H2 Physics 9749 – 2024 A Level Exam

Paper 1

1	**Essential Question(s):** • How to calculate the area of the circular orbit of the Moon around the Earth? **Solution:** The radius of the circular orbit is 4×10^8 m. The area of the circular orbit is $\pi \times (4 \times 10^8)^2$ $= 50 \times 10^{16}\ m^2 = 0.5 \times 10^{18}\ m^2 = 0.5 \times (10^9\ m)^2 = 5 \times 10^{-1}\ (Gm)^2$ **Answer: A**
2	**Essential Question(s):** • How to relate velocity (goal) to the a-t graph (given info)? **Solution:** Change in velocity = Area under a-t graph Note that the positive area (positive change in velocity) is lesser than the negative area (negative change in velocity). **Answer: B**
3	**Essential Question(s):** • What kinematics equation can be used to determine the time of flight of a projectile? • What do I know about v_y or s_y for a 2-D projectile motion where the object returns to the initial height? **Solution:** Resistance from the gases on the Moon is negligible. Take upwards as positive direction. Consider the vertical component of the initial speed $u_y = 15 \sin 40°$ and the final speed of the vertical component $v_y = 0$ when the golf reaches its maximum height. Using $v_y = u_y + a_y t$, $t = (v_y – u_y) \div a_y = (0 – 15 \sin 40°) \div (-1.62) = 5.95$ s Time of flight of the golf ball = $2 \times t = 11.9$ s OR At maximum height, $s_y = 0$ $s_y = u_y t + ½a_y t^2$ $0 = (15 \sin 40°)t + ½ (-1.62)t^2$ t = 0 (at the start) or t = 11.9 s (returns to the ground) **Answer: C**

4	**Essential Question(s):** • What is the force vector diagram that represents the equilibrium of forces acting on the cylinder? **Solution:** Smooth → No friction. Only contact force by the planes on the cylinder is the normal contact force. The angle between the planes X and Y is 90°. The force acting on the cylinder by plane X, F_X, points to the centre of the cylinder at 30° from the vertical. The force acting on the cylinder by plane Y, F_Y, points to the centre of the cylinder at 60° from the vertical. The force acting on the cylinder by gravity, W, points vertically downward. For 3 non-parallel coplanar forces in equilibrium, their lines of action should intersect at a common point, and, these 3 forces when joined head-to-tail should form a closed polygon vector diagram that represents a zero net force. **Answer: B**
5	**Essential Question(s):** • What is the change in the setup? • What determines the extension of each spring? • What is the original force in each spring? What is the new force in each spring? **Solution:** The 3 springs are identical. From the diagram, the force acting on each spring is W/3 and the extension of each spring is x. When the middle spring is removed and a weight of 2W is hanging from the middle of the beam, the force acting on each of the spring is (2W) / 2 = W which is 3 times of W/3. Hence the extension of each spring should also be 3 times of x. OR Before: 3kx = W ---(1) After: 2ky = 2W ---(2) where y is the new extension (2)/(1): (2y)/(3x) = 2 y = 3x ***Most candidates did not realise there were only two springs used in the final setup.*** **Answer: D**
6	**Essential Question(s):** • What is the area from the tensile load-extension graph that represents the net work done on the specimen? **Solution:** Work done by force on the elastic body, $W = \int_{x_i}^{x_f} F\,dx$ When the tensile load is increased from zero to the maximum value at point Q on the tensile load-extension graph, the total work done on the specimen is represented by the area OPQT. When the tensile load is reduced to zero at point S on the tensile load-extension graph, negative work is done on the specimen because extension is reduced and is represented by the area SRQT. Hence the net work done on the specimen during this process = area OPQT – area SRQT = area OPRS. **Answer: B**

7	**Essential Question(s):** • What determines the power output of the car engine? • What are the forces on the car? / What is the energy transformation as the car moves up the slope? **Solution:** The power provided by the engine of the car to do work against resistive force = F × v = 600 × 16 = 9600 W Per second the car moves 16 m along the slope, i.e. a height of 16 sin 10°. The gain in gravitational potential energy per second = 900 × 9.81 × 16 sin 10° = 24530 J The power provided by the car engine in increasing the gravitational potential energy of the car = 24530 W The total power provided by the car engine = 24530 + 9600 = 34130 W = 34.13 kW ***Most candidates did not realise the power provided by the engine is also used to increase the gravitational potential energy of the car.*** **Answer: C**
8	**Essential Question(s):** • Given a p-V graph, how to tell when there is work done BY gas, and, when there is work done ON gas? → Expansion (V increases) implies work done BY gas, and, Compression (V decreases) implies work done ON gas. **Solution:** The change from P to Q involves a drop in the gas pressure while its volume increases. During this change work is done by the gas. The change from Q to R involves a drop in the gas pressure while its volume increases. During this change work is done by the gas. The change from R to S involves an increase in the gas pressure while its volume is reduced. During this change work is done on the gas. The change from S to P involves an increase in the gas pressure while its volume is reduced. During this change work is done on the gas. **Answer: D**
9	**Essential Question(s):** • How to calculate angular velocity of a particle moving through a circular arc? → $\omega = \frac{d\theta}{dt}$, rate of change of angular displacement. **Solution:** The angle the point mass moves through an arc of length *l* = *l* ÷ *r*, where *r* is the radius of the circular arc. Angular velocity = change in angle ÷ change in time = (*l* ÷ *r*) ÷ *t* = *l* ÷ (*r* × *t*), where *t* is change in time. **Answer: A**
10	**Essential Question(s):** • How to calculate centripetal acceleration?

Solution:
The angular velocity of the object $\omega = 2\pi \div (24 \times 60 \times 60)\ \text{s}^{-1}$
The centripetal acceleration of the object = $r\omega^2 = (1.3 \times 10^7 \div 2) \times (2\pi \div (24 \times 60 \times 60))^2$
$= 0.034\ \text{m s}^{-2}$

Answer: A

11

Essential Question(s):

- What determines the gravitational potential at a point from a point mass? How would the gravitational potential of two points P and Q change when they move away from a point mass? → $\phi = -GM/r$
- For the same change in distance away from the point mass, is the change in gravitational potential lesser, greater or same when r is greater compared to when r is smaller? What is the shape of the ϕ-r graph? → hyperbolic → $\Delta\phi$ is lesser for the same Δr when r is greater.

Solution:
As the **magnitude** of gravitational potential of a point is inversely proportional to its distance from a point mass, the **magnitude** of gravitational potential of both P and Q decreases when they move away from the point mass.

Next, consider the shape of the ϕ-r graph → hyperbolic → **$\Delta\phi$ is lesser for the same Δr when r is greater.**

Answer: A

12

Essential Question(s):

- What determines the average force exerted?
- How can the kinetic theory of gases & Newton's laws of motion be applied to determine the force?

Solution:
Ideal gas assumption → collision is perfectly elastic, i.e. total KE conserved, so rebound speed is the same as v.
Change in the particle's momentum $\Delta p = 2mv$.

The time taken between two successive collisions with the same shaded wall, $\Delta t = (2x) \div v$ where x is the distance between two sides of the box in the x direction.
By Newton's 2nd law, average force exerted on the particle by the side of the box = rate of change of the particle's momentum = $\Delta p \div \Delta t = mv^2 \div x$.

By Newton's 3rd law, the force exerted on the side of the box by the particle = the force exerted on the particle by the side of the box.

Answer: A

13

Essential Question(s):

- What happens when waters at different temperatures are mixed? → Heat transfer from hotter to cooler water, and, thermal equilibrium is reached.
- How to determine the equilibrium temperature when two different volumes and temperatures of water are mixed together? What Physics law can be applied?

Solution:
Assume that density of water does not vary between 20°C and 60°C.
If mass of water at 60°C is m, then mass of water at 20°C is ¼m.

	When the two volumes of water are added together, heat energy will be transferred from the volume of water at 60°C to the volume of water at 20°C until both volumes of water reach an equilibrium temperature Θ°C. Lost of heat energy from the volume of water at 60°C = gain in heat energy by the volume of water at 20°C Lost of heat energy from the volume of water at 60°C = mc(60 – Θ) Heat energy gain by the volume of water at 20°C = (1/4)mc(Θ − 20) where c is the specific heat capacity of water. Hence mc(60 – Θ) = (1/4)mc(Θ − 20) and 4(60 – Θ) = Θ – 20 and 5Θ = 260, Θ = 52 **Answer: D**
14	**Essential Question(s):** • What is the E_K-t graph of a mass that oscillates with SHM? → sine^2 or cosine^2 function, depending on the initial condition. • What is the initial condition (i.e. E_K at t = 0) in this scenario? → starts from amplitude position, so E_K = 0 at t = 0. **Solution:** At t = 0, the mass is released from rest at its amplitude position, hence its E_K = 0. At t = T/4, the mass moved to the equilibrium position where its velocity is maximum and its E_K is also maximum. At t = T/2, the mass moved to its highest point vertically and is instantaneously at rest and its E_K = 0. At t = 3T/4, the mass drops back to the equilibrium position where its velocity is maximum and its E_K is maximum. At t = T, the mass moved back to its lowest point vertically and is instantaneously at rest and its E_K = 0. **Answer: C**
15	**Essential Question(s):** • What is the x-t graph for critical damping? **Solution:** When a suspended mass from a spring is displaced through a displacement x_0 from its equilibrium position and then released, it undergoes critical damping if it returns to the equilibrium position within the shortest time without oscillation. **Answer: C**
16	**Essential Question(s):** • What determines the power received/intercepted by the solar panel? → $P_{intercepted}$ = Intensity × $A_{intercepted}$ • How to calculate Intensity of the Sun at Earth & at Mars? → Intensity = P_{Sun} / (Area of the wavefront) = P_{Sun} / $4\pi r^2$ assuming Power from Sun transferred uniformly in all directions. **Solution:** Intensity of Sun light on the solar panel on the satellite orbiting around the Earth, I_E = 1.3 kW m^{-2} The distance of the satellite orbiting around the Earth is approximately equal to the distance from Earth to Sun, r_E = 1.5 × 10^{11} m. Let A be the area of the solar panel on the satellite orbiting around Mars. To receive 1.3 kW power from the Sun, intensity of Sun light on the solar panel of the satellite orbiting around Mar, I_M = 1.3 kW ÷ A

	The distance of the satellite orbiting around Mars is approximately equal to the distance from Mars to Sun, $r_M = 2.3 \times 10^{11}$ m. Intensity of Sunlight at a point a distance r away from the Sun is inversely proportional to the square of the distance of that point to the Sun. [Intensity = $P_{Sun} / 4\pi r^2$.] Hence $I_M \div I_E = (r_E \div r_M)^2$ and $I_M = I_E \times (r_E \div r_M)^2$ and $1.3 \div A = 1.3 \times (1.5 \div 2.3)^2$ and $A = (2.3 \div 1.5)^2 = 2.35$ m^2 **Answer: C**
17	**Essential Question(s):** • How to determine the amplitude of a polarised light transmitted by a polarizing filter whose transmission axis is non-parallel to the plane of polarization of the polarized light? → Draw a vector diagram, and resolve the amplitude of the incident light into the directions parallel and perpendicular to the transmission axis of the filter. **Solution:** Vertically polarised light is incident on a polarising filter. The plane of polarization of the filter is at angle ϕ to the vertical. The amplitude of the light transmitted by the polarising filter is directly proportional to cos ϕ. When $\phi = 0°$, the amplitude transmitted is A_0. When $\phi = 15°$, let the amplitude transmitted be A. $A = A_0 \cos 15°$ $A = 0.97\, A_0$ **Answer: D**
18	**Essential Question(s):** • What is found using the Rayleigh criterion? **Solution:** Rayleigh criterion is the limiting condition for two images to be just distinguished or resolved. Hence using the Rayleigh criterion, the resolving power of a single aperture is found. **Answer: D**
19	**Essential Question(s):** • What determines the number density of mobile charge carriers in a wire? → type of material and temperature • What determines the drift velocity of the mobile charge carriers in a wire used in an electric circuit? → Use $I = nqAv_d$ **Solution:** The number density of mobile charge carriers in a wire is a property of the material that made up the wire and temperature. Hence since the material is the same for both wires and assuming same temperature, their number densities are the same. $I = nqAv_d = ne\left(\frac{\pi d^2}{4}\right)v_d$ Since current I is the same in both wires, and n and e also the same, the drift velocity of charge carriers in a wire in an electric circuit is inversely proportional to the square of its diameter. Hence a wire with a smaller diameter has higher drift velocity in it. **Answer: C**
20	**Essential Question(s):** • What is the resistance between two opposite faces of a metal block?

	• How to determine which pair of opposites face of the block will give the **minimum** resistance? → Imagine connecting a source of EMF across two opposite faces, then resistance across = $\frac{\rho L}{A}$ where L is measured **parallel** to the current flow, and, A is the cross-sectional area **perpendicular** to the current flow. → **minimum** resistance is where **ratio** $\frac{L}{A}$ **is the smallest.** **Solution:** The resistance between two opposite faces of a metal block = ρL/A, where ρ is the resistivity of the metal, L is the distance between the two opposite faces of the metal block and A is the area of one of the two opposite faces. Resistance when A = xy and L = z is $\frac{\rho L}{A} = \frac{\rho z}{xy}$ Resistance when A = yz and L = x is $\frac{\rho L}{A} = \frac{\rho x}{yz}$ Resistance when A = xz and L = y is $\frac{\rho L}{A} = \frac{\rho y}{xz}$ Since x < y < z, $\frac{\rho L}{A} = \frac{\rho x}{yz}$ is the **minimum**. Answer is Option B. Options C and D are not resistance. **Answer: B**
21	**Essential Question(s):** • Under what conditions will the galvanometer show zero current? → e.m.f. of cell across PQ = p.d. across the 2.0 Ω resistor, and, P is at lower potential than Q so that no current flows through the galvanometer. **Solution:** When the cell is connected between P and Q and the reading on the galvanometer is zero, no current flow passes the cell. The only current flow passes the circuit passes the 1.0 Ω and 2.0 Ω resistors and the current $I = V / R$ = 0.60 / (1.0 + 2.0) = 0.20 A. the p.d. across the 2.0 Ω resistor = $I \times R$ = 0.20 × 2.0 = 0.40 V Since no current flow passes the cell connected across PQ, the e.m.f of the cell equals the p.d. of the 2.0 Ω resistor and the polarity of the cell connected to P is negative. **Answer: A**
22	**Essential Question(s):** • How does the resistance of a thermistor change with its temperature? • How to calculate the current in A_1 and in A_2? **Solution:** The resistance of a thermistor decreases when its temperature increases. As the resistance of the thermistor decreases, the effective resistance of the parallel circuit decreases, causing the current flowing pass the entire circuit to increase and the reading on A_1 increases.

	As the current flowing pass the entire circuit increases, the p.d. across the resistor that is connected in series to the parallel circuit increases and the p.d. across the parallel circuit decreases. As the p.d. across the parallel circuit decreases, the reading on A_2 decreases. **Answer: A**
23	**Essential Question(s):** • What is the direction of the force acting on a negative ion in a uniform electric field? • What is the direction of the force acting on a moving negative ion in a uniform magnetic field? **Solution:** The direction of the electric force acting on a negative ion in a uniform electric field is opposite to the direction of the electric field. The direction of the magnetic force acting on a moving negative ion in a uniform magnetic field is in a direction given by the Fleming's left-hand rule. In option A, the uniform electric field exerts a force on the negative ion in the direction out of the page while the uniform magnetic field exerts a force on the moving negative ion in the direction into the page. If these two forces are equal in magnitude, the net force on the negative ion will be zero and the negative ion will continue to move in a straight line. In option B, the uniform electric field exerts a force on the negative ion that has a downward and rightward components while the uniform magnetic field exerts a force on the moving negative ion in an upward direction. If the upward magnetic force equals the downward component of the electric force in magnitude, the net force on the negative ion acts rightward and the negative ion accelerates in a straight line towards the right. In option C, the uniform electric field exerts a force on the negative ion in the direction into the page while the uniform magnetic field exerts a force on the moving negative ion downward with a net force that changes the direction of the moving negative ion making it impossible for it to pass through the holes P and Q. In option D, the uniform electric field exerts a rightward force on the negative ion while the uniform magnetic field exerts no force on the moving negative ion. The net rightward force accelerates the negative ion from P to Q. ***This question was difficult and required candidates to think carefully about the forces on the negative ion.*** **Answer: C**
24	**Essential Question(s):** • What is the time for a charged particle to complete one revolution in a circular motion in a plane perpendicular to a uniform magnetic field? **Solution:** The magnitude of the magnetic force acting on the charged particle = qvB. This magnetic force provides the centripetal force for the charged particle to go into circular motion. Hence $qvB = mv^2/\text{r}$, giving $v = qrB/m$. For circular motion $v = 2\pi r/T$, where T is the time for one complete revolution in a circle. Hence $qrB/m = 2\pi r/T$ and $T = 2\pi m/(qB)$ Hence T is independent of r but directly proportional to m and inversely proportional to q and B.

	This question required the link between circular motion and magnetic force. Common incorrect answer is option A. **Answer: B**
25	**Essential Question(s):** • What is the magnitude of the magnetic flux cut by a length moving with a speed? → Flux cut = Change in flux linkage = B × Area swept perpendicular to the field **Solution:** The aircraft wing moves across an area *A* that is perpendicular to the vertical component of the Earth's magnetic field. The magnitude of the magnetic flux cut = $B \times A$, where $B = 1.0 \times 10^{-5}$ T and $A = 80 \times 150 \times 60 = 7.2 \times 10^{5}$ m^2 Hence magnetic flux cut = $7.2 \times 10^{5} \times 1.0 \times 10^{-5} = 7.2$ Wb **Answer: D**
26	**Essential Question(s):** • What fraction of a cycle of an a.c. voltage can the magnitude of its voltage <u>change by</u> 2 times the peak value? **Solution:** In one quarter of a cycle an a.c. voltage can change from its positive peak value to zero. The a.c. voltage can then change from zero to its negative peak value in another quarter cycle. Sum of two quarter cycles equals half a cycle. **Answer: B**
27	**Essential Question(s):** • What is energy transformation in this circuit? → Power output of the station = Power input at sub-station + Power dissipated in the transmission cables. • How to calculate the Power dissipated in the transmission cables? → $P_{cables} = I_{cables}V_{cables} = I_{cables}{}^{2}R_{cables} = \frac{V_{cables}{}^{2}}{R_{cables}}$ [Beware: p.d. across the cables is NOT equal to the p.d. across the output of the power station! The p.d. across the output of the station is equal to the sum of the p.d. across the cables and also the p.d. across the sub-station!] **Solution:** There is no mention of the electric power being transmitted as a.c. voltage, hence effective or r.m.s. voltage need not be considered. The current output, from the power station, $I = P / V$, where *P* is the power output of the power station and *V* is p.d. at the output of the power station. $I = 100.00 \times 10^{6} / (400 \times 10^{3}) = 250$ A Total resistance of the two overhead cables = $100 \times 0.030 \times 2 = 6.0\ \Omega$ Power dissipated in the two overhead cables = $I^2R = 250^2 \times 6.0 = 0.375$ MW Power input to the sub-station = 100.00 – 0.375 = 99.63 MW ***This is the most challenging question on the paper. Note that the power dissipated by the overhead cables cannot be calculated using the p.d. at the output of the power station as there is a p.d. at the input of the sub-station.*** **Answer: A**

28	**Essential Question(s):** • What is the momentum of a photon? • What is the energy of a photon? **Solution:** The particle nature of photon implies that the momentum of a photon, $p = h / \lambda$. The quantization of light energy is stated as energy of a photon of light = hf. The speed of light in vacuum $c = f\lambda$ and therefore $f = c / \lambda$. Hence energy of a photon of light = $hf = hc / \lambda = (h / \lambda)c = pc$. ***There is significant number of candidates think that the energy of a photon of light = ½ pc.*** **Answer: D**
29	**Essential Question(s):** • What is stated in Heisenberg's uncertainty principle? **Solution:** Heisenberg's uncertainty principle stated that there is fundamental limit to how precisely certain pairs of complementary physical properties of a particle, like its position and momentum, can be known simultaneously. If a particle moving with a precisely defined velocity, then it has a precisely defined momentum and therefore cannot have a precisely defined position at the same time. **Answer: B**
30	**Essential Question(s):** • What is the mass defect of an isotope? **Solution:** Mass defect is the difference between the sum of the masses of the protons, neutrons and electrons in an atom from the actual mass of the atom. The atom of the isotope Fe-56 has an actual mass of 55.93493 u. The atom of the isotope Fe-56 has an atomic number of 26. Hence the atom of the isotope Fe-56 has 26 electrons, 26 protons, and (56 – 26) = 30 neutrons. The total mass of all these sub-atomic particles in the atom of the isotope Fe-56 $= (1.00728 + 0.00055) \times 26 + 1.00867 \times 30 = 26.20358 + 30.2601 = 56.46368\ u$. Mass defect = $56.46368 - 55.93493 = 0.52875\ u$ $1\ u = 1.66 \times 10^{-27}$ kg Mass defect = $0.52875 \times 1.66 \times 10^{-27} = 8.78 \times 10^{-28}$ kg ***Candidates who chose option B have not included the mass of electrons.*** **Answer: D**

Paper 2

1	**a**		**Essential Question(s):** How to relate the maximum height (goal) to the given info (maximum increase in GPE)? **Solution:** When the projectile reaches its maximum height, the maximum increase in gravitational potential energy is given by mgh where m = 0.43 kg g = 9.81 m s^{-2} h = maximum change in height hence 0.43 × 9.81 × h = 27 J and h = 27 ÷ 0.43 ÷ 9.81 = 6.4007 = 6.4 m **Examiners' Report:** Using g = 10 m s^{-2} results in h = 6.27 m and is considered a wrong answer. The answer of this question cannot be determined using trigonometric function such as tan 32°.	 M1 A1
1	**b**		**Essential Question(s):** How is the vertical component of the initial velocity (goal) related to the known info from earlier parts of the question? **Solution:** $v_y^2 = u_y^2 + 2a_ys_y$ Take upwards as positive direction. maximum s_y = +6.4007 m a_y = − 9.81 m s^{-2} at maximum height v_y = 0 hence $u_y = (2 \times 9.81 \times 6.4007)^{0.5}$ = 11.206 = 11.2 m s^{-1} **Examiners' Report:** This question was generally well answered. Giving answers in the form of an expression without substituting values into the expression will not be awarded marks.	 M1
1	**c**	**i**	**Essential Question(s):** What type of collision is this? → Perfectly in elastic; objects stick together and move off with a common velocity. What Physics law can be applied to find the common velocity after collision? **Solution:** Immediately after collision the velocity v should be in the same direction as u_x, the horizontal component of the initial velocity of the original projectile. u_y / u_x = tan 32° u_x = u_y / tan 32° = 11.206 / tan 32° = 17.934 m s^{-1} By conservation of linear momentum Total final momentum = Total initial momentum (0.43 + 0.67) × v = 0.43 × 17.934 v = 0.43 × 17.934 ÷ (0.43 + 0.67) = 7.0 m s^{-1} **Examiners' Report:** Many candidates answered this question correctly.	 B1 M1 M1 A1

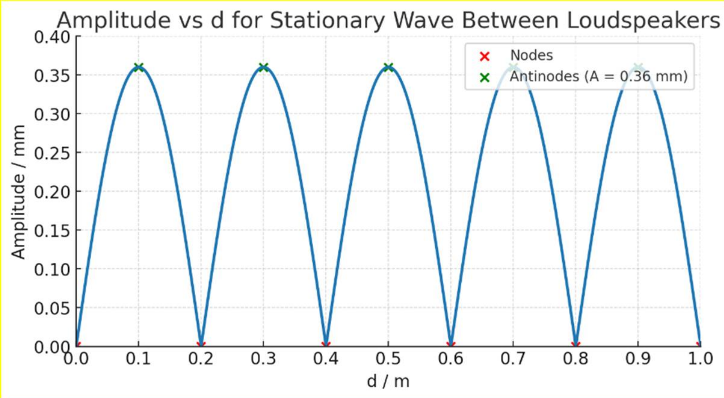
			Those who answer incorrectly calculated the horizontal component of the initial velocity using wrong trigonometric functions or using tan 32° wrongly. Some use the vertical component of the initial velocity from 1(b) wrongly as the horizontal component of the initial velocity. Some candidates do not realise at maximum height vertical component of the velocity of the combined projectile is zero.	
1	**c**	**ii**	**Essential Question(s):** What is horizontal distance travelled by the original projectile as it rises? What is horizontal distance travelled by the combined projectile as it falls? ➔ $s_x = u_x$ t, where u_x for both motions already known ➔ t can be derived from the vertical motion equation $v_y = u_y + a_y$ t. Since v_y, u_y and a_y are the same for both motions, t same for both. **Solution:** The horizontal distance travelled by the combined projectile as it falls is shorter than the horizontal distance travelled by the original projectile as it rises. The reasons are: 1. Horizontal component of the initial velocity of the original project is greater than the horizontal velocity of the combined projectile after collision. 2. The time taken for the rising motion and falling motion are equal, since the vertical change in displacements, the vertical acceleration, and the vertical components of velocities at the ground level and maximum height are same for both motions. **Examiners' Report:** Many candidates made the correct comparison but explained the comparison solely in terms of the horizontal velocity. A number referred only to the reduced kinetic energy without further explanation. There were also frequent references to the greater weight of the combined object causing the vertical acceleration of the combined object to be less than or greater than that of the initial object. Conclusions derived from these premises were usually incorrect.	B1 B1

2	**a**		**Essential Question(s):** What assumption about intermolecular forces is made in the kinetic theory of ideal gases? **Solution:** The intermolecular forces between molecules are negligible, and contact forces exist only for an infinitesimally short duration during collisions. **Examiners' Report:** This question was well answered. A few responses made no mention of the forces between molecules and instead referred to the separation of molecules or to another assumption of the kinetic theory.	B1
2	**b**		**Essential Question(s):** What contributes to the **internal energy** of an **ideal gas**? What are the **assumptions** of an **ideal gas**? **Solution:** Internal energy is equal to the sum of the kinetic energies of the molecules and the potential energy between molecules.	

			For an **ideal gas**, there are **no intermolecular forces**, and hence **no potential energy between the molecules**. Hence **internal energy is solely equal to the total kinetic energy of the molecules** arising from the **random motion of its molecules**. **Examiners' Report:** This question was challenging for candidates. A significant number made no reference to the random motion of molecules.	B1
2	**c**	**i**	**Essential Question(s):** How can we calculate the total kinetic energy of molecules in an ideal gas from the known info (T, N)? **Solution:** For an ideal gas, the total kinetic energy of N molecules is: $E_k = \frac{3}{2}NkT$ Given: $N = 2.50 \times 10^{23}$ T = 21°C = 294.15 K $k = 1.38 \times 10^{-23}$ J K^{-1} Substitute: $E_k = \frac{3}{2} \times (2.50 \times 10^{23}) \times (1.38 \times 10^{-23}) \times 294.15$ = 1520 J Therefore, total kinetic energy = 1520 J. **Examiners' Report:** Most candidates used the correct formula and obtained the right value. A few forgot the (3/2) factor or used the wrong temperature.	M1 A1
2	**c**	**ii**	**Essential Question(s):** How is thermal energy supplied (Q) to an ideal gas related to its change in temperature and the change in volume? ➔ Change in temperature is related to change in internal energy (ΔU). ➔ Change in volume is related to work done on gas (W). ➔ Apply First Law of Thermodynamics. **Solution:** Thermal energy supplied: Q = ΔU – W Step 1: INCREASE in internal energy $\Delta U = \frac{3}{2}NK\Delta T = \frac{3}{2} \times 2.50 \times 10^{23} \times 1.38 \times 10^{-23} \times 15$ = 77.6 J Step 2: Work done ON the gas (the gas is heated at constant pressure so its volume increases and work done on the gas is negative). Work done ON gas, W = –p ΔV $W = -(1.0 \times 10^5) \times (+6.3 \times 10^{-4}) = -63$ J Step 3: Total thermal energy supplied TO the gas Q = ΔU – W = 77.6 – (-63) = 141 J	M1 M1 A1

			Examiners' Report: Most candidates applied both components of the First Law correctly. Some omitted either the internal energy change or the work done term.	

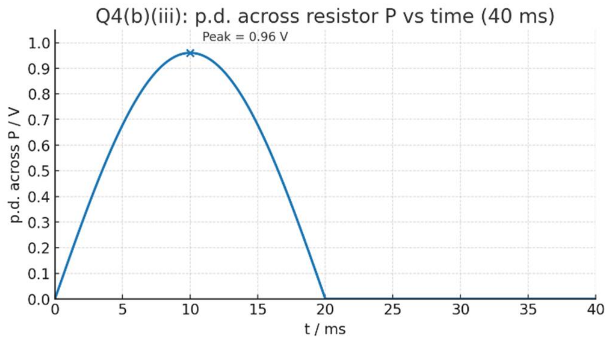
3	**a**	**i**	**Essential Question(s):** What are the conditions to produce a steady hence observable interference? Which condition does having the same signal generator satisfy? **Solution:** The two loudspeakers must **emit waves of the same frequency (or wavelength) and be coherent ensuring a constant phase difference** (in this setup, in phase) — so that a steady interference pattern is produced, resulting in fixed positions of nodes and antinodes. **Examiners' Report:** Many candidates realised that the waves generated by the loudspeakers needed to have equal frequencies or wavelengths for a stationary wave to be formed. Many candidates suggested other quantities that did not need to be exactly equal or which were not equal because the loudspeakers were connected to the same signal generator, including amplitude and speed. Such answers were not totally incorrect but were not themselves a sufficient answer to the question.	B1
3	**a**	**ii**	**Essential Question(s)** In a stationary wave, how can the wavelength be measured? → distance between two successive nodes or two successive antinodes = half a wavelength. How can you detect the positions of nodes or antinodes in a stationary sound wave? **Solution:** Place a **microphone connected to an oscilloscope** along the line between the two loudspeakers. Move the microphone to **detect successive pressure nodes / displacement antinodes (minimum loudness) OR successive pressure antinodes / displacement nodes (maximum loudness)**. **Measure the distance** between several adjacent nodes or antinodes using a **metre rule**. The **spacing between adjacent nodes (or antinodes) is equal to half a wavelength $\frac{\lambda}{2}$**. Calculate λ using the average spacing: **λ = 2 × (average spacing between adjacent nodes/antinodes)** **Examiners' Report:** Most candidates correctly used a microphone and oscilloscope to detect nodes or antinodes. Some incorrectly focused on finding frequency or timing sound travel between speakers. Many also forgot to mention the instrument used to measure distances.	B1 B1 B1
3	**b**	**i**	**Essential Question(s)** What is the equation linking wave speed, frequency, and wavelength? **Solution:**	

			f = v / λ f = 340 / 0.40 f = 850 Hz	A1
3	**b**	**ii**	**Essential Question(s)** Amplitude refers to displacement. How should the amplitude vary along the distance between two loudspeakers for a stationary wave? At which positions are the amplitude maximum and where are the amplitude minimum? → Maximum amplitude at the displacement antinodes (constructive interference), and minimum amplitude at the displacement nodes (destructive interference). How to determine the exact positions where the displacement nodes & antinodes are? → Consider phase difference between the two sources, and path difference between the two waves. **Solution:**  The loudspeakers are producing waves in phase with each other. The loudspeakers are 2.5 λ apart, so path difference between the two waves at each end (d = 0 m and d = 1.0 m) is 2.5 λ. Since the waves from both speakers have the same amplitude (0.18 mm) but meet in antiphase, they undergo destructive interference and the resultant displacement equal to zero. At the midpoint where path difference equal to zero, the two waves meet in phase and undergo constructive interference, so maximum resultant displacement at the midpoint and equal to 0.18 + 0.18 = 0.36 mm Separation between two successive nodes = 0.40 m ÷ 2 = 0.20 m Separation between two successive antinodes = 0.40 m ÷ 2 = 0.20 m Separation between a node and successive antinode = 0.40 m ÷ 4 = 0.10 m Amplitude variation graph should be sine/cosine shape. [Contrast with Intensity variation graph which should be $sine^2$/$cosine^2$ shape.] **Mark scheme:** Mark 1: Correct node spacing and positions • Node–node spacing = λ / 2 = 0.20 m • Nodes at d = 0.00 m, 0.20 m, 0.40 m, 0.60 m, 0.80 m, and 1.00 m Mark 2: Correct maximum amplitude • A_{max} = 2 × 0.18 mm = 0.36 mm at each antinode Mark 3: Correct overall shape **Examiners' Report:** Common mistakes included:	

			• Spacing the minima 0.40 m apart instead of the correct 0.20 m. • Using incorrect maximum amplitudes such as 0.38 mm or 0.40 mm instead of the expected 0.36 mm.	

4	**a**		**Essential Question(s)** For a sinusoidal a.c., what is the general equation of V in terms of t? → $V = V_o \sin(\omega t) = V_o \sin(2\pi f t) = V_o \sin\left(\frac{2\pi}{T}t\right)$ What is the peak value (amplitude V_o) of V from the graph? What is the time for one complete cycle (period T)? How do you convert T into angular frequency ω using $\omega = \frac{2\pi}{T}$? Are the units on Fig. 4.1 consistent with the required units of t in s? **Solution:** From Fig. 4.1: Amplitude: V_o = 4.8 V Period: T = 40 ms = 0.040 s Angular frequency: $\omega = \frac{2\pi}{T} = \frac{2\pi}{0.04}$ = 157 rad s^{-1} Final equation: V = 4.8 sin157 t **Examiners' Report:** Most students answered this part well. A few lost marks because they: • Misread the graph and used 4.4 V instead of the correct peak voltage of 4.8 V. • Used the wrong period, e.g. 20 ms or 40 s, instead of the correct value. • Left the angular frequency as $\frac{2\pi}{0.04}$ without calculating the numerical value.	M1 A1
	b	**i**	**Essential question(s)** Which resistors are in series and which are in parallel? How to combine resistances in parallel, and, resistances in series? **Solution:** $R_{parallel} = \frac{6}{2}$ = 3 Ω R_{total} = 12 Ω + 3 Ω = 15 Ω	A1
	b	**ii**	**Essential question(s)** What is V_{rms} for a sinusoidal a.c. with peak value V_0? How is mean power found from V_{rms} and R? **Solution:** V_0 = 4.8 V For a sinusoidal a.c., $V_{rms} = \frac{V_0}{\sqrt{2}} = \frac{4.8}{\sqrt{2}}$ = 3.39 V Mean power: $P_{mean} = \frac{V_{rms}^2}{R_{total}} = \frac{3.39^2}{15}$ = 0.768 W	M1 A1

<table>
<tr><td></td><td></td><td></td><td>Examiners’ Report:
Most students answered this part well. A few lost marks by using the factor of 2 incorrectly, which led to mean power values that were either double or half the correct value.</td><td></td></tr>
<tr><td></td><td>b</td><td>iii</td><td>Essential question(s)
During which half-cycle does the diode conduct?
What is the peak p.d. across P when the diode conducts?
What is the p.d. across P when the diode is reverse-biased?

Solution:


Key reasoning
When the diode conducts (positive half-cycle): the circuit is 12 Ω in series with (6 Ω ‖ 6 Ω).
The parallel pair is 3 Ω.
$V_{\text{peak of parallel}} = \frac{3}{12+3} \times 4.8 = \frac{1}{5} \times 4.8 = 0.96$ V.
At each t, V is $\frac{1}{5}$ of the V-coordinate in Fig. 4.1 when the diode is forward-bias and conducting. Plot a few points to draw a curve on the graph grid: e.g.
- At t = 10, V_P = 0.96 V
- At t = 6 and 14, $V_P = \frac{1}{5} \times 4 = 0.8$ V
- At t = 3 and 17, $V_P = \frac{1}{5} \times 2.4 = 0.48$ V
- At t = 1 and 20, V_P = 0
Choose a good scale for y-axis (i.e. Acceptable scales of 1:1, 1:2, 1:4 or 1:5, and, covers at least half the graph grid in the y-direction). E.g. choose 1 big square to be 0.4 V.

When the diode is reverse-biased (negative half-cycle): current in branch P is zero ⇒ V = 0.

1 mark: Correct shape for forward-bias, and, zero for reverse-bias.
1 mark: Precision of at least 6 plots. Good scale for y-axis.

Examiners’ Report:
The sketch needed to show a p.d. of 0 V for 20 ms, but some did not clearly draw the line along the horizontal axis. A number of answers lacked a vertical axis scale. Some students drew a |sin| curve but with the wrong peak value — common incorrect peaks were 4.8 V, 2.4 V, or 0.48 V instead of the correct 0.96 V.</td><td></td></tr>
</table>

<table>
<tr><td>5</td><td>a</td><td></td><td>Essential question(s)
What is the magnetic flux density of a long straight wire at distance r away from the wire given by?
How do you solve for I when B and r are given?</td><td></td></tr>
</table>

			Solution: $B = \frac{\mu_0 I}{2\pi r}$ Rearrange: $I = \frac{B\,(2\pi r)}{\mu_0}$ $I = \frac{2.8 \times 10^{-4}\,(2\pi \times 8.5 \times 10^{-3})}{4\pi \times 10^{-7}}$ I = 11.9 A or 12 A **Examiners' Report:** A few candidates supplied incorrect answers that were due to arithmetic miscalculations or the use of an incorrect equation.	A1
	b	i	**Essential question(s)** How to calculate the magnitude of magnetic force on a current-carrying straight rod? → $F_{rod} = B_{external} I_{rod} L_{rod}$ **Solution:** Force per unit length on rod: $\frac{F}{L} = B_{external} I_{rod}$ $\Rightarrow \frac{F}{L} = \frac{\mu_0 I_{wire}}{2\pi r} \times I_{rod}$ $\frac{F}{L} = \frac{4\pi \times 10^{-7} \times 11.9 \times 9.2}{2\pi \times 8.5 \times 10^{-3}}$ $= 2.58 \times 10^{-3}$ N m^{-1} or 2.6×10^{-3} N m^{-1}	A1 A1
	b	ii	**Essential question(s)** What is the weight per unit length of the rod? How does the magnetic force change the force on each support? How to compute the percentage change at each support? **Solution:** Convert mass per unit length: $\frac{m}{L}$ = 63 g m^{-1} = 0.063 kg m^{-1} Weight per unit length: $\frac{W}{L} = \frac{m}{L} g = 0.063 \times 9.81 = 0.618$ N m^{-1} For parallel conductors carrying **current in opposite directions**, the **magnetic force is repulsive**. The rod is pushed upwards (away from the wire). This means the supports need to provide less upward force to hold the rod in place. Magnetic force per unit length from (b)(i)): $\frac{F}{L} = 2.58 \times 10^{-3}$ N m^{-1} Original force per unit length on each support: $F_{original}$ per support $= \frac{W}{2L}$ Change in force per unit length on each support: ΔF per support $= \frac{F_{magnetic}}{2L}$ Percentage change on each support: $= \frac{\frac{F_{magnetic}}{2L}}{\frac{W}{2L}} \times 100\%$ $= \frac{2.58 \times 10^{-3}}{0.618} \times 100\%$ = 0.417% or 0.42%	M1 A1

			Examiners' Report: Many students correctly found the weight per unit length as 0.618 N m^{-1} but did not always use it correctly for the percentage change. Some wrongly subtracted the magnetic force from this value before calculating the percentage. Fig. 5.2 shows two supports — if you halve both the magnetic force and the weight consistently, the halves cancel and the percentage is unchanged. Errors occurred when students halved only one part of the calculation, leading to an answer that was double or half of the correct value.	
	b	**iii**	**Essential question(s)** Is the magnetic force on the rod upward or downward? Do the supports experience an increased or decreased load? **Solution:** The **current** in the rod is **opposite direction** to the current in the wire. By Fleming's left-hand rule, the **magnetic force on the rod is upward**. This upward magnetic force **acts opposite direction to the weight of the rod**, **so the upward force exerted by each support to maintain equilibrium of forces decreases**. **Examiners' Report:** Some students only wrote "increase" or "decrease" without explaining why, so they lost marks. You must give both the direction of the change and the reasoning. A common mistake was saying opposite currents attract — this is wrong, they repel — which led to the wrong prediction for the change in support force.	B1
	b	**iv1**	**Essential question(s)** What is the direction of the magnetic field at the rod due to the straight wire? Using Fleming's LHR, what is the direction of the force on the rod? **Solution:** By the right-hand grip rule, a current to the right in the wire produces a magnetic field out of the page at points above the wire (where the rod is placed). Using Fleming's left-hand rule, this magnetic field exerts a magnetic force **to the right on the rod**. **Examiners' Report:** Most students explained their reasoning clearly and got the correct direction of force. Common mistakes: Getting the wrong magnetic field direction, which led to the wrong force direction. Thinking there is no force just because the rod and wire are no longer parallel — there is still a force as long as the current and magnetic field are not parallel.	B1 A1
		iv2	**Essential question(s)** How does the magnetic field from a long straight wire vary with distance, and hence how does the magnetic force per unit length on the rod vary with distance?	

			Solution: The magnetic flux density at distance d frow a long straight wire is $B = \frac{\mu_0 I_{wire}}{2\pi d}$ Since current in wire I_{wire} is constant, ***B* is inversely proportional to the distance d from the wire.** The magnetic force per unit length on the rod is $\frac{F}{L} = B\ I_{rod}$ Since current in the rod I_{rod} is constant, thus $\frac{F}{L}$ **is (directly) proportional to B and hence inversely proportional to d.** **Examiners' Report:** Simply stating "the force per unit length decreases with distance" is incomplete. You must also explain that the magnetic field strength B from a long straight wire is inversely proportional to distance ($B \propto 1/d$), and since the magnetic force per unit length F/L = B × I (for a perpendicular rod) is directly proportional to B, it is also inversely proportional to d.	A1

6	**a**		**Essential question(s)** What does the fact that most α-particles pass straight through imply about the atom's structure? What does the small fraction of α-particles deflected through large angles imply about the concentration of positive charge and the size of this positive core relative to the atom? **Solution:** **Most α-particles pass straight through → Most of the atom is empty space.** **A small number are deflected by large angles → The large deflections imply that all of the atom's positive charges were concentrated in a very small volume (called the nucleus) and that most of the mass were concentrated in this small volume too. / Atom contains a very small, dense, positively charged nucleus that repels the positively charged α - particles.** Since **only a small fraction** were deflected by large angles implies that the **nucleus is very small compared to the size of the atom**. **Examiners' Report:** Many candidates gave only the first two deductions; the "mass concentrated in the nucleus" point was often missed. Avoid confusing nucleus with atom and gold atoms with α -particles. Do not say the nucleus is mostly empty space — that is incorrect. Ensure you are deducing the structure of the atom, not the α -particle.	B1 B1 B1
6	**b**		**Essential question(s)** What form of energy does the α-particle have initially, and what does it all convert into at the closest approach? What is the correct expression for electric potential energy between two point charges? How do you use the charges of the α -particle and the gold nucleus in the equation?	

			Solution: At the distance of closest approach d, the α-particle is instantaneously at rest and its initial kinetic energy is converted entirely into electric potential energy stored in the system: Loss in kinetic energy = Gain in electric potential energy $E_{k,\text{alpha}} - 0 = \frac{Q_{gold}\,Q_{alpha}}{4\pi\varepsilon_0 d} - 0$ (Assuming initial separation is finite, hence initial EPE is zero.) $d = \frac{Q_{gold}\,Q_{alpha}}{4\pi\varepsilon_0 E_{k,alpha}} = \frac{79 \times 1.60\times10^{-19} \times 2 \times 1.60\times10^{-19}}{4\pi \times 8.85 \times 10^{-12} \times 1.23 \times 10^{-12}}$ $= 2.96 \times 10^{-14}$ m **Examiners' Report:** Do not confuse electric potential (V) with electric potential energy (EPE). EPE ∝ 1/d, not $1/d^2$. Always include both charges (Q_{alpha} and Q_{gold}) in the calculation, each expressed in coulombs, not just 2 and 79. Do not add the charges together. Use multiplication $Q_1 \times Q_2$. Remember the constant ($1 / (4\pi\varepsilon_0)$) in the calculation. The de Broglie equation is not relevant here. This is an electric (Coulomb) interaction, not a gravitational one.	B1 M1 A1

7	**a**		**Essential question(s)** Why do photoelectrons have a range of kinetic energies even when monochromatic light is used? **Solution:** There is a 1-to-1 interaction between the incident photon and an electron in the metal. For an electron to be emitted, the energy per photon E_p must be greater or equal to the work function energy of the metal surface Φ. The excess of energy supplied by the photon (E_p – Φ) transforms into kinetic energy KE of the emitted electron. Electrons at the surface use *just enough* energy to overcome the work function Φ and so are emitted with maximum kinetic energy. Electrons deeper in the metal need to do more work against the electrostatic force of attraction exerted by the metal cations on them to reach the surface, so they have less kinetic energy when emitted. This causes a range of kinetic energies for the photoelectrons. **Examiners' Report:** Most students understood that the maximum kinetic energy comes from electrons that only need to overcome the work function and do no other work. However, fewer explained clearly that electrons starting deeper inside the metal need extra energy to reach the surface, so they have less kinetic energy. Answers that only mentioned photon energy or discrete energy levels were incomplete. The best answers clearly stated that different electrons need to do different amounts of work, which causes the range of kinetic energies.	 B1 B1 B1
	b		**Essential question(s)**	

			What determines the maximum (threshold) wavelength for photoelectric emission to occur? $E_p \geq \Phi_{metal}$ minimum $E_p = \Phi_{metal}$ $hf_o = \Phi_{metal}$ $\frac{hc}{\lambda_o} = \Phi_{metal}$ How to calcuate the work function Φ_{metal} from the given info (E_p and KE_{max})? **Solution:** Work function: $\Phi = E_p - KE_{max}$ $= 7.95 - 3.48 = 4.47$ eV Convert to joules: $\Phi = 4.47 \times 1.60 \times 10^{-19} = 7.15 \times 10^{-19}$ J Maximum wavelength: $\lambda_{max} = \frac{hc}{\Phi}$ $= \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{7.15 \times 10^{-19}}$ $= 2.78 \times 10^{-7}$ m **Examiners' Report:** Many students answered well and got the correct wavelength. Common mistakes were: • Assuming the work function was just one of the given energies, instead of the **difference** between them. • Forgetting to convert eV to joules. • Using the wrong conversion factor (e.g. for MeV instead of eV).	M1 M1 A1
	c		**Essential question(s)** Does changing intensity affect photon energy? How does photon number per second relate to photoelectron emission rate? **Solution:** Increasing the intensity (with the same frequency) increases the number of photons incident per second. Photons interact with the electrons in the metal on a 1-to-1 basis. More photons incident cause more electrons to be emitted per second, so the plate discharges faster and the time taken to fully discharge is reduced. **Examiners' Report:** Most students explained this well — many clearly stated that higher intensity means more photons hitting the surface each second, which causes more electrons to be emitted per second. Some students mixed up photons and electrons, or forgot to mention electrons in their explanation.	B1 B1
	d		**Essential question(s)** What is the relationship between photon energy and the work function for photoemission? Why does illumination time not affect emission if photon energy is insufficient?	

			Solution: The incident photon and the electron in the metal interact on a 1-to-1 basis. An electron cannot combine the energy of multiple photons over time — each photon acts independently and is absorbed instantly. No electron is emitted because the energy of each infrared photon is less than the work function of the metal. Thus, the photon cannot provide enough energy to free an electron from the metal surface, regardless of how long the plate is illuminated. **Examiners' Report:** Most students correctly said that the infrared photon energy is less than the work function (or that its frequency is below the threshold), so electrons cannot be emitted. However, many forgot to mention that electrons cannot combine the energy of multiple photons over time — each photon acts independently and is absorbed instantly. Therefore, even long exposure will not cause emission.	B1 B1

8	**(a)**		**Essential Question(s):** • What is "half-life" and how does it relate to radioactive decay? • How does the half-life of plutonium-238 compare with the mission duration of Perseverance (14 years)? • Why is long-term stability in power output important for space missions? Use data from paragraphs 6 and 7. **Solution:** Plutonium-238 has a long half-life of 87.7 years, ensuring that it provides a steady and long-lasting source of thermal energy over the entire 14-year mission of Perseverance, with only a small decrease in activity and power output at the end of its lifespan. **Examiners' Report:** Only a minority of answers referred to the lifespan of Perseverance or to the vehicle at all. Answers tended to be rather general and mentioned only that this isotope of plutonium would last a long time.	B1
8	**(b)**		**Essential Question(s):** • How energetic are alpha particles? • How far can α-particles travel in materials, and why does that matter in a power generator? • What happens to the energy of emitted α-particles in a sealed RTG container? **Solution:** α-particles have low penetrating power, so their energy is confined within a small volume of the RTG. This allows the radioactive material to reach a high temperature, making it efficient for generating thermal energy used by the thermocouples. **Examiners' Report:** This was not well answered and many answers referred to the harmful effects of α-radiation on humans. This is referred to in the passage and is not especially relevant for a remotely operated vehicle. Some of the statements	B1

			given were incorrect or imagined: α-radiation is not the least ionising, the most penetrating or necessarily the most energetic. Few candidates stated that its low penetrating power ensured that the energy of the particles was very largely dissipated within the RTG and that this resulted in the sample reaching the highest possible temperature.	
8	(c)		**Essential Question(s):** • Why is the ionising property of α-particles especially harmful inside living tissue? • What are the possible health consequences of damage caused by α-radiation inside the body? **Solution:** When plutonium is absorbed into the body, the α-particles it emits are highly ionising and release their energy over a short distance. This can damage nearby cells and DNA, increasing the risk of cancer and other health problems. **Examiners' Report:** Many candidates offered a correct consequence of the absorbing of plutonium by living tissue but rather fewer explained it in terms of the ionising property of the α-particles. That plutonium eventually decays to lead, and that lead is itself harmful was not considered to be a correct reason for preventing the plutonium from being absorbed.	B1 B1

8	(d)	(i)	**Essential Question(s):**
			• What are the mass number and atomic number of an alpha particle?
			• How do the mass number and atomic number change in the parent nucleus after alpha emission?
			• How do you write a balanced nuclear equation for alpha decay?
			
			Solution:
			$^{238}_{94}\mathrm{Pu} \rightarrow {}^{234}_{92}\mathrm{U} + {}^{4}_{2}\alpha$
			
			Explanation:
			• An alpha particle (α) is a helium nucleus with 2 protons and 2 neutrons: $^{4}_{2}\mathrm{He}$.
			• When plutonium-238 emits an alpha particle, it loses 2 protons and 2 neutrons, so:
			  • Mass number decreases by 4: $238 - 4 = 234$
			  • Atomic number decreases by 2: $94 - 2 = 92$
			• The resulting nucleus is uranium-234: $^{234}_{92}\mathrm{U}$.
			
			Examiners' Report:
			The equation was very commonly completed correctly. Incorrect answers were rare.
				A1

8	(d)	(ii)	**Essential Question(s):** • How do you calculate the total binding energy of a nucleus? • How do you calculate the energy released in the decay from the binding energies of the reactant and products? • How do you convert energy from MeV to joules? **Solution:** E released = BE products – BE reactant	

			$= (E_U + E_\alpha) - E_{Pu}$ $= [(7.601 \times 234) + (7.074 \times 4)] - (7.568 \times 238)$ $= 1778.634 + 28.296 - 1801.184$ $= 5.746$ MeV $= 5.746 \times 10^6 \times 1.60 \times 10^{-19}$ $= 9.1936 \times 10^{-13}$ J **Solution Steps:** • When a nucleus decays, the **energy released** is due to the **difference** in **total** binding energies of the products and the reactant. • Total binding energy = (binding energy per nucleon) × (number of nucleons). • The difference in total binding energy between the products and the reactant gives the energy released. **Examiners' Report:** This was well answered, and many candidates gave the correct final energy. A frequently seen error was to use the binding energy values in the table unmodified or to use them multiplied by the number of protons rather than the number of nucleons. A few candidates did not notice that the binding energy values were expressed in MeV rather than in eV; this led to final values that were a million times too small.	M1 A1
8	**(d)**	**(iii)**	**Essential Question(s):** • How do you calculate the number of moles from a given mass and molar mass? • What is Avogadro's number, and how is it used to find the number of atoms from moles? • What is the chemical formula of plutonium dioxide, and how many plutonium atoms does each molecule contain? Use info from paragraphs 6 and 7. **Solution:** number of moles of plutonium dioxide molecules, $n = m / M$ $n = 4.9 \text{ kg} / 0.276 \text{ kg mol}^{-1} = 17.75$ mol number of plutonium dioxide molecules, $N_{PuO2} = n \times N_A$ $N_{PuO2} = 17.75 \times 6.02 \times 10^{23} = 1.07 \times 10^{25}$ Each plutonium dioxide molecule contains **1 plutonium atom**, so: $N_{Pu} = N_{PuO2} = 1.07 \times 10^{25}$ nuclei **Examiners' Report:** This calculation required the use of a value given in Table 8.1. Many candidates gave the correct final number but there were those who did not realise that the value 4.9 kg was significant and those who tried other incorrect approaches. There were answers supplied (including numbers expressed in standard form with significant negative exponents) that might perhaps have suggested to the candidate that a different approach was needed.	A1
8	**(d)**	**(iv)**	**Essential Question(s):** • How do you find the total initial energy released per second (initial power output) from the decay of plutonium? → (d)(ii) gives the energy released when 1 Pu nucleus decays. Need to find the initial number of Pu nuclei that decays per second, i.e. the	

			initial Activity of the Pu source in the RTG. Then total initial energy released per second = initial Activity × answer in (d)(ii). • How to calculate the initial Activity of the Pu source in the RTG? → $A_o = \lambda N_o$ • How do you calculate the decay constant from the known data (half-life)? Use answers in (d)(ii) and (d)(iii) and paragraph 6 (half-life). **Solution:** **Given:** • Energy released per Pu nucleus that decays, $E = 9.1936 \times 10^{-13}$ J (part d(ii)) • Number of Pu nuclei initially, $N_o = 1.07 \times 10^{25}$ (part d(iii)) • Half-life of plutonium-238, $t_{1/2}$ = 87.7 years = 87.7 × 365 × 24 × 3600 s = 2.766×10^{9} s decay constant $\lambda = \ln 2 / t_{1/2} = \ln 2 / 2.766 \times 10^{9}$ $= 2.506 \times 10^{-10}\ s^{-1}$ initial activity A_0 (number of Pu nuclei that decay per second) $A_0 = \lambda N_0$ $= 2.506 \times 10^{-10} \times 1.069 \times 10^{25}$ $= 2.679 \times 10^{15}$ Bq Energy released per decay, $E = 9.1936 \times 10^{-13}$ J Initial power output of RTG = $A_0 \times E$ $= 2.679 \times 10^{15} \times 9.1936 \times 10^{-13}\ J\ s^{-1}$ = 2460 W **Examiners' Report:** This was a challenging calculation and only a minority of candidates worked their way through to the correct answer. The most direct approach required the calculation of the decay constant from the expression ln2 / *t*½. Other methods rarely included relevant details.	M1 A1
8	**(d)**	**(v)**	**Essential Question(s):** • How does alpha decay change the nucleon number and proton number of a nucleus? • How does beta (β^-) decay affect the nucleon and proton numbers? **Solution:** Each type of decay affects the nucleon number (A) and proton number (Z) as follows: • Alpha (α) decay: o Nucleon number decreases by 4 o Proton number decreases by 2 • Beta (β^-) decay: o Nucleon number stays the same o Proton number increases by 1 Starting nucleus: $^{238}_{94}Pu$ Final nucleus: $^{206}_{82}Pb$	

			Change in nucleon number: 238 − 206 = 32 → Since each α decay reduces mass number by 4: **8 alpha decays** are needed Change in proton number: 94 − 82 = 12 → Alpha decay reduces Z by 2, and 8 alpha decays would reduce Z by 16 But we only need a reduction of 12, so total beta decays must increase Z by 4. → Each beta decay increases Z by 1. So, we need **4 beta decays**. Final Answer: **8 alpha decays, and, 4 beta decays** **Examiners' Report:** Many candidates answered this correctly.	M1 A1
8	**(e)**	**(i)**	**Essential Question(s):** • How is exponential decrease different from linear or other types of decrease? • What does it mean for a decrease to be proportional to the amount remaining? **Solution:** An exponential decrease is when the rate of decrease is proportional to the amount remaining. This means the quantity decreases by a constant fraction in equal time intervals, such as halving in radioactive decay. **Mathematical Basis for Exponential Decrease:** The key defining feature of exponential decrease is that the **rate of change of P** is **proportional to P itself**, but **negative** because it is decreasing: $\frac{dP}{dt} = -kP$ $\frac{dP}{P} = -k\ dt$ • The negative sign indicates P decreases with time. By integrating, it can be shown that $P = P_o e^{-\lambda t}$ where P: the amount of that quantity remaining at time t. P_0: the initial amount of that quantity (i.e. at t = 0) **Examiners' Report:** Very few correct answers were seen as many answers did not explain the term exponential. The two most common answers were to describe the decrease as one that occurs at a decreasing or at an increasing rate. Although both could be considered a correct description of an exponential decrease, they also describe other decreases which are not exponential. Only a few candidates answered in terms of the proportionality that defines the term.	B1
8	**(e)**	**(ii)**	**Essential Question(s):** • What is the formula for exponential decay?	

			• What do you substitute into the formula to find the power at the end of a given number of years? **Solution:** Information given: • Initial electrical power output: paragraph 7 P_0 = 110 W • Power decreases exponentially by **0.79% per year** (paragraph 9) • Lifespan of Perseverance: paragraph 7 t = 14 years Power output at time t, $P_t = P_o e^{-kt}$ Drawing links between k and decay constant λ (fraction that decays per unit time), **k is the fraction of quantity P the decreases per unit time** = 0.0079 year^{-1}. $P_t = P_o e^{-\left(0.0079 year^{-1}\right)t}$ $P_t = 110e^{-\left(0.0079 year^{-1}\right)\left(14 years\right)} = 98.483$ W **OR** $P_t = P_o\left(1-0.0079\right)^t$ $P_t = 110\left(1-0.0079\right)^{14} = 98.439$ W **Examiners' Report:** This question proved challenging. Some candidates did not use the power of 110W, which is the electrical output power of the RTG at launch. The expression $(1.0 - 0.0079)^{13}$ was seen often, suggesting confusion of exclusive and inclusive counting. This would lead to a value of the power output at the very beginning of the last year of the lifespan of Perseverance rather than at its end. Other candidates used $(1.0 - 0.79)^{14}$ or 0.79^{14}. Other approaches were possible and there were candidates who used such approaches carefully to obtain the correct final output power. Candidates who used a method that required the use of the multiplying factor exp(–14 ln(2)/87.7) tended not to use the incorrect number 13 instead of 14.	M1 A1
8	**(f)**		**Essential Question(s):** • What is the formula for calculating the e.m.f. of a thermocouple? Use info in paragraphs 5 and 7. **Solution:** e.m.f = $\Delta S \Delta T$ = [240 – (-200)] x 10^{-6} x (1273 – 573) = 0.308 V **Examiners' Report:** This calculation was only occasionally correct. The answer 3.1×10^5 V was seen extremely often and expressed as 308 000 V. This was possibly obtained by candidates who did not notice that the unit of the Seebeck constants in Table 9.1 is the μV K^{-1}. Other incorrect answers were deduced either by adding the two Seebeck constants or by using just one of them.	A1
8	**(g)**		**Essential Question(s):** • What is the formula for gravitational field strength at a planet's surface?	

			• How can you utilize the information on ratios of radius and mass of Earth to Mars given in the question? **Solution:** $\frac{g_M}{g_E} = \frac{\frac{GM_M}{r_M^{\ 2}}}{\frac{GM_E}{r_E^{\ 2}}}$ $\frac{g_M}{g_E} = \frac{M_M \text{ x } r_E^{\ 2}}{M_E \text{ x } r_M^{\ 2}}$ $\frac{g_M}{9.81} = \frac{1}{9.30} \text{ x } (1.88)^2$ $g_M = 3.73$ N kg^{-1} **Examiners' Report:** A significant number of responses did not show how the equation $g = GM/r^2$ was used. Some candidates confused the two ratios and either squared the wrong term or perhaps multiplied by it rather than divided by it. This led to a considerable range of incorrect answers.	C1 M1 A1
8	**(h)**	**(i)**	**Essential Question(s):** • What is the electrical power output of the RTG? • How much power does MOXIE require during operation? • Can the RTG directly supply 300 W at once? If not, what can be done? **Solution:** The electrical power required by MOXIE (300 W) cannot be directly supplied from the RTG which can supply only a maximum electrical power of 110 W initially. However, the continuous power generated by the RTG can be stored in a battery which can be used to power MOXIE later. **Examiners' Report:** Very few candidates realised what was required and so an appropriate method of storing energy so that it can be later used to supply energy electrically at a rate of 300W was rarely seen.	B1
8	**(h)**	**(ii)**	**Essential Question(s):** • What is the power output of the RTG at the time MOXIE was used? Is it enough to power MOXIE directly? • How much power does MOXIE require to operate? • How do you calculate how long the RTG needs to generate the energy required? **Solution:** From Fig. 8.2, • Total time MOXIE operated to produce 5.37 g of oxygen = 12400 s • Power required by MOXIE over this duration = 300 W • Power generated by RTG = 110 W Energy required to operate MOXIE = Pt = 300(12400) = 3720000 J Time for RTG to generate that energy = 3720000 / 110 = 33818.18 s = 33818.18 / 3600 hours = 9.4 hours	M1 A1

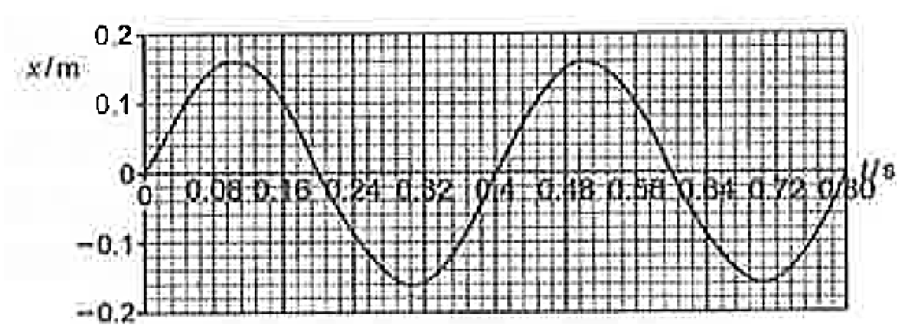
			Examiners' Report: This question proved challenging with most candidates simply converting a time value from the graph from seconds to hours. The time taken for the RTG to generate enough energy at a power of 110W so that it could be dissipated subsequently at a power of 300W was only occasionally considered.	
8	**(h)**	**(iii)**	**Essential Question(s):** • Since oxygen is an ideal gas, what is the ideal gas law that defines the relationship between pressure, volume and temperature? • What do the symbols used in the ideal gas law stand for? **Solution:** number of moles of oxygen, $n = m / M = 5.37$ g / 32 g mol^{-1} $= 0.1678$ mol Using, $PV = nRT$ $V = \dfrac{0.1678 \ x \ 8.31 \ x \ \left(-60 \ + \ 273.15\right)}{610}$ $V = 0.49$ m^3 **Examiners' Report:** This was commonly correct. Many responses used the correct expression correctly rearranged and gave the appropriate volume. There were some candidates who confused the expressions *NkT* and *nRT*. Both of these can be used to obtain the correct answer but a confusion in the meaning of the *N* and the *n* often led to answers that were either too large or too small by significant factors.	M1 A1

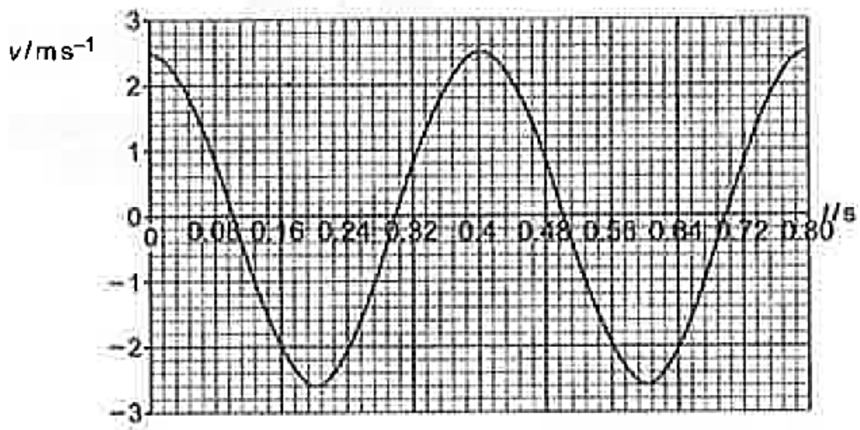
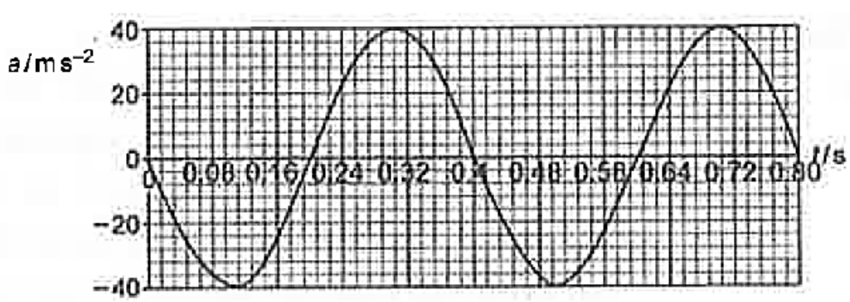
Paper 3

1	**(a)**	**(i)**	**Essential Question(s):** • What is the initial and final KE? • Recall equation for finding KE. • Is KE a scalar or vector? **Solution:** Increase in KE = ½ m v^2 – ½ m u^2 = ½ (0.060)(30)^2 – ½ (0.060)(19)^2 = 16.2 J **Examiners' Report:** Most candidates answered this question correctly. There were a few candidates who thought that kinetic energy was a vector quantity, and some others who subtracted the speeds before squaring.	M1 A1
		(ii)	**Essential Question(s):** • How is force on the ball related to its change in momentum? • Recall Newton's Law of Motion. **Solution:** Draw vector diagram to determine the change in velocity which is a vector quantity: $\Delta v = v_f - v_i = v_f + (-v_i)$ Hence, $\lvert \Delta v \rvert = \sqrt{30^2 + 19^2}$ $= 35.5106$ m s^{-1}	M1

			$F = \frac{\Delta p}{\Delta t}$ $= \frac{m\Delta v}{\Delta t}$ $= \frac{(0.060)(35.5106)}{16 \times 10^{-3}}$ = 133 N **Examiners' Report:** Most candidates realised that the force was the rate of change of momentum, but some did not know how to calculate the change in momentum.	M1 A1
	(b)		**Essential Question(s):** • The actual work done is greater than what was computed. What are possible energy outputs that were neglected / excluded in computation? • Do not bring in spins of the tennis ball that are unverified in questions and complicate the question. What are possible energy losses that are familiar to us? **Solution:** 1. Some of the work done by the tennis racket is converted to thermal and sound energy. 2. Some of the work done by the tennis racket is used to increase the gravitational potential energy of the ball as the upward component of the force by the racket acts on the ball over the time interval of 16 ms. 3. The racket (and ball) is slightly elastic. As ball hits the racket, loss in kinetic energy of the ball transforms into increase in elastic potential energy. As ball leaves the racket, the elastic potential energy decreases but not fully restored to initial value. The difference is transformed to heat which is dissipated to the surroundings. **Examiners' Report:** Many candidates overcomplicated their answers to this question and talked about the work done to change the direction of the ball. There were also many responses which discussed friction, air resistance and gains in gravitational potential energy.	 B1 B1
2	**(a)**		**Essential Question(s):** • What keeps the satellite moving in a circle without falling towards the earth? • Which force provides the centripetal force on the satellite? **Solution:** Gravitational force F_G exerted by the planet on S provides the centripetal force F_c required for S's circular motion. $F_G = F_c$ $\frac{GMm}{(R+h)^2} = \frac{mv^2}{(R+h)}$	 B1 M1

			$\frac{1}{2}mv^2 = \frac{GMm}{2(R+h)}$ $E_k = \frac{GMm}{2(R+h)}$ **Examiners' Report:** Most candidates were able to produce the expression for the kinetic energy of a satellite in orbit by using the correct expression for the centripetal force acting. There were some who confused *r*, *R* and *h*. Some used centripetal acceleration rather than centripetal force which was an acceptable alternative method.	M1 A0
	(b)		**Essential Question(s):** • What constitutes the total energy of orbit? **Solution:** $E_T = E_K + E_p$ $= \frac{GMm}{2(R+h)} + (-\frac{GMm}{(R+h)})$ $= \frac{GMm}{2(R+h)} + (-\frac{2GMm}{2(R+h)})$ $= \frac{-GMm}{2(R+h)}$ **Examiners' Report:** Candidates generally knew the expression for the gravitational potential energy of an object and the negative sign was usually present in their expression. A few candidates then made algebraic mistakes in producing the expression for the total energy. There were occasional responses where the potential energy was not correctly identified or confused with the kinetic energy.	M1 M1 A1
	(c)		**Essential Question(s):** • Satellite is moving in a circular motion. How to find the velocity of an object moving in circular motion? • Velocity is related to which form of energy of the satellite? **Solution:** $\frac{1}{2}mv^2 = \frac{GMm}{2(R+h)}$ $v^2 = \frac{GM}{(R+h)}$ $v = \sqrt{\frac{GM}{(R+h)}}$ $= \sqrt{\frac{(6.67\times10^{-11})(7.35\times10^{22})}{1.74\times10^6 + 110\times10^3}}$ $= 1630 \text{ m s}^{-1}$ **Examiners' Report:**	M1 M1 A1

			Candidates generally performed well on this question.	
	(d)	(i)	**Essential Question(s):** • Since it is orbiting at a lower altitude, h decreases. Look at the previous sections, how is E_k changing as h decreases? **Solution:** Since $E_k = \dfrac{GMm}{2(R+h)}$, E_k will increase as h decreases. E_k of P is **larger** than that of S. **Examiners' Report:** Candidates performed well on this question.	B1 B1
		(ii)	**Essential Question(s):** • Refer to previous sections, what happens to the value of E_T as h decreases? • As the absolute value of E_T increases, E_T actually becomes more negative. Is (the more negative) E_T now more or less compared to S? **Solution:** Since $E_T = \dfrac{-GMm}{2(R+h)}$ E_T is more negative as h decreases. Total energy of P is **smaller** than that of S. **Examiners' Report:** This question posed a few problems for candidates. Although most realised that with the satellite closer, the magnitude of the energy would increase, some did not realise that this meant that the value was therefore more negative and so the total energy of the satellite was less than that of S.	B1 B1
3	(a)		**Essential Question(s):** • How to sketch a positive sine curve (as per the given equation)? • Take note of critical values such as amplitude and period. **Solution:**  with amplitude 0.160 m and period 0.400 s [$\dfrac{2\pi}{T} = 15.7 \Rightarrow T = 0.400\,\text{s}$]	

			1 mark – correct shape **1 mark – critical values** **Examiners' Report:** Candidates generally answered this question well. Most candidates knew the phases that were required for the velocity and the acceleration, and they understood the periods would remain the same for all three graphs. Candidates who performed less well did occasionally get the period and/or the amplitudes incorrect, but on the whole, both the mathematics and the draughtsmanship were of a high standard.	B1 B1
	(b)		**Essential Question(s):** • How do you obtain a v-t equation from a x-t equation? → differentiate → Positive Cosine function • Take note of critical values such as maximum velocity and period. **Solution:**  with maximum velocity of 2.51 m s^{-1} and period 0.400 s **1 mark – correct shape** **1 mark – critical values** **Examiners' Report:** Same as 4(a)	 B1 B1
	(c)		**Essential Question(s):** • How do you obtain a a-t equation from a v-t equation? → differentiate → Negative Sine function. • Take note of critical values such as maximum acceleration and period. **Solution:**  with maximum acceleration of 39.4 m s^{-2} and period 0.400 s	

			1 mark – correct shape **1 mark – critical values** **Examiners' Report:** Same as 4(a)	B1 B1
4	**(a)**		**Essential Question(s):** • What is the definition of centre of gravity? **Solution:** Centre of gravity of an object is the **point** through which the **entire weight** of the body **appears to act.** *Common Mistake*: weight of body that appears to act on/through the centre of gravity is a force. Do not confuse with centre of mass. Mass is a scalar quantity, unlike force which is a vector quantity. **Examiners' Report:** Most candidates knew this definition although some confused it with the centre of mass of the object.	 B1 B1
	(b)		**Essential Question(s):** • How many equations are needed to calculate two unknowns? • What physics equations can be set up to solve for the two unknowns? → Conditions for equilibrium. Since force at the hinge is unknown, in addition to the two unknowns to be found (W and x), feasible method is to apply Principle of Moments, taking pivot at the hinge so that the unknown force at the hinge will not appear in the equation. → Two scenarios given in Fig. 4.1 and 4.2. Use these to set up two equations. **Solution:** Fig. 4.1: Take moments about A, Sum of anticlockwise moments = Sum of clockwise moments $Wx = 12\ (3.0)$ $Wx = 36$ --- (1) Fig. 4.2: Take moments about B, $W(3.0 - x) = 16(3.0)$ $3.0W - Wx = 48$ --- (2) Substitute (1) into (2): $3.0W - 36 = 48$ $3.0W = 84$ $W = 28.000 = 28$ N --- (3) Substitute (3) into (1): $28x = 36$ $x = 1.2857 = 1.29$ m **Examiners' Report:** Candidates were generally able to set up the simultaneous equations to find the weight and centre of gravity of the beam.	 M1 M1 A1 A1
	(c)		**Essential Question(s):** • When the Principle of Moments is applied, - What aspect of the expression for the total clockwise moment change? What aspect of the expression of the total anticlockwise moment	

			change? →Perpendicular distances from the pivot at B decreases by the same factor of cos 30˚ for both expressions. - What aspects remain unchanged? → W remain unchanged, hence if total clockwise moment = total anticlockwise moment, then F will remain unchanged too! **Solution:** Both the **perpendicular distances** of *W* from the pivot at B and *F* from the **same pivot at B decrease by the same factor of cos 30°:** Total clockwise moments = *W*.(3.0 – x) cos 30° Total anticlockwise moments = *F*.3.0 cos30° To **maintain rotational equilibrium**, the **total clockwise moments due to *W* must be equal to the total anticlockwise moments due to *F***, and since ***W* and *x* are fixed**, therefore ***F* remains unchanged at 16 N**. **Examiners' Report:** This question proved challenging for candidates. Those who realised that the force would be the same usually went on to correctly explain why. Candidates who did not realise that the force was the same either said that the force *F* was multiplied by cos 30° or said that the weight was multiplied by cos 30° without realising that both distances were multiplied by the same factor. Mathematical arguments were also an acceptable answer.	 B1 B1

5	**a**		**Essential Question(s):** • What is the definition of pressure? • What is the definition of density? • What is the pressure acting on the base of the cylinder due to? How can we derive its formula using the definitions of pressure and density? **Solution:** Pressure acting on a surface is the force exerted on it normally per unit area. Density is the mass per unit volume of a substance. Volume of the liquid: $V = A \times h$ Mass of the liquid: $m = \rho V = \rho A h$ Since the liquid is in vertical equilibrium, Upward normal contact force by base on liquid = Downward weight of the liquid By Newton's 3rd law, Downward normal contact force by liquid on base = Upward normal contact force by base on liquid Thus, pressure on base of cylinder: $p = \frac{\text{Weight of the liquid}}{A} = \frac{mg}{A} = \frac{\rho A h g}{A} = \rho g h$ (Shown) **Examiners' Report:** Candidates were generally able to show this proof. Some candidates perhaps did not consider the requirements of the question adequately, which asked candidates to use the definitions of pressure and density, and there were occasions where one or other of these were not defined.	 1 1 1
	b	**i**	**Essential Question(s):** • What is the relationship between volume, cross-sectional area and height of a cylinder? **Solution:**	

			Volume of a cylinder, $V = A \times h$. Therefore, $h = \frac{V}{A}$. $h = \frac{(3.70 \times 10^{-4})}{\pi \times 0.030^2} = 0.131\text{ m}$ = 0.13 m **Examiners' Report:** A few candidates made a power of ten error here, but the majority of candidates got this answer correct.	1
	b	**ii**	**Essential Question(s):** • What earlier info can be used to calculate the pressure? **Solution:** $p = \rho g h$ $= 880 \times 9.81 \times 0.131$ = 1100 Pa **Examiners' Report:** A few candidates made a power of ten error here, but the majority of candidates got this answer correct.	1
	b	**iii**	**Essential Question(s):** • What determines the reading on the newton meter? → tension in the thread • What is the state of motion of the object? What is the free body diagram of the object? → at rest → forces in equilibrium • How to calculate upthrust? **Solution:** The newton meter measures the apparent weight when the object is submerged, given by the tension *T* in the thread. Since the object is in equilibrium, weight *W* = upthrust *U* + tension *T* $T = W - U$ $= W - \rho V g$ $= 3.32 - (880 \times 130 \times 10^{-6} \times 9.81)$ = 2.2 N **Examiners' Report:** This caused few problems, and most candidates answered correctly.	1 1 1

6	**a**		**Essential Question(s):** • What is meant by electromotive force (e.m.f.) and potential difference (p.d.)? • How are electromotive force (e.m.f.) and potential difference (p.d.) related to the energy transferred in a circuit component? **Solution:** Similarity: Both e.m.f. and potential difference (p.d.) represent energy transferred per unit charge in a circuit. Difference: E.m.f. is the amount of energy transferred per unit charge from non-electrical to electrical form by the source when charge is moved round a complete circuit.	1 1

			P.d. is the amount of energy transferred per unit charge from electrical to non-electrical forms when charge passes between two points in a circuit. **Examiners' Report:** Most candidates performed well on the second part of this question–the idea of an electromotive force (e.m.f.) being the energy transferred to electrical from other sources and potential difference (p.d.) being the opposite was generally understood. Some candidates specified energy types apart from electrical. The idea that both are measured in volts was not considered sufficient for the similarity.	1
	b	**i**	**Essential Question(s):** • What does the voltmeter read? → terminal p.d., not e.m.f. directly. • What is the difference between e.m.f. and terminal p.d.? • Why and when is the terminal p.d. of a cell less than the e.m.f.? **Solution:** When current (*I*) flows through the cell which has non-zero internal resistance (*r*), there is a p.d. across *r* (= *Ir*). Hence terminal p.d. across the cell (*V*) is the e.m.f. (E) less by the amount *Ir* (i.e. *E* = *V* – *Ir*). The voltmeter reads the terminal p.d. *V*. **Examiners' Report:** Candidates generally understood the concept of internal resistance but did not always explain why this meant that the terminal p.d. was different from the e.m.f. Some candidates talked about the resistance of the wires and/or that of the voltmeter.	1 1
	b	**ii**	**Essential Question(s):** • What is the meaning of terminal p.d.? What are the different ways to calculate terminal p.d.? → p.d. across the terminals of the cell = p.d. across the circuit external to the cell = e.m.f. less the p.d. across the internal resistance of the cell **Solution:** $V = IR_{\text{total}}$ $= 0.15 \times \left[3.0 + \left(\frac{1}{6.0 + 4.0} + \frac{1}{10}\right)^{-1}\right]$ = 1.2 V **Examiners' Report:** Candidates generally performed well on this calculation.	1 1
	c	**i**	**Essential Question(s):** • How does the total resistance of the circuit change? → increases • How does this change in the total circuit resistance affect the total circuit current (which is the current in the cell)? → decreases • What determines the voltmeter reading? → terminal p.d. → How does this change? → V = E – Ir. Since E and r remain constant, when **I** decreases, V increases. **Solution:** Replacing the 4.0 Ω resistor with a 9.0 Ω resistor increases the total resistance of the circuit. This causes the current in the circuit to decrease.	1 1

With a smaller current and the same internal resistance, there is lesser potential difference across the internal resistance of the cell. As a result, the terminal potential difference, i.e. the reading on the voltmeter, increases.

	increases	decreases	remains the same
current in cell		✓	
reading on voltmeter	✓		

Examiners' Report:
Most candidates answered both parts correctly.

c ii

Essential Question(s):

- How does the arrangement of resistors in series and parallel affect the potential difference across them in a circuit?
- What approaches can be used to determine the p.d. across the 10 Ω resistor?
- How to determine the internal resistance of the cell?

Solution:
Circuit in Fig. 6.1:

$V = E - Ir$

$1.2 = 1.5 - (0.15)r$ 1

r = 2.0 Ω

Circuit in Fig. 6.2:
Effective resistance across 6.0 Ω, 9.0 Ω and 10 Ω

$= \left(\frac{1}{6.0 + 9.0} + \frac{1}{10.0} \right)^{-1}$ 1

= 6.0 Ω

By potential divider principle, p.d. across 10 Ω resistor

$= 1.5 \times \left(\frac{6.0}{2.0 + 3.0 + 6.0} \right)$ 1

= 0.82 V 1

Examiners' Report:
Some candidates found this calculation difficult as they did not realise that the terminal p.d. had changed. Some candidates used the terminal p.d. of 1.2V from the first circuit.

7 a

Essential Question(s):

- What is Faraday's law about?

Solution:
Faraday's law states that the <u>magnitude</u> of the <u>electromotive force (e.m.f.)</u> 1
<u>induced</u> in a conductor is <u>directly proportional</u> to the <u>rate of change of magnetic</u> 1
<u>flux linkage</u> of the conductor.

Examiners' Report:
This definition was well known.

b

Essential Question(s):

- What causes changes in state of motion? → Net force
- What are the forces acting on the magnetized steel block versus the unmagnetized steel block? (Free body diagrams)

- Why is there a difference in the forces acting on the magnetized steel block versus the unmagnetized steel block? What interactions produce these forces?
- Which force remain constant, and, which force change during the motion, how do the force change and what physics laws govern the magnitude & direction of this force?
- How does the net force on each block affect the motion of each block?

Solution:
The magnetised steel block takes longer to fall through copper tube A than the unmagnetised block through tube B because of electromagnetic induction.

As the magnetised block falls through copper tube A, the magnetic flux linkage through the copper changes with time. According to Faraday's law, this induces an electromotive force (e.m.f.) in copper tube A proportional to the rate of change of magnetic flux linkage. 1
This induced e.m.f. causes eddy currents to flow in the walls of copper tube A.
As the block speeds up as it falls, rate of change of magnetic flux linkage increases, causing the magnitudes of the induced e.m.f. and hence induced currents and the induced magnetic fields to increase.
By Lenz's law, the direction of the magnetic fields produced by these eddy currents opposes the motion of the falling magnet. 1
As a result:

- A magnetic force acts upwards on the block, opposite to the block's weight.
- The magnitude of the magnetic forces increases as block's speed increases, but the weight remains constant.
- This causes the net downward force acting on the block to decrease with time.
- So the acceleration of the block is less than that of the acceleration of free fall g and decreases with time.
- Consequently, the block speeds up at a decreasing rate of less than g.

In contrast, the unmagnetised steel block falling through copper tube B does not produce a changing magnetic flux linkage, so no e.m.f. or eddy currents are induced. There's no magnetic force opposing its motion. Only the weight acts. Therefore, it speeds up at a constant rate of g (acceleration of free fall) throughout. 1

Overall, the average speed of the magnetized steel block is much lesser than that of the unmagnetized steel block, therefore the former takes a much longer time to travel through the same length of tube. (time taken = distance / average speed).

Note: Wrong to say the magnetized steel block slows down. It does not slow down but speeds up at a decreasing rate and takes longer to travel the same length of the copper tube compared to the unmagnetized steel block.

Examiners' Report:
There were some excellent responses. However, for many candidates, this question proved difficult. Common errors included not maintaining a logical order in the explanation of the phenomenon observed, not explaining where and why an e.m.f. is induced, why that then leads to a current and what effect the current then has on the magnetised steel block. Some responses were not accurate and/or did not make the correct causal links between relevant points.

8 (a) (i)

Essential Question(s):

- Is air resistance negligible? → No, otherwise will not reach terminal velocity.
- What are the significant features of a displacement-time graph? → gradient represent velocity
- How does the displacement and rate of change of displacement of the oil drop change during the acceleration and after it reaches constant velocity? → Draw a 'motion diagram' of how the free body diagram changes with time, labelled with changes in the velocity & acceleration vectors.

Solution:

At **t = 0**, only weight (W) acts. v=0 so air resistance (R) = 0.

- **Since v = 0, gradient of displacement-time graph = 0**.

From **t = 0 to t = 12 μs**, the oil drop is accelerating from rest. Weight acts downwards and remain constant. Air resistance acts upwards opposite the velocity and increases from zero.

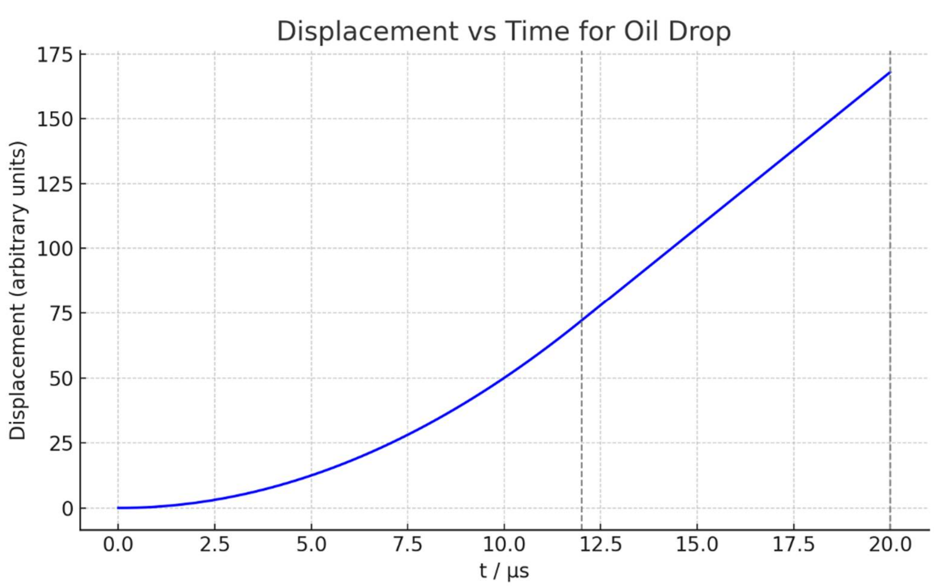
- Since **velocity is increasing** (though at a decreasing rate), the **displacement-time graph is a curve** starting from the origin and **with increasing gradient with time**.

At **t = 12 μs**, the oil drop reaches terminal velocity v_0 and begins to move at **constant speed**.

- From **t = 12 μs to t = 20 μs**, the graph is a **straight line**.
- The straight-line portion must be **tangent to the curve at t = 12 μs** to show continuity of velocity.

Graph key points:

- Starts at (0, 0) with gradient = 0, and, Curve with increasing positive gradient up to t = 12 μs — B1
- Linear increase after t = 12 μs — B1
- Smooth transition (no sharp corner) at t = 12 μs — B1



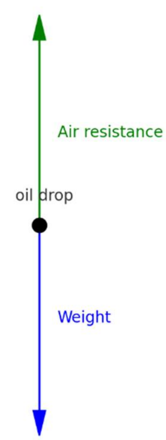
Examiners' Report:

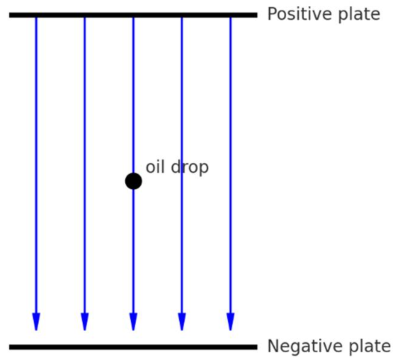
This graph was drawn well by most candidates. There were some issues for candidates who started their graphs too steeply and so ran out of room for the second part of the graph, but these were a minority.

8 (a) (ii)

Essential Question(s):

- What are the forces acting on an object falling at terminal velocity?

			• What are the magnitudes and directions of these forces? **Solution:** At terminal velocity, the oil drop is falling at **constant velocity**, which implies **zero net force** acting on it (Newton's First Law). There are two forces acting on the oil drop: 1. **Weight (W)** – Acting **vertically downwards**, due to gravitational force by Earth. 2. **Air resistance (R)** – Acting **vertically upwards**, opposing velocity. Since terminal velocity has been reached, these forces are **equal in magnitude** and **opposite in direction**, resulting in no acceleration. On Fig. 8.2:	
			• Draw a **downward arrow** from the centre of the oil drop and label it **"Weight"** or **"W"** and draw an **upward arrow** of the same length and label it **"Air resistance"** or **"R"**.	B1
			• **Both arrows must have equal length, but point in opposite directions**	B1
			 **Examiners' Report:** Most candidates realised that the forces would be of equal magnitude at terminal velocity and labelled their diagrams correctly.	
8	**(b)**	**(i)**	**Essential Question(s):** • How to determine the direction of the electric field between the two parallel plates? → Oil droplet is negatively charged and accelerates upwards. • What is the electric field pattern like between two oppositely charged parallel plates? → Uniform field. How to represent? **Solution:** The **electric field between two parallel plates** is **uniform**. Since the oil drop is **negatively charged** and **accelerates upwards**, the **upper plate must be at higher electric potential than the lower plate** so that the electric field acts downwards and the electric force on the negatively charged droplet acts upwards. To draw the field:	
			• Use **at least three evenly spaced, parallel, straight lines** pointing **vertically downward** from the upper plate to the lower plate.	B1

			• **Arrowheads** should point **downwards**, indicating the direction of the electric field (from positive to negative).  **Examiners' Report:** This question was answered well by most candidates.	B1
8	(b)	(ii)	**Essential Question(s):** • What are the forces acting on the oil drop when it is moving upwards at constant velocity? What are the directions of these forces? • How do we apply Newton's First Law to relate these forces? • How is electric force calculated in terms of the know info? **Solution:** At constant upward velocity, the **net force** on the oil drop is **zero**. This means the **upward electric force** is exactly balanced by the **downward forces** acting on the oil drop. These are: 1. **Weight**, $W = mg$ 2. **Drag force**, which equals the weight W when falling at terminal velocity v_o initially [part (a)]. So when rising at the same terminal velocity v_o, drag force also of same magnitude W [part (b)]. Hence, the **total downward force** = W + Drag = $2mg$ The **electric force acting upwards** is: Electric force = $qE = q\left(\frac{V}{d}\right)$ **Using Newton's First Law:** $q\left(\frac{V}{d}\right) = 2mg$ Rearranging to find the charge, q: $q = \frac{2mgd}{V}$ Substitute values: $m = 8.2 \times 10^{-16}$ kg $g = 9.81$ m/s² $d = 0.20$ m $V = 5030$ V	M1 M1 M1

			q = (2 × 8.2 × 10^{-16} × 9.81 × 0.20) / 5030 q = **6.39 × 10^{-19} C or 6.4 × 10^{-19} C** **Examiners' Report:** Many candidates did not determine the drag force correctly for this part, and consequently obtained an answer which was half of that required. **Explanation of Issue:** Some candidates ignored the presence of air resistance when the oil drop moved upwards. They equated the electric force to only the weight omitting the drag force. This led to an answer that was exactly **half** of the correct value. The key is to recognise that at constant upward velocity, the electric force must balance **both** weight and drag.	A1
8	(b)	(iii)	**Essential Question(s):** • How is electric charge quantised in terms of elementary charge? • What kind of particle transfer results in a negative charge? **Solution:** We already found that the charge on the oil drop is approximately: **q = 6.39 × 10^{-19} C** The charge of one electron is: **e = 1.60 × 10^{-19} C** To find the **number of electrons transferred**, divide the total charge by the charge of one electron: number of electrons = q / e = (6.39 × 10^{-19}) / (1.60 × 10^{-19}) = **4** Since the oil drop is **negatively charged**, this means it **gained** electrons. **Final Answers:** **number of electrons transferred = 4** **direction of electron transfer = to the oil drop** **Examiners' Report:** Candidates generally performed well on this question.	M1 A1
8	(c)	(i)	**Essential Question(s):** • What determines acceleration? → Net force • What is the net force on the oil drop given by? • What type of force acts between two point charges? • How is the electric force between them calculated? **Solution:** We are given: • Charge on the sphere, Q = +2.0 × 10^{-6} C • Charge on the oil drop, q = +1.1 × 10^{-18} C • Distance between them, r = 0.15 m • Mass of the oil drop, m = 8.2 × 10^{-16} kg The electrostatic force between two point charges is given by Coulomb's Law: $F = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r^2}$ The constant (1 / $4\pi\varepsilon_0$) is approximately 8.99 × 10^9 N·m²/C².	

			Substitute values: $F = (8.99 \times 10^9) \times (2.0 \times 10^{-6}) \times (1.1 \times 10^{-18}) / (0.15)^2$ $F \approx (8.99 \times 10^9 \times 2.2 \times 10^{-24}) / 0.0225$ $F \approx (1.978 \times 10^{-14}) / 0.0225$ $F \approx 8.79 \times 10^{-13}$ N Now use Newton's Second Law to find acceleration: $a = F / m$ $= (8.79 \times 10^{-13}) / (8.2 \times 10^{-16})$ = **1072 m/s²** or **1.1 × 10³ m/s²** **Examiners' Report:** Candidates generally performed well on this question.	M1 M1 A1
8	**(c)**	**(ii)**	**Essential Question(s):** • What is the direction and nature of the force acting on the oil drop after it is released? • How does this electrostatic force change with distance? • What other force acts on the drop, and how does it affect the motion? • Does the oil drop ever stop accelerating? • Is there drag or air resistance? → No. Vacuum. **Solution:** Immediately after release, the oil drop **accelerates away from the positively charged sphere** due to **repulsive electric force** between like charges. As the oil drop moves farther away, the electrostatic force **decreases** because it is **inversely proportional to the square of the separation** between the charges ($F \propto 1/r^2$). This means the **acceleration gradually decreases** over time and the oil drop continues to **gain speed**, but **at a decreasing rate.** Additionally, the **weight of the oil drop acts downwards throughout**, causing **the path to deviate downwards from the horizontal** as well. **Examiners' Report:** Most candidates gave a description of how the motion of the oil drop varies with time, but some did not explain. The idea of the weight contributing to the path of the oil drop was not always appreciated. Some candidates brought in air resistance, and some responses stated that the oil drop ceased to move once it was far enough away from the sphere. Some responses had the oil drop accelerating towards the sphere.	 B1 B1 B1 B1

9	**(a)**	**(i) & (ii)**	**Essential Question(s):** • What is the Principle of Superposition about? • What is the meaning of coherent waves? **Solution:** **(i) Principle of Superposition:** When **two or more waves of the same nature meet at a point**, the **resultant displacement** is equal to the **vector sum of the individual displacements** of the waves at that point. *Common mistake:* Some candidates wrongly referred to the sum of the **amplitudes** instead of **displacements**. The principle applies to displacement, which may be positive or negative, not just the maximum wave height. **(ii) Coherent Light Waves:** Light waves are **coherent** when the **phase difference** between them **remains constant**. This requires to waves to be of the **same frequency/wavelength**. **Examiners' Report:** **(i)** Most candidates had the correct idea for this definition, but there were a significant number who talked about the amplitudes of the waves rather than the displacements. **(ii)** This definition was well known.	B1 B1 B1
9	**(b)**	**(i)**	**Essential Question(s):** • Why is there a minimum intensity at R? What is happening? → destructive interference between the 2 waves from the 2 slits • What is the condition for destructive interference between 2 waves? → 2 waves meet in antiphase • How is path difference related to whether 2 waves meet in antiphase or in phase? In general, what factors/conditions determine whether 2 waves meet in antiphase or in phase? → phase difference between the 2 sources, and, path difference between the 2 waves arriving at the point of interest. • What does it mean by R is the 2^{nd} minimum? How does the path difference vary with the order of minimum? **Solution:** Point **R** is the **second minimum** from P, which corresponds to the **second order minimum**. For **destructive interference** in a double-slit pattern: • **Waves from the 2 slits meet in antiphase**, and this happens when • the **path difference** between the 2 waves equal to **an odd integer multiple of 0.5λ**, since the **2 sources are in phase**. • Thus, the first minimum is at **0.5λ**, the second at **1.5λ**, and so on. Since **R is the second minimum**, the path difference between the light from the two slits at R is **1.5λ** **Examiners' Report:** Although most answered correctly, a number of candidates obtained the wrong path difference, with 0.5 and 2.5 wavelengths being common incorrect answers.	A1
9	**(b)**	**(ii)**	**Essential Question(s):** • Why is there a minimum intensity at R? What is happening? → destructive interference between the 2 waves from the 2 slits	

			- What is the condition for destructive interference between 2 waves? → 2 waves meet in antiphase - general, what factors/conditions determine whether 2 waves meet in antiphase or in phase? → phase difference between the 2 sources, and, path difference between the 2 waves arriving at the point of interest. **Solution:** The **light through the 2 slits (sources) are in phase** and the **path difference** between the waves at R is an **odd integer multiple of half-a-wavelength.** **This causes the two waves to meet in antiphase / out of phase by 180° (or π radians)** at R. As a result, the two waves undergo **destructive interference**, producing a point of **minimum resultant displacement hence minimum intensity**. **Examiners' Report:** Most candidates realised that R was a point of destructive interference, but in some responses candidates mixed up phase difference and path difference. Some tried to use a mathematical formula to explain why R is a minimum, but all terms must be defined to use that method.	B1 B1
9	**(b)**	**(iii)**	**Essential Question(s):** - What is the relationship between fringe spacing and wavelength in a double-slit experiment? - What values are needed to apply the double-slit fringe formula? **Solution:** We use the Young's Equation for double-slit interference: $\lambda = \frac{ax}{D}$ Where: λ = wavelength of the light x = fringe spacing = 2.9 mm = 2.9×10^{-3} m a = slit separation = 0.60 mm = 0.60×10^{-3} m D = distance from slits to screen = 2.70 m Substitute into the formula: $\lambda = (2.9 \times 10^{-3}\text{ m} \times 0.60 \times 10^{-3}\text{ m}) / 2.70\text{ m}$ $= (1.74 \times 10^{-6}) / 2.70$ $=$ **6.44×10^{-7} m or 6.4×10^{-7} m** **Examiners' Report:** Candidates generally got this calculation correct.	M1 A1
9	**(b)**	**(iv)**	**Essential Question(s):** - What two effects contribute to the intensity distribution in a double-slit pattern? → double-slit interference, and, single-slit diffraction effect. - What does the graph of intensity variation with distance from the centre of a double-slit pattern look like? Why is the central maximum brighter than the others? **Solution:** The **double-slit interference pattern** is **modulated** by the **two single-slit diffraction patterns**.	B1

			Diffraction through **non-infinitely small** double-slits causes the **amplitude of the wave at larger angle of diffraction to be smaller.** The maximum at point **P** lies at the **centre of the diffraction envelope**, where the single-slit diffraction intensity is **highest**. All other observable maxima lie **away from the centre**, where the single-slit diffraction **intensity is lower**. ***Common Mistake***: Candidates often misattributed the brightness of the central maxima to distance-related intensity decrease. However, in interference-diffraction systems, the intensity variation arises from **diffraction**, not from the reduction of intensity due to spreading. **Examiners' Report:** Most candidates got this question wrong. Those who answered correctly generally understood that the double-slit diffraction pattern was modulated by the two single-slit diffraction patterns. Candidates often tried to answer in terms of the intensity being inversely proportional to the square of the distance. The observation cannot be explained by this reasoning.	B1 B1
9	(c)		**Essential Question(s):** • What physics law can be applied to determine the resultant intensity where 2 waves interfere? → Principle of Superposition • What does the Principle of Superposition state? What is added up? → displacement/amplitude, NOT intensity/power/energy! • Are the 2 waves meeting in phase or antiphase at P? Should their amplitudes be added up or subtracted? • How to relate amplitude and intensity? **Solution:** We are told: • Light from slit A alone has **intensity *I*** • Light from slit B alone has **intensity *I*/2** • **Intensity is maximum at P** which implies the **waves interfere constructively** and **hence must meet in phase at P** (since the 2 sources are in phase). Step 1: Recall that interference is governed by the **Principle of Superposition**, which states that **what is added up are the individual displacements, not the intensity.** ➔ **Relate the given intensities to amplitudes before summing up!** Step 2: Recall that **intensity is proportional to the square of amplitude.** $Intensity \propto Amplitude^2$, so $Amplitude \propto \sqrt{Intensity}$ **Let A_1 be the amplitude of wave of intensity I.** **Then $\frac{A_1}{\sqrt{2}}$ is the amplitude of wave of intensity $\frac{I}{2}$** Step 3: Apply the Principle of Superposition. **At P, there's constructive interference, which means the 2 waves meet in phase,** $\therefore A_{net} = A_1 + \frac{A_1}{\sqrt{2}} = \left(1 + \frac{1}{\sqrt{2}}\right) A_1$	 M1 B1 M1

			Step 4: Now find resultant intensity using $Intensity \propto Amplitude^2$. $\therefore I_{net} = \left(1+\frac{1}{\sqrt{2}}\right)^2 I$ = 2.9142 I = **2.91 *I*** ***Common Mistake:*** Many students incorrectly calculated the total intensity as $I + 0.5I = 1.5I$. This is not valid for wave interference. You must first add amplitudes, then square the result. **Examiners' Report:** Candidates found this calculation challenging. Most realised that the intensity was proportional to the square of the amplitude, but then many tried to add the intensities directly.	A1
9	**(d)**	**(i)**	**Essential Question(s):** • What equation relates the wavelength to the given info for a diffraction grating? • How do you calculate the angle from the geometry of the screen setup? • What is the correct number of significant figures to use? **Solution:** We are given: • Diffraction grating slit separation, **d = 1.67 × 10⁻⁶ m** • Distance from grating to screen, **L = 2.70 m** • Vertical displacement of first-order maximum, **y = 1.12 m** • Order of the maximum, **n = 1** **Step 1: Calculate angle θ using trigonometry** From the triangle formed: $\tan(\theta) = \frac{y}{L} = \frac{1.12}{2.70}$ $\theta = \tan^{-1}\left(\frac{1.12}{2.70}\right) = 22.6^\circ$ **Step 2: Use diffraction grating formula** $n\lambda = d\sin\theta$ Rearranged: $\lambda = \frac{d\sin\theta}{n}$ = $(1.67 \times 10^{-6}) \times \sin(22.6^\circ) / 1$ ≈ $(1.67 \times 10^{-6}) \times 0.384$ **≈ 6.40×10^{-7} m** Note: Final answer should reflect the precision of input data (3 significant figures). ***Common Mistake***: Some candidates incorrectly applied the double-slit formula λ = ax/D, which is not valid here. Others used the small angle approximation sinθ ≈ tanθ, which is **not appropriate at 22.6°** (too large), and thus, the exact trigonometric approach is much more accurate in this case. **Examiners' Report:** Candidates generally got this calculation correct and to an appropriate number of significant figures. There was some use of the small angle approximation, and some candidates continued to use the double-slit formula.	M1 M1 A1

9	**(d)**	**(ii)**	**Essential Question(s):** • What is the main difference between the setups and measurement process in 9(b)(iii) and 9(d)(i)? → double-slit vs diffraction grating; slits separation smaller in the diffraction grating leading to greater fringe separations. • What are the main differences in the appearance of the interference fringes formed from the double-slit versus the diffraction grating? → maxima fringes narrower and more intense for the grating with many slits. • What could affect the precision of measurement of quantities needed to calculate the wavelength in each case? → Both measured distance of one fringe-separation only, and is larger for (d)(i). **Solution:** In part **(d)(i)**, the distance measured from P to S (1.12 m) is **much larger** than the fringe separation measured in part **(b)(iii)** (2.9 mm). This means for the **same absolute uncertainty in measurement of the length** (e.g. ±1 mm) results in a **much smaller percentage (or fractional) uncertainty** in **(d)(i),** which in turn results in a **more precise value of wavelength**. Additionally, **the maxima fringes are narrower and more intense for the grating with many slits, and hence their positions can be more precisely determined leading to more precise measurement of the fringe separation**. **Examiners' Report:** Most candidates did not realise that this question was asking them to use the measured values given in the paper to look at the uncertainty in the wavelength. Some candidates realised what was being asked for but then did not mention that this decreased the percentage or fractional uncertainty in their answer.	 B1 B1