H2 Physics 9749 – 2023 A Level Exam

Paper 1

1	**Essential Question(s):** • What is the difference between systematic error & random error? **Solution:** Options A, B and D contributes to deviation of reading from the true reading by the same amount in the same direction. **Answer: C**
2	**Essential Question(s):** • How to relate displacement (goal) to the v-t graph (given info)? **Solution:** Change in displacement = Area under v-t graph **Answer: D**
3	**Essential Question(s):** • How is force related to energy? → via work done • What is the energy transformation here? **Solution:** Loss in KE of the arrow = Negative work done by F on arrow $E - 0 = F.\Delta s$ $E = F.\ v_{av}t$ where v_{av} is average velocity of the arrow moving through the target Since E is the 'arrival' value, to relate velocity to E, we need to express v_{av} in terms of the 'arrival' speed. Assuming arrow is brought to rest with a approximately uniform acceleration, $E = F\left(\frac{u+v}{2}\right)t$ $E = F\left(\frac{u+0}{2}\right)t$ $E = \frac{1}{2} Ft\ u$ ------(1) $E = \frac{1}{2} m\ u^2$ Since m is constant for all arrows used, $E \propto u^2$ $\sqrt{E} \propto u$ Let $u = k\sqrt{E}$ -----(2) Sub (2) into (1): $E = \frac{1}{2} Ft\ (k\sqrt{E})$ $Ft \propto \sqrt{E}$ **Answer: A**

4

Essential Question(s):

- What equations apply for an elastic head-on collision between 2 bodies?

Solution:

Take right as positive direction.

Relative speed of approach = Relative speed of separation.

Note that u_1, u_2, v_1 and v_2 are 'speeds' meaning only the magnitude.

$u_1 - (-u_2) = v_2 - v_1$

$\mathbf{u_1 + u_2 = v_2 - v_1}$ ---------(1)

By Conservation of Momentum,

$m_1u_1 + m_2(-u_2) = m_1v_1 + m_2v_2$ ---------(2)

Since no information on whether the two masses are equal, equation (2) cannot be further simplified.

Answer: C

5

Essential Question(s):

- What is the meaning of 'centre of gravity'? → point on a body through which its entire weight can be modelled as acting through.

Solution:

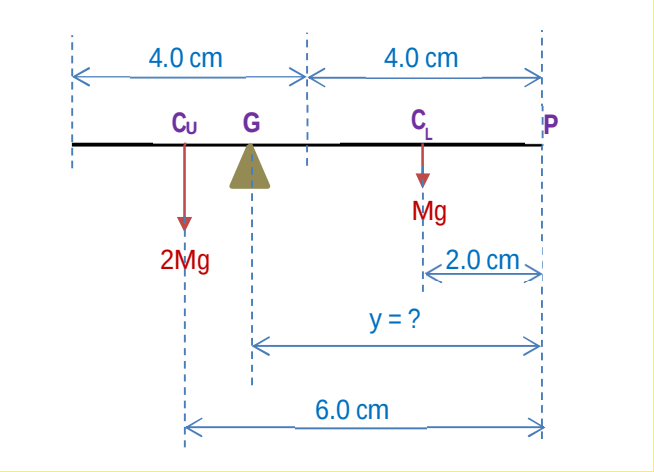
By symmetry,

c.g. of the lower half of the sheet alone (C_L) is at 2.0 cm vertically above P (let mass be M);

c.g. of the upper half of the sheet alone (C_U) is at 6.0 cm vertically above P (let mass be 2M).

To find the c.g. of the entire sheet (G), consider balancing the sheet HORIZONTALY about G so that the sheet is horizontal when balanced.

Side view:



Take moments about G,

Sum of anticlockwise moments = Sum of clockwise moments

$(2Mg)(6.0\text{ cm} - y) = (Mg)(y - 2.0\text{ cm})$

$12 - 2y = y - 2$

$3y = 14$

$y = 4.6667 = 4.7$ cm

Answer: B

6

Essential Question(s):

- What is the energy transformation?

	• What is efficiency? How to relate to the output V and I? → use the definition of efficiency in terms of power rather than energy. **Solution:** $\frac{\text{Useful power output}}{\text{Useful power input}} = 0.60$ ---(1) Total power input = **Rate of** KE loss by air to turbine blades = ½ x (mass flow rate of air) x ($v_i^2 - v_f^2$) = ½ x (9.7 kg s^{-1})($4.0^2 - 1.5^2$) = 66.6875 W From (1), Useful power output = 0.60 x 66.6875 W = 40.0125 W Option A: IV = 18 W Option B: IV = **39.6 W** Option C: IV = 14.4 W Option D: IV = 67.2 W ***Option B is the most feasible answer which is Less than the maximum possible value of 40.0125 W and close to it. There could be other losses e.g. not all translational KE of the air transferred to the turbine. The 60% efficiency of the generator accounts for only what has been transferred to the generator and then the efficiency of it in being converted into electrical energy.*** **Answer: B**
7	**Essential Question(s):** • What is an 'orbit'? • What is meant by 'angular displacement'? **Solution:** 1 year = Period → angular displacement = 2π rad ½ year → angular displacement = π rad **Answer: C**
8	**Essential Question(s):** • What are the definitions of the quantities listed in A, B, C and D? **Solution:** By definition of gravitational field strength. **Answer: B**
9	**Essential Question(s):** • What affects the motion / the path travelled by an object? → Net force **Solution:** Draw the free body diagram of the spacecraft for paths A, B, C and D. Without the force from firing the rocket, the only force is gravitational pull of Earth which is always attractive in nature. Path A: Possible. Spacecraft speeds up moving towards Earth in a straight line. Path D: Possible. Spacecraft slows down moving away from Earth in a straight line.

	Path B: Possible. Gravitational pull exerted by Earth always acting perpendicularly to the spacecraft's instantaneous velocity, hence changes only the direction of its velocity and not the magnitude of velocity. Spacecraft move in uniform circular motion. Path C: Not possible without additional force from firing rockets. The gravitational force along path C is not acting parallel to the velocity in path C and will therefore tend to cause a change in the direction of the velocity. An additional force equal in magnitude and opposite in direction to the component of the gravitational force perpendicular to the velocity is needed for the spacecraft to move in the straight line C. **Answer: C**
10	**Essential Question(s):** • How to apply the kinetic theory of gases to derive an expression for the force/pressure exerted by the molecules with a wall of the container? • What are the basic assumptions for an ideal gas? **Solution:** By Newton's 2nd law of motion, Average total force exerted on the shaded wall exerted by all N molecules <F> = Average total rate of change of momentum of all the N molecules = N.$\frac{\Delta p}{\Delta t}$ = N $\frac{m\Delta v}{\Delta t}$ Ideal gas assumption → all gas molecules collide elastically with the wall of the container → no change in KE before and after collision, so Δv = 2v. Δt is the time interval between successive collisions of per molecule with the shaded wall, Δt = $\frac{2p}{v}$ <F> = N $\frac{m(2v)}{\left(\frac{2p}{v}\right)}$ = $\frac{Nmv^2}{p}$ **Answer: A**
11	**Essential Question(s):** • What is the relationship between Internal Energy and Temperature for an ideal gas? **Solution:** For an ideal gas, no intermolecular forces so p.e. between all molecules equal to 0. Internal energy = Total k.e. of the molecules only = 3/2 NkT for a monoatomic ideal gas Since 3/2 Nk remains constant, **Internal energy ∝ T, where T is in kelvins** 0°C = 273.15 K → internal energy = U 273 °C = 546.15 K → internal energy = 546.15 / 273.15 x U = 1.00045 U **Answer: B**
12	**Essential Question(s):** • What are the definitions of specific heat capacity (c), and, specific latent heat of fusion (l)? • How to relate c and l to information on rate of heat supplied, mass, temperature and time?

Solution:

For specific heat capacity (c), look at the graph where T is changing.
$Q = mc\Delta\theta$
$P\,\Delta t = mc\Delta\theta$
$c = \frac{P}{m}\frac{\Delta t}{\Delta\theta}$
where P and m are same for both solids, and $\frac{\Delta t}{\Delta\theta}$ is the reciprocal of the gradient of the graph where T is changing.
$c = \frac{P}{m}\frac{1}{gradient}$
Since gradient of graph of P is greater, c of P is smaller than Q → either option C or D.

For specific latent heat (l), look at the graph where T is constant.
$Q = ml$
$P\,\Delta t = ml$
$l = \frac{P}{m}\Delta t$
where P and m are same for both solids, and Δt is the duration for each solid to melt completely.
Since Δt is longer for solid P, l of P is greater than Q → Answer is C not D.

Answer: C

13

Essential Question(s):

- What kind of motion is the molecule undergoing? → x-t graph is sinusoidal, hence SHM.
- How to calculate maximum KE for SHM?

Solution:
x-t graph is sinusoidal, hence SHM.

Maximum KE = $\frac{1}{2} m v_{max}^2 = \frac{1}{2} m (\omega x_o)^2$
$= \frac{1}{2}\left(\frac{M_m}{N_A}\right)\left(\frac{2\pi}{T}x_o\right)^2$
$= \frac{1}{2}\left(\frac{2.9x10^{-2}}{6.02x10^{23}}\right)\left(\frac{2\pi}{3x10^{-3}}x\ 2x10^{-6}\right)^2$
$= 4.23 \times 10^{-31}$ J

Answer: B

14

Essential Question(s):

- How to determine phase different between 2 waves from the graph? Which graph feature to use?
- How to determine ratio of intensities from the graph? Which graph feature to use?

Solution:

Phase difference between X and Y:

$$\frac{\Delta\phi}{360°} = \frac{\Delta t}{T}$$
$$\frac{\Delta\phi}{360°} = \frac{1}{3}$$
$$\Delta\phi = 120°$$

Ratio of intensities:

$$\text{Intensity} \propto \text{Amplitude}^2$$
$$\frac{I_X}{I_Y} = \left(\frac{A_X}{A_Y}\right)^2$$
$$\frac{I_X}{I_Y} = \left(\frac{3}{2}\right)^2 = 2.25$$

	Answer: D
15	**Essential Question(s):** • How to determine intensity of the emergent beam from a polarisor? **Solution:** By Malus Law, $I = I_o \cos^2\theta$ After first polarisor, intensity = I_o After second polarisor, intensity = $I_o \cos^2(45°) = ½ I_o$ After third polarisor, intensity = $(½ I_o) \cos^2(45°) = ¼ I_o = 0.25 I_o$ **Answer: B**
16	**Essential Question(s):** • How to relate width central maximum fringe of single-slit diffraction pattern to the single-slit diffraction formula? **Solution:** Single-slit diffraction formula: $\sin\theta = m\lambda / b$ For m = 1, $\sin\theta = \lambda / b$ For very small θ, $\theta \approx \sin\theta = \lambda / b$ -----(1) From geometry, $\tan\theta = (x/2) / D$ $\theta \approx \tan\theta = (x/2D)$ -----(2) (1) = (2): $\lambda / b = x/2D$ $b = 2D\lambda / x = 2Dc/fx$ **Answer: D**
17	**Essential Question(s):** • What is the diffraction grating formula? What are the definitions of the terms in this formula? Which term links to number of line per mm? **Solution:** $d \sin\theta = m\lambda$ where θ is angle between the m order diffracted beam and the incident beam, so $\theta = 60 / 2 = 30°$ $d \sin 30° = 2 (500 \times 10^{-9})$ slits separation, $d = 2 \times 10^{-6}$ m = 2×10^{-3} mm This means there is 1 line every 2×10^{-3} mm. So number of lines per mm = $1 / (2 \times 10^{-3}$ mm) = 500 mm^{-1} **Answer: A**
18	**Essential Question(s):** • What is the formula for double-slit experiment?

	Solution: x = λD/a Since λ and a remain constant, x ∝ D $\frac{dx}{dt} \propto \frac{dD}{dt}$ Since D is increasing & at a constant rate, $\frac{dD}{dt}$ must be constant & positive. So $\frac{dx}{dt}$ must be constant & positive. **Answer: A**
19	**Essential Question(s):** • What is the shape of the path of charged particles moving non-parallel to a uniform electric field? • What is the free body diagram of the proton like? **Solution:** Charged particles moving non-parallel to a uniform electric field experience an electric force that is unchanged in both magnitude and direction throughout. So path is parabolic in shape, not circular. E acts downwards. Since proton is positively charged, the electric force on it acts downwards. So protons are deflected towards plate Y. **Answer: D**
20	**Essential Question(s):** • What is the relationship between electric potential and distance for a point charge? **Solution:** For a point charge, $V = \frac{Q}{4\pi\varepsilon_o r}$ where V and Q are of the same sign. Since $\frac{Q}{4\pi\varepsilon_o}$ is a constant, $V \propto \frac{1}{r}$. $\frac{V_P}{V_R} = \frac{r_R}{r_P}$ $\frac{V_P}{636} = \frac{2x\sqrt{2}}{3x}$ $V_P = 599.6 = 600$ V **Answer: B**
21	**Essential Question(s):** • What are the definitions of e.m.f. and p.d.? **Solution:** By definitions of e.m.f. and p.d. **Answer: B**
22	**Essential Question(s):** • How is a potentiometer set up? How is balanced potential achieved?

	Solution: Let D be the e.m.f. of the driver cell in the potentiometer circuit. Given E < D. Deductions: Since there is a non-zero p.d. across the resistor, the p.d. across the potentiometer wire is **less than** D. To balance, the "+" of E and D must face each other. ➔ **Y** must connect to the **higher potential** point of the potentiometer wire. ➔ **Eliminate options A and C.** Also need either X or Y to be connected to the moveable contact. ➔ **Eliminate B.** **Answer: D**
23	**Essential Question(s):** • How does the resistance of an LDR vary with light intensity? **Solution:** Resistance of an LDR decreases as light intensity increases. So R should decrease. Options A and D show that R increases → Eliminate! Option B shows that R remains constant →Eliminate! **Answer: C**
24	**Essential Question(s):** • What does the arrowhead of a magnetic field line represent? • What does the separation between field lines represent? • To deduce the motion when released, draw the free body diagram of the magnet. **Solution:** Arrowhead of a magnetic field line represents the direction of magnetic force acting on a magnetic north-pole. Greater separation between field lines represent smaller magnitude of force. Free body diagram of magnet: Leftward magnetic force acting on its south-pole (F_S) and Rightward magnetic force acting on its north-pole (F_N). From separation of the field lines, $\|F_S\|$ is greater than $\|F_N\|$. When released from rest, magnet accelerates from rest towards the left. **Answer: A**
25	**Essential Question(s):** • How to determine the direction of electric force on a moving charge, and negative charge? • How to determine the direction of magnetic force on a moving charge, and negative charge? • What is the direction of the net force? (Draw free body diagram.) **Solution:** Direction of electric force (F_E) on a negative charge is opposite direction of E.

	Direction of magnetic force (F_B) on a moving negative charge is determined using Fleming's Left Hand Rule: - Index finger points in direction of B; - Middle finger points in the direction of conventional current so opposite direction of velocity of the negative charge, i.e. OUT OF PAGE in all four options. - Thumb will then point in the direction of F_B. A: F_E acts upwards & F_B acts upwards too. B: F_E acts rightwards & F_B acts leftwards. C: F_E acts downwards & F_B acts leftwards. D: F_E acts rightwards & F_B acts upwards. → The resultant force in this case will cause the beam the deflect as shown. **Answer: D**
26	**Essential Question(s):** • What are the SI units of flux and flux density? **Solution:** T is a SI unit for flux density. Wb is a SI unit for flux or flux linkage $\Phi = B A$ So 1 Wb = 1 T m^2 **Answer: C**
27	**Essential Question(s):** • What are the differences in the 4 circuits? → d.c. source versus a.c. source. Orientation of diodes. • What are the characteristics of a diode in forward bias and in reverse bias? • What determines the p.d. across the load resistance R? **Solution:** Recap characteristics of an ideal diode: - In forward bias, resistance = 0. - In reverse bias, resistance is infinite. A: d.c. source. One diode is always in revise bias. Current I = 0 always. So p.d. across load resistance R, V_R = IR = 0 always. B: a.c. source. One of the two diodes will be in reverse bias for each half of the period. So I = 0 and V_R = 0 always. C: d.c. source. Both diodes always in reverse bias. So I = 0 and V_R = 0 always. D: a.c. source. Both diodes are in reverse bias for one-half per period; and both diodes in forward bias for the other half per period. So I = 0 and V_R = 0 for half a period only, and proportional to the terminal p.d. of the a.c. supply for the other half period. **Answer: D**
28	**Essential Question(s):** • What is the energy transformation here? • How to relate energy to wavelength of photon? **Solution:** Energy of photon emitted = Loss of electron excitation energy $hc/\lambda = \Delta E$ $(6.63 \times 10^{-34})(3.00 \times 10^{8}) / \lambda = [-30.6 - (-122.4)] \times 1.60 \times 10^{-19}$

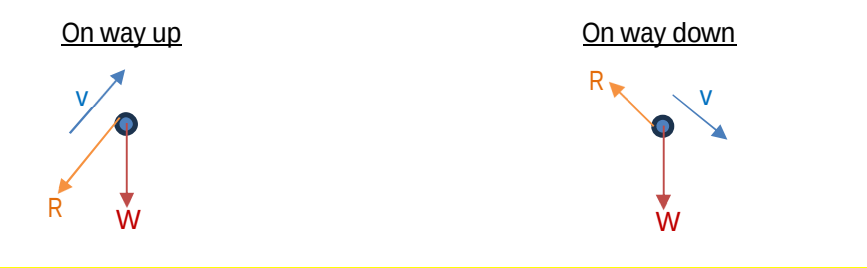
	$\lambda = 1.35 \text{ z } 10^{-8}$ m **Answer: A**
29	**Essential Question(s):** • What is the equation relating de Broglie wavelength and momentum? **Solution:** $\lambda = h / p$ $\lambda p = h$ = constant. **Answer: A**
30	**Essential Question(s):** • Is this a sinusoidal or non-sinusoidal AC? • How to determine root-mean-square value of a non-sinusoidal AC? **Solution:** Non-sinusoidal AC → use a Graphical Approach. Sketch V^2-t graph for 1 period. $\langle V^2 \rangle = V_o^2$ $V_{rms} = V_o$ **Answer: C**

Paper 2

1	**a**		**Essential Question(s):** • What is the origin of upthrust? **Solution:** Upthrust arises due to the fact that **pressure increases <u>proportionally</u> to depth in a fluid**. So **lower parts of the block experience greater pressure compared to higher parts of the block**. The **pressure <u>differences</u>** result in a **<u>net upward</u> force exerted by the fluid** on the block, called upthrust. **Examiners' Report:** A significant number of candidates described the greater pressure on the base of the block compared to the pressure on the top of the block. Few went on to explain how this pressure difference produced a net force. A large number stated there was a pressure difference without giving any detail.	1 1
	b	**i**	**Essential Question(s):** • What are the ways to determine upthrust here? ➔ By balancing moments → too many unknowns! ➔ By Archimedes' Principle **Solution:** By Archimedes' Principle, Upthrust = weight of water displaced by block = Volume of water displaced by block x Density of water x g	1

			Since block fully submerged, Volume of water displaced = Volume of block Upthrust = Volume of block x Density of water x g = $(27.8 \times 10^{-6})(1000)(9.81)$ = 0.2727 = 0.27 N **Examiners' Report:** Explanation of working is required. Some responses named the quantities represented by the symbols in the formula for upthrust without further explanation.	1 0
	b	**ii**	**Essential Question(s):** • What are the conditions for equilibrium? **Solution:** Take moments about pivot, From Fig. 1.1, W x 8.3 = F x 18.0 -----(1) From Fig. 1.2, W x 7.8 = (F – U) x 19.0 W x 7.8 = (F – 0.2727) x 19.0 ----(2) (1) / (2): 8.3 / 7.8 = 18.0 F / (19.0 F – 5.1813) 1.0641 (19.0 F – 5.1813) = 18.0 F 2.2179 F = 5.5134 F = 2.49 N (or 2.5 N) **Examiners' Report:** A significant number of candidates obtained the value for the force *F*. Moment statements for the initial set up of the block were usually correct. Some candidates gave an incorrect anticlockwise moment when the block was immersed in the water as they only included the upthrust or the force *F*.	1 1 1

2	**a**		**Essential Question(s):** • At which point is KE minimum? What is the speed at this point? • How to resolve v into its vertical and horizontal components? **Solution:** Minimum KE is when object is at the maximum height where vertical velocity $v_y = 0$; and object only has horizontal velocity v_x. $v_x = v \cos 42°$ throughout KE = ½ m $(\text{speed})^2$ 65 J = ½ (0.55 kg) $(v \cos 42°)^2$ v = 20.688 m s^{-1} Hence vertical component of v at launch = v sin 42° = 20.688 sin 42° = 13.843 = 14 m s^{-1} (shown) **Examiners' Report:** The majority of candidates supplied their working in the detail required for this 'show that' question. Some did not identify the horizontal and vertical components of the	1 1 1 0

			velocity and labelled them both *v*. This information was given in the question as the initial velocity of the object.	
	b		**Essential Question(s):** • What are the kinematics equations for 2-D projectile motion? • What is the implicit information given that the landing point and launching point are at the same vertical height? **Solution:** Vertical motion: Take up as positive direction. Since the landing point and launching point are at the same vertical height, $s_y = 0$. $s_y = u_y t + ½ a_y t^2$ $0 = 13.843 t + ½ (-9.81) t^2$ $4.905 t^2 - 13.843 t = 0$ $t = 0$ (at launch) or $t = 2.8222$ s (at landing) Horizontal motion: Take right as positive direction. $s_x = u_x t$ $= (20.688 \cos 42°) (2.8222)$ $= 43.389 = 43$ m (Or, also accept 44 m, if used v = 14 m s^{-1} from 'Show' question in part (a).)	1 1 1
	c		**Essential Question(s):** • What determines motion? → Net force → Draw free body diagrams on way up and way down. • In which direction does air resistance act? • What do the accelerations on the way up and way down compare? How does this differ from case where air resistance is neglected? Hence what is the effect on time taken? **Solution:**  Air resistance R always acts opposite direction to velocity v, while weight W is unchanged in both magnitude and direction throughout. **On the way up,** the vertical component of R acts downwards in the same direction as W. Thus the net vertical downward force is greater than W and hence **vertical downward acceleration is greater than the acceleration of free fall g.** **On the way down,** the vertical component of R acts upwards opposite direction to W. Thus the net vertical downward force is lesser than W and hence **vertical downward acceleration is lesser than g**. Since the **average acceleration when moving up is greater than when moving down**, the **final speed is lesser than the launch speed**. So **average speed <v> for upward motion is greater than that for downward motion**. So **for the same vertical distance H travelled up and down, the time taken t = H / <v> for upward journey will be shorter than for downward journey**. Method 2: Energy consideration	1

			Due to work done against air resistance, the final speed is lesser than the launch speed. So average speed <v> for upward motion is greater than that for downward motion. So **for the same vertical distance H travelled up and down, the time taken t = H / <v> for upward journey will be shorter than for downward journey**. **Examiners' Report:** Many candidates stated that the time would be shorter for the object to reach its maximum height rather than to return to the ground. However, the reason given for the shorter time often lacked detail. Suggestions such as the air resistance acts against the motion, or the air resistance increases with velocity increase did not answer the question. A significant number of candidates thought the object would take longer to rise than to fall.	

3	**a**	**i**	**Essential Question(s):** • What is the force keeping the satellite in orbit? **Solution:** Force required for orbit = Centripetal force $= m r \omega^2 = m r (2\pi / T)^2$ $= (6800) (36000 + 6400)(10^3) [2\pi / (24 \times 3600)]^2$ $= 1.5248 \times 10^3 = 1.5 \times 10^3$ N OR Gravitational force provides the centripetal force required for orbit $= GMm/r^2$ $= (6.67 \times 10^{-11})(6.0 \times 10^{24})(6800) / [(36000 + 6400)(10^3)]^2$ $= 1.51375 \times 10^3 = 1.5 \times 10^3$ N (or 1500 N)	1 1
		ii	**Essential Question(s):** • What determines the period of orbit? How to derive? **Solution:** Gravitational force provides for centripetal force required. $F_G = F_C$ $GMm/r^2 = m r \omega^2 = m r (2\pi / T)^2$ $T = 2\pi \sqrt{\frac{r^3}{GM}}$ All satellites in geostationary orbit must have a period of 24 hours. However, the above equation shows that the period T of orbit is independent of satellite's mass m. So <u>not</u> necessary for all geostationary satellites to have the same mass. **Examiners' Report:** Most candidates gave relevant equations and showed that the period was independent of the mass of the satellite.	1
	b	**i**	**Essential Question(s):** • What force is providing for the centripetal force required? **Solution:** Magnetic force provides for the centripetal force required. $Bqv \sin 90° = mv^2 / r$ $Bq \sin 90° = mv / r$ $Bq \sin 90° = p / r$	1

			$r = p / Bq = p / Be$ $= (3.4 \times 10^{-23}) / (1.8 \times 10^{-3})(1.60 \times 10^{-19})$ $= 0.11806 = 0.12$ m	1
		ii	**Essential Question(s):** • What determines the radius of the circular path? **Solution:** From bi, $r = p/Bq$ For the same magnetic flux density B, and same charge q, radius of the circular path r is proportional to momentum p of the ion. So if the momentum or product of mass and velocity ($p = mv$) is different, the ion will not have the same radius of circular path.	1

4	**a**	**i**	**Essential Question(s):** • What are the conditions for a stationary wave to form? • How are these conditions met here? → Contextualise! **Solution:** Sound wave from the loudspeaker travels towards metal plate and almost all of its energy is reflected back. The incident wave and reflected wave are of the same type, speed, frequency, approximately same amplitude, and travelling in opposite directions along the same line. There is only one boundary condition of a displacement node at the metal plate. This is met at any frequency of sound wave. Thus stationary wave will form. **Examiners' Report:** This was generally well answered. Some responses quoted the general conditions required for the formation of stationary waves rather than applying the conditions to the investigation described in the question. There were some descriptions where it was not always clear which waves superposed.	1 1
		ii	**Essential Question(s):** • How to determine frequency from Fig. 4.2? What feature of the graph is related to frequency? **Solution:** Horizontal axis is time axis. Period $T = 5.0$ cm $\times$ 0.50 ms cm^{-1} = 2.5 ms Frequency $f = 1/T = 1/(2.5 \times 10^{-3})$ = 400 Hz	1 1 0
		iii	**Essential Question(s):** • How to relate the goal (distance between adjacent nodes in a stationary wave) to know information (frequency & speed of sound)? **Solution:** In a stationary wave, Distance between adjacent nodes = ½ λ = ½ (v / f) = ½ (340 / 400) = 0.425 m (or 0.43 m)	1 1

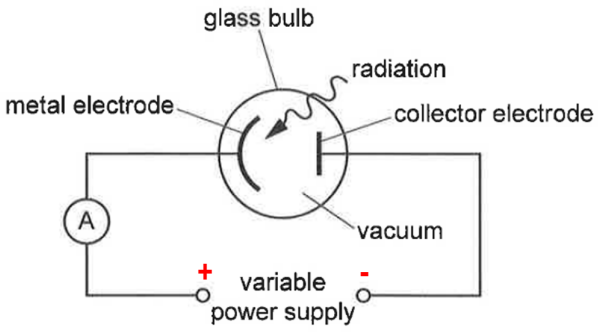
	b	**i**	**Essential Question(s):** • What determines if an intensity maximum or minimum is detected when there is interference? → Constructive or destructive interference. • How to determine if interference is constructive of destructive at P? What factors affect? → Phase difference between sources & Path difference between the 2 waves arriving at P. **Solution:** Path difference between the 2 waves at P = 1.8 – 1.4 = 0.4 m = 2 wavelengths Since the wave sources (X and Y) are in phase, and, path difference between the two waves arriving at P equals to 2 wavelengths which is an integer multiple of a wavelength, the two waves will arrive in phase at P and undergo constructive interference at P, producing an intensity maximum at P. **Examiners' Report:** Some confused 'path difference' and 'phase difference' and stated 2λ as the phase difference instead of path difference. Some stated a maximum intensity at P due to the sources being in phase.	1 1
		ii	**Essential Question(s):** • How to determine the goal (intensity) from the given information? **Solution:** For a point source, wavefront from the loudspeaker is spherical or part of a spherical surface. Intensity = (Power of source) / (Area normal to direction of energy transfer) $= P_s / (k.4\pi r^2)$ where k is a fraction Since constant power source P_s, Intensity $\propto \frac{1}{r^2}$ where r is the distance of the point of interest from the source. $\frac{I_Y}{I_X} = \left(\frac{r_X}{r_Y}\right)^2$ $\frac{I_Y}{4.5x10^{-6}} = \left(\frac{1.4}{1.8}\right)^2$ $I_Y = 2.72222x10^{-6} = 2.7x10^{-6}$ W m^{-2}	1 1
		iii	**Essential Question(s):** • What is the relationship between amplitude and intensity? **Solution:** Intensity $\propto$ Amplitude^2 Amplitude $\propto \sqrt{\text{Intensity}}$ $\frac{A_X}{A_Y} = \sqrt{\frac{I_X}{I_Y}} = \sqrt{\frac{4.5x10^{-6}}{2.7222x10^{-6}}}$ $\frac{A_X}{A_Y} = 1.2857 = 1.3$	1 1

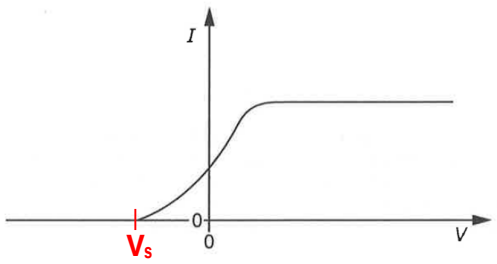
5	**a**		**Essential Question(s):** • What feature of the graph indicates resistance? → Ratio V/I which can be deduced from the gradients of lines drawn from (0,0) to various parts of the graph. It is NOT given by the gradient of the graph itself! **Solution:** (On Fig. 5.1, use a ruler to mark off the value of V where the *linear* segment of the graph ends. Label as V_1.) From V = 0 to V = V_1, **ratio** V/I and therefore resistance remains constant. For V > V_1, **ratio** V/I decreases which shows that resistance decreases as V increases. **Examiners' Report:** This question proved challenging for the majority of candidates. There were many that referred to the resistance as being given by the reciprocal of the gradient. There were some answers that did not refer to the figure. Reference to thermal effects was not required because the question was about what the graph showed.	 1 1
	b	**i**	**Essential Question(s):** • What are the equations to calculate power? Which is the most convenient to use for resistors in series connection? **Solution:** <u>Current I is the same</u> for both resistors in series. Required ratio = $\frac{I^2R_{220}}{I^2R_{640}} = \frac{220}{640}$ = 0.34375 = 0.34 **Examiners' Report:** Candidates are expected to explain their working.	 1 1 0
		ii	**Essential Question(s):** • How will change in current in the circuit affect the result? **Solution:** <u>Ratio is unchanged</u>, since <u>current</u> in <u>both</u> resistors is <u>always common and cancels out in the ratio</u>, and their <u>resistances also fixed</u>. **Examiners' Report:** The fact that the current cancelled in the ratio of powers meaning that the current did not influence the ratio was only stated by a minority of candidates.	 1
		iii	**Essential Question(s):** • How to determine the total current in each circuit? **Solution:** Effective resistance in **series** circuit R_s = 220 + 640 = 860 Ω Effective resistance in **parallel** circuit $R_p = [1/220 + 1/640]^{-1}$ = 163.72 Ω Let E be the e.m.f. of the d.c. source. Current **from supply** = Total circuit current = E/(effective circuit resistance)	 1 1

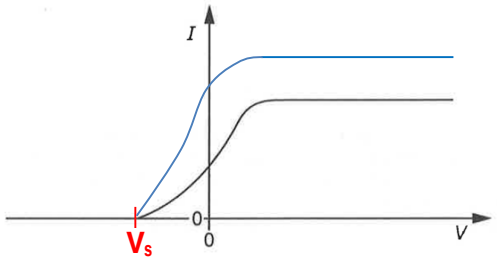
			Required ratio = $\frac{\frac{E}{R_s}}{\frac{E}{R_p}} = \frac{R_p}{R_s} = \frac{163.72}{860}$ = 0.19037 = 0.19	1
		iv	**Essential Question(s):** • How will the change affect the ratio? **Solution:** Ratio remains unchanged, since the ratio solely depends on the ratio of the effective resistances in the series and parallel circuits which are unchanged.	 1

6	**a**		**Essential Question(s):** • What is Faraday's law of electromagnetic induction? **Solution:** The **magnitude** of the **induced electromotive force** is **proportional** to the **rate** of **change** of **magnetic flux linkage**.	
	b		**Essential Question(s):** • Key words are "induced" and "alternating". • Why is there an induced e.m.f.? What is causing the change in magnetic flux linkage? → Contextualise! • What is the induced e.m.f. alternating, i.e. reverses in direction periodically? **Solution:** When the wire oscillates, it continuously sweeps an area non-parallel to the magnetic field, thus there is a changing magnetic flux linkage experienced by the wire. By Faraday's law, there will be an induced e.m.f. in the wire of magnitude proportional to the rate of change of magnetic flux linkage. The <u>direction</u> of the induced e.m.f. reverses every half a period of oscillation, i.e. alternating, because by Lenz's law the direction of the induced e.m.f. will be such that if a current were able to flow through the wire it would produce a magnetic force that opposes the motion of the wire. So the direction of the induced e.m.f. during the downward movement of the wire will be opposite to that during the upward movement of the wire.	 1 1
	c		**Essential Question(s):** • How to calculate the induced e.m.f. in a straight conductor moving in a uniform magnetic field? **Solution:** (Note that the wire here is no longer oscillating but moving horizontally.) $E = BLv_{\perp B} = (250 \times 10^{-3})(15 \times 10^{-2})(0.80)$ L is the length moving through the field. = 0.030 V **Examiners' Report:** Some candidates used the full length of wire rather than the length in the magnetic field.	 1 1
	d		**Essential Question(s):**	

			• What is the magnitude & direction of induced e.m.f. in each half of the wire? **Solution:** The direction and also magnitude of the induced e.m.f. in the two halves of the wire will be the same, so potentials of X and Y will be equal. The induced e.m.f. across X and Y equals zero.	 1 1

7	**a**	**i**	**Essential Question(s):** • Which experiment proved the particulate nature of EM radiation? **Solution:** Photoelectric effect.	 1
		ii	**Essential Question(s):** • What is meant by wave nature? What phenomenon can be exhibited by a wave but not a particle? **Solution:** Interference / Diffraction. **Examiners' Report:** A common incorrect response was electron diffraction; these candidates did not realise the question was asking about electromagnetic radiation.	 1
	b	**i**	**Essential Question(s):** • What should be the polarity of the emitter and collector in order for the current in the ammeter to decrease to zero? **Solution:** Ammeter reading decreases to zero implies that the photoelectrons experience a retarding force between the emitter and collector. So the electric force on the photoelectrons must act leftwards, meaning the polarity of the emitter is + and that of the collector is -. So for the power supply, the terminal connected to the emitter should be +, and the terminal connected to the collector should be -.  	 1
		ii	**Essential Question(s):** • How to relate the goal (stopping potential) to the given info (photon energy and work function)? **Solution:** $E_p = \Phi + KE_{max}$ $E_p = \Phi + eV_s$	

			$12.4\ eV = 4.2\ eV + eV_s$ $12.4\ V = 4.2\ V + V_s$ $V_s = 8.2\ V$	1 1
		iii	**Essential Question(s):** • What determines the stopping potential? → KE_{max} • What determines KE_{max} and why? → Einstein's photoelectric equation, based on conservation of energy and the 1-to-1 interaction between photon and electron in the metal. • What are the key ideas about the particulate nature of electromagnetic radiation? **Solution:** When intensity is varied, by the particulate nature of electromagnetic radiation, it means that the number of photons incident per unit time on the metal electrode is varied but the energy per photon (E_p) is unchanged for the same frequency (f) of radiation, since $E_p = hf$. The particulate nature of radiation also implies that each electron in the metal can only absorb one photon regardless of the total number of photons incident (1-to-1 interaction). The maximum kinetic energy of emitted photon, which is given by the difference between E_p and the work function of the metal surface (Φ), is thus independent of intensity of radiation. The stopping potential (V_s) is proportional to the maximum kinetic energy (KE_{max}) of emitted photon and is therefore also independent of the intensity of radiation. ($eV_s = KE_{max}$) **Examiners' Report:** Candidates found this question challenging. There were few good descriptions in terms of photons. The results of changing the intensity were often described rather than why the stopping potential was not affected.	 1 1 1
	c	i	**Essential Question(s):** • How to interpret the photoelectric effect experiment graph? • What is meant by stopping potential? **Solution:** V_s is where I = 0. The horizontal intercept is V_s  	 1
		ii	**Essential Question(s):** • What is the effect of increase in intensity on the Right side and Left side of the graph? What factors determine the saturation current on the Right side? What factors determine the stopping potential on the Left side? **Solution:**	

			Increase in intensity increases number of photoelectrons collected per unit time. So saturation current is greater. → Right side of graph is higher, but same shape. Increase in intensity has no effect on the stopping potential. → Left side, V_s same. 	1
8	**a**		**Essential Question(s):** • What feature of the graph relates to angular velocity? **Solution:** From Fig. 8.1, Pulse period = 0.6 s = rotation period (since in paragraph 5, it states that Earth only detects radio signal from ONE pole). $\omega = 2\pi/T = 2\pi/0.6 = 10.472 = 10.5$ rad s^{-1}	 1 1
	b		**Essential Question(s):** • How to apply the conservation of angular momentum in this context? • Which quantities affecting L change as the pulsar forms? **Solution:** From paragraph 2, - Nuclear fusion implies energy is emitted while total mass is reduced (conservation of mass-energy). → m decreases. - Core collapses under gravitational forces implies that radius of the star decreases. → r decreases. Since angular momentum is conserved in a closed system, Final L = Initial L Since final values of m and r are both much smaller, for total angular momentum to be conserved, it implies that final ω is much greater. So the pulsar star spins much faster than the star from which it was formed.	 1
	c		**Essential Question(s):** • When will nuclear fusion occur? • What do you know about iron? **Solution:** Iron-56 has the most stable nucleus, with the highest binding energy per nucleon. If they were to fuse, large amount of energy would need to be supplied. **Examiners' Report:** Few candidates answered this question correctly in full. A significant number of candidates explained that iron has the greatest binding energy per nucleon. Many described the element or atom rather than the nucleus of iron. A very small number explained the energy consequences if fusion or fission was to take place.	 1 1
	d	**i**	**Essential Question(s):**	

			• How to calculate gravitational field strength from know information of mass & radius? **Solution:** From paragraph 3, Mass of first pulsar, M_p = 1.4 solar masses. Radius of first pulsar, R_p = 10 km At the surface, $g = GM_p / R_p^2$ $= (6.67 \times 10^{-11})(1.4 \times 2.0 \times 10^{30}) / (10\,000)^2$ $= 1.8676 \times 10^{12} = 1.9 \times 10^{12}$ N kg^{-1}	
		ii	**Essential Question(s):** • How to calculate gravitational field strength at the second point? What are the definitions of the terms in the equation "$g = GM/r^2$"? → r is measured from centre of the mass **Solution:** At the second point, $g_2 = G M_p / (R_p + h)^2$ $= (6.67 \times 10^{-11})(1.4 \times 2.0 \times 10^{30}) / (10\,000 + 1.0)^2$ $= 1.8672 \times 10^{12}$ N kg^{-1} $\Delta g = g - g_2 = (1.8676 \times 10^{12}) - (1.8672 \times 10^{12})$ $= 0.00040 \times 10^{12} = 4.0 \times 10^{8}$ N kg^{-1}	1
		iii	**Essential Question(s):** • What is the effect of differences in gravitational field strength at varying heights above the surface on the rod's length? **Solution:** Points on the rod closer to the pulsar experience a gravitational pull significantly greater than points further away from the pulsar. So the length of the rod increases.	1
	e	**i**	**Essential Question(s):** • Which paragraph gives the information required on limits to rotational period? **Solution:** Use information in paragraph 6. Speed of surface of pulsar, $v = R_p\omega = R_p(2\pi/T)$ $= (100000)\ (2\pi / 2.0 \times 10^{-3})$ $= 3.14 \times 10^{8}$ m s^{-1} This exceeds the speed of light of 3.00×10^{8} m s^{-1}, thus impossible.	1 1
		ii	**Essential Question(s):** • How to use info on the second limit in paragraph 6? **Solution:** Centripetal acceleration at the surface, $a_c = R_p\omega^2 = R_p(2\pi/T)^2$ Gravitational field strength at the surface, $g = GM_p/R_p^2$ To NOT disintegrate, $a_c \leq g$	1 1 1

			$R_p\left(\frac{2\pi}{T}\right)^2 \le \frac{GM_p}{R_p^{\,2}}$ $R_p\left(\frac{2\pi}{T}\right)^2 \le \frac{G\left(\rho.\frac{4}{3}\pi R_p^{\,3}\right)}{R_p^{\,2}}$ $\frac{4\pi^2}{T^2} \le \frac{4}{3}\pi G\rho$ $\rho \ge \frac{3\pi}{GT^2}$ $\min \rho = \frac{3\pi}{GT^2}$	1 0
		iii	**Essential Question(s):** • What is the value of T for the first pulsar? **Solution:** $\rho = \frac{3\pi}{GT^2} = \frac{3\pi}{G(0.6)^2} = 3.9250x10^{11} = 3.93x10^{11}\text{kg m}^{-3}$	1
	f		**Essential Question(s):** • Beware of the units. **Solution:** From paragraph 7, Age (in s) = $\frac{33.5x10^{-3}\text{s}}{2x38x10^{-9}\text{s day}^{-1}}$ = 4.40789 x 10^5 days = 1207.6 years (Assume 1 year = 365 days) = 1210 years (or 1200 years)	1
	g		**Essential Question(s):** • How to calculate wavelength from energy of photon? • What is the prefix tera, T equal to? **Solution:** $E_p = hc/\lambda$ 400 x 10^{12} x 1.60 x 10^{-19} = (6.63x10^{-34})(3.00x10^8)/λ λ = 3.11 x 10^{-21} m (or 3.1 x 10^{-21} m)	1 1
	h		**Essential Question(s):** • What does the collecting area of the telescope affect? **Solution:** For an aperture, $\theta_{\text{min}} \approx \frac{\lambda}{b}$, where θ_{min} is the minimum angular separation of two objects for them to be resolvable/distinguishable by the telescope, λ is the wavelength of light and b is the diameter of the aperture of the telescope. The greater effective collecting area of the SKA causes the value of b to be greater so θ_{min}	1

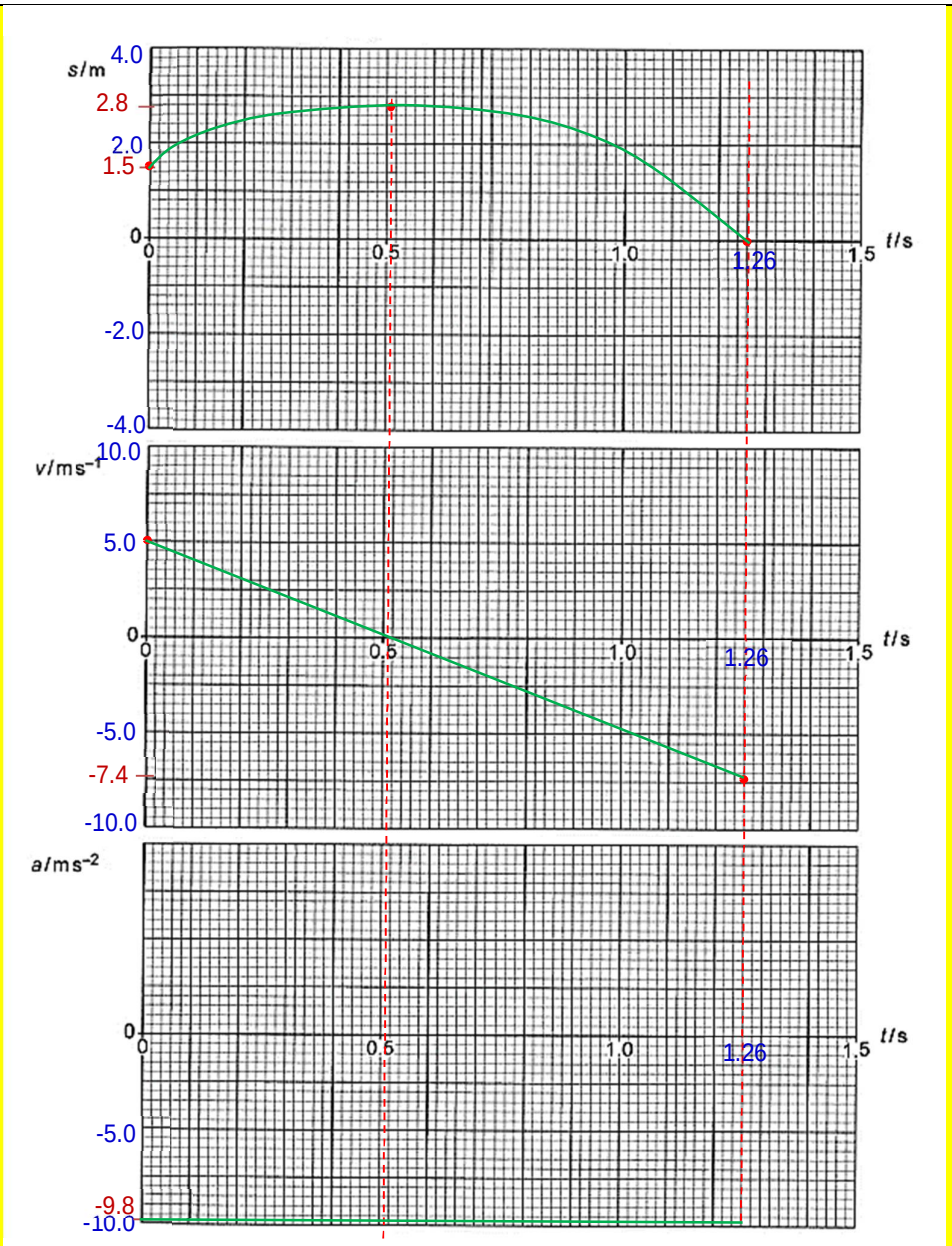
			is smaller. Thus the resolving power of SKA is higher, enabling it to detect pulsars that cannot be detected by the Parkes Telescope. **Examiners' Report:** There were few correct answers. The majority of responses interpreted the larger collecting area to mean you could 'see' more of the sky.	

Paper 3

1	**a**		**Essential Question(s):** • What are the 7 SI base units? • What does "homogenous equation" mean? **Solution:** Let [] denote units of. Units of left side of equation = [x] = m Units of right side of equation = $\frac{[L^3][g][M]}{[w][t^3][E]} = \frac{\text{m}^3\ \text{m s}^{-2}\ \text{kg}}{\text{m m}^3\ \text{Pa}}$ $= \frac{\text{m}^3\ \text{m s}^{-2}\ \text{kg}}{\text{m m}^3\ \text{kg m}^{-1}\ \text{s}^{-2}}$ (1 Pa = 1 N m^{-2} = 1 kg m s^{-2} m^{-2} = 1 kg m^{-1} s^{-2}) = m Thus, **units of left and right sides of the equation are the same**, hence homogenous.	1 1 1
	b		**Essential Question(s):** • What is the product-quotient rule for determining uncertainty of a derived quantity? • What are the rules when quoting a quantity with its uncertainty? **Solution:** Make E the subject in the equation, $E = \frac{L^3 gM}{4wt^3 x}$ $E = \frac{(0.800^3)(9.81)(300x10^{-3})}{4(2.10x10^{-2})(4.56x10^{-3})^3(1.00x10^{-2})}$ $E = 1.8918x10^{10}\ \text{Pa}$ $\frac{\Delta E}{E} = 3\frac{\Delta L}{L} + \frac{\Delta M}{M} + \frac{\Delta w}{w} + 3\frac{\Delta t}{t} + \frac{\Delta x}{x}$ $\frac{\Delta E}{E} = 3\frac{0.005}{0.800} + \frac{2}{300} + \frac{0.02}{2.10} + 3\frac{0.01}{4.56} + \frac{0.01}{1.00}$ $\frac{\Delta E}{E} = 0.0515 = 0.05$ (1 sig. fig) $\frac{\Delta E}{E} x100\% = 5\%$ Recall that E is quoted to the same precision as ΔE, so rounded off to 2 d.p. E = 1.89 x 10^{10} Pa (2 d.p.)	1 1 1 1

			Final answer: 1.89×10^{10} Pa ± 5%	

2	**a**	**i**	**Essential Question(s):** • Draw a pictorial representation of the problem scenario. • Which kinematics equation is most convenient? **Solution:** Take upwards as positive direction. $v^2 = u^2 + 2as$ $v^2 = (+5.0)^2 + 2(-9.81)(-1.5)$ $v^2 = 54.43$ $v = 7.3777 = 7.4$ m s^{-1}	 1 1
		ii	**Essential Question(s):** • Which kinematics equation is most convenient? **Solution:** $v = u + at$ $-7.3777 = (+5.0) + (-9.81)t$ $t = 1.2617 = 1.3$ s	 1 1
	b		**Essential Question(s):** • What are the mathematical functions for the relationship between s-t, v-t and a-t? Hence what are the graphs like? • How to translate between the 3 graphs? How are they related? **Solution:** Take upwards as positive. $s = ut + \frac{1}{2} at^2$ $s = (5.0)t + \frac{1}{2} (-9.81)t^2$ → Negative quadratic function. $V = u + at$ $v = 5.0 + (-9.81)t$ → Negative linear function. $A = -9.81$ → Negative constant function. Which graph to sketch first? ➔ You have more info on v-t and a-t. Sketch these graphs first. ➔ Use the v-t graph to determine - Time when maximum height is reached → Draw a vertical line across all 3 graphs to indicate. (From v-t graph, this is at around t = 0.51 s.) - Maximum height H reached, using area under graph. (From v-t graph, H = ½ x 0.51 x 5.0 = 1.3 m. To be more specific, this is the maximum CHANGE IN vertical displacement from the start.) Since question defined ground level to be zero displacement, and the initial displacement is 1.5 m, maximum displacement reached = 1.3 + 1.5 = 2.8 m. All 3 graphs should end at t = 1.26 s (or 1.3 s).	



Marks scheme:

- Shape of 3 graphs — 1
- Good vertical scale (graph spans at least half the graph grid vertically) — 1
- Significant values of t labelled (at max. height & when hit ground) — 1
- Significant values of s, v and a labelled, including additional calculation to determine maximum height reached. — 2

3	**a**		**Essential Question(s):** • What is the definition of electric current? **Solution:** It is the rate of flow of electric charge.	1
	b		**Essential Question(s):** • How to derive the equation from definition of current?	

			Solution: $I = \frac{\text{Total charge flowing through A in time t}}{\text{time t}}$ $I = \frac{nALq}{L/v}$ $I = nAqv$ Where t is the time taken for the charge carriers to travel a net displacement L.	1 1 1
	c	**i**	**Essential Question(s):** • What are the definitions of the terms in the equation I = nAqv? **Solution:** Let N be the total number of conduction electrons. $I = nAqv = \left(\frac{N}{AL}\right)Aqv = \frac{Nqv}{L}$ $2.00 = \frac{(1.45x10^{23})(1.60x10^{-19})v}{3.00}$ $v = 2.5862x10^{-4} = 2.59x10^{-4}\text{m s}^{-1}$	1 1 1
		ii	**Essential Question(s):** • What is meant by drift velocity? **Solution:** The conduction electrons **experience electric forces/accelerations is <u>all</u> directions as a result of collisions with the lattice ions.** Thus the individual conduction electrons have a **range of velocities of different magnitudes as well as directions, and the electron paths are rather random/erratic.** The **mean <u>speed</u>, regardless of direction, is large**. Whereas **drift velocity is the average <u>velocity</u>, which is quite small since there is a large number of conduction electrons and their individual velocities are rather random in direction.**	1 1

4	**a**		**Essential Question(s):** • What is the definition of magnetic flux density? **Solution:** Magnetic flux density **at a point** is the **force <u>per</u> unit current <u>per</u> unit length** experienced by a **<u>straight current-carrying</u> conductor** placed **at <u>right angle</u> to a <u>uniform</u> magnetic field**.	
	b	**i**	**Essential Question(s):** • What determines the balance reading? • When current flows in a magnetic field, what additional force acts? • Given that the balance reading decreases, what can be deduced about the direction of magnetic force on the magnet and on the rod? What is the free body diagrams of the balance, magnet & rod like? • How to determine direction of the current once direction of magnetic force on the rod is known? **Solution:** Balance reading decrease implies the downward normal contact force by the magnet on the balance decrease.	1

			This means when the current was switched on, the magnetic force produced acted upwards on the magnet. By Newton's 3rd law, the magnetic force acted downwards on the rod. By Fleming's Left Hand Rule, current flowed from X to Y.	1 1
		ii	**Essential Question(s):** • What determines the balance reading in each case? • What happens when the current reversed direction? • Given that the final reading is greater than initial reading, what can you deduce about the directions of the magnetic force initially and finally? **Solution:** Since initially the balance reading is smaller, Initially → magnetic force on magnet is upwards and on rod is downwards. Finally → magnetic force on magnet is downwards and on rod is upwards. When current reversed direction, direction of magnetic force F_B on magnet reversed direction causing the change in the balance reading. Let W be the weight of the magnet. Initially: $W - F_B = (201.62 \times 10^{-3}) \times 9.81$ ----(1) Finally: $W + F_B = (202.17 \times 10^{-3}) \times 9.81$ ----(2) (2) – (1): $2F_B = 5.3955 \times 10^{-3}$ $2(BIL \sin 90°) = 5.3955 \times 10^{-3}$ $2\ B\ (1.60)\ (12 \times 10^{-2}) = 5.3955 \times 10^{-3}$ $B = 0.014051 = 0.0141$ T	 1 1 1 1
		iii	**Essential Question(s):** • What determines the change in the balance reading when current is reversed? **Solution:** Change in balance reading = $2F_B = 2BIL$ Where F_B is the magnetic force, B is flux density, I is current, L is length of rod within the field. Since the magnetic force F_B is independent of resistivity, and since 2BIL is unchanged, hence the change in balance reading is the same.	 1

5	**a**		**Essential Question(s):** • What is the definition of gravitational potential? **Solution:** Gravitational potential <u>at a point</u> in a gravitational field is defined as the **work done <u>per</u> unit <u>mass</u> by an <u>external agent</u> in bringing a <u>small test mass</u> <u>from infinity</u> to <u>that point</u>** (without a change in kinetic energy).	
	b		**Essential Question(s):** • What is the energy transformation? • What does 'minimum' speed imply about the projectile's speed when it just reaches infinity?	

- Draw a pictorial representation to visualize. Are there additional quantities which you need to introduce & define in your derivation?

Solution:
Let m be the mass of the projectile,
and v_∞ be its speed at infinity.

By conservation of energy, as the projectile moves from planet's surface to infinity,
Loss in kinetic energy of the projectile
= Gain in gravitational potential energy of the system 1

$E_{K,\,surface} - E_{K,\,\infty} = E_{P,\,\infty} - E_{P,\,surface}$

Since v is the minimum speed, $v_\infty = 0$. Thus $E_{K,\,\infty} = 0$. 1
Also, by definition, $E_{P,\,\infty} = 0$.

$\frac{1}{2} mv^2 - 0 = 0 - [-GMm/R]$

$$v = \sqrt{\frac{2GM}{R}}$$ 1

Examiners' Report:
Although most candidates could produce an expression for the escape velocity from the surface of a planet, some thought that the energy was only zero at infinity and did not realise that the total energy is zero at all times. Some also mixed up the decrease in kinetic energy and the increase in gravitational potential energy.

c **i, ii**

Essential Question(s):
- What is the shape of the graphs for GPE and KE? What equations describe their variation with distance from centre of the planet?
- We are told that initial KE is 8.0×10^6 J, but what is the initial GPE? (Where should the graph of GPE start from?)
- How is conservation of energy applied here?

Solution:
Q: What is the initial value of GPE?
- ➔ **Total energy is conserved**. Since $E_{T,\,\infty} = E_{K,\,\infty} + E_{P,\,\infty} = 0$, therefore **at every instant, $E_T = 0$**.
- ➔ So, **$E_K + E_P = 0$ throughout**.
- ➔ Thus, if $E_{K,\,surface} = 8.0 \times 10^6$ J, then **$E_{P,\,surface} = -8.0 \times 10^6$ J.**

Q: What is the variation of GPE with distance from centre of planet like?
- ➔ $E_P = -GMm/r$, where GMm remains constant.
- ➔ $E_P \propto \frac{1}{r}$ and negative. (i.e. when r is doubled, E_P is halved, etc…)

(i) Tabulating,

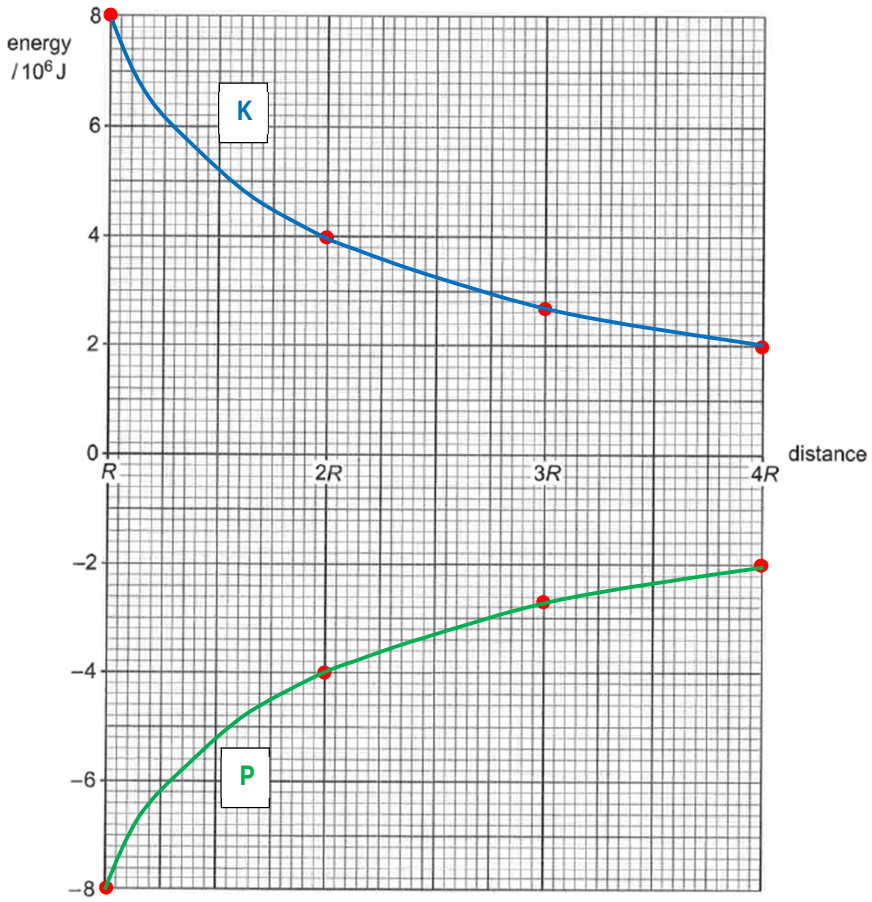
r	E_P / 10^6 J	Remarks
R	-8.0	Value of $E_{P,\,surface}$ found earlier.
2R	-4.0	½ (-8.0)
3R	-2.67	1/3 (-8.0)
4R	-2.0	¼ (-8.0)

(ii) **Since $E_T = 0$ throughout**, we can deduce the corresponding values of E_K at these instances. Tabulating,

r	E_K / 10^6 J
R	+8.0
2R	+4.0

3R	**+2.67**
4R	**+2.0**

E_P-r graph is a negative hyperbola; E_K-r graph is a positive hyperbola.
And the sum of both graphs at every point equals zero since $E_T = 0$.



Marks scheme:

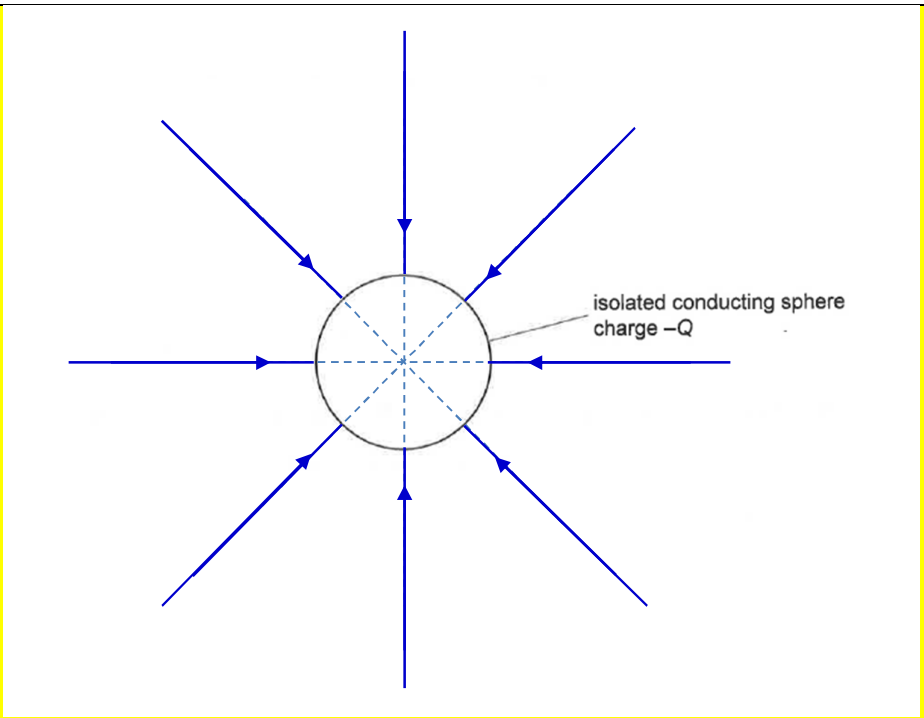
- Hyperbolic shape of both graphs, and, GPE negative while KE positive. Both graphs labelled as instructed. — 2
- Precision of both graphs – GPE and KE values at R, 2R, 3R and 4R determined and plotted. (Knowledge that TE = 0 throughout.) — 2

6	**a**	**i**	**Essential Question(s):** • How to calculate the mean KE per molecule for an ideal gas? **Solution:** **Mean** KE **per molecule** of an ideal gas, $\langle E_K \rangle = 3/2\ k\ T$ Thus, $\langle E_K \rangle \propto T$. Since A and B are at same temperature T, Ratio = 1.	1
		ii	**Essential Question(s):** • What ideal gas equation relates N to known information?	

			Solution: Use "pV = NkT" → "N = pV/kT" Since A and B have same p & T, and k is a constant, N ∝ Volume Ratio, $\frac{N_A}{N_B} = \frac{V_A}{V_B} = \frac{V}{4V} = \frac{1}{4} = 0.25$ **Evaluate your answer. Do not leave in fraction form.*	1
		iii	**Essential Question(s):** • What ideal gas equation relates r.m.s. speed of molecules to known info? **Solution:** Use "½ m <c^2> = 3/2 kT" → "<c^2> = 3kT/m" → $\sqrt{< c^2 >} = \sqrt{\frac{3kT}{m}}$ Since A and B have same T, $\sqrt{< c^2 >} \propto \frac{1}{\sqrt{m}}$ Ratio, $\frac{\sqrt{< c^2 >_A}}{\sqrt{< c^2 >_B}} = \sqrt{\frac{m_B}{m_A}} = \sqrt{\frac{2m}{m}} = \sqrt{2} = 1.41$ (or 1.4) Or, use "$p = \frac{1}{3}\frac{Nm}{V} < c^2 >$" and earlier found information. This working will be longer.	1 1
	b		**Essential Question(s):** • What equation relates T to r.m.s speed? What are the definitions of the terms in this equation? • What is meant by molar mass? **Solution:** *Thinking:* - *Since we know r.m.s speed of gas molecules in B, can use "½ m <c^2> = 3/2 kT" for B. But first we need to find the mass per molecule in B.* - *From given info about molecules in A, we can find the mass per molecule in A and then times 2 to get the mass per molecule in B.* Mass per molecule in A, $m = \frac{4.0x10^{-3}}{6.02x10^{23}}$ kg Mass per molecule in B, $2m = 2\left(\frac{4.0x10^{-3}}{6.02x10^{23}}\right)$kg Consider container B, using "*½ m <c^2> = 3/2 kT*", $T = \frac{(2m) < c^2 >_B}{3k}$	1 1

			$T = \dfrac{2\left(\dfrac{4.0x10^{-3}}{6.02x10^{23}}\right)\left(940^2\right)}{3\left(1.38x10^{-23}\right)}$ $T = 283.63 = 280\ \text{K}$	1 1

7	**a**		**Essential Question(s):** • What is the definition of electric field strength? **Solution:** Electric field strength <u>at a point</u> in an electric field is the **<u>electric</u> <u>force</u> <u>per</u> unit <u>positive</u> <u>charge</u> acting on a <u>stationary small test</u> charge placed <u>at that point</u>**.	
	b	**i**	**Essential Question(s):** • What are the rules for drawing electric field lines? • What is the shape of the field lines? • How to determine the direction of the field lines? • What does "conducting" imply when drawing the field lines? **Solution:** Conducting ➔ Field lines **meet surface of sphere at 90°**. ➔ Since charges reside on the surface & uniformly on the surface, the shape of the field lines is similar to that of all the charge concentrated at the centre of the sphere, hence field is **radial**. ➔ **Use ruler** to draw the field lines. ➔ **Lines should be equally spaced out around the sphere.** ➔ **When extrapolated, all field lines should meet at the centre of the sphere. BUT sphere is a conductor so E=0 inside the sphere. Do NOT draw field lines inside the sphere.** Direction of field lines ➔ Use an imaginary stationary positive test charge → Since sphere negatively charged, field lines all directed **towards** the sphere.	1 1 1



Examiners' Report:
Although candidates generally got the direction of the field lines correct, the lines were not always equally spaced around the sphere and not always perpendicular to the surface.

ii

Essential Question(s):

- What does potential gradient equal to?

Solution:

$$E = -\frac{dV}{dr}$$

$$|E| = \left|\frac{dV}{dr}\right| \qquad \text{where } r \text{ is distance from CENTRE of sphere}$$

At r = 15+40 = 55 cm, $|E| = 130\ \text{V m}^{-1}$ 1

For a radial field,

$$|E| = \frac{|q|}{4\pi\varepsilon_o r^2} = \frac{Q}{4\pi\varepsilon_o r^2}$$

$$130 = \frac{Q}{4\pi\left(8.85x10^{-12}\right)\left(0.55^2\right)}$$ 1

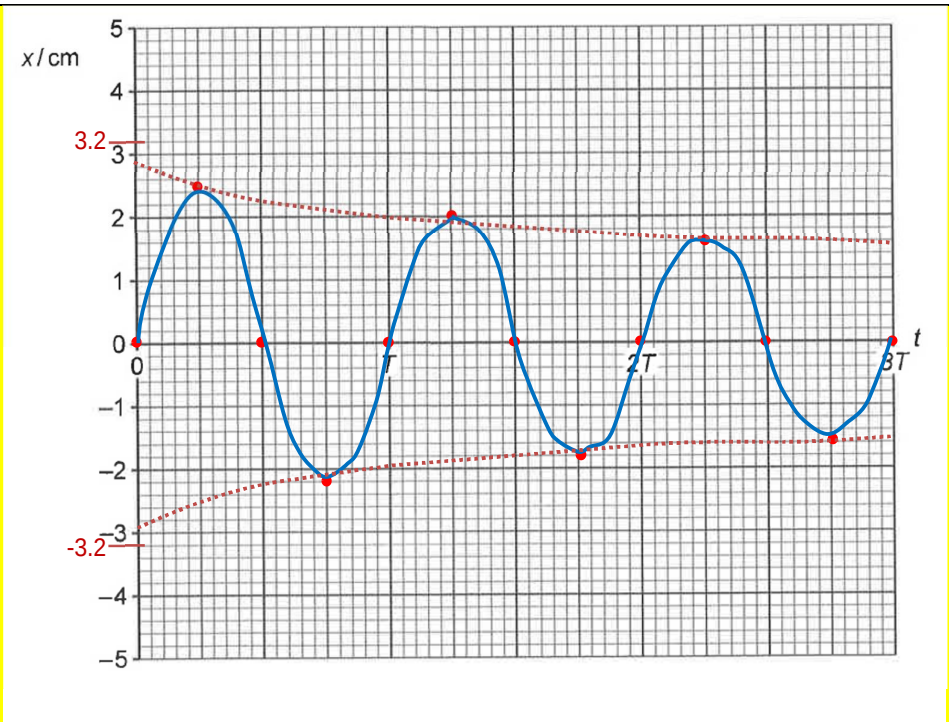
$$Q = 4.3734x10^{-9} = 4.4x10^{-9}\ \text{C}$$ 1

8	**a**	**i**	**Essential Question(s):** • How to relate k to the given graph? **Solution:** F = kx k = gradient of F-x graph = 3.0 / 0.15 = 20 N m^{-1} 1
		ii	**Essential Question(s):**

			• How to relate energy stored in spring to the give graph? **Solution:** When F = 3.0 N, x = 0.15 m (from graph) Energy stored in spring = Area under graph from x=0 to x=0.15 m = ½ (0.15)(3.0) = 0.225 J (or 0.23 J)	 1 1
		iii	**Essential Question(s):** • How to calculate the change in GPE of the object? **Solution:** Loss in GPE of the object = mgx = (mg)x = (3.0 N) (0.15 m) = 0.45 J	 1
	b		**Essential Question(s):** • What is the energy transformation? • How is the object being lowered such that it can be stationary at the equilibrium position? **Solution:** **Before the object reaches its equilibrium position, there is a net downward force on it that tends to increase its kinetic energy**. But **since the object is stationary at the equilibrium position, there must be an externally applied upward force on the object as it is being lowered**. (This externally applied upward force must be adjusted to be always equal in magnitude to the difference between the object's weight and the spring force.) The **energy difference between (a)(ii) and (a)(iii) equals to the work done by the spring-mass system against this external upward force**. *Note: If the object was not quasi-statically lowered but released suddenly, KE would be gained and the object oscillates. The energy difference between (a)(ii) and (a)(iii) would be the maximum KE of the object. Recall that in SHM, maximum KE is attained at the equilibrium position.*	 1 1
	c		**Essential Question(s):** • What determines acceleration? → Net force • What contributes to the Net force? → Draw free body diagrams / consider the forces acting at equilibrium position, and also at displacement x away from the equilibrium position. **Solution:** **At Equilibrium position, no net force.** Upward Spring force = Downward Weight $k x_o = mg$ where x_o: spring extension at Equilibrium —(1) **Take direction down as positive.** **At displacement x (downwards) below the Eqm pt, spring extension is now ($x_o + x$), and net force is non-zero.** Net force = - (New Spring force) + Weight = $- k(x_o + x) + mg$ —--(2)	 1 1

			Sub (1) into (2): Net force = - k(x_o + x) + kx_o = -kx **By Newton's 2nd law,** Net force = ma -kx = ma a = - (k/m) x [Shown] OR **Take direction down as positive.** **At equilibrium position, Upward spring force = Downward weight, so Net force = 0.** **At displacement x (downwards) below the equilibrium position, spring force increases while weight is unchanged, so** **Upward spring force > Downward weight.** **Net force = -(increase in spring force) = -kx** (negative direction since Net force acts upwards) **By Newton's 2nd law,** **Net force = ma** **-kx = ma** a = - (k/m) x [Shown] Marks scheme: - Apply Hooke's law for Spring force. - Sign convention (show clearly how "-" sign appear). - Apply Newton's 2nd law.	1 0
	d	**i**	**Essential Question(s):** • What is the relationship between goal (displacement) and t for SHM? • What is the initial condition? Hence which of the x-t equation to use? **Solution:** Compare a = - (k/m) x with SHM equation a = - ω^2x ω^2 = k/m $\omega = \sqrt{\frac{k}{m}}$ At t = 0, x = 0. Take upwards as positive direction. Use $x = +x_0 \sin(\omega t) = +x_0 \sin\left(\sqrt{\frac{k}{m}}\, t\right)$ $x = (3.2\text{ cm}) \sin\left(\sqrt{\frac{20}{3.0 \div 9.81}}(0.50)\right)$ = -2.5105 = -2.5 cm ***Use Radians mode!*** Magnitude of displacement is 2.5 cm.	1 1
		ii	**Essential Question(s):** • How to obtain the relationship v-t from x-t?	

			Solution: $v = \frac{dx}{dt} = \omega x_o \cos(\omega t) = \sqrt{\frac{k}{m}} x_o \cos\left(\sqrt{\frac{k}{m}} t\right)$ $v = \sqrt{\frac{20}{3.0 \div 9.81}} (3.2 \text{ cm}) \cos\left(\sqrt{\frac{20}{3.0 \div 9.81}} (0.50)\right)$ $v = -16.047 = -16 \text{ cm s}^{-1}$ ***Use Radians mode!*** Magnitude of velocity is 16 cm s^{-1}. OR $v = \pm\omega\sqrt{x_o^2 - x^2}$ $v = \pm\sqrt{\frac{k}{m}}\sqrt{x_o^2 - x^2}$ $v = \pm\sqrt{\frac{20}{3.0 \div 9.81}}\sqrt{3.2^2 - (-2.5105)^2}$ $v = \pm 16.047 = \pm 16 \text{ cm s}^{-1}$ Magnitude of velocity is 16 cm s^{-1}.	1 1
	e		**Essential Question(s):** • What is the shape of the x-t graph for SHM? • What is the effect of light damping on x-t? **Solution:** Graph should start from t = 0, x = 0. With light damping (in air), - Amplitude decreases exponentially with time. Amplitude will be lesser than 3.2 cm. - Period increases slightly but negligible since difference between vacuum and air not too significant. Period close to T. **First, mark out the INITIAL amplitude positions at x = 3.2 cm and x = -3.2 cm.** **Second, sketch the exponential envelopes lower than the initial amplitude.** **Third, starting from (0,0), sketch a smooth sine graph bounded between the two exponential envelopes.**	1 1 1



Examiners' Report:
The lightly damped graph was generally of the correct shape although some candidates did not realise that the period remained constant. Most graphs started at the origin, but many candidates did not realise that this meant that the first peak/trough of the graph would be at **less than** 3.2 cm. Some candidates did not draw the graph with each successive peak or trough being of a smaller amplitude than its predecessor.

f **i**

Essential Question(s):

- What determines the extension of a spring? → F and k.
- How do F and k of the springs in the combination compare with that in the single original spring?

Solution:
The **force in each spring in the series combination is the same**, so **each spring extends by same amount, each 0.15 m**. 1
Thus **total extension of the combination is 0.30 m**, which is **double the extension of the single original spring**. 1

ii

Essential Question(s):

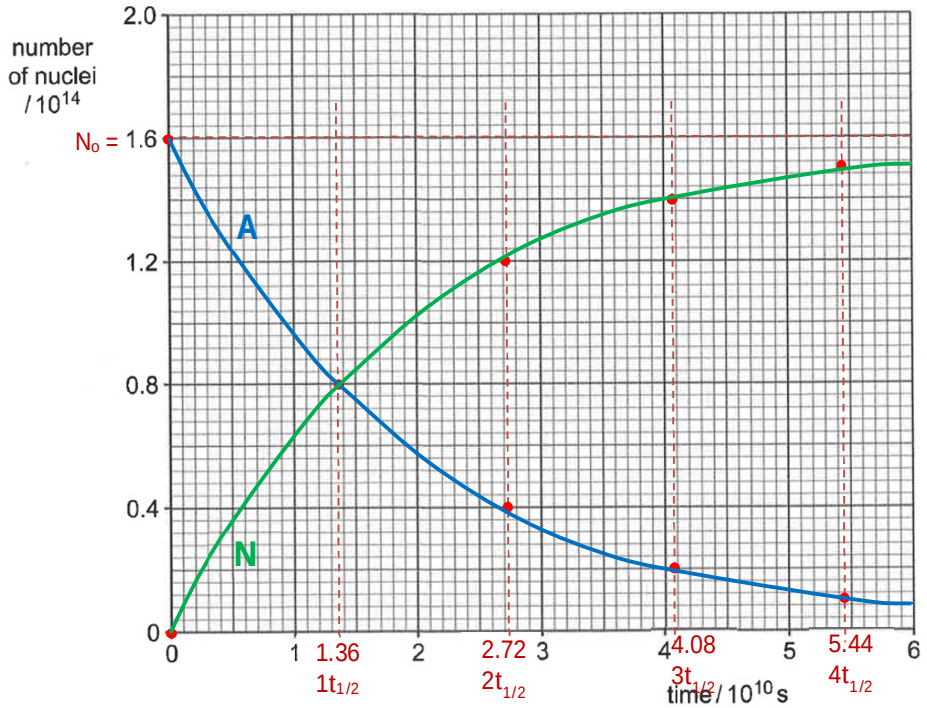
- What determines the period of oscillations of the spring-mass system?

Solution:
Force constant k of the series spring combination is half the force constant of a single original spring. 1
Since $\omega = \sqrt{\frac{k}{m}} \Rightarrow T = 2\pi\sqrt{\frac{m}{k}} \Rightarrow T \propto \frac{1}{\sqrt{k}}$, the **period T is inversely proportional to** $\sqrt{k}$ **.** Thus the **period of the spring combination is** $\sqrt{2}$ **times the original period in (c), i.e. longer period.** 1

Examiners' Report:
Some candidates did not answer the question in terms of *k* and correctly relate *k* to *T*.

9	**a**	**i**	**Essential Question(s):** • How to determine goal (energy released) from given info (masses)? **Solution:** $^{241}_{95}Am \rightarrow {}^{237}_{93}Np + {}^{4}_{2}He$ Energy released = (Decrease in total mass).c^2 = (400.19774 – 393.54304 – 6.64466)(10^{-27}).(3.00 x 10^8)^2 = 9.036 x 10^{-13} = 9.0 x 10^{-13} J **Examiners' Report:** Full working is needed in 'show that' questions.	1 1 0
		ii	**Essential Question(s):** • What does the principle of conservation of linear momentum state? **Solution:** The **total** linear momentum of a **system** will **remain constant** if **no net external force acts on it.** **Examiners' Report:** Although candidates understood the principle of conservation of linear momentum, not all correctly stated it. To say 'momentum is conserved' is a circular definition repeating the stem of the question. (i.e. Do NOT use the same root word!)	
		iii	**Essential Question(s):** • What conservation law can be applied? **Solution:** $E_K = \frac{p^2}{2m}$ $p = \sqrt{2mE_K}$ Take direction of the α-particle's momentum to the positive direction. By conservation of momentum, Total momentum before decay = Total momentum after decay $p_{AM} = (-p_{Np}) + p_{He}$ $0 = \left(-\sqrt{2m_{Np}E_{K,Np}}\right) + \sqrt{2m_{He}E_{K,He}}$ $m_{Np}E_{K,Np} = m_{He}E_{K,He}$ $E_{K,Np} = \frac{m_{He}}{m_{Np}}E_{K,He}$ $E_{K,Np} = \frac{6.64466}{393.54304}\left(8.784x10^{-13}\right)$ $E_{K,Np} = 1.483x10^{-14}\,\text{J}$	1 1 1 1 0
		iv	**Essential Question(s):** • What energy transformations occur during nuclear decay? **Solution:** Most of the energy released in the decay is converted into kinetic energies of the α-particle and Np-237 nucleus. However, **some of the energy released is converted**	

			into the energy of a gamma-ray photon when the daughter nucleus (Np-237) de-excites. **Examiners' Report:** The most common incorrect answer was to say that the extra energy is carried away by a neutrino, which is mixing up alpha and beta decay. Some responses also incorrectly talked about heat energy.	1
	b	**i**	**Essential Question(s):** • How to relate the goal (N_o) to the known info (λ and A_o)? **Solution:** $A_o = \lambda N_o$ $8.13 \times 10^3 = (5.08 \times 10^{-11}) N_o$ $N_o = 1.60039 \times 10^{14} = 1.60 \times 10^{14}$	 1 1
		ii	**Essential Question(s):** • How to determine half-life from known info? **Solution:** $t_{1/2} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{5.08x10^{-11}} = 1.3645x10^{10} = 1.36x10^{10}\,s$ **Examiners' Report:** Most candidates answered this correctly though a few did not give the answer to an appropriate number of significant figures.	 1
		iii, iv	**Essential Question(s):** • What is the N-t function for a sample of decaying nuclei? How does the graph for the parent nuclei and daughter nuclei compare? • What points can be plotted to draw a precise graph? **Solution:** Steps: (iii) 1. Note the axes units. 2. Mark out the half-lives for the time interval t = 0 to t = $6.0x10^{10}$ s. 3. Plot the initial point (0, N_o). 4. Plot the number of undecayed nuclei at various number of half-lives elapsed. 5. Draw a smooth exponential decay curve through the plotted points. Graph should end at $6.0x10^{10}$ s as instructed. 6. Label the graph A. (iv) 7. At t = 0, N = 0. 8. At all other timings, grand total number of parent and daughter nuclei must be equal to the initial number of undecayed parent nuclei N_o. Plot the points for the daughter nuclei. 9. Draw a smooth exponential curve that is increasing with time. 10. Label the graph N.	



2
2

Marks scheme:

- Shape of both graphs
- Precision of both graphs

Examiners' Report:
(iii) Candidates generally knew that this was an exponential decay curve, and it was often drawn to a high degree of accuracy. However, some candidates did not produce a curve of sufficient accuracy.
(iv) Candidates did not always realise that this curve would be the mirror of the curve drawn in (b)(iii). Some also did not label their graphs as instructed.

c **i**

Essential Question(s):

- What determines the initial activity?

Solution:

The initial activity A_o equals to the product of the decay constant λ and the initial number of undecayed nuclei N_o ($A_o = \lambda N_o$). 1

Since N_o is same for both, while λ is much greater for the beta emitter, A_o for the beta emitter is proportionally much greater. 1

ii

Essential Question(s):

- How do the half-lives compare?

Solution:

Half-life of the beta emitter is much shorter since it is inversely proportional to the decay constant. 1

Thus the number of disintegrations per unit time (activity) decreases at a much greater rate and falls to 1 Bq within a shorter timeframe. 1

Examiners' Report:
Candidates generally understood that the half-life of the beta emitter is shorter than that of the americium-241 but did not always relate that correctly to the time taken.