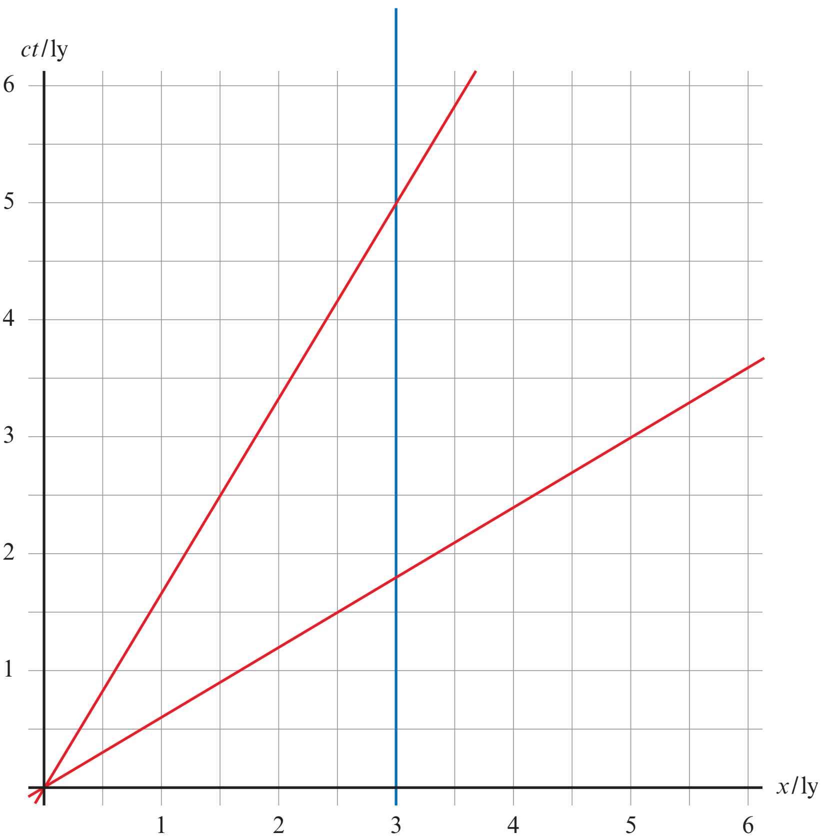
# Markscheme

| 1 | | | | |
|---|---|---|---|---|
| a | | $\frac{16}{2.0} = 8.0\text{ m s}^{-2}$ ✓ | | [1] |
| b | | Impulse = area = 32 N s ✓<br>$2 \times v - 2 \times (-4) = 32 \Rightarrow v = 12\text{ m s}^{-1}$ ✓<br>Change in KE: $\frac{1}{2} \times 2 \times 12^2 - \frac{1}{2} \times 2 \times (-4)^2 = 128\text{ J}$ ✓<br>Average power: $\frac{128}{4} = 32\text{ W}$ ✓<br>**OR**<br>Impulse = area = 32 N s ✓<br>$2 \times v - 2 \times (-4) = 32 \Rightarrow v = 12\text{ m s}^{-1}$ ✓<br>$\overline{P} = \overline{F}\frac{u+v}{2}$ ✓<br>$\overline{P} = 8.0 \times \frac{-4.0+12}{2} = 32\text{ W}$ ✓ | | [4] |

| 2 | | | | |
|---|---|---|---|---|
| a | | $\frac{3.0}{5.0} = 0.60c$ ✓ | | [1] |
| b | I | Vertical line through 3.0 ly ✓<br> | | [1] |

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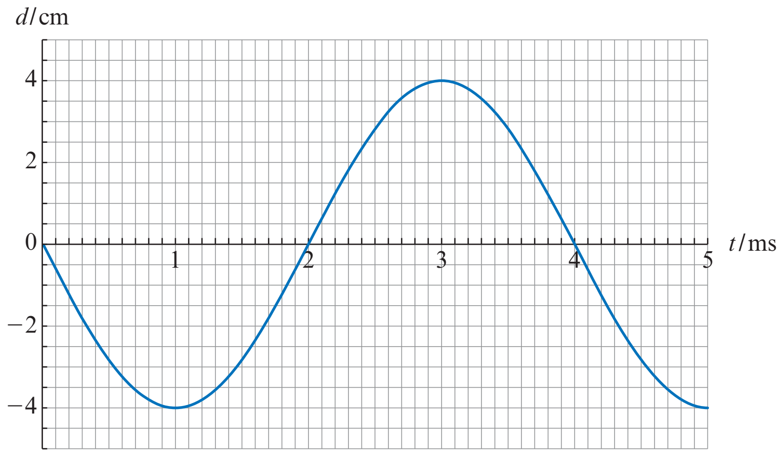
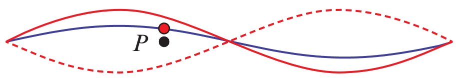
| | II | 5.0 years read from graph at intersection point ✓<br>**OR**<br>$\frac{3.0\text{ ly}}{0.60c} = 5.0\text{ yr}$ ✓ | | [1] |
| | III | $\gamma = \frac{5}{4}$ ✓<br>$\Delta t' = \gamma(\Delta t - \frac{v}{c^2}\Delta x) = \frac{5}{4} \times (5.0 - \frac{0.60c}{c^2} \times 3.0\text{ ly}) = 4.0\text{ yr}$ ✓<br>**OR**<br>$\gamma = \frac{5}{4}$ ✓<br>$\Delta t' = \frac{5.0}{\gamma} = 4.0\text{ yr}$ ✓<br>**OR**<br>$\gamma = \frac{5}{4}$ ✓<br>$\Delta t' = \frac{\frac{3.0}{1.25}}{0.60c} = \frac{2.4\text{ ly}}{0.60c} = 4.0\text{ yr}$ ✓ | | [2] |

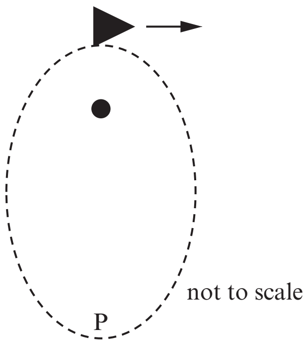
| 3 | | | | |
|---|---|---|---|---|
| a | | A very small percentage of the incident alpha particles were scattered at very large scattering angles ✓<br>This required a huge electric force that could only be provided if the positive charge of the atom was concentrated in a very small, massive object ✓ | | [2] |
| b | I | ${}^{239}_{94}\text{Pu} \rightarrow {}^{235}_{92}\text{U} + {}^{4}_{2}\alpha$ ✓<br>Correct numbers for U ✓ | | [2] |
| | II | $235 \times 7.5909 + 4 \times 7.0739 - 239 \times 7.5603$ ✓<br>5.25 MeV ✓ | | [2] |
| | III | Binding energy per nucleon is a measure of the stability of a nucleus ✓<br>And uranium is more stable than plutonium ✓ | | [2] |
| c | | Protons tend to break a nucleus apart because the electric force is repulsive ✓<br>Putting extra neutrons means average distance between protons increases and so tendency to split decreases ✓<br>And neutrons contribute to bonding through the strong nuclear force ✓ | | [3] |

| 4 | | | | |
|---|---|---|---|---|
| a | | In a transverse wave the displacement is at right angles to the direction of energy transfer ✓<br>In a longitudinal wave the displacement is parallel to the direction of energy transfer ✓ | | [2] |
| b | I | $\lambda = 0.30\text{ m}$✓<br>$v = f\lambda = 250 \times 0.30 = 75\text{ m s}^{-1}$ ✓ | | [2] |

| | | | | |
|---|---|---|---|---|
| | II | <br>Correct shape ✓<br>Correct period ✓ | | [2] |
| | III | $y = -4\sin(500\pi t)$ ✓<br>$y = 4\sin(500\pi t + \pi)$ ✓ | | [2] |
| c | I |  ✓ | | [1] |
| | II |  ✓ | | [1] |

| 5 | | | | |
|---|---|---|---|---|
| a | | Luminosity also depends on area ✓<br>Star Z has a much larger area than X ✓ | | [2] |
| b | I | $\frac{L_Z}{L_Y} = \frac{4\pi\sigma R_Z^2 T_Z^4}{4\pi\sigma R_Y^2 T_Y^4} = 10^6$ ✓<br>$\frac{R_Z}{R_Y} = \sqrt{10^6 \times \frac{20000^4}{2500^4}}$ ✓<br>$= 6.4 \times 10^3$ | | [3] |
| c | I | X: by radiation pressure caused by fusion reactions ✓ | | [1] |
| | II | Y: by electron degeneracy pressure ✓ | | [1] |

| 6 | | | | |
|---|---|---|---|---|
| a | | Uniform lines from left to right in the interior ✓<br>Edge effects ✓ | | [2] |
| b | | $E = \frac{V}{d} = \frac{240}{2.0 \times 10^{-2}} = 2.2 \times 10^4\ \text{N C}^{-1}$ ✓ | | [1] |
| c | | $qV = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2qV}{m}}$ ✓<br>$\frac{v_p}{v_\alpha} = \sqrt{\frac{q_p m_\alpha}{q_\alpha m_p}} = \sqrt{\frac{1}{2} \times 4} = \sqrt{2}$ ✓ | | [2] |

| 7 | | | | |
|---|---|---|---|---|
| a | | The speed at launch so that the projectile reaches infinity with zero speed ✓ | | [1] |
| b | | $\frac{1}{2}mu^2 - \frac{GMm}{R} = -\frac{GMm}{r}$ ✓<br>$\frac{1}{2}m \times \frac{1}{4} \times \frac{2GM}{R} - \frac{GMm}{R} = -\frac{GMm}{r}$ ✓<br>$r = \frac{4R}{3}$ ✓ | | [3] |
| c | I | Along top part of major axis ✓<br><br> | | [1] |
| | II | It is less ✓<br>Because at P the potential energy is a maximum and so kinetic energy a minimum ✓<br>***OR***<br>Angular momentum $mvr$ is conserved ✓<br>$r$ is maximum at P so speed is minimum ✓ | | [2] |

| 8 | | | | |
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| a | I | $N = 7.0 \times 6.02 \times 10^{23} = 4.2 \times 10^{24}$ ✓<br>$4.2 \times 10^{24} \times 3.0 \times 10^{-30} = 1.3 \times 10^{-5}\ \mathrm{m}^3$ ✓ | | [2] |
| | II | $V = \frac{RnT}{P}$ ✓<br>$V = \frac{8.31 \times 7.0 \times 270}{3.0 \times 10^5} = 5.2 \times 10^{-2}\ \mathrm{m}^3$ ✓ | | [2] |
| | III | $7 \times 4 = 28$ g ✓ | | [1] |
| b | | One of the assumptions of the kinetic theory of gases states that the volume of the molecules is negligible compared to the volume of the gas ✓<br>Here $\frac{V_{\text{molecules}}}{V_{\text{gas}}} = \frac{1.3 \times 10^{-5}}{5.2 \times 10^{-2}} = 2.5 \times 10^{-4}$ which is very small ✓ | | [2] |
| c | | $\frac{P_1}{T_1} = \frac{P_2}{T_2} \Rightarrow T_2 = T_1 \times \frac{P_2}{P_1}$ ✓<br>$T_2 = 270 \times \frac{5.0}{3.0} = 450$ K ✓ | | [2] |

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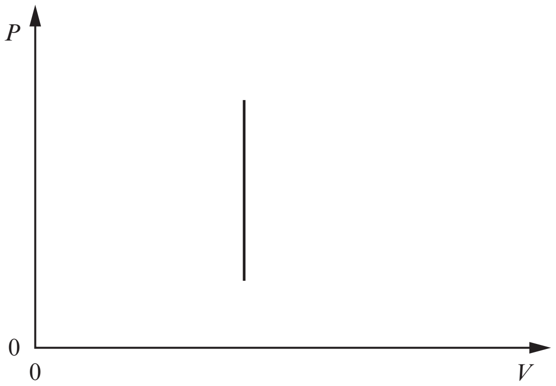
|---|---|---|---|---|
| d | | <br>Vertical straight line ✓ | | [1] |
| e | I | $\Delta U = \frac{3}{2}Rn\Delta T = \frac{3}{2} \times 8.31 \times 7.0 \times (450 - 270) = 15706$ J ✓ | | [1] |
| | II | Realization that $Q = \Delta U$ ✓<br>$c = \frac{Q}{m\Delta T} = \frac{15705}{0.028 \times (450 - 270)} = 3.1 \times 10^3$ J kg$^{-1}$ K$^{-1}$ ✓ | | [2] |
| f | | $E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E}$ ✓<br>$\lambda = \frac{1.24 \times 10^{-6}}{1.86} = 666.6 \approx 667$ nm ✓ | | [2] |
| g | I | [2] max from<br>Electromagnetic radiation with an infinite range of wavelengths ✓<br>With a peak determined by temperature ✓<br>Radiation emitted by a body at some finite kelvin temperature ✓<br>Radiation with an intensity proportional to the 4th power of the kelvin temperature ✓ | | [2] max |
| | II | Helium has energy levels separated by 1.86 eV ✓<br>This energy difference is unique to helium ✓<br>The dip implies that photons of this energy are absorbed by helium ✓ | | [3] |

| 9 | | | | |
|---|---|---|---|---|
| a | | $v = \frac{2\pi R}{T} = \frac{2\pi \times 1.5 \times 10^{11}}{365 \times 24 \times 60 \times 60}$ ✓<br>$v = 2.99 \times 10^4 \approx 3.0 \times 10^4$ m s$^{-1}$ = 30 km s$^{-1}$ ✓ | | [2] |
| b | I | $Mv - mv = (M + m)u$ ✓<br>Result follows | | [1] |
| | II | $m = \frac{2 \times 2 \times 10^{25}}{(2.99 \times 10^4)^2} = 4.47 \times 10^{16}$ kg ✓ | | [1] |
| c | I | $R = \frac{GM_\odot}{u^2}$ ✓<br>$u < v$ so $R$ increases ✓ | | [2] |

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|---|---|---|---|---|
| | II | The mass of the asteroid is much smaller than that of earth so change in $R$ is not significant ✓<br><br>(For the aficionados!<br>$u^2 = \frac{GM_\odot}{R'} \Rightarrow R' = \frac{GM_\odot}{\left(\frac{M-m}{M+m}v\right)^2} = \frac{GM_\odot(M+m)^2}{v^2(M-m)^2} = \frac{GM_\odot}{v^2}\frac{M^2(1+\frac{m}{M})^2}{M^2(1-\frac{m}{M})^2}$<br>$R = \frac{GM_\odot}{v^2} \times \frac{(1+\frac{m}{M})^2}{(1-\frac{m}{M})^2} = R\frac{(1+\frac{m}{M})^2}{(1-\frac{m}{M})^2}$<br>From Mathematics HL we know that<br>$\frac{(1+\frac{m}{M})^2}{(1-\frac{m}{M})^2} \approx (1+\frac{2m}{M})(1+\frac{2m}{M}) \approx 1+\frac{4m}{M}$<br>Hence the change in orbit radius is an increase of<br>$\Delta R \approx R \times \frac{4m}{M} \approx 1.5 \times 10^{11} \times 4 \times \frac{5 \times 10^{16}}{6 \times 10^{24}} \approx 5$ km and so insignificant.) | | [1] |
| d | I | Thermal energy needed<br><br>$M \times 850 \times (1700 - 300) + M \times 1.6 \times 10^5 + M \times 1450 \times (2600 - 1700) + M \times 1.1 \times 10^7$ ✓<br><br>$= M \times 1.3655 \times 10^7$ ✓<br><br>$M = \frac{2 \times 10^{25}}{1.3655 \times 10^7}$ ✓<br><br>$M = 1.46 \times 10^{18} \approx 1.5 \times 10^{18}$ kg ✓ | | [4] |
| | II | Smaller ✓<br><br>Some of the kinetic energy will go as thermal energy in the asteroid and the surrounding air ✓ | | [2] |
| | III | Volume of rocks vaporized is $\frac{1.46 \times 10^{18}}{2800} = 5.21 \times 10^{14}$ m$^3$ ✓<br><br>Side of cube $(5.21 \times 10^{14})^{1/3} = 8 \times 10^4$ m $\approx 80$ km ✓ | | [2] |
| e | I | $Z = 18$ ✓<br><br>$A = 40$ ✓ | | [2] |
| | II | Decay constant is $\frac{\ln 2}{1.2 \times 10^{10}} = 5.78 \times 10^{-11}$ yr$^{-1}$ ✓<br><br>$0.996 = e^{-5.78 \times 10^{-11} \times t}$ ✓<br><br>t = $6.9 \times 10^7$ yr ≈ 69 million years ✓ | | [3] |