H2 Physics 9749 – 2025 A Level Exam

Paper 1

<table>
<tr><td>1</td><td colspan="2">Essential Question(s):
• How can magnetic flux density be expressed in terms of other physical quantities?

Approach: Recall the formulas that contain Magnetic flux density (B)
1. $B = \Phi/A$
2. $F = BIL$
3. emf = $-d\Phi/dt$
$= -d(BA)/dt$

Unit of B = T</td></tr>
<tr><td></td><td>Suggested Solution 1: (Proving if options are correct)

Option A: Using $B = \Phi/A$
Unit of B = unit of Φ / unit of A
T = Wb m^{-2}.

Option B: Using emf = $-d\Phi/dt = -d(BA)/dt$
Unit of emf = unit of BA / unit of time
V = (T m^2)/t
T = V s m^{-2}

Option C: Using $F = BIL$,
Unit of B = N A^{-1} m^{-1}
= N m A^{-1} m^{-2}
= J A^{-1} m^{-2}

Option D: Using $F = BIL$
$F = B(Q/t)L$
Unit of B = [Ft]/ [QL]
= N m^{-1} s C^{-1}. ✗

Answer: C</td><td>Suggested Solution 2: (Check if the options are correct)

Option A:
Wb m^2
= (T m^2) m^2 → unit of Wb = T m^2

Option B:
V s
= Wb s^{-1} s → unit of V = Wb s^{-1}
= T m^2 s^{-1} s

Option C:
Use Solution 1

Option D:
Use Solution 1</td></tr>
<tr><td>2</td><td colspan="2">Essential Question(s):
• How do you calculate percentage uncertainty when quantities are multiplied and divided?
• What is the formula for combining uncertainties in multiplication and division?
• How do you handle powers in uncertainty calculations?

Solution:
$a = bc^2/d$,
$\Delta a/a = \Delta b/b + 2(\Delta c/c) + \Delta d/d$
$\Delta a/a = 3/24 + 2(2/13) + 1/18$
$\Delta a/a = 0.125 + 0.308 + 0.056$
$\Delta a/a = 0.489$
$(\Delta a/a) \times 100\% = 49\%$

Answer: D</td></tr>
<tr><td>3</td><td>Essential Question(s):
• What are the key equations for projectile</td><td>To derive range R</td></tr>
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motion?
• How do you relate maximum height and range in projectile motion?
• What is the relationship between launch angle and trajectory parameters?

Solution:
For projectile motion:
Range $R = (2u^2\sin\theta\cos\theta)/g$ -- (3)
Maximum height $H = (u^2\sin^2\theta)/(2g)$ – (4)

Divide eqn (4) by (3),
$H/R = (\tan\theta) / 4$
$\tan\theta = 4H/R$

Given: $H = x$ and $R = 6x$
$\tan\theta = 4/6 = 2/3$

Answer: B
</td>
<td>
Let t be the time to return to ground level.
Then t/2 is time taken to reach maximum height.

Horizontal direction: Take right as positive direction.
Use "$s_x = u_x t$"
$R = (u\cos\theta)t$ -- (1)

Vertical direction: Take upwards as positive direction.
Use "$v_y = u_y + a_y t$"
At max. height, $v_y = 0$
$0 = u\sin\theta + (-g)(\mathbf{t/2})$
$u\sin\theta = g(t/2)$
$t = 2u\sin\theta/g$ -- (2)

Sub (2) into (1):
$R = (u\cos\theta)(2u\sin\theta/g)$
$R = (2u^2\sin\theta\cos\theta)/g = (u^2\sin 2\theta)/g$

To derive max height H

Vertical direction:
Use "$v_y^2 = u_y^2 + 2a_y s_y$"
$0 = (u\sin\theta)^2 + 2(-g)H$
$(u\sin\theta)^2 = 2gH$
$H = (u\sin\theta)^2/2g$
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<td>4</td>
<td colspan="2">
Essential Question(s):
• What determines acceleration? → net force
• What are the forces acting on the ice cube? → Draw free body diagram to visualize. Buoyant force acts upwards and Weight of ice cube acts downwards.
• How do you calculate buoyant force when an object is fully submerged?
• Which force, buoyant force or weight of ice cube, is larger? What then is the net force? → Since ice cube was floating initially, it was initially in vertical equilibrium. After it was pushed downwards, its weight is unchanged but because it displaced more fluid the buoyant force increased. So buoyant force exceeds weight of ice cube & the net force acts upwards and equal to (buoyant force – weight of ice cube).
• How to relate acceleration and net force? → Newton's 2nd law.

Solution:
When fully submerged:
Buoyant force = $\rho_{water} \times V_{cube} \times g = 1000 \times (0.02)^3 \times 9.81 = 0.0785$ N → This formula is not in Syllabus for 2026 Exam onwards.
Weight of cube = $\rho_{ice} \times V_{cube} \times g = 920 \times (0.02)^3 \times 9.81 = 0.0722$ N
Net upward force = 0.785 - 0.722 = 0.0063 N
Mass of cube = $0.92 \times (2.0)^3 = 7.4$ g = 0.074 kg
Initial acceleration = net force / mass = 0.0063 / 0.0074 = 0.85 m/s²

Answer: B
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<tr>
<td>5</td>
<td colspan="2">
Essential Question(s):
• What features of a velocity-time graph relates to resultant force? → gradient gives acceleration, and, resultant force = mass x acceleration.
• What does it mean when velocity is constant on a v-t graph?
• How do you interpret the forces acting on a falling object with air resistance?
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Solution:
From Newton's second law, $F_{net} = ma$, where a is the gradient of the v-t graph.

The velocity is constant (acceleration = 0) at t = 30 s (terminal velocity when parachute is not opened yet) and t = 60 s (terminal velocity when parachute is fully opened).

This means the net force on parachutist is zero (weight of parachutist equals air resistance) at both of these timings.

Answer: C

6 **Essential Question(s):**

- How do you calculate torque about a pivot?
- What happens to torque when both force magnitude and distance change?

Solution:
Let distance between any two labelled points be *d*.
Take clockwise as positive direction.

Initially: $F_1 = F_2 = F$ in magnitude
Torque about pivot = $F_1 d – F_2(3d) = Fd – F(3d) = -2Fd = -T$

After changes: $F_1 = F_2 = F/2$ in magnitude
F_2 moves to R.
New torque about the same pivot = $F_1 d – F_2(2d) = (F/2)d – (F/2)(2d) = -Fd/2 = -T/4$

Answer: B

7 **Essential Question(s):**

- How does Hooke's law apply to wires under tension?
- What is the relationship between extension and applied force for elastic materials?
- How does the configuration of the wire affect its effective force constant?

Solution:

<u>Method 1:</u>
Initially: extension d produced by force W, so force constant k = W/d for the whole wire.

When folded in half: Each half has force constant 2k (length shortened by half, same material).
Two halves in parallel: Effective force constant = 2k + 2k = 4k
New extension produced by the same force W: x = W/(4k) = W/(4W/d) = **d/4**

<u>Method 2:</u>
Initially:
$T_1 = W$
kd = W   where k is the force constant for the wire   -----(1)

When folded in half:
$2T_2 = W$
$2(kx_2) = W$ same k considering same continuous length of wire   -----(2)

(1) = (2):
$x_2 = d/2$
This is the <u>**total** extension</u> of the wire <u>to produce tension equal to T_2</u>.
Since wire is folded in half, vertical distance moved = ½ x d/2 = **d/4**

	Answer: B
8	**Essential Question(s):** • What conservation laws apply for elastic collisions? → conservation of total momentum throughout, and, conservation of total kinetic energy before & after the collision. • What is the relationship between initial and final velocities in elastic collisions? → Solving the 2 conservation laws simultaneously, we can derive “relative speed of approach = relative speed of separation”. **Solution:** $v = v_Q - v_P$ represents the relative speed of separation. In elastic collisions, the relative speed of approach equals the relative speed of separation. Since Q is initially at rest: relative speed of approach = u - 0 = u Therefore: v = u , v is directly proportional to u. The graph should be a straight line through the origin with slope = 1. **Answer: A**
9	**Essential Question(s):** • What is the relationship between power, work done, and time? • How do you calculate work done against gravity? • What is the energy transformation taking place? **Solution:** Power out P = (work done against gravitational force) / time = (weight × vertical displacement) / time = (W × h) / t Rearranging: h = Pt / W OR Assume no change in kinetic energy, All energy supplied by motor transforms into gain in GPE. Pt = mgh Pt = Wh since W = mg h = Pt / W **Answer: B**
10	**Essential Question(s):** • How do you calculate the speed of a point on a rotating object? **Solution:** $v = r\omega$ $v = r\left(\frac{2\pi}{T}\right) = 0.30\left(\frac{2\pi}{66\times 60}\right) = 4.8\times 10^{-4}\ \text{m s}^{-1}$ OR Circumference of circle = 2πr = 2π × 0.30 = 1.885 m Actual time for one revolution = 66 minutes = 66 x 60 = 3960 s Average speed = distance/time = 1.885/3960 = 4.8×10^{-4} m s^{-1}

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<tr><td></td><td>Answer: A</td></tr>
<tr><td>11</td><td>Essential Question(s):
• How does gravitational field strength vary with distance from Earth?
• Why is g ≈ 9.81 m s^{-2} only valid at or near Earth's surface?

Solution:
The expression W = 9.81 × m assumes gravitational field strength g is constant at 9.81 N kg^{-1}.
However, g = GM/r², so g decreases with distance r from Earth's centre.
Far above Earth's surface, g is significantly smaller than 9.81 N kg^{-1}, making the expression invalid.
Note: N kg^{-1} = m s^{-2}

Recap how g = 9.81 N kg^{-1} is derived:
Consider a mass at height h about Earth's surface, where radius of Earth is R_E and mass of Earth is M_E:
$g = \frac{GM_E}{(R_E + h)^2}$
For h <<< R_E, $g \approx \frac{GM_E}{{R_E}^2}$
Substituting known values of R_E and M_E, we get g ≈ 9.81 N kg^{-1}.

Answer: A</td></tr>
<tr><td>12</td><td>Essential Question(s):
• What does thermal equilibrium mean? → no net heat transfer between 2 bodies in thermal contact.
• When will there be no net heat transfer between 2 bodies? → 2 bodies are at the same temperature.

Solution:
Objects in thermal equilibrium have no net heat transfer between them and must be at the same temperature.

Option A: Internal energy depends on both temperature and mass, in this case, objects with different masses at the same temperature have different internal energies
Option B: In thermal equilibrium, objects have the same temperature.
Option D: Both objects are made of the same material hence the specific heat capacity is the same for both objects.

Answer: C</td></tr>
<tr><td>13</td><td>Essential Question(s):
• What equation relates pV and temperature for an ideal gas?
• How to determine the number of moles from a pV-temperature graph?

Solution:
From ideal gas equation: pV = nRT   where T is in kelvins.
However θ on the graph is in °C.
So pV = nR(θ + 273.15)
Therefore, on the graph of pV against θ,
gradient = nR</td></tr>
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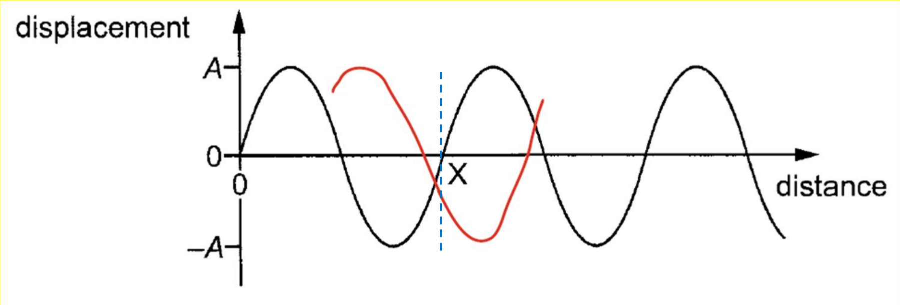
	$$\frac{150-135}{30-0}=n(8.31)$$ $$n=\frac{0.5}{8.31}=0.060 \text{ mol}$$ **Answer: A**
14	**Essential Question(s):** • How does internal energy relate to temperature and amount of substance? • What determines the average kinetic energy of molecules? **Solution:** The mean microscopic KE of molecules of a system is directly proportional to the thermodynamic temperature of the system. Therefore, since both beakers of water are at the same temperature, the mean/average KE of the molecules is the same. Internal energy equal to sum of the random KE and random PE of <u>all</u> molecules of the system. Both beakers contain water in the same phase/state, hence same mean PE between molecules. The mean KE of the molecules, as explained above, is also the same. However, different volumes of water have different numbers of molecules, so different internal energies. **Answer: C**
15	**Essential Question(s):** • How to relate the goal (ΔU) to the given information (Q and W)? → First law of thermodynamics • What are the sign conventions when applying this law? **Solution:** First law of thermodynamics: ΔU = Q + W Q = heat supplied **to** gas = +50 J W = work done **on** gas = -30 J (negative, since in fact there is work done ***by*** gas) Therefore: ΔU = 50 + (-30) = +20 J The magnitude of change in internal energy is 20 J. **Answer: A**
16	**Essential Question(s):** • What is the principle of conservation of energy in SHM? • How do kinetic and potential energies vary during oscillation? • What remains constant throughout the motion? **Solution:** In undamped SHM, total mechanical energy (KE and PE) is conserved. At every point: KE + PE = constant. This can be rearranged as: PE = constant – KE Option C: KE is maximum at equilibrium position and decrease to zero at the amplitude positions. **Answer: B**
17	**Essential Question(s):** • What is resonance and when does it occur?

	• How do you distinguish between resonance and simple amplitude increase? **Solution:** Resonance occurs when the driving frequency matches the natural frequency of oscillations of a system. Option A: increasing amplitude of vibration is due to increasing input energy and not due to a different driving frequency. Options B, C, and D all involve driving frequencies matching natural frequencies of the systems. **Answer: A**
18	**Essential Question(s):** • How do standing waves form in a closed tube? • What is the relationship between tube length and wavelength for standing waves? (What are the boundary conditions for a closed tube? • How do you interpret the pattern of powder heaps? **Solution:** In a closed tube, standing waves form with a displacement node at the closed end and displacement antinode at the open end. In a standing wave, the air molecules at displacement nodes have zero amplitude of vibration, while across a displacement node the air molecules vibrate in antiphase. This causes the powder to collect at the displacement nodes. From the picture given, there are 1¾ wavelengths within the tube. 1¾ wavelengths is 3.5 m long. 1 wavelength is 2.0 m **Answer: B**
19	**Essential Question(s):** • How do standing waves form from two progressive waves? • What is the phase relationship in standing wave formation? • How do you determine displacement at specific times and positions? **Solution:** Refer to graph below. Assume original wave is moving to the right, and second wave (red graph, rough sketch) moving to the left. Graph shows the instant of the two waves which gives **resultant** displacement = -A/2 at X.  For the two waves to be at this same position again (i.e. displacement = -A/2) as time passes, it has to be the earliest 1 period later. **Answer: D**
20	**Essential Question(s):** • How to determine the force between 2 point charges? **Solution:**

	Coulomb's law: $F = q_1q_2/4\pi\varepsilon_0 r^2$ Electrostatic force between 2 point charges is inversely proportional to the square of separation between them. When distance changes from 9.00 mm to 1.00 mm (factor of 1/9): New force = original force × $(9/1)^2 = 2.84 \times 10^{-24} \times 81 = 2.30 \times 10^{-22}$ N **Answer: D**
21	**Essential Question(s):** • How to calculate electric field strength from potential? • What is the relationship between field strength and distance for point charges? • How to determine the resultant field strength due to more than one field? **Solution:** Let distance between charge and X be 2r. Step 1: Find negative charge Q, $V = Q/(4\pi\varepsilon_0 \mathbf{2r})$ $Q = V \times 4\pi\varepsilon_0\mathbf{2r} = (-1.2 \times 10^{-4})\, 4\pi\, \varepsilon_0\mathbf{2r}$ **At midpoint (0.6×10^{-5} m from fixed charge = r):** Electric field strength E_1 due to negative charge Q at midpoint $= \|Q\| / (4\pi\varepsilon_0\mathbf{r}^2)$ $= \|(-1.2 \times 10^{-4})\|\, 4\pi\, \varepsilon_0\mathbf{2r}\ / (4\pi\varepsilon_0\mathbf{r}^2)$ $= (1.2 \times 10^{-4})\, 2 / (0.6 \times 10^{-5})$ = 40 N C^{-1}, to the left E_2 due to alpha particle (charge +2e) at midpoint $= 2e / (4\pi\varepsilon_0\mathbf{r}^2)$ $= 2(1.60 \times 10^{-19}) / (4\pi\varepsilon_0\mathbf{r}^2)$ $= 2(1.60 \times 10^{-19}) / (4\pi\varepsilon_0(0.6 \times 10^{-5})^2)$ = 80 N C^{-1}, to the left Since the electric field strength due to each particle are both directed to the left, resultant electric field strength = 40 + 80 = 120 N C^{-1}, to the left. **Answer: D**
22	**Essential Question(s):** • What is the relationship between power, current, and resistance? **Solution:** From the graph at I = 3.4 A, R = 2.4 Ω Power $P = I^2R = (3.4)^2 \times 2.4 = 27.7 = 28$ W **Answer: D**
23	**Essential Question(s):** • How to analyse a potentiometer circuit? When will the galvanometer show zero deflection? • How to determine the p.d. across the 1.0 m resistance wire? **Solution:** When galvanometer shows zero deflection, we can analyse the upper circuit independently from the lower circuit.

	Upper circuit: Total circuit resistance = 4.4 + 7.5 = 11.9 Ω Circuit current = 6.0/11.9 = 0.504 A For zero deflection of galvanometer, p.d. across length x must equal 1.2 V. Resistance of length x = (x/1.0)(7.5) = 7.5x Ω Potential difference across length x = IR 1.2 = (0.504)(7.5x) Therefore: x = 1.2/(0.504 × 7.5) = 0.32 m **Answer: D**
24	**Essential Question(s):** • What is the circuit diagram like? • What is the I-V characteristic graph of a resistor? → ohmic, I proportional to V • What is the I-V characteristic graph for the component? → I = 0 when V < 2.0 V, and, I = non-zero constant when V ≥ 2.0 V. • How to determine total current in parallel circuits? **Solution:** Below 2.0 V: Only the 4.0 Ω resistor is conducting, so I = V/4.0 At and above 2.0 V: both resistor and component are conducting From 0 to 2.0 V: The resistor follows Ohm's law and the graph shows a straight line with positive gradient. Ratio V to I equal resistance 4.0 Ω. At 2.0 V and above: The graph has the same positive gradient but with a constant amount of increase in current due to the component conducting. **Answer: C**
25	**Essential Question(s):** • How to determine the direction of magnetic field produced by a current-carrying coil? → RH Grip Rule • How to determine the direction of magnetic force on a current carrying wire? → FLHR **Solution:** Using RH Grip Rule: clockwise current I_1 in circular coil creates magnetic field into the page at the centre (where horizontal wire is). Using FLHR: index finger (field direction → into the page), middle finger (current I_2), therefore thumb (magnetic force → which is upwards). **Answer: A**
26	**Essential Question(s):** • What phenomenon happens when a magnet falls through a coil? → electromagnetic inductor, EMF is induced in the coil • What laws govern electromagnetic induction? → Faraday's law and Lenz's law • What does number of turns (N) of coil affect? → rate of change of flux linkage → larger N results in larger magnitude of induced EMF. • When/why/how will motion of the magnet be affected? → If the induced EMF does not cause an induced current to flow (e.g. open circuit), no induced magnetic field produced, and motion of magnet is unaffected. However, if induced current flows, then there will be induced magnetic field which by Lenz's law will act in a direction that opposes the motion

	of the magnetic causing the induced EMF, hence the magnet will experience a force of repulsion from the induced magnetic field and its downward net force hence acceleration will reduce, causing its average velocity to decrease, and hence takes a longer time to travel the same length of coil. • What is the difference between an ammeter and a voltmeter and how will the induced current be affected? → ammeter has very low resistance, while voltmeter has very high resistance. So for the same magnitude of induced EMF, a larger induced current will flow when the ammeter is connected compared to when a voltmeter is connected. **Solution:** For a given magnitude of induced EMF, greater induced current flows when there is lower circuit resistance, which creates stronger induced magnetic field opposing the magnet's motion, reducing the downward acceleration of the magnet by a greater extent. Magnitude of induced current depends on: rate of change of magnetic flux linkage and circuit resistance. More turns → greater rate of change of flux linkage → greater induced EMF Ammeter (low resistance) → greater induced current → stronger induced magnetic field → greater upward magnetic force of repulsion on magnet → lesser downward net force and downward acceleration of magnet → smaller average velocity → takes longer time to travel the same distance (length of coil). Therefore: ammeter and 400 turns gives longest fall time. **Answer: B**
27	**Essential Question(s):** • How are X-rays produced and what determines their spectrum? • What happens to X-ray spectrum when electron energy increases? • How do continuous and characteristic X-rays respond to energy changes? **Solution:** Higher electron energy means: 1. More energy available for characteristic X-rays → Peak P shifts to shorter wavelength ✓ 2. Intensity changes at each wavelength (more high-energy X-rays produced) ✗ 3. Minimum wavelength decreases (λ_{min} = hc/eV, higher V gives shorter λ) ✗ Only statement 1 is correct. **Answer: B**
28	**Essential Question(s):** • How do frequency and intensity affect photoelectric emission? • What determines the current and kinetic energy of photoelectrons? **Solution:** In photoelectric effect: 1. Current is NOT proportional to frequency ✗ 2. Current ∝ intensity (more photons → more electrons) ✓ 3. Maximum KE increase with frequency, NOT intensity ✗ Only statement 2 is correct. **Answer: D**
29	**Essential Question(s):** • How do you balance nuclear equations? • What conservation laws apply to nuclear reactions?

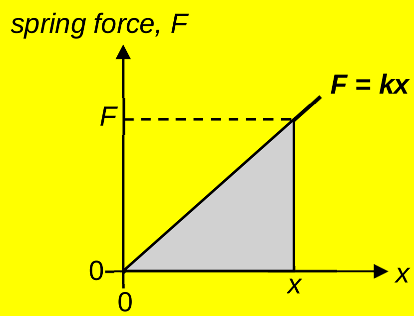
	Solution: Conservation of mass number: 235 + 1 = X + 90 + (Y × 1) Conservation of atomic number: 92 + 0 = 55 + 37 + (Y × 0) From atomic number: 92 = 92 ✓ From mass number: 236 = X + 90 + Y If Y = 2: X = 236 - 90 - 2 = 144 If Y = 1: X = 236 - 90 - 1 = 145 (not an option) **Answer: D**
30	**Essential Question(s):** • What are the properties of alpha radiation? • How does ionising ability relate to biological damage? • Why is alpha radiation internal of a human body particularly dangerous? **Solution:** An alpha particle is the helium-4 nucleus. Alpha particle is highly ionizing, low penetrating ability, has a positive charge. As it is stopped by human skin, it is not dangerous outside the human body. However as it is highly ionsing, if it enters the human body it can cause cell mutation and organ failure thus dangerous. **Answer: C**

Paper 2

1	**(a)**		**Essential Question(s):** • What is the expression for upthrust on a fully submerged object? **Solution:** Upthrust = weight of displaced water: $U = \rho_{water}\ g\ V(4/3)\ \pi\ (0.180)^3$ U = 1020 × 9.81 × U = 244.44 = 244 N	M1 A1	[1]
1	**(b)**		**Essential Question(s):** • Which measured quantities does U depend on? • How to determine the absolute uncertainty of a derived quantity? How to combine uncertainties? **Solution:** Express the derived quantity U in terms of its direct measurements: $U = \rho_{water}\ g\ (4/3\ \pi\ r^3)$ Apply Product-Quotient Rule for combining uncertainties: $\frac{\Delta U}{U} = \frac{\Delta\rho_{water}}{\rho_{water}} + 3\frac{\Delta r}{r}$ $\frac{\Delta\rho_{water}}{\rho_{water}}$ = 5 / 1020 = 0.0049020 $\frac{\Delta r}{r}$ = 0.004 / 0.180 = 0.022222		

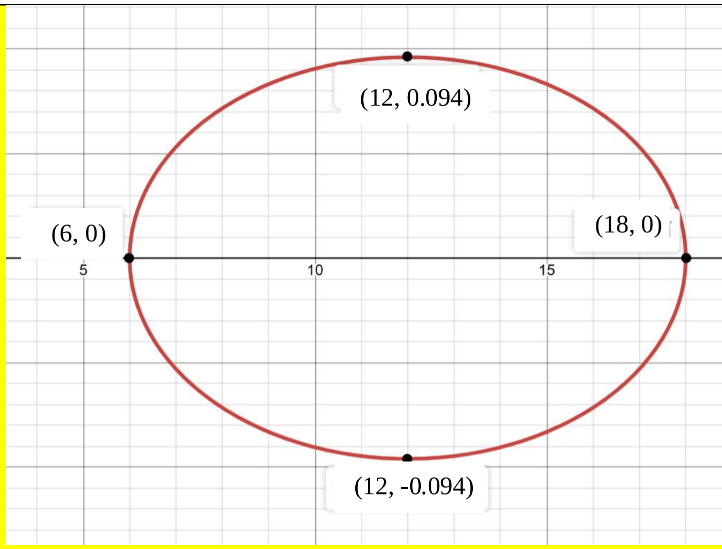
			$\frac{\Delta U}{U}$ = 0.0049020 + 0.022222 x 3 = 0.071569 ΔU = 0.071569 × 244.44 N = 17.494 N ≈ 20 N (to one significant figure). Round off U to same precision as ΔU: **(U ± ΔU) = (240 ± 20) N**	M1 A1 A1	[3]
1	(c)		**Essential Question(s):** • What forces act on the stationary sphere? • How does equilibrium (resultant force = 0) relate these forces? **Solution:** Vertical forces on the sphere: • Upthrust U (upwards) • Weight W of the sphere (downwards) • Tension T in the cable (downwards) For vertical equilibrium: U = W + T and therefore T = U – W weight of sphere, W = $\rho_{sphere}Vg$= 85 × (4/3) π $(0.180)^3$ x 9.81 ≈ 20.370 N T = 244.44 – 20.370 = 224.07 = 224 N	M1 A1	[2]
1	(d)		**Essential Question(s):** • What forces act after the cable breaks? (Upthrust upward, weight downward, and **increasing viscous drag as speed increases**.) • How will the resultant force, and hence acceleration, change as the sphere speeds up through the water? • What does the acceleration approach once a terminal velocity is reached? **Solution:** • Immediately after the cable breaks, the only forces are **upthrust and weight**, so the resultant upward force is **U – W**, giving a **maximum initial upward acceleration**. • As the sphere **speeds up**, **viscous drag (water resistance) increases, reducing the net upward force.** • Therefore, the **acceleration decreases with time**, approaching **zero** as the sphere approaches terminal velocity. **Graph features:**		

			 • Start at a **positive value** of acceleration at t = 0 with a curve **decreasing smoothly** towards **0 m s⁻²**, approaching a horizontal line (asymptote) at zero acceleration. **Examiners' Report:** Many different lines were drawn. Both horizontal lines and lines from the origin with a constant positive gradient were quite frequently seen but there were several other suggestions as well. The horizontal lines were drawn by candidates who did not take into account the drag force acting on the sphere even though it was rising through water.	B1	[1]
2	**(a)**	**(i)**	**Essential Question(s):** • What does the principle of moments state? **Solution:** For a body in equilibrium, **<u>the sum of the clockwise moments about any point is equal to the sum of the anticlockwise moments</u>** **<u>about that same point.</u>** **Examiners' Report:** Although the answer to this part was essentially the recall of a known principle, there were a significant number of candidates whose answers were not as detailed as they may well have been. A few candidates merely gave the definition of the moment of a force and rather more made no reference to the sum of the moments, only balancing when the object on which the moments are acting is in equilibrium.	B1 B1	[2]
2	**(a)**	**(ii)**	**Essential Question(s):** • What is the definition of centre of gravity? **Solution:** The centre of gravity of an object **<u>is the point at which the entire weight of the object may be considered to act</u>**. **Examiners' Report:** There were many good descriptions of the centre of gravity but answers that were couched entirely in terms of mass rather than weight were seen from time to time. Not all answers made clear that the centre of gravity is a single point rather than a region or area. Answers that referred to the line of action of the	A1	[1]

			weight did not always state that the centre of gravity is a specific point on the line.		
2	**(b)**	**(i)**	**Essential Question(s):** • What is on the axes of a force–extension graph for a spring? • If force obeys Hooke's law (F = kx), what is the shape of the graph? • How is work/energy related to the area under a force–displacement graph? **Solution:** **Since the spring obeys Hooke's law,**  *Graph sketch shows a straight line passing through origin (0, 0).* **Energy stored in the spring, *W*** **= work done on spring in stretching it [by work-energy relationship]** **=** $\int F\,dx$ **[by definition of work done]** **= area under the F–x graph from extension 0 to x** **<u>For a straight line from (0,0) to (*x, F*), the area is the area of a triangle:</u>** **∴ W = ½ (base)(height)** **= ½ x F** **= ½ x (kx)** = ½ k x^2 (shown) **Examiners' Report:** Stronger responses provided the required detailed working with all the necessary stages made clear. A very few answers were extremely brief and delivered very little more than that which was supplied in the text itself.	M1 M1 A0	[2]
2	**(b)**	**(ii)**	**Essential Question(s):** • What equation relates the goal to the known information? **Solution:** From W = 1/2 k x^2: k = 2W / x^2 k = (2 x 0.16) / 0.0081^2 k = 48.773 ≈ **49 N m^{-1}**	A1	[1]
2	**(c)**	**(i)**	**Essential Question(s):** • What equations can be applied when a body is in equilibrium? • What is the free body diagram of the rod? How many unknown forces are there? Which equilibrium equation is most useful to determine m?		

			Solution: **Take moments about the hinge.** **By principle of moments,** **Sum of anticlockwise moments = Sum of clockwise moments** $\mathbf{F_{spring}\ L \sin 38° = (mg)(L/2)}$ $m = (2\ F_{spring} \sin 38°) / g$ $m = (2\ kx \sin 38°) / g$ $m = 2\ (48.773 \times 0.12)\ (\sin 38°) / 9.81$ m = 0.73462 = **0.73 kg** **Examiners' Report:** Very many candidates supplied either the correct answer or a value that was equal to half of the correct answer. The latter incorrect value was usually obtained by candidates who did not take into consideration the fact that the weight of the uniform rod acts at its exact centre. Occasionally, the sin (38°) term was omitted from the calculation or perhaps even replaced with cos (38°). Other errors were made rather more rarely.	M1 A1	 [2]
2	**(c)**	**(ii)**	**Essential Question(s):** • What changes when an extra load is added at X? • What must happen to the tension in the wire (or spring) to keep the rod horizontal? • If the tension increases, how must the hinge force adjust so that the net horizontal and vertical forces are still zero, and net moment of force about any point is zero? • How do I describe both the **magnitude** and **direction** of H? **Solution:** **Take moments about the hinge. Since total clockwise moment increases, the total anticlockwise moment must increase to maintain rotational equilibrium. Thus the magnitude of the pull of the wire *T* must increase (since the perpendicular distance from hinge to line of action of *T* is unchanged).** **To maintain horizontal equilibrium, since the leftward force provided by the horizontal component of *T* increases, the horizontal component of *H* acting to the right must also increase.** **Take moments about X. Since anticlockwise moment due to rod's weight unchanged and since horizontal component of *H* produce zero moment about X, to maintain rotational equilibrium, vertical component of *H* must remain unchanged.** **Therefore magnitude of the resultant H increases and direction of H is at smaller angle above the horizontal.** **Examiners' Report:** This part proved to be very challenging. A common incorrect approach was to suggest that the vertical component of force *H* increased and that its horizontal component did not change. This often led to an answer that was almost completely inaccurate, although sometimes a candidate did make a correct and relevant comment in addition to this. The statement that the horizontal forces did not change was commonly included in an incorrect response.	 B1 B1 B1	 [3]

3	**(a)**	**(i)**	**Essential Question(s):** • From the y–t graph, what is the period T of the motion? • How is angular frequency ω related to the period? **Solution:** From the graph: Period $T = 0.40$ s Angular frequency for SHM: $\omega = 2\pi / T$ $\omega = 2\pi / 0.40 = 15.708$ rad s^{-1} Rounded to 2 s.f.: $\omega \approx 16$ rad s^{-1} (shown).	M1 A0	[1]
3	**(a)**	**(ii)**	**Essential Question(s):** • What is the amplitude A of the oscillation from the graph? • Which SHM formula links maximum acceleration to ω and A? **Solution:** From the graph, displacement varies between 6 mm and 18 mm. Equilibrium position is the midpoint: (6 + 18) / 2 = 12 mm Amplitude A = 18 – 12 = 6 mm = 0.0060 m For SHM, maximum acceleration: $a_0 = \omega^2 A = 15.708^2 \times 0.0060$ $a_0 = 1.4804 = 1.5$ m s^{-2}	M1 A1	[2]
3	**(a)**	**(iii)**	**Essential Question(s):** • Which SHM expression gives maximum speed? **Solution:** For SHM, maximum speed: $v_0 = \omega A = 15.708 \times 0.0060$ $v_0 = 0.094248 = 0.094$ m s^{-1}	A1	[1]
3	**(a)**	**(iv)**	**Essential Question(s):** • At which displacements are the speed zero and where is it maximum? • How does SHM look on a v–y graph? • Is my sketch symmetric about the equilibrium position? • Did I plot the values found in earlier parts accurately to half the smallest division on the graph grid? **Key features for full marks:** B1: The graph is a **closed ellipse centered at y = 12 mm**, **v = 0**. B1: **v = 0** at **y = 6 mm and y = 18 mm**. B1**: v is maximum and equal ±0.094 m s⁻¹** at **y = 12 mm**.	B1 B1 B1	[3]

			 **Examiners' Report:** The correct answer was an elliptical curve centred on the point (12, 0). This part was well answered, with many candidates understanding what was wanted even when the final curve was not drawn with sufficient precision. A significant source of error was a misinterpretation of the horizontal scale on the graph. This often led to the point (6, 0) being plotted at (5.5, 0) although a similar error was not always made at (18, 0). Other errors were due to a misunderstanding of what was wanted and various answers that included straight lines, sine curves and misplaced semiellipses were not especially rare.		
3	**(a)**	**(v)**	**Essential Question(s):** • When does the object first lose contact with the platform in vertical SHM? • What is the platform's maximum downward acceleration equal to at that instant? • Which SHM expression do I use for maximum downward acceleration? **Solution:** The object first loses contact at the higher point (upper amplitude position) when the normal contact force first reduces to zero. At this instant, the maximum net force on the object equals to the object's weight, and the maximum downward acceleration equals g. For SHM, acceleration: $a = -\omega^2 y$ Maximum downward acceleration has magnitude: $\lvert a_0 \rvert = \omega^2 A_0$ When it just loses contact, $a_0 = g$, so $\omega^2 A_0 = g$ $A_0 = g / \omega^2$ $A_0 = 9.81 / 15.708^2$ $A_0 \approx 0.03976 = 0.040$ m **Examiners' Report:** Many candidates struggled with this part and approaches that did not involve the use of the value of *g* could not lead to a correct answer. A significant minority did not know how to proceed and simply left the answer space blank.	M1 A1	[2]

3	**(b)**	**(i)**	**Essential Question(s):** • What happens to an oscillating system when it is just critically damped? • How does it return to equilibrium compared with underdamping or overdamping? **Solution:** Critical damping is when a **system <u>returns to equilibrium</u> in the <u>shortest possible time</u> without oscillating.** **Examiners' Report:** The answers were rarely sufficiently detailed. Many answers could have been applied to any form of damping and the exact definition of critical damping was, in general, merely hinted at rather than specifically stated.	A1	[1]
3	**(b)**	**(ii)**	**Essential Question(s):** • What is the practical importance of critical damping in a car suspension system? **Solution:** Critical damping **<u>dissipates the total energy of oscillations</u> of the car suspension system in the shortest possible time** to **allow the suspension to <u>return to its equilibrium position as quickly as possible after hitting a bump, without oscillating</u>.** It **<u>maximises passenger comfort and maintains crucial tyre-to-road contact which is crucial for steering, braking and avoiding accidents.</u>** **Examiners' Report:** Many answers were incomplete and poorly expressed. Despite the wording of the text, few candidates made any reference to energy and a noticeable proportion of the answers referred exclusively to the braking system of a car and described the supposed consequences of not having critically damped brakes. Even those answers that were aware, to some extent, of the importance of critical damping in suspension systems occasionally referred to how critical damping affected the ride or the passengers.	A1	[1]
4	**(a)**		**Essential Question(s):** • What happens to the displacement when more than one wave passes through the same point? **Solution:** When **<u>two or more waves of the same nature meet at a point</u>**, the **<u>resultant displacement</u> at that point** is the **<u>vector sum of the displacements of each wave</u> at that point**.	B1 B1	 [2]
4	**(b)**		**Essential Question(s):** • What determines how much diffraction occurs at an opening? • How do the wavelengths of sound and light compare with the size of a doorway? **Solution:** **<u>Significant diffraction occurs when</u>** the **<u>wavelength of the wave is comparable to the size of the aperture.</u>** **<u>Sound waves have wavelengths similar to the size of a doorway</u>**, so they spread out significantly and diffraction is observed. **<u>Light waves have wavelengths very much smaller than the doorway width</u>**, so they pass through with very little spreading, and diffraction is not noticeable.	B1 B1	 [2]

			Examiners' Report: Although there were many accurate and detailed explanations of the phenomenon referred to in the question, there were also a very noticeable number of answers that were incorrect and suggested that some guesswork may have been involved. Some ascribed the different behaviours of sound and light to the distinction between longitudinal and transverse waves. Some of these erroneous answers were rather detailed and described the lack of observable diffraction effects with light to its vertical polarisation or to its very large speed in air. Occasionally, an answer described diffraction accurately and the effect of the ratio of the wavelength to the slit width, but did not make any reference to the context in which the question was set, by ignoring the doorway and different ways in which sound and light behave.		
4	**(c)**	**(i)**	**Essential Question(s):** • What is the diffraction grating condition for maxima? **Solution:** For a diffraction grating: $d \sin \theta = n \lambda$ For laser X (wavelength λ_x), a second-order maximum (n = 2) is seen at P: $d \sin \theta = 2 \lambda_x$ --- (1) For laser Y (wavelength λ_Y), a first-order maximum (n = 1) is seen at the same point P, so the angle θ is the same. Same grating used so same d. Thus: $d \sin \theta = \lambda_Y$ --- (2) Equate the right-hand sides of (1) and (2): $2 \lambda_x = \lambda_Y$ (shown) **Examiners' Report:** In general, the answers were well expressed and showed the expression supplied to be correct in a convincing and transparent manner. A very occasional candidate did not indicate that what was being asked for was understood and other candidates gave responses that were not sufficiently detailed in explaining the working out. The amount of detail required in a show-that calculation is almost invariably significantly greater than that which would suffice in a calculation where the answer is not given in the text.	M1 M1 A0	[2]

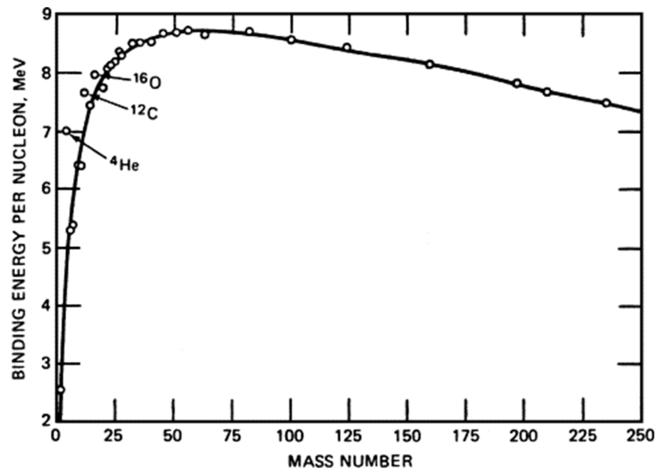
4	**(c)**	**(ii)**	**Essential Question(s):** • How do I find the maximum order of diffraction for a given λ? • Once I know the maximum order n, how many maxima does that give in total (on both sides plus the central)? **Solution:** $d\sin\theta = n\lambda$ To find maximum n visible, let $\theta = 90°$ $d\sin 90° = n_{max}\lambda$ $\left(\frac{1\times10^{-3}}{500}\right)(1) = n_{max}\lambda$ $n_{max}\lambda = 2.00\times10^{-6}$ $n_{max} = \frac{2.00\times10^{-6}}{\lambda}$ $n_{max,\,X} = \frac{2.00\times10^{-6}}{340\times10^{-9}} = 5.9$ Maximum **order** seen with **X** is 5. Maximum **total number** of maxima seen (including central maximum) with **X** = 5 x 2 + 1 = 11 $n_{max,\,X} = \frac{2.00\times10^{-6}}{2\left(340\times10^{-9}\right)} = 2.9$ Maximum **order** seen with **Y** is 2. Maximum **total number** of maxima seen (including central maximum) with **Y** = 2 x 2 + 1 = 5 Therefore, Difference in total number of maxima seen between X and Y = 11 – 5 = **6** [OR, difference in maximum order seen is (5 – 2) = 3. So 3 more seen on each side of central maximum for X. So total 6 more. Note central max. is see for both X and Y.] **Examiners' Report:** There were candidates who did not reveal that they fully grasped what was wanted. Some candidates attempted to find a value of θ for the first order maximum at the two wavelengths and then to divide 90° by this value; this did not generate the correct answer. Other candidates, quite correctly, set θ to 90° and obtained values of 2.94 and 5.88 for the number of maxima on each side of the central maximum. Some candidates had by this point lost track of the context and rounded these values to 3 and 6; this ignores the context, of course. The single largest source of inaccuracy, however, was simply to ignore one side of the curved screen and not to double the number of maxima obtained for one side of the screen.	M1 M1 A1	[3]

5	**(a)**		**Essential Question(s):** • What is the definition of e.m.f.? → the energy transferred per unit charge from some other form of energy into electrical energy in the cell when charge is moved round a complete circuit. • How to contextualise for a cell? → chemical energy to electrical energy **Solution:** e.m.f. is the **energy transferred per unit charge from some other form of energy (chemical energy for a cell) into electrical energy** when **charge is moved round a complete circuit**. **Examiners' Report:** There were many good answers and a number of candidates showed a clear understanding of the term electromotive force (e.m.f.). Some candidates gave answers in terms of work done on unit charge rather than in terms of work done per unit charge; these two terms are not dimensionally equivalent and whilst the unit for the first is simply the joule, the second has units of joule coulomb^{-1}. Candidates who gave answers in terms of maximum voltage or potential difference were not supplying a definition.	A1	[1]
5	**(b)**	**(i)**	**Essential Question(s):** • What is the relationship between charge, time, and current? • Have I converted minutes into seconds? **Solution:** Total charge passing through: $Q = (3.5 \times 10^{20})\ (1.60 \times 10^{-19})$ C Time: $t = 2.4$ minutes $= 144$ s Current: $I = Q / t = (3.5 \times 10^{20})\ (1.60 \times 10^{-19})\ / 144$ $I = 0.38889 = 0.39$ A	M1 A1	[2]
5	**(b)**	**(ii)**	**Essential Question(s):** • What data about the circuit do I have from the question and part (i)? • What is the equation relating e.m.f, internal resistance and R? **Solution:** $E = I\ (R + r)$ $1.5 = 0.38889\ (R + 0.45)$ $R = 3.4071 = 3.4\ \Omega$	M1 A1	[2]
5	**(b)**	**(iii)**	**Essential Question(s):** • How is terminal p.d. related to internal resistance? **Solution:** $V_t = I R$ $V_t = (0.38889)\ (3.4071)$ $V_t = 1.3250 = 1.3$ V OR $V_t = E - I r$ $V_t = 1.5 - (0.38889 \times 0.45)$ $V_t = 1.3$ V	A1	[1]

			Examiners' Report: This part was reasonably well answered but a noticeable minority of candidates gave a potential value of approximately 0.176 V, which is the potential difference across the internal resistance. Some of these candidates specifically stated that the potential difference across the internal resistance was the potential difference between the terminals of the cell. Other confusions were also seen.		
5	**(b)**	**(iv)**	**Essential Question(s):** • What happens to the total circuit resistance when resistors are placed in parallel? • How does the total circuit current change? • What does the terminal p.d. depend on? **Solution:** Adding a second resistor in parallel **reduces the total circuit resistance**. **Assuming the e.m.f. E and internal resistance r of the cell remain constant**, the **total circuit current I increases**. With greater current flowing through the cell, **p.d. across r (= Ir) increases.** Since **terminal p.d. = E – Ir,** the **terminal p.d. of the cell decreases**. *Note: Using the potential divider method is not, on its own, an adequate explanation of the process used to reach the conclusion.* **Examiners' Report:** A number of candidates approached the problem by treating the resistances in the circuit as a potential divider. They tended not to give enough explanation in their answers. Using the potential divider method is not, on its own, an adequate explanation of the process used to reach the conclusion.	B1 B1 B1	[3]
6	**(a)**	**(i)**	**Essential Question(s):** • What part of the graph represents one full cycle of the AC power? **Solution:** Period: T = 50 ms = 0.050 s (twice the time interval between successive peaks, as there are two peaks per period for the power – time graph) Frequency: f = 1 / T = 1 / 0.050 f = 20 Hz **Examiners' Report:** Although this question was not especially challenging, a majority of the answers given were 40 Hz rather than the correct 20 Hz.	M1 A1	[2]
6	**(a)**	**(ii)**	**Essential Question(s):** • How to relate peak power (from graph) to peak current (given) and voltage (goal)? → peak voltage found • How to relate peak voltage to r.m.s. voltage for a sinusoidal AC? **Solution:** From the graph, peak power = 0.90 W $P_0 = I_0 V_0$	C1	

			$0.9 = (0.12)\ V_0$ $V_0 = 7.5$ V For sinusoidal AC, $V_{rms} = V_0 / \sqrt{2}$ $V_{rms} = 5.3033 = 5.3$ V	M1 A1	[3]
6	**(b)**		**Essential Question(s):** • How does power relate to voltage and current in a resistor? • If voltage is sinusoidal, what does that imply about power (which depends on V^2)? • What is the average value of $\sin^2$ over one full cycle? • Can I interpret this visually from the graph as well? **Solution:** The P-t graph is **symmetrical about the line P = 0.45 W**. So the **total area under the graph of P = 0.45 W** is **equal to** the **total area under the original P-t graph <u>for the same time interval</u>, showing that the mean power <P> = 0.45 W, which is half the peak power at 0.9 W.** *<u>Answer should be based on the symmetry of the graph in Fig. 6.2.</u>* *Approach by using* $\langle P\rangle = I_{rms} V_{rms} = \left(\frac{I_0}{\sqrt{2}}\right)\left(\frac{V_0}{\sqrt{2}}\right) = \frac{1}{2} P_o$ *is <u>not</u> adhering to the question requirement.* **Examiners' Report:** This part was not well understood and many candidates gave answers that revealed little more than was included in the question itself. A common approach observed was to use $P_{av} = V_{rms} I_{rms}$ and then to substitute in expressions for V_{rms} and I_{rms}. <u>These answers tended not to refer to Fig. 6.2 at all or to do so merely in words rather than by referring to a specific feature of the graph. A minority of candidates used the intrinsic symmetry of the graph about the P_0 = 0.45 W line and very simply, often by drawing on Fig. 6.2, gave a complete answer in the way that was asked for.</u>	 B1 B1	 [2]

7	**(a)**		**Essential Question(s):** • What defines an isotope? • How do I apply that definition specifically to hydrogen? **Solution:** Isotopes of hydrogen are **<u>atoms that all have one proton</u>** in their nucleus (since they are all hydrogen), but they have **<u>different numbers of neutrons</u>**.	B1	[1]
7	**(b)**	**(i)**	**Essential Question(s):** • What pattern should I expect in binding energy per nucleon across all nuclei? • Where is the maximum of this curve, and why is that physically important? • Does my sketch correctly show the rise, peak, and slow fall? **Solution:**		

			The graph should show the **general trend** of binding energy per nucleon for all nuclei: • **At very small nucleon numbers**, the binding energy per nucleon is **low** and as nucleon number increases, the binding energy per nucleon **rises steeply**. • It reaches a **maximum around iron** **(A ≈ 56)**, the most stable nucleus and for nuclei heavier than iron, the curve **decreases gradually**.  **Examiners' Report:** Despite the expression 'all isotopes', a noticeable minority of candidates only sketched a graph for the hydrogen isotopes mentioned in the text. Candidates who did attempt to sketch what was asked for did not always produce a convincing diagram. In some examples, the peak of the graph was too far to the right and the binding energies per nucleon of the largest nuclei were sometimes shown as being very close to zero.	B1 B1	[2]
7	**(b)**	**(ii)**	**Essential Question(s):** • How does binding energy per nucleon tell me whether energy is released in fusion? • Where is iron on this curve, and what does that imply for fusion fuel? **Solution:** **Fusion releases energy only when** the **product has higher binding energy (b.e.) per nucleon**. When 2 nuclei fuse together, the **product nucleus has greater nucleon number** **(i.e. product nuclide is further to the right of the b.e. per nucleon curve).** **Since iron-56 has the highest b.e. per nucleon, only nuclei with smaller nucleon number than iron-56 will *release energy* when they fuse because the b.e. per nucleon curve is rising with increase in nucleon number to the left of iron-56** but falling to the right of iron-56. **Examiners' Report:** Many answers dealt exclusively with the binding energy per nucleon of iron and the effect of this on its stability.	B1	[1]
7	**(c)**	**(i)**	**Essential Question(s):** • What are the ways to determine energy released in a nuclear reaction? → Method 1: BE of pdts = BE of rtns; Method 2: (decrease in total mass).c^2 → Based on known info, which Method is feasible here?		

			Solution: energy released = total BE of products – total BE of reactants **Reactants** ^{2}H binding energy = 1.112 × 2 = 2.224 MeV ^{3}H binding energy = 2.827 × 3 = 8.481 MeV Total BE (reactants) = 2.224 + 8.481 = 10.705 MeV **Products** ^{4}He binding energy = 7.074 × 4 = 28.296 MeV neutron is a free unbound nucleon, thus its binding energy = 0. Total BE (products) = 28.296 MeV **(M1 for all binding energies computed correctly)** **Energy released** = 28.296 – 10.705 = **17.591 MeV** **Examiners' Report:** This section was well answered and the correct final answer was supplied very often. The most significant incorrect approach was to ignore the fact that the values in the text are essentially quoted in MeV per nucleon and then to omit the numbers 4, 3 and 2 from the expression representing the energy released. This approach does not lead to the correct value.	M1 A1	[2]
7	(c)	(ii)	**Essential Question(s):** • If total momentum is zero, what does that mean for the individual momenta? • How does kinetic energy depend on momentum and mass? • Which particle is lighter, and how does that affect KE? **Solution:** Since total momentum of the system is zero, the **momenta of the neutron and the helium nucleus must be equal in magnitude and opposite in direction**. Kinetic energy is given by $E_K = \frac{momentum^2}{2 \times mass} = \frac{p^2}{2m}$ Since **both have equal magnitude of momentum, but mass of the neutron (≈ 1u) is about 4 times smaller than the mass of the helium nucleus (≈ 4u), therefore the neutron's E_K is about 4 times greater than the helium nucleus's E_K.** OR Since total momentum of the system is zero, the **momenta of the neutron and the helium nucleus must be equal in magnitude and opposite in direction**. Since **mass of the neutron (≈ 1u) is about 4 times smaller than the mass of the helium nucleus (≈ 4u), therefore speed of neutron is about 4 times more than speed of helium nucleus.** **Kinetic energy E_K = ½ × mass × speed^2, therefore E_K of neutron is 4 times more than E_K of helium nucleus.**	B1 B1 B1	[3]

			Examiners' Report: This explanation was approached sensibly by most candidates and many fully correct answers were given. The very few candidates who did not clearly distinguish between momentum and kinetic energy or who tried to apply conservation of kinetic energy, tended to give answers that were confused and contradictory.		
7	(d)		**Essential Question(s):** • What are the reactants and products described in the passage? • How do I ensure nucleon number and proton number both balance? **Solution:** From paragraph 4: Tritium is formed when a lithium-6 nucleus is bombarded by a neutron and splits into helium-4 and tritium. **Nuclear equation:** ${}^{6}_{3}\mathrm{Li} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{3}_{1}\mathrm{H} + {}^{4}_{2}\mathrm{He}$ 1 mark: correct products (H and He) 1 mark: correct nucleon number and proton number for all products and reactants **Examiners' Report:** A noticeable minority of candidates suggested a reaction in which three neutrons combined with a lithium nucleus to produce three nuclei of tritium; this equation balances but does not align with the description in the text.	A1 A1	[2]
7	(e)		**Essential Question(s):** • What force acts on a moving charged particle in a magnetic field? • In what direction is this force relative to the particle's velocity and the magnetic field? • If the force is always perpendicular to the velocity, what happens to the speed and the path? From paragraph 6. **Solution:** The deuterium and tritium nuclei are **<u>charged particles</u>** moving through the magnetic field as their **<u>electrons have been stripped</u>** in the plasma state, **<u>The charged particles moving in the magnetic field experiences a magnetic force</u> which <u>always acts perpendicular to the velocity</u> of the nuclei and to the magnetic field, <u>so it continuously changes the direction of their velocity, moving them in a circular or helical path within the magnetic field.</u>** **Examiners' Report:** Although many candidates described in detail how the forces on the nuclei were centripetal, and described the consequences of this, there were many candidates who did not state that the forces acted because the particles are charged and moving in a magnetic field.	B1 B1	[2]
7	(f)	(i)	**Essential Question(s):** • What is the link between mean kinetic energy of a particle and temperature in an ideal gas? • Have I converted 105 keV to joules correctly before substituting?		

			From paragraph 6. **Solution:** For an ideal gas, mean kinetic energy per particle = $\frac{3}{2}kT$ From the passage: $\langle E_K \rangle$ = 105 keV $\langle E_K \rangle$ = $105 \times 10^3 \times 1.60 \times 10^{-19}$ J = 1.68×10^{-14} J $\frac{3}{2}kT = 1.68 \times 10^{-14}$ J $T = \frac{2}{3}\left(\frac{1.68 \times 10^{-14}}{1.38 \times 10^{-23}}\right)$ T = 8.1159×10^8 = 8.12×10^8 K **Examiners' Report:** The temperature value was very often correctly calculated but a proportion of candidates doubled the value of the kinetic energy and used $2 \times 105 \times 10^3 \times 1.60 \times 10^{-19}$ in the calculation. It is not clear whether this is because of the ½ in ½ m v^2 or because two nuclei are involved in the fusion reaction.	M1 A1	[2]
7	(f)	(ii)	**Essential Question(s):** • How are the kelvin and degree Celsius scales related? • At temperatures of order 10^8, does the difference of 273 between K and °C matter? **Solution:** The **difference between temperature in K and °C is 273.15**, which is **negligible when compared to temperatures of plasma that is 10^6 times larger than the difference 273.15.** (i.e. difference between 10^8 K and 10^8 °C is negligible.) **Examiners' Report:** There were several suggestions put forward for this part and many of the weaker answers lacked in appropriate detail.	A1	[1]
	(g)		**Essential Question(s):** • What quantities do I already know (E, m, rotational speed), and which one do I need (r)? • How do I convert the given rotational speed in rev/min to angular velocity ω in rad/s? **Solution:** From paragraph 6. **Step 1: Convert rotational speed to angular velocity ω:** Given: speed of rotation = 225 revolutions per minute So: frequency f = 225 / 60 = 3.75 rev s^{-1} Angular velocity: ω = 2 π f = 2 π × 3.75 ≈ 23.562 rad s^{-1}	C1	

			Step 2: Rearrange and substitute values into the equation for r $E = \dfrac{mr^2\omega^2}{4}$ $r = \sqrt{\dfrac{4E}{m\omega^2}}$ $r = \sqrt{\dfrac{4(3.75 \times 10^9)}{775000 \times 23.562^2}}$ $r = 5.9045 = 5.90$ m **Examiners' Report:** There were two important sources of error here. The calculation of the angular velocity ω was not always conducted correctly with some candidates omitting the factor of 2π whilst others used an incorrect time period or converted minutes into hours rather than into seconds; other similar errors were also made. The second error that was seen from time to time was to omit the power of 2 from the ω in the expression supplied at some point between writing down the expression initially and pressing the keys of the calculator.	M1 A1	 [3]
7	**(h)**	**(i)**	**Essential Question(s):** • What is the definition of inertia? **Solution:** Inertia is the <u>**tendency**</u> **of an object with** <u>**mass**</u> **to** <u>**resist any change in its state of motion**</u>. **Examiners' Report:** This part led to some good and exact answers and other answers that were incomplete or unclear. There were those who concentrated on a specific example where inertia is involved but who did not give a more general explanation of the meaning of inertia. There were also a few answers that made specific statements that were incorrect. In some examples, inertia was referred to either as a time or a force.	A1	[1]
7	**(h)**	**(ii)**	**Essential Question(s):** • What speed do I use for a laser beam (light)? From paragraph 7. **Solution:** distance = speed × time where for light: speed c = 3.00×10^8 m s^{-1} time = distance / speed time = 1500 m / (3.00×10^8 m s^{-1}) = 5.00×10^{-6} s **Examiners' Report:** Although this part is essentially an application of speed = distance/time, the information needed had to be extracted from the text and from the data at the start of the paper. It then had to be used correctly. A significant fraction of the candidature did not calculate the correct answer.	A1	[1]
7	**(h)**	**(iii)**	**Essential Question(s):** • What does each D–T fusion reaction produce, and how is that linked to the number of neutrons?		

			- How do I use "2.0% of the available fuel" to find the initial number of nuclei? - Once I know the number of deuterium and tritium nuclei, how do I convert that to mass? From paragraph 7. **Solution:** **Step 1: Relate neutrons to number of reactions and the number of nuclei initially** Each fusion reaction produces one neutron so: Number of reactions = number of neutrons produced = 4.8×10^{17} These reactions used 2.0% of the available fuel. Let N be the initial number of deuterium nuclei (and also N tritium nuclei, since there are equal numbers). Number of reactions = 0.02 N So $0.02\ N = 4.8 \times 10^{17}$ $N = 4.8 \times 10^{17} / 0.02 = 2.4 \times 10^{19}$ Thus initially there are 2.4×10^{19} deuterium nuclei and 2.4×10^{19} tritium nuclei **Step 2: Convert number of nuclei to mass** Since the mass per nucleon is 1.67×10^{-27} kg and deuterium has 2 nucleons while tritium has 3 nucleons. Total fuel mass = (mass of all D nuclei) + (mass of all T nuclei) $= (2 \times 1.67 \times 10^{-27} \times 2.4 \times 10^{19}) + (3 \times 1.67 \times 10^{-27} \times 2.4 \times 10^{19})$ $= 2.0 \times 10^{-7}$ kg **Examiners' Report:** This part was not especially well answered and only a minority of candidates obtained the correct final answer. Various approaches were tried but candidates who did not recognise the significance of the production of 4.8×10^{17} neutrons from the fuel in the small sphere would not have been able to obtain the correct answer.	M1 A1	[2]
7	**(h)**	**(iv)**	**Essential Question(s):** - What particles are emitted in fusion that can interact with the container walls? - What happens to a nucleus if it absorbs an extra high-energy neutron? From paragraph 8. **Solution:** The fusion reactions produce a huge number of high-energy neutrons and these neutrons can be absorbed by nuclei in the container material, forming new unstable isotopes which are radioactive. *[You can read up more on the internet on 'neutron activation process']* **Examiners' Report:**	B1	[1]

			This was poorly answered by almost all candidates. Few candidates related the production of huge numbers of neutrons to the production of radioactive isotopes in the container wall.		

Paper 3

1	**(a)**		**Essential Question(s):** • What relationship links angular displacement and time? **Solution:** Use $\theta = \omega t$ $\omega = 2\pi / T = 2\pi / 3.4 = 1.848$ rad s^{-1} $\theta = \omega t = 1.848\ (0.53) = 0.98$ rad	A1	[1]
1	**(b)**	**(i)**	**Essential Question(s):** • Which definition should I recall for angular speed in terms of period? **Solution:** Period, $T = 3.4$ s. Angular velocity, $\omega = 2\pi / T = 1.85$ rad s^{-1} (shown) *For "Show" question, it is essential to show:* • *Formula* • *Substitution of values* • *Answer with units* **Examiners' Report:** Although this was generally answered very well, some candidates did not show all their working.	A1	[1]
1	**(b)**	**(ii)**	**Essential Question(s):** • What equations can I set up for horizontal circular motion? **Solution:** Let F be the pull of the string. *Avoid symbol T used for period earlier on.* Vertically, no net force: F cos(10°) = mg ------(1) Horizontal component of F provide the centripetal force required: F sin(10°) = $m\omega^2 r$ -------(2) (2) / (1): tan(10°) = $\omega^2 r/g$ $r = g \tan(10°)/\omega^2 = 9.81 \times \tan(10°)/(1.85)^2 = 0.50541 = 0.51$ m **Examiners' Report:** Candidates generally resolved the forces in two dimensions and divided their equations to get the correct answer. Those who did not realise that this was what was required found the question difficult. Some candidates used mv^2 / r instead of $mr\omega^2$ and put the value found in **(b)(i)** as v, which is incorrect physics.	M1 M1 A1	[3]
1	**(c)**		**Essential Question(s):** • What is the definition of work done by a force?		

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When does a force do zero work even though there is displacement moved by the object? (Does the direction of the force act along the direction of the bob's changes in displacement?)
How can I visualize the bob's path relative to each force?

Solution:
Work done by a force equals to the product of the average force and the displacement moved in the direction of that force.
The weight acts vertically downward while the bob moves horizontally, tangential to the circle. Since there is no vertical displacement, the weight does no work.
The tension in the string acts along the string, which is also perpendicular to the direction of the displacement moved by the bob at all times and hence tension does no work.
Examiners' Report:
A large number of candidates did not show a good understanding of work done. Some candidates also did not realise that the tension was perpendicular to the direction of motion of the bob at all times even though it was at an angle to the vertical.
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<td>B1

B1</td>
<td>[2]</td>
</tr>
<tr>
<td>2</td>
<td>(a)</td>
<td></td>
<td>
Essential Question(s):

What does Newton's Third Law state?

Solution:
The force exerted by one body on a second body is equal in magnitude and opposite in direction to the force simultaneously exerted by the second body on the first body.
Both forces are of the same nature.
</td>
<td>B1

B1</td>
<td>[2]</td>
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<tr>
<td>2</td>
<td>(b)</td>
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Essential Question(s):

For each force acting on the student, what object is exerting that force?
According to Newton's Third Law, what object must the student exert a force on in return?
How do the directions and magnitudes of action–reaction pairs compare?
Am I distinguishing clearly which force acts on which body?

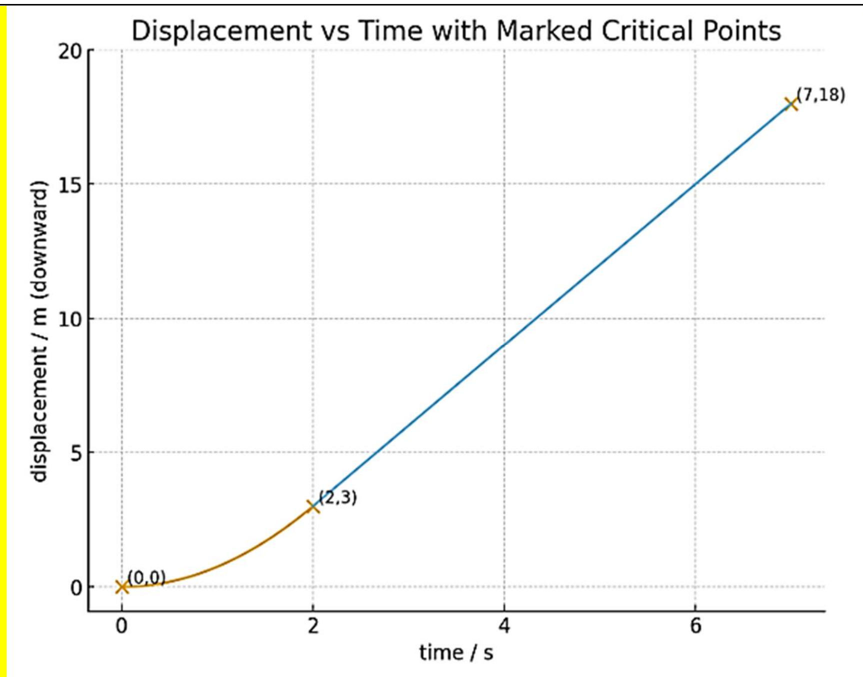
Solution:
<table>
<tr><th></th><th>direction</th><th>magnitude</th><th>body on which the force acts</th></tr>
<tr><td>Newton's third law pair with weight</td><td>upward</td><td>W</td><td>Earth</td></tr>
<tr><td>Newton's third law pair with normal contact force</td><td>downward</td><td>N</td><td>Elevator</td></tr>
</table>
Explanation:
The weight on the student is the gravitational pull of the Earth acting downward.
By Newton's Third Law, the student pulls upward on the Earth.
These two forces are equal in magnitude (both W) and opposite in direction.
</td>
<td>B3</td>
<td>[3]</td>
</tr>
</table>

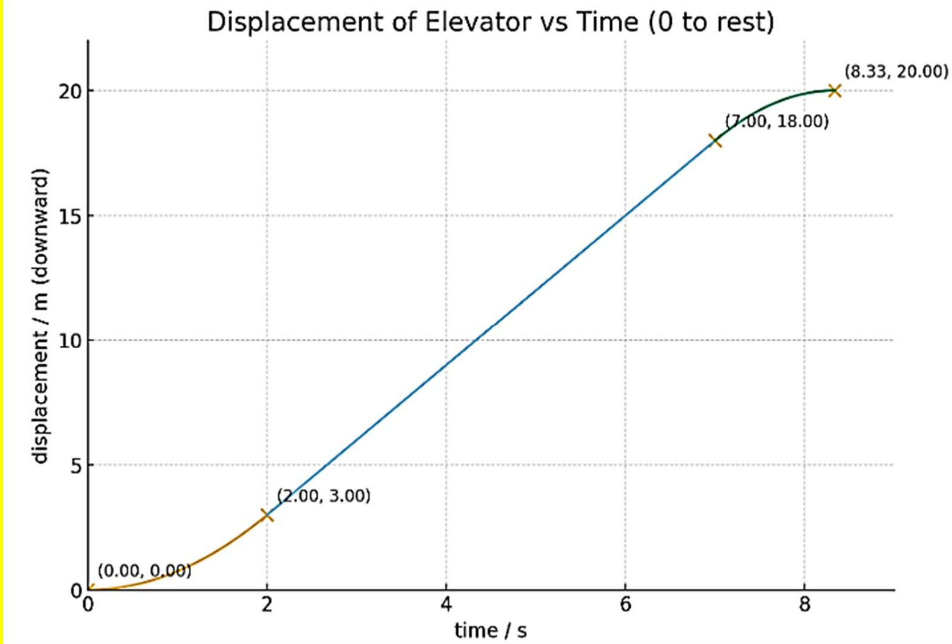
<table>
<tr><td></td><td></td><td></td><td>The normal contact force on the student is the push of the elevator floor acting upward on the student.
The reaction force is the student pushing downward on the elevator floor.
These two forces are equal in magnitude (both N) and opposite in direction.

Examiners' Report:
Candidates generally realised that the forces were opposite in direction and of equal magnitude but did not always realise on which bodies the forces were acting.</td><td></td><td></td></tr>
<tr><td>2</td><td>(c)</td><td>(i)</td><td>Essential Question(s):
How does the acceleration of the elevator affect the normal contact force?
What is the free body diagram of the student?
What relationship links the resultant force and the acceleration?
What is my sign convention?
Solution:
The elevator accelerates downwards. Hence, the student will also accelerate downwards with the same acceleration.
Taking downwards as positive direction,
Resultant force = ma
W – N = ma
65(9.81) – N = 65(1.5)
N = 540.15 = 540 N

Examiners' Report:
Most candidates had little difficulty with this question, although some added the resultant force to the weight instead of subtracting it from the weight.</td><td>M1
A1</td><td>[2]</td></tr>
<tr><td>2</td><td>(c)</td><td>(ii)
(A)</td><td>Essential Question(s):
What kind of motion is happening during the first two seconds?
Which kinematics relationship links displacement, acceleration, time, and initial velocity?
How does constant acceleration affect how displacement grows with time?
Solution:
From t = 0 to t = 2.0 s, the elevator starts from rest and accelerates downward at 1.5 m s^{-2}.

Take downwards as positive direction.
Using
$s = ut + ½ at^2$
$= 0 + (0.5)(1.5)(2.0)^2$
= 3.0 m</td><td>M1
A0</td><td>[1]</td></tr>
<tr><td>2</td><td>(c)</td><td>(ii)
(B)</td><td>Essential Question(s):
How to obtain the total displacement at the end of 7.0 s given that the second part of the motion has constant velocity?
Solution:</td><td></td><td></td></tr>
</table>

			 **Mark scheme:** [1] – Parabolic curve from (0,0) to (2.0, 3.0), with zero gradient at (0,0). [1] – Straight line from (2.0, 3.0) to (7.0, 18) [1] – Total displacement at the end of 7.0 s is 18 m **Explanation:** Final velocity at the end of 2.0 s is the initial velocity of the second segment of motion. $v = u + at$ $= 0 + (1.5)(2.0) = 3.0\ m\ s^{-1}$ $s = ut + \frac{1}{2} at^2$ $= 3.0(5.0) = 15\ m$ Total displacement at the end of 7.0 s = 3.0 + 15 = 18 m **Examiners' Report:** The initial part of the graph was generally well-drawn, but not all candidates realised that this part of the graph ended at (7, 18).	B3	[3]
2	**(c)**	**(iii)**	**Essential Question(s):** • What is the velocity at the start of the deceleration phase and how much distance must still be covered to reach the total 20 m? • What is the (uniform) deceleration needed? • What time does the elevator actually come to rest once deceleration begins? **Solution:**		

			 **Mark scheme:** [1] – Graph <u>ends at t = 8.3 s</u> with a <u>total displacement of 20 m</u> [1] – <u>Parabolic curve</u> from (7.0,18) to (8.3, 20), with <u>zero gradient at (8.3, 20)</u>. <u>Smooth curve at (7.0,18), i.e. no ‘kink’.</u> **Explanation:** From 2(c)(ii)B, at t = 7.0 s the elevator has displacement 18 m and is moving downward with speed of 3.0 m s^{-1}. The elevator then decelerates uniformly to rest and the total distance travelled from t = 0 to rest is 20 m. So, during deceleration the elevator must move a further 2 m downward. Using, $v^2 = u^2 + 2as$ $0 = (3.0)^2 + 2a(2.0)$ $a = -2.25$ m s^{-2} (upwards) $v = u + at$ $0 = 3.0 + (-2.25)(t)$ $t = 1.33$ s So, elevator comes to a stop at t = 7.0 + 1.33 = 8.33 s OR $s = \left(\frac{u+v}{2}\right)t$ $2.0 = \left(\frac{3.0+0}{2}\right)t$ $t = 1.33$ s So, elevator comes to a stop at t = 7.0 + 1.33 = 8.33 s **Examiners’ Report:** Most candidates realised that the gradient of the graph decreased and became horizontal, but very few realised that this happened at 8.3 seconds.	B2	[2]
3	(a)	(i)	**Essential Question(s):** • Which microscopic quantities contribute to the internal energy of a system?		

			Solution: the **sum of** a **random distribution** of **microscopic kinetic and potential energies** of the **individual atoms/molecules/particles of the system**. **Examiners' Report:** This definition is given in the syllabus but most candidates were not able to answer the question correctly. While most knew that the kinetic energies of the molecules were distributed randomly, the most common mistake was not to realise that this also applied to the potential energies of the molecules.	B2	[2]
3	**(a)**	**(ii)**	**Essential Question(s):** • What happens to the arrangement and motion of particles during a change of state from solid (ice) to liquid (water)? • Which part of internal energy changes when temperature stays constant? • How does overcoming intermolecular forces affect internal energy? • How does the fact that temperature remains constant during a change of state affect internal energy? **Solution:** Internal energy increases because **work is done to overcome intermolecular forces of attraction between particles which thus increases the potential energy between the particles,** while the **temperature and hence kinetic energy of the particles stays constant** during the melting process. **Explanation:** 1. During melting, the temperature stays constant, so the average kinetic energy of the particles does not change. 2. However, energy supplied to the ice is used to weaken and overcome the intermolecular bonds that hold the particles in a fixed lattice. 3. This increases the potential energy of the particles because they become less tightly bound as they move into a liquid arrangement. 4. Since internal energy is the sum of microscopic kinetic and potential energies, an increase in potential energy alone means the internal energy increases even though the temperature remains constant. **Examiners' Report:** A significant proportion of candidates thought that the kinetic energy of the molecules would increase as heat was being supplied to the ice. The fact that work had to be done to overcome the intermolecular forces of attraction was also not appreciated by a lot of the candidates. Some candidates also incorrectly said that the potential energy would increase because the forces of attraction increased as the molecules moved further apart.	B1 B1	[2]
3	**(b)**		**Essential Question(s):** • Which objects lose heat and which absorb heat during the process? • Which energy relationships link temperature change, mass, specific heat capacity and specific latent heat of fusion? • What is the final temperature if both ice and water are present and in thermal equilibrium? **Solution:** **Since there is both ice and water at thermal equilibrium, the final temperature is 0 °C.**	C1	

			Heat loss by cooling water + Heat loss by cooling glass = Heat absorbed warming ice from -15 to 0 °C + Heat absorbed to melt mass m of ice at 0 °C Heat released by the boiling water cooling from 100 °C to 0 °C = 90 g × 4.18 J g^{-1} $°C^{-1}$ × (100 − 0) °C = 37620 J Heat released by glass from 28 °C to 0 °C = 170 g × 0.84 J g^{-1} $°C^{-1}$ × (28 − 0) °C = 3998.4 J Heat absorbed to warm ice from -15 to 0 °C = 120 g × 2.05 J g^{-1} $°C^{-1}$ × [0 − (−15)] °C = 3690 J Heat to melt m grams of ice = m × 334 J g^{-1} Putting all terms into the energy balance equation: 37620 + 3998.4 = 3690 + 334 m m = 113.56 = 110 g **Examiners' Report:** Candidates had difficulty with this calculation. The main area of difficulty was in realising that as it was an ice-water mixture, the final temperature of the system would be 0 °C. The other area that caused problems was that the beaker would lose energy to the ice-water mixture. Candidates tended to think that the beaker gained energy.	C1 A1	[3]

4	**(a)**		**Essential Question(s):** • What is the difference between light wave versus sound wave? • What is polarization? In which plane is oscillation restricted relative to the direction of propagation of wave? • **Recall: Polarisation involves the restriction of oscillations in a wave to a certain direction perpendicular to the direction of the wave's propagation** **Solution:** **Light waves are transverse waves** so its oscillations can be restricted to a single plane perpendicular to the direction of energy transfer. **Sound waves are longitudinal waves** where **oscillations in the wave are all parallel to the direction of energy transfer and thus cannot be restricted to a single plane perpendicular to the direction of energy transfer.** **Examiners' Report:** This was a question that was overcomplicated by a great many candidates. The question asked candidates to state why light waves can be polarised and sound waves cannot be polarised. Most candidates tried to explain why, rather than just stating the reason. This led to misconceptions and wrong physics. The most common misconception was to talk about the particles in the light wave oscillating perpendicular to the direction of wave travel.	B1
	(b)	**(i)**	**Essential Question(s):** • Is the incident light unpolarized or polarized? • Key words: ' Until no light is transmitted'	

Solution:
Recall when <u>displacement is perpendicular to axis of polaroid</u>, no light passes through.

angle = $90°$ or $270°$ A1

Examiners' Report: Question has very few problems

(b) (ii)

Essential Question(s):

- Where is filter Q located and what is its initial orientation with respect to filter P?
- Which filter is being rotated? What is the angle of rotation relative to filter P's axis?
- What is the intensity of light leaving filter Q and incident on P?
- What is the expression for this intensity? Recall Malus's Law?
- What happens to intensity of light after passing filter P with respect to angle of rotation of filter Q?

As Q rotates by angle θ:

- Light leaving Q now polarized will have intensity $I_Q = I_o\cos^2\theta$ (Malus's law), where θ is angle of rotation of filter Q

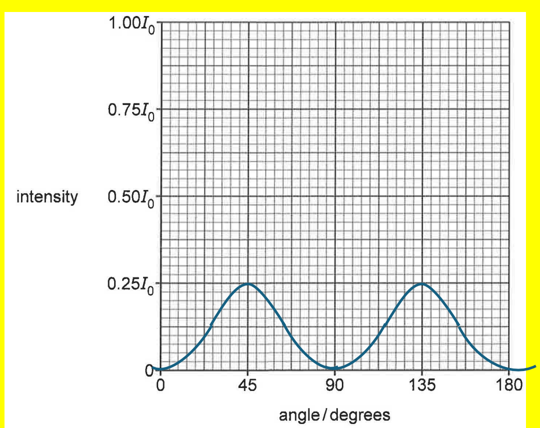
When light passes through polarizer P, angle the light makes relative to P's axis is given by $\theta_p = (90-\theta)°$

- Light leaving P will have intensity $I_p = I_Q\cos^2\theta_p$
  $I_p = I_Q\cos^2(90-\theta) = I_o\cos^2\theta\cos^2(90-\theta) = I_o\cos^2\theta\sin^2\theta$

(sine double-angle formula; $\sin(2\theta) = 2\cos\theta\sin\theta$ and squaring to obtain $\sin^2 2\theta = 4\cos^2\theta\sin^2\theta$)

$$I_p = I_o\cos^2\theta\sin^2\theta = \frac{I_o}{4}\sin^2 2\theta$$

Solution:
Sketch:
Max intensity of $\frac{I_o}{4}$ at $\theta = 45°$ and $135°$, Zero intensity at $\theta = 0°, 90°, 180°$ [A1]
graph of $\sin^2 2\theta$ sketched [A1]
Max intensity of $\frac{I_o}{4}$ [A1]



Examiners' Report:
This was a very difficult conceptual question. The most common wrong answer was to draw the variation of intensity with orientation for plane polarised light

<table>
<tr><td></td><td></td><td></td><td>passing through a single polarizing filter, rather than thinking about what happens with two polarising filters.</td><td></td></tr>
<tr><td></td><td>(c)</td><td>(i)</td><td>Essential Question(s):
• What is the relationship between intensity of light and distance from point source for a constant power source?
• How does intensity of light change/varies as distance increases?

Solution:
Given intensity of light at r = 50 m is I_0

Assume power from the point source is emitted uniformly in all directions → spherical wavefronts
$I_{\text{distance r away from source}} = \dfrac{P_{source}}{4\pi r^2}$
Assume P_{source} is constant, then $I_r \propto \dfrac{1}{r^2}$
$\dfrac{I_{r=10}}{I_o} = \left(\dfrac{50}{10}\right)^2$
$I_{r=10} = 25 I_o$

Examiners' Report:
This was a relatively straightforward question, and candidates had little difficulty with it. Some candidates attempted to apply the inverse square law but used the cube of the distance instead.</td><td>[M1]
[A1]</td></tr>
<tr><td></td><td></td><td>(ii)</td><td>Essential Question(s):
• What is the relationship between intensity and amplitude?
• How will amplitude change as distance away from source increases?

Solution:
$Intensity \propto Amplitude^2$
$\dfrac{I_o}{25 I_o} = \left(\dfrac{A_{r=50}}{A}\right)^2$
$A_{r=50} = \sqrt{\dfrac{1}{25}} A = \dfrac{1}{5} A = 0.20 A$

Examiners' Report:
Candidates had little difficulty with this question. The most common mistake was to think that the amplitude increased by a factor of 5 rather than decreased by a factor of 5.</td><td>[M1]
[A1]</td></tr>
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<table>
<tr><td>5</td><td>(a)</td><td></td><td>Essential Question(s):
• First part of question is a 'describe' to describe how does the emission line spectrum look like? Key words 'appearance".
• What is the distinguishing characteristics of an emission line spectrum?
• Second part of question is a 'explain' question. Why does the emission spectrum have the described appearance?
• How are the lines in the line spectrum produced?</td><td></td></tr>
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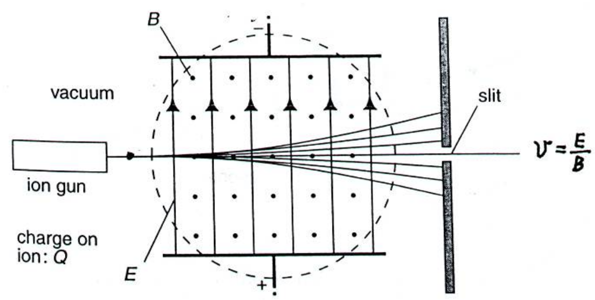
			• What does emission line spectrum signify about the structure of atoms? **Solution:** An emission line spectrum consists of a series of **discrete, bright lines at specific wavelengths against a dark background** (not a continuous band). This happens because **electrons in atoms can only possess certain discrete (quantised) energy values, called energy levels**. When **an electron de-excites from a higher level to a lower one, it emits a photon of energy exactly equal to the difference in energy levels**. Since **only certain energy differences exist in the atom, only photons of certain energies and hence certain frequencies/wavelengths are emitted — hence discrete lines**. **Examiners' Report:** The majority of candidates answered this question well. Some candidates simply explained how the spectrum was formed rather than describing it as well, which was an incomplete answer. A few candidates talked about an absorption spectrum rather than an emission spectrum. Some candidates did not link the appearance of the spectrum to the de-excitation of electrons within the atom.	[B1] [B1]
	(b)	**(i)**	**Essential Question(s):** • What will happen to the electron at the ground state as it absorbs energy from the incoming travelling electron? • What is the energy of the incoming electron traveling? How is the energy of the incoming electron absorbed by the electron at the ground state? • Which difference in energy levels between ground state and higher excited level is less than or equal to the energy of incident electron? • What are the possible transitions /excitations that the ground state electron can make? **Solution:** **Kinetic energy of incoming electron,** **KE = ½ mv^2 = ½ x 9.11x 10^{-31} x (1.93 x10^6)^2** **= 1.70x 10^{-18} J = 10.604 eV** The maximum energy that the electron in the ground state can absorb from the incoming electron will be equal to **maximum energy difference between the ground state and another energy level that is less than the kinetic energy of the incoming electron.** Hence the electron in the ground state **can only be excited to the -3.40 eV level (first excited state)** **Maximum energy that can be absorbed** **= 13.59 – 3.40** **= 10.19 eV** **= 10.2 eV** (3 s.f) **Examiners' Report:** Candidates generally calculated the energy of the incoming electron and usually realised that the electron in the atom could only gain specific energies	[M1] [C1] [M1] [A1]

			depending on the energy level differences in the atom. Some candidates thought that the energy of the incoming electron was the energy gained by the electron in the atom and some thought that the incoming electron had enough energy to ionise the atom.	
		(ii)	**Essential Question(s):** • How is the energy of the photon emitted related to the energy difference between energy states? • What is the formula for the energy of photon? **Solution:** Photon energy = $\Delta E = \frac{hc}{\lambda}$ $10.19 \times 1.60 \times 10^{-19} = \frac{6.63 \times 10^{34} \times 3.00 \times 10^{8}}{\lambda}$ $\lambda = 1.21995 \times 10^{-7}$ m $\lambda = 1.22 \times 10^{-7}$ m (3 sf)	 [M1] [A1]
		(iii)	**Essential Question(s):** • What happened when the travelling incoming electron collides with the atom? • What is the remaining kinetic energy of the travelling electron after some of its energy has been absorbed by electron at ground state? • How is the kinetic energy related to momentum of the electron? • What is the formula for the deBroglie wavelength? *Only some of the energy of the incoming electron is absorbed by the electron at ground state. The remaining energy (difference between incident energy and energy absorbed) will be the kinetic energy of the deflected electron.* **Solutions** Kinetic energy of deflected electron = 10.604 – 10.19 = 0.414 eV = 6.624×10^{-20} J Momentum, p = $\sqrt{2mE_k}$ = $\sqrt{2 \times 9.11 \times 10^{-31} \times 6.624 \times 10^{-20}}$ = 3.474×10^{-25}Ns De Broglie's wavelength, λ = h/p $\lambda = \frac{6.63 \times 10^{-34}}{3.474 \times 10^{-25}}$ = 1.91×10^{-9} m **Examiners' Report:** Although this was answered correctly by the majority of candidates, there were some who tried to apply the conservation of linear momentum to this situation, leading to an incorrect answer.	 [M1] [M1] [M1] [A1]

6	**(a)**		**Essential Question(s):** • How does a velocity selector work?	

- How should the direction of these 2 forces be relative to each other in a velocity selector? Therefore, how should the direction of the 2 fields be? → 2 forces must act opposite each other so that the charged particle exits the selector undeflected; 2 fields directed perpendicular to each other and also perpendicular to the velocity of the charge to produce 2 opposite forces.
- How is the direction of electric force on a charged particle moving in an electric field determined? How is the direction of magnetic force on a charged particle moving in a magnetic field determined?
- How should the magnitude of the electric force and magnetic force compare with each other?

Solutions:



[B1]

In a velocity selector, an **electric field and magnetic field are applied perpendicular to each other.**

[B1]

Charged particles have to be projected with initial velocity perpendicular to both fields and such that

[B1]

the charged particles will experience electric force and magnetic force in opposite directions and **the two forces must have equal magnitude**:

Electric force, F_E = Magnetic force, F_B

$$qE = Bqv$$

$$v = \frac{E}{B}$$

[B1]

Only particles that have speed v equal to $\frac{E}{B}$ will exit the velocity selector.

With this setup, **by adjusting the values of E and/or B, and hence the ratio $\frac{E}{B}$, we will be able to choose the velocity of the particles that can pass through undeflected.**

Examiners' Report:
This was a difficult question and candidates struggled to cover all the salient points. Most realized that the two forces acting on the charged particle had to be equal in magnitude and opposite in direction for the particle to pass through the electric and magnetic fields undeflected, but they did not always realise that the two fields had to be perpendicular to each other and that the particle had to be perpendicular to both fields. Candidates tended to use algebra to

			explain about the forces and the velocity at which the particle passes through undeflected, which was acceptable.	
	(b)		**Essential Question(s):** • What are the conditions for the proton 's velocity to leave the plate undeflected? • What is the relationship between electric field strength and potential difference in a uniform electric field? **Solutions:** Electric field, E = $\Delta V/\Delta d$ = 410/0.030 In velocity selector; electric force, F_E = magnetic force, F_B velocity, $v = \frac{E}{B}$ $B = \frac{E}{v} = \frac{(\frac{410}{0.030})}{8.6 \times 10^5}$ B = 0.015891 = 0.016 T (2 s.f)	[M1] [M1] [A1]

7	(a)		**Essential Question(s):** • How to relate the goal (activity) to the given info (sample mass, atomic mass, half-life)? • What is the equivalent unit of Bq? • Are the values given in SI units? A = λ N where λ, decay constant = ln 2/ $t_{½}$ and N can be obtained from the sample mass & atomic mass. SI unit for Ativity: 1 Bq = 1 s^{-1} Need to convert the half-life to SI units of seconds and the mass of the sample to kilograms. **Solutions:** Atomic mass of phosphorus = 32 u number of nuclei present, N = sample mass / atomic mass = [3.0 x 10^{-6} x 10^{-3}] / [32 x 1.66 x 10^{-27}] = 5.6476 x 10^{16} λ = ln 2/ $t_{½}$ = ln 2 / (14.3 x 24 x 3600) = 5.61 x10^{-7} s^{-1} A = λ N = (5.6476 x 10^{16})(5.61 x10^{-7} s^{-1}) = 3. 1683 x 10^{10} = 3.2 x 10^{10} Bq (2 s.f.) **Examiners' Report:** In general, candidates managed to calculate the decay constant. The difficulty arose when calculating the number of atoms in the sample. There were a	[M1] [M1] [M1] [A1]

			significant number of candidates who did not correctly convert μg to g or kg, depending on the route used to find the number of atoms.	
	(b)		**Essential Question(s):** • What are the products of beta decay? How many products are there? • What conservation laws are applicable to explain the wide range of KE of the beta particles? **Solution:** **In β-decay, a neutron in the parent nucleus disintegrates into a proton, an electron (β-particle) as well as <u>a third product, the antineutrino</u>.** [3 products, not 2, unlike α-decay]. **The decrease in rest mass per β-decay is fixed, hence the energy released per decay is also fixed by <u>conservation of mass-energy</u>. The total kinetic energy of the 3 products is thus a fixed value. –(1)** **Also, by <u>conservation of momentum</u>, the vector sum of the momenta of all 3 products must be equal to the initial momentum of the parent nucleus which is also a fixed value. –(2)** **<u>Taking (1) and (2) simultaneously, there is no unique solution for the velocities of each of the 3 products</u>, thus explaining the wide range of speeds and therefore kinetic energy of the β-particles.** NOTE: Considering both conservation of mass-energy and conservation of momentum, if β only produces if only 2 products (proton and β-particle), there is only one solution for the velocities of the 2 products using the simultaneous equations representing conservation of momentum and mass-energy. Therefore, it was expected that the beta particles be emitted at only one velocity, and one value of kinetic energy. However, this contradicts what was found experimentally that the kinetic energies of the beta particles are spread over a wide range. The antineutrino cannot be detected based on balancing proton number, mass number or charge because it does not consist of proton/electron/neutron and carries no charge! **Examiners' Report:** A significant proportion of the candidates did not know of the existence of the neutrino and those that did were not always capable of linking it to the varying energies of the β-particle.	[A1] [A1]

8	**(a)**		**Essential Question(s):** • Recall the definition of flux. What is the difference between flux and flux density? **Solution:** The magnetic flux ϕ through a surface is the product of the component of the magnetic flux density β perpendicular to the plane of the surface, and the area A of the surface. **Examiners' Report:** Most candidates performed well here, as this is a definition given in the syllabus. Some candidates confused the definition of flux with that of flux density.	B1 B1	[2]
	(b)	**(i)**	**Essential Question(s):** • Which Physics law is linked to induced emf?		

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Solution:
By Faraday's law,
$|E| = N\dfrac{d\phi}{dt}$
$= N \times \dfrac{d}{dt}(BA)$
$= N \times \dfrac{d}{dt}(Blx)$
$= N \times Bl\dfrac{dx}{dt}$
$= N \times Blv$
$= 300 \times 4.2 \times 10^{-3} \times 0.060 \times 0.040$
$= 3.024 \times 10^{-3}\,\text{V}$
$= 3.0\text{mV}$

Examiners' Report:
This was answered well by most candidates, but there were some who performed less well as they did not show all their working.
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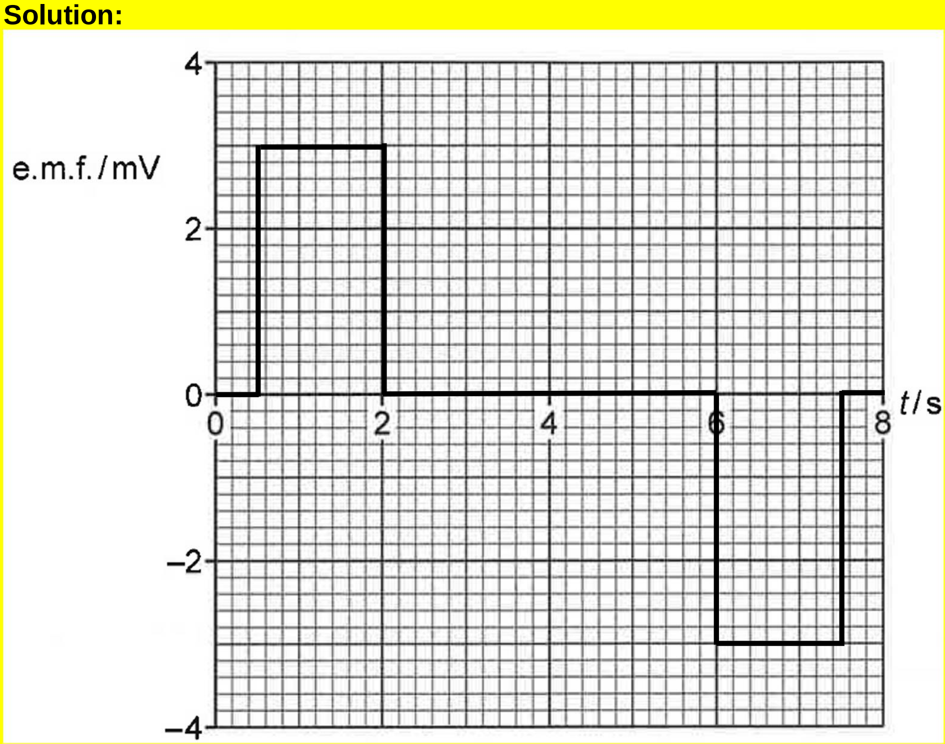
Essential Question(s):
• What causes the emf to be induced in the coil?
• What laws govern magnitude and direction of induced emf?
• What is the difference in induced emf when the coil is entering the magnetic field versus when the coil is fully in the magnetic field?
• What is the difference in induced emf when the coil is entering the magnetic field versus when the coil is exiting the magnetic field?
• What are the timings at which the coil is: entering, within, and, exiting the field?

Solution:


$t < 0.5$ s
coil have not started entering the magnetic field. Zero magnetic flux.
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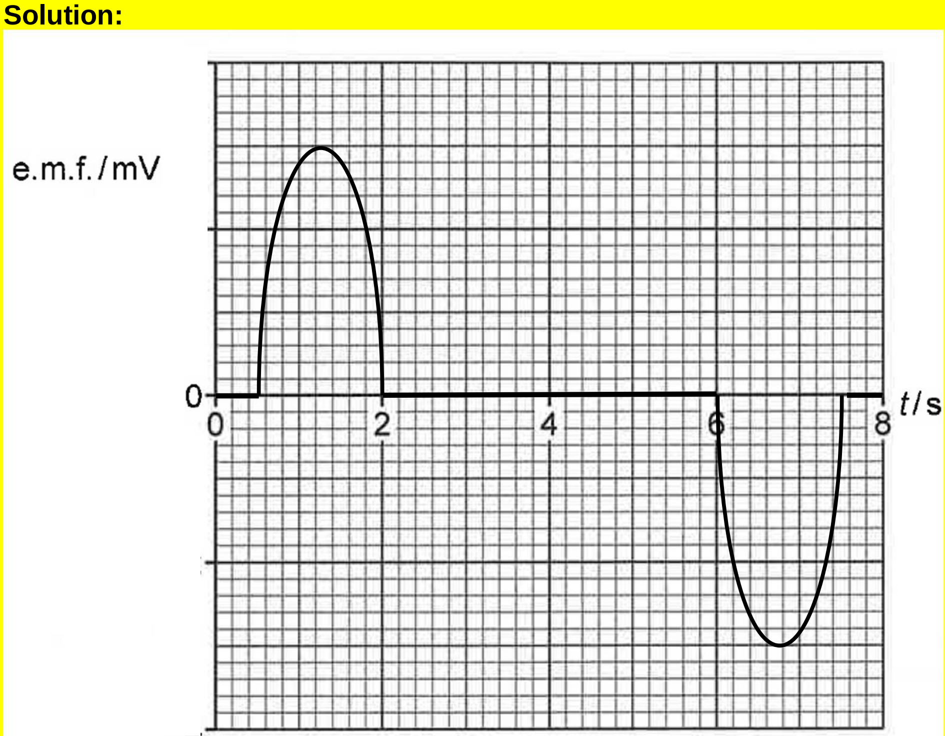
			t=0.5 s to 2 s coil enters the magnetic field, magnetic flux increases at a constant rate t = 2 s to 6 s: coil fully inside the magnetic field, no change in magnetic flux t = 6 s to 7.5 s coil exiting the magnetic field, magnetic flux decreases at a constant rate. t > 7.5 s coil completely exited the magnetic field. zero magnetic flux By Lenz's law, to oppose the increase in flux linkage on entry, and, to oppose the decrease in flux linkage on exit, the directions of the induced emf are opposite. 1 mark for zero induced emf at correct time intervals i.e. before & after the magnetic field and fully inside. 1 mark for constant induced emf at the correct time intervals 1 mark for opposite directions of induced emf when entering and when exiting **Examiners' Report:** Many candidates produced excellent answers to this question.	B1 B1 B1	[3]
	(c)		**Essential Question(s):** • What is the distinction between a square coil and a circular coil in terms of the change in flux per unit time? Will the induced emf be a constant value? **Solution:**  When the coil is fully outside and fully inside the magnetic field, it is zero magnetic flux, graph remains unchanged.		

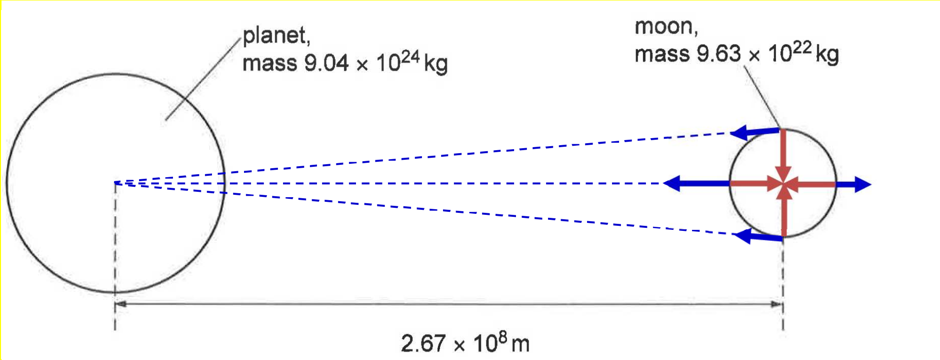
			When coil is entering or exiting the magnetic field, the rate of change of magnetic flux is **not constant**. When coil is entering, rate of change (increase) of flux increases. It reaches a maximum when the circular coil is exactly half inside the magnetic field. Thereafter, the rate of change (increase) of flux decreases as the remaining half of the coil enters the magnetic field. When coil is exiting, rate of change (decrease) of flux increases then decreases. By Faraday's law, induced emf increases then decreases. By Lenz's law, to oppose the increase in flux linkage on entry, and, to oppose the decrease in flux linkage on exit, the directions of the induced emf are opposite. 1 mark for non-constant induced emf of correct profile 1 mark for correct time intervals **Examiners' Report:** Candidates who got **(b)(ii)** correct generally got this part correct as well. The idea that the change in flux was not constant, so the induced e.m.f. would not be constant was understood by most candidates.	B1 B1	[2]
	(d)		**Essential Question(s):** • What happens when the ends of the coil are now connected together? • What happens when the coil is entering the magnetic field? Will it move at a constant speed if no external force is exerted? • What is the condition for the coil to move at a constant speed? • How to ensure that the condition for the coil to move at constant speed is met? **Solution:** With the ends of the coil connected together, induced current now flows in the coil, which by Lenz's law flows in a direction such that it produces a magnetic field that acts opposite direction to the external uniform magnetic field in an attempt to reduce the increase in magnetic flux linkage as the coil enters the field. This direction of induced current produces a magnetic force F_B on the right side of the coil that acts opposite to the velocity, which tends to retard the motion of the coil. Therefore to maintain constant velocity, an external force F_{ext} must be applied of equal magnitude and opposite direction to the induced F_B, which means that positive work has to be done by F_{ext} against F_B which is doing negative work on the coil. **Examiners' Report:** Possibly only those candidates who were confident in explaining this phenomenon chose to answer this question, but there were some excellent answers here. Common misconceptions were to talk about the current and the magnetic field induced without talking about the force and also not to explain why a retarding force on the coil meant that work had to be done to maintain a constant velocity.	B1 B1 B1	[3]
	(e)	**(i)**	**Essential Question(s):**		

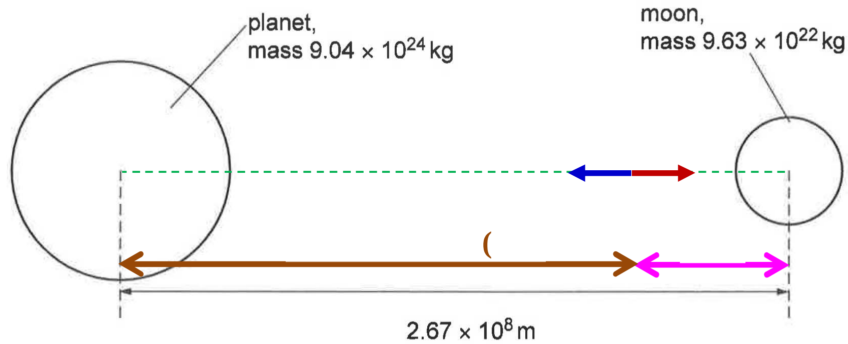
			• What is the formula relating to the magnetic flux density at the centre of a solenoid? • Question asked for length of solenoid. How does this formula relate to the length of solenoid? • Also, revise the important parameters of the solenoid. E.g. total number of turns vs number of turns per unit length, total length of wire vs length of solenoid, diameter of wire vs diameter of solenoid. **Solution:** $B = \mu_o nI = \mu_o \frac{N}{L_s} I$ $L_s = \frac{\mu_o NI}{B}$ $= \frac{\mu_o \times \frac{L_{wire}}{2\pi r} \times (\frac{V}{R})}{B}$ $= \frac{4\pi \times 10^{-7} \times \frac{12}{2\pi \times 0.015} \times (\frac{1.2}{0.27})}{4.2 \times 10^{-3}}$ $= 0.16931 = 0.17\,\text{m}$ **Examiners' Report:** Nearly all candidates correctly calculated the current in the coil. However, they did not always realise that the *n* in the formula was the number of turns per unit length. In finding out how many turns could be made from the wire; candidates sometimes used the area of each turn rather than the circumference.	M3 A1	[4]
		(ii)	**Essential Question(s):** • Recall the magnetic field produced by solenoid. How do you draw the magnetic field lines? • Anything else (about the magnetic field) in the question that is hard to produce using the solenoid? **Solution:** 1. The diameter of the solenoid is 3.0 cm, which is smaller than the width of the square coil (6.0 cm), so the square coil cannot fit with the uniform field of the solenoid. 2. The square coil's plane area must move perpendicular to the uniform magnetic field while the solenoid's uniform magnetic field is parallel to the length of the solenoid and only at its centre (not ends). The square coil cannot enter the solenoid from its side as it will be hindered by the solenoid's wire. 3. For a solenoid to produce a uniform magnetic field, its length must be much larger than its radius and its cross-sectional area also must be significantly larger than the required magnetic field (only the center of the solenoid is uniform), to reduce any fringe effects. Since the required magnetic field is large (at least 22.0 cm in Fig. 8.1), the required size of the solenoid must be extremely large. 4. The experiment requires a sharp transition between 4.2 mT and zero magnetic field. However, a solenoid produces a **non-zero** magnetic field outside the inner core region of the solenoid. Any 2.	B2	[2]

			Examiners' Report: A significant proportion talked about the solenoid being cardboard, which was not relevant.		
		(iii)	**Essential Question(s):** • Recall the formula for resistance of a wire. **Solution:** R = $\frac{\rho l}{A}$ $= \frac{\rho l}{\left(\frac{\pi d^2}{4}\right)}$ d = $\sqrt{\frac{4\rho l}{\pi R}}$ $= \sqrt{\frac{4 \times 1.7 \times 10^{-8} \times 12}{\pi \times 0.27}}$ = 9.8082×10^{-4} m = 0.98 mm **Examiners' Report:** This was a straightforward question and candidates answered it well. There were some issues with powers of ten, but most candidates got this correct.	M1 A1	[2]

9	**a**	**i**	**Essential Question(s):** • What are the differences in the definitions of *field of force*, *gravitational field* & *electric field*? **Solution:** A field of force is the <u>region in space</u> where an object <u>possessing a certain property</u> <u>experiences</u> a <u>force</u>. **Examiners' Report:** Candidates had little problem with this definition, but some were not general enough and talked about the force on a mass or a charge rather than talking about a region where a force acts.	1
		ii	**Essential Question(s):** • What are the definitions of *gravitational field* & *electric field*? How are their definitions different? • What concept is represented by a *field of force*? How is it different from other types of forces that do not have an associated field? • How does the magnitude of gravitational force & electric force vary? • What is the direction of gravitational force & electric force like? **Solution:** Similarities: 1. Both exert forces without 2 bodies being in contact (i.e. non-contact forces). 2. Both are inverse-square law fields, where the magnitude of the field strength decreases with the square of the distance from the source (i.e. the point mass producing the gravitational field / the point charge producing the electric field).	B2

			3. Both fields have associated potential energy and follows the relationship $F=-\frac{dE_P}{dx}$, where F is the gravitational/electric force, E_P is the gravitational/electric potential energy, and $\frac{dE_P}{dx}$ is the potential energy gradient. Differences: 1. A gravitational field is created by a body with mass and exert force on other masses. An electric field is created by a body with electric charge and exert force on other charges. 2. All masses at the same point in a given gravitational field will experience forces in the same direction. Positive charges and negative charges at the same point in a given electric field will experience forces in opposite directions. **Examiners' Report:** Candidates found this question difficult, especially with the similarities between the fields, because they chose to describe the fields due to point charges or masses without saying that they were describing that type of field. The fact that uniform electric and gravitational fields can be produced as well as radial/inverse square fields meant that they also needed to describe the type of field involved. Candidates performed much better when describing the differences between the two.	B2
	b	**i**	**Essential Question(s):** • How to determine the gravitational field strength due to moon's mass alone? • How to relate the goal (i.e. gravitational field strength due to moon's mass) to the known info (i.e. radius of moon, mass of moon)? • Is the field strength at the 'surface' different from other locations? → g is location-specific! **Solution:** Gravitational field strength <u>due to moon's mass</u> <u>at moon's surface</u>, $g_{m,surface}=\frac{GM_m}{{R_m}^2}$ $2.71=\frac{(6.67\times10^{-11})(9.63\times10^{22})}{{R_m}^2}$ $R_m=1.5395\times10^{6}=1.54\times10^{6}$ m **Examiners' Report:** Candidates needed to ensure that they answer 'show that' questions fully.	M1 A0
		ii	**Essential Question(s):** • What contributes to the field strength of 2.71 N kg^{-1} that was calculated in (b)(i)? In reality, what contributes to the total/resultant field strength at the moon's surface? → Resultant (vector sum) of both the field strength due to planet's mass & moon's mass! • Suppose both the planet's field strength & moon's field strength are considered, why does the resultant field strength vary with position around the moon's surface? → Field strength is a location-specific vector quantity! Draw a vector diagram with the 2 field strength vectors at various positions on the moon's surface to analyse why the resultant field strength varies!	

			Solution: Firstly, 2.71 N kg^{-1} is the field strength due to the moon's mass alone. If the field strength due to the planet's mass is also considered, the resultant field strength will not be 2.71 N kg^{-1}. Secondly, the gravitational field strength due to the moon g_m is always directed towards the centre of the moon, and, the gravitational field strength due to the planet g_P is always directed towards the centre of the planet. Hence the directions of both g_m and g_P vary with position around the moon's surface. Thirdly, the magnitudes of g_m and g_P decrease with the square of the distance from the moon and the planet respectively. Hence around the moon's surface, while the magnitude of g_m is approximately similar, the magnitude of g_P is greatest at the point on the surface closest to the planet and least at the point furthest from the planet The directions and magnitudes of g_m and g_P at various point on the moon's surface are illustrated below:  **Examiners' Report:** A significant number of candidates said that the moon was not a sphere, when the question stated that it was a sphere. Those candidates who understood that the field strength on the surface of the moon was affected by that of the planet did not always realise that there were two factors affecting the field strength – the distance from the planet and the vector nature of the field strengths. Very few candidates gave complete answers to this question.	B1 B1 B1
		iii (A)	**Essential Question(s):** • At what point will the resultant field strength be zero? **Solution:** Resultant field strength is zero at the point where g_m and g_P are equal in magnitude and opposition in directions. Due to the attractive nature of gravitational force, g_m and g_P will be opposite in direction somewhere along the straight line joining the centres of the moon and the planet and will be in between the moon and the planet. Let the null point be distance x from the centre of the moon:	B1 B1



At the null point,

$$|g_P| = |g_m|$$

$$\frac{GM_P}{\left(2.67\times10^{8}-x\right)^2}=\frac{GM_m}{x^2}$$ M1

$$\frac{9.04\times10^{24}}{\left(2.67\times10^{8}-x\right)^2}=\frac{9.63\times10^{22}}{x^2}$$

$$\frac{\sqrt{9.04\times10^{24}}}{2.67\times10^{8}-x}=\frac{\sqrt{9.63\times10^{22}}}{x}$$

$$\frac{x}{2.67\times10^{8}-x}=0.10321$$

$$x=(0.10321)\left(2.67\times10^{8}\right)-0.10321x$$

$$1.10321x=(0.10321)\left(2.67\times10^{8}\right)$$

$$x=2.4979\times10^{7}\text{ m}$$ A1

Distance of the null point from the moon's surface
$= 2.4979 \times 10^7 - 1.54 \times 10^6$
$= 2.3439 \times 10^7$ = **2.34×10^7 m**

Examiners' Report:
In general, candidates realised that at the null point, the field strengths due to the two bodies had the same magnitude. There were some who could not then solve the resultant quadratic, but not many. The most common mistake was to forget to subtract the radius of the moon from the solution to the quadratic.

iii (B)

Essential Question(s):

- What is the difference in determining the resultant field strength at a point versus the resultant potential at a point? → Unlike field strength which is a vector quantity, potential is a scalar quantity related to work done by an external force. Gravitational potential at a point is always negative, except at infinity. The resultant potential at a point is given by the scalar sum of the individual potentials at that point.

Solution:

The null point is not infinitely far away from the planet and the moon. Hence the gravitational potential at the null point due to each of them is negative. B1

The resultant potential at the null point is given by the scalar sum of the potentials due to the planet and the moon, which is therefore negative. B1

Examiners' Report:

			Although most candidates realised that gravitational potential was a scalar, they did not always go on to explain why the gravitational potential at the null point is not zero.	
		iii (C)	**Essential Question(s):** • How to determine the resultant gravitational potential at a point? **Solution:** Resultant gravitational potential at the null point, $\phi_{net} = \left(-\frac{GM_P}{(2.67\times10^8)-x}\right)+\left(-\frac{GM_m}{x}\right)$ $\phi_{net} = \left(-\frac{(6.67\times10^{-11})(9.04\times10^{24})}{(2.67\times10^8)-(2.4979\times10^7)}\right)+\left(-\frac{(6.67\times10^{-11})(9.63\times10^{22})}{(2.4979\times10^7)}\right)$ $\phi_{net} = (-2.4914\times10^6)+(-2.5714\times10^5) = -2.75\times10^6 \text{ J kg}^{-1}$ **Examiners' Report:** Candidates generally selected the correct equation for gravitational potential but then did not always add the two, tending to get into difficulties with their negative signs.	M1 M1 A1
	c		**Essential Question(s):** • What can be deduced about the 2 point charges given the fact that in between them there is a point where the resultant electric potential is zero? → The 2 point <u>charges</u> must be of <u>opposite signs</u>! • What are the electric field strength vectors due to 2 point charges of opposite signs like along the line joining their centres and in between them? → the <u>electric field strength vectors</u> due to the 2 point charges <u>act in the same direction at all points in between them</u> along the centreline. **Solution:** Since in between the 2 point charges there is a point where the resultant electric potential is zero, the 2 point charges must be of opposite signs. At all points in between 2 point charges of opposite signs, the electric field strength due to both charges act in the same direction. Therefore their vector sum will be non-zero. **Examiners' Report:** Most candidates realised that for the potential to be zero, the charges had to have opposite signs but they did not always go on to explain why the electric field strength on the line between the charges cannot be zero.	 B1 B1