx$ 1.69 hours). **M1 A1**

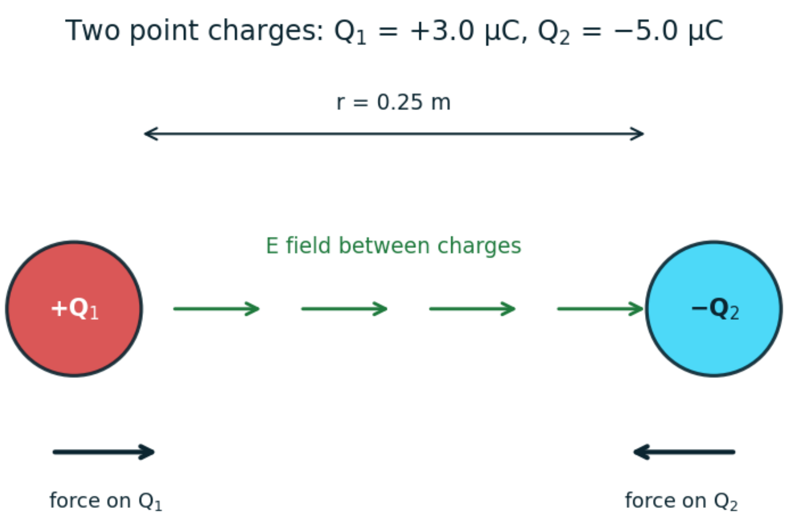
(c) State, using Kepler's third law, how the orbital period would change if the satellite were moved to a larger orbital radius. **[2]**

Kepler's third law: $T^2 \in r^3$. A larger orbital radius r therefore corresponds to a **longer** orbital period T. **R1 A1**

D.2 Electric and Magnetic Fields

Question 4 [7 marks]

Two point charges, Q_1 = +3.0 μC and Q_2 = −5.0 μC, are fixed 0.25 m apart, as shown.



The two point charges and the electric field between them.

(a) Calculate the magnitude of the electric force between the two charges. **[2]**

$F = kQ_1Q_2/r^2 = (8.99 \times 10^9 \cdot 3.0 \times 10^{-6} \cdot 5.0 \times 10^{-6})/0.25^2 = \mathbf{2.16\ N}$. **M1 A1**

(b) State the direction of the force on each charge, and explain your reasoning. **[2]**

Since the charges have opposite signs, the force is **attractive**: each charge experiences a force directed towards the other charge, along the line joining them. **A1 R1**

(c) Calculate the magnitude of the net electric field at the midpoint between the two charges. **[3]**

At the midpoint, distance from each charge = 0.125 m. **M1 M1 A1**
E_1 (due to Q_1) = $kQ_1/(0.125)^2 = 1.73\times10^6$ N C^{-1}; E_2 (due to Q_2) = $kQ_2/(0.125)^2 = 2.88\times10^6$ N C^{-1}.
Both fields point in the same direction (from Q_1 towards Q_2), so they add: E_{total} = $\mathbf{4.60\times10^6}$ **N** $\mathbf{C^{-1}}$.

Question 5 [6 marks]

A straight wire of length 0.40 m carries a current of 5.0 A, oriented perpendicular to a uniform magnetic field of flux density 0.30 T.

(a) Calculate the magnitude of the force on the wire. **[2]**

F = BIL = 0.30·5.0·0.40 = **0.60 N**. **M1 A1**

(b) State how the direction of this force can be determined. **[2]**

The direction is given by F = I**L**×**B** (or, equivalently, the right-hand or left-hand slap rule): the force is perpendicular to both the current direction and the magnetic field direction. **A1 A1**

(c) State and explain the force on the wire if it were instead oriented parallel to the magnetic field. **[2]**

The force would be **zero**. Since F = BIL sinθ, and θ = 0° when the wire is parallel to B, sinθ = 0 and no force is produced. **A1 R1**

Question 6 [6 marks]

A charge of +2.0 μC is moved from a point in an electric field where the potential is 500 V to a point where the potential is 200 V.

(a) Calculate the work done by the electric field on the charge as it moves between these points, and state whether this work is positive or negative. **[3]**

$W = q(V_1 - V_2) = 2.0\times10^{-6}\cdot(500 - 200)$ = $\mathbf{6.00\times10^{-4}}$ **J** (positive – the field does positive work on the charge as it moves to lower potential). **M1 A1 A1**

(b) Calculate the change in electric potential energy of the charge, and state whether it increased or decreased. **[3]**

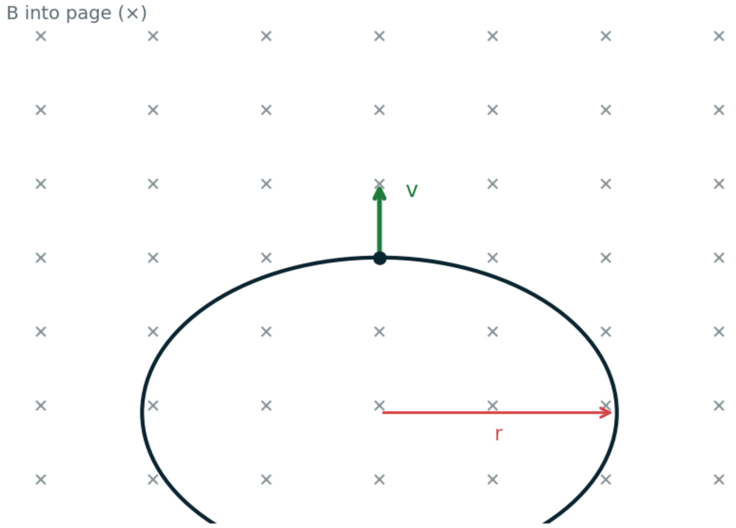
$\Delta E_p = q(V_2 - V_1) = 2.0\times10^{-6}\cdot(200 - 500)$ = $\mathbf{-6.00\times10^{-4}}$ **J**. The potential energy **decreased** (consistent with the field doing positive work on the charge, converting PE to KE). **M1 A1 A1**

D.3 Motion in Electromagnetic Fields

Question 7 [7 marks]

An electron (mass 9.11×10^{-31} kg, charge magnitude 1.6×10^{-19} C) enters a uniform magnetic field of flux density 0.50 mT, directed into the page, moving at 4.0×10^6 m s^{-1} perpendicular to the field, as shown.

Electron entering a uniform magnetic field



The electron follows a circular path while in the field.

(a) Calculate the radius of the electron's circular path. **[3]**

The magnetic force provides the centripetal force: $qvB = mv^2/r \Rightarrow r = mv/(qB)$. **M1 M1 A1**
$r = (9.11\times10^{-31}\cdot4.0\times10^{6})/(1.6\times10^{-19}\cdot0.50\times10^{-3})$ = $\mathbf{4.55\times10^{-2}}$ **m** (≈ 4.55 cm).

(b) Calculate the period of the circular motion. **[2]**

$T = 2\pi m/(qB) = (2\pi\cdot9.11\times10^{-31})/(1.6\times10^{-19}\cdot0.50\times10^{-3})$ = $\mathbf{7.155\times10^{-8}}$ **s**. **M1 A1**

(c) State how the radius of the path would change if the electron's speed were doubled, with all other quantities unchanged. **[2]**

Since $r = mv/(qB) \in v$, doubling the speed would **double the radius** of the circular path. **A1 R1**

Question 8 [6 marks]

In a velocity selector, charged particles pass through a region containing a uniform electric field of magnitude 2.0×10^4 V m^{-1} and a perpendicular uniform magnetic field of magnitude 0.25 T.

(a) Calculate the speed of particles that pass straight through the selector undeflected. **[2]**

For undeflected motion, the electric and magnetic forces balance: $qE = qvB \Rightarrow v = E/B$ = $2.0\times10^4/0.25$ = $\mathbf{8.00\times10^{4}}$ **m s^{-1}**. **M1 A1**

(b) Explain why particles travelling at a different speed do not pass straight through the selector. **[2]**

For particles at any other speed, the electric and magnetic forces (qE and qvB) no longer have equal magnitude, so there is a net sideways force that deflects the particle out of a straight path. **R1 R1**

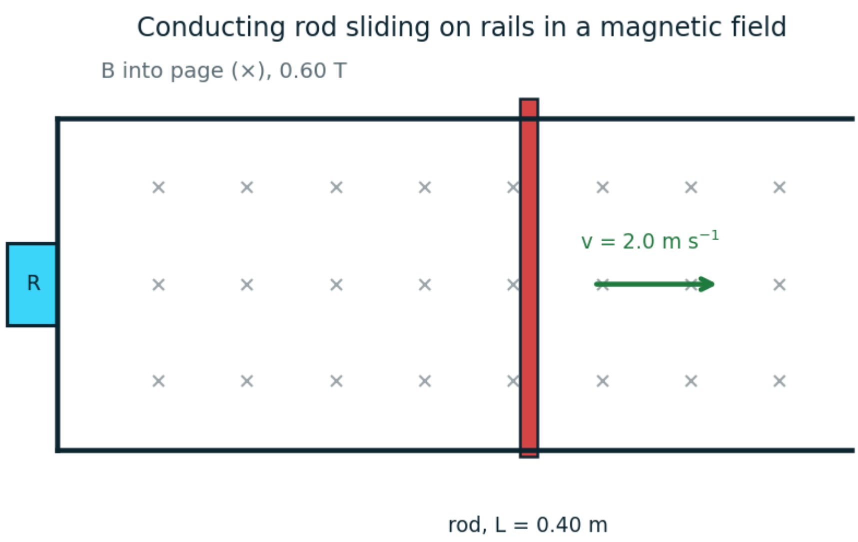
(c) State how the magnetic field strength would need to be changed, with the electric field kept fixed, to select particles moving at twice this speed. **[2]**

Since $v = E/B$, for the selected speed to double (with E fixed), B must be **halved**: $B_{new} = E/(2v)$ = **0.125 T**. **M1 A1**

D.4 Induction (HL)

Question 9 [7 marks]

A conducting rod of length 0.40 m slides at a constant speed of 2.0 m s^{-1} along horizontal frictionless rails, in a region of uniform magnetic field of flux density 0.60 T directed into the plane of the rails, as shown. The rails are connected to a resistor of resistance 2.0 Ω.



A conducting rod sliding on rails generates a motional EMF.

(a) Calculate the EMF induced in the rod. **[2]**

EMF = BLv = 0.60·0.40·2.0 = **0.48 V**. **M1 A1**

(b) Calculate the current in the circuit, and the force required to keep the rod moving at constant speed. **[3]**

I = EMF/R = 0.48/2.0 = **0.24 A**.
F = BIL = 0.60·0.24·0.40 = **0.0576 N** (needed to balance the opposing magnetic force on the current-carrying rod). **M1 A1 M1 A1**

(c) State the direction of the induced current predicted by Lenz's law, and explain your reasoning. **[2]**

By Lenz's law, the induced current flows in the direction that opposes the change in flux through the circuit produced by the rod's motion – i.e. it creates a magnetic force on the rod that opposes its motion, and a magnetic effect that opposes the increasing flux through the circuit as the enclosed area grows. **R1 R1**

Question 10 [6 marks]

A transformer has 800 turns on its primary coil and 100 turns on its secondary coil. The primary is connected to a 230 V AC supply, and the secondary delivers a current of 12 A to a resistive load. Assume the transformer is 100% efficient.

(a) Calculate the secondary voltage. **[2]**

$V_s/V_p = N_s/N_p \Rightarrow V_s = V_pN_s/N_p$ = 230·100/800 = **28.75 V**. **M1 A1**

(b) Using conservation of power (assuming 100% efficiency), calculate the current in the primary coil. **[2]**

$V_p I_p = V_s I_s \Rightarrow I_p = V_s I_s / V_p = (28.75 \cdot 12)/230 =$ **1.50 A**. **M1 A1**

(c) State whether this is a step-up or step-down transformer, and explain how you know. **[2]**

This is a **step-down** transformer. It has fewer turns on the secondary than the primary ($N_s < N_p$), so the output (secondary) voltage is lower than the input (primary) voltage. **A1 R1**