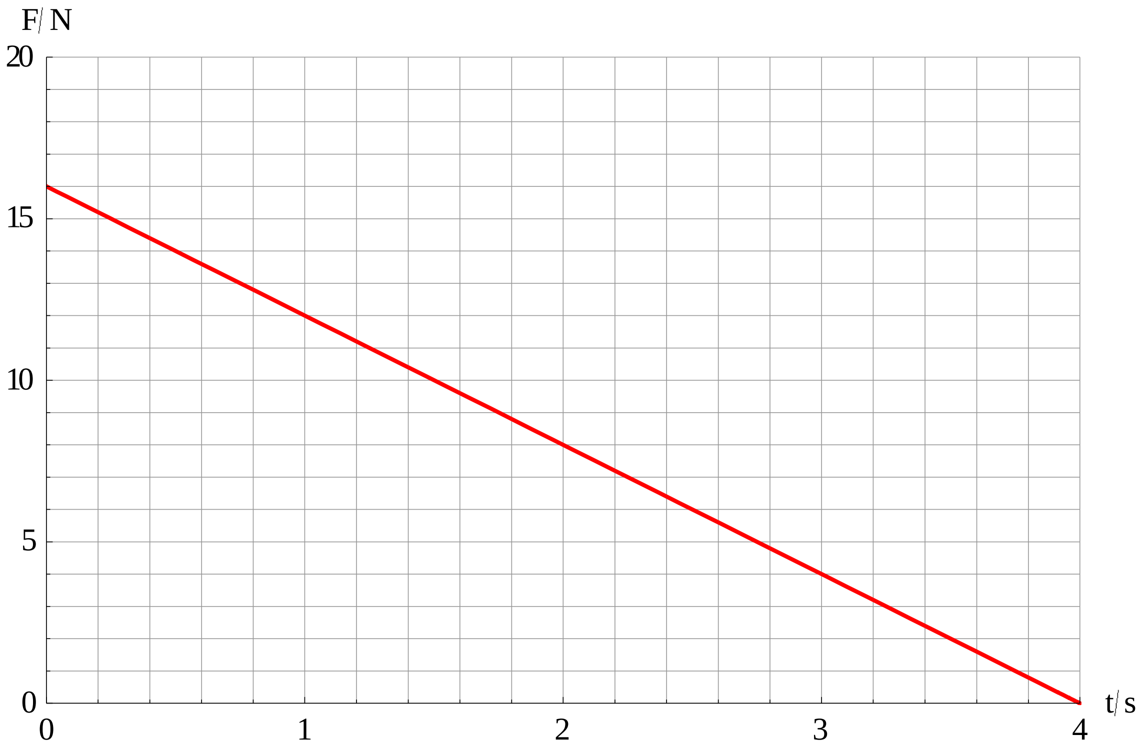
K.A. Tsokos

Specimen Paper 2 HL

Q1 [5 marks]

The graph shows the variation with time *t* of the net force *F* acting on a body of mass 2.0 kg.



Initially the body moves to the left with speed 4.0 m s^{-1}. The net force is directed to the right. During the 4.0 seconds of this motion

(a) Determine the maximum acceleration experienced by the body. [1]

………

………

(b) Estimate the average power developed by the force. [4]

………

………

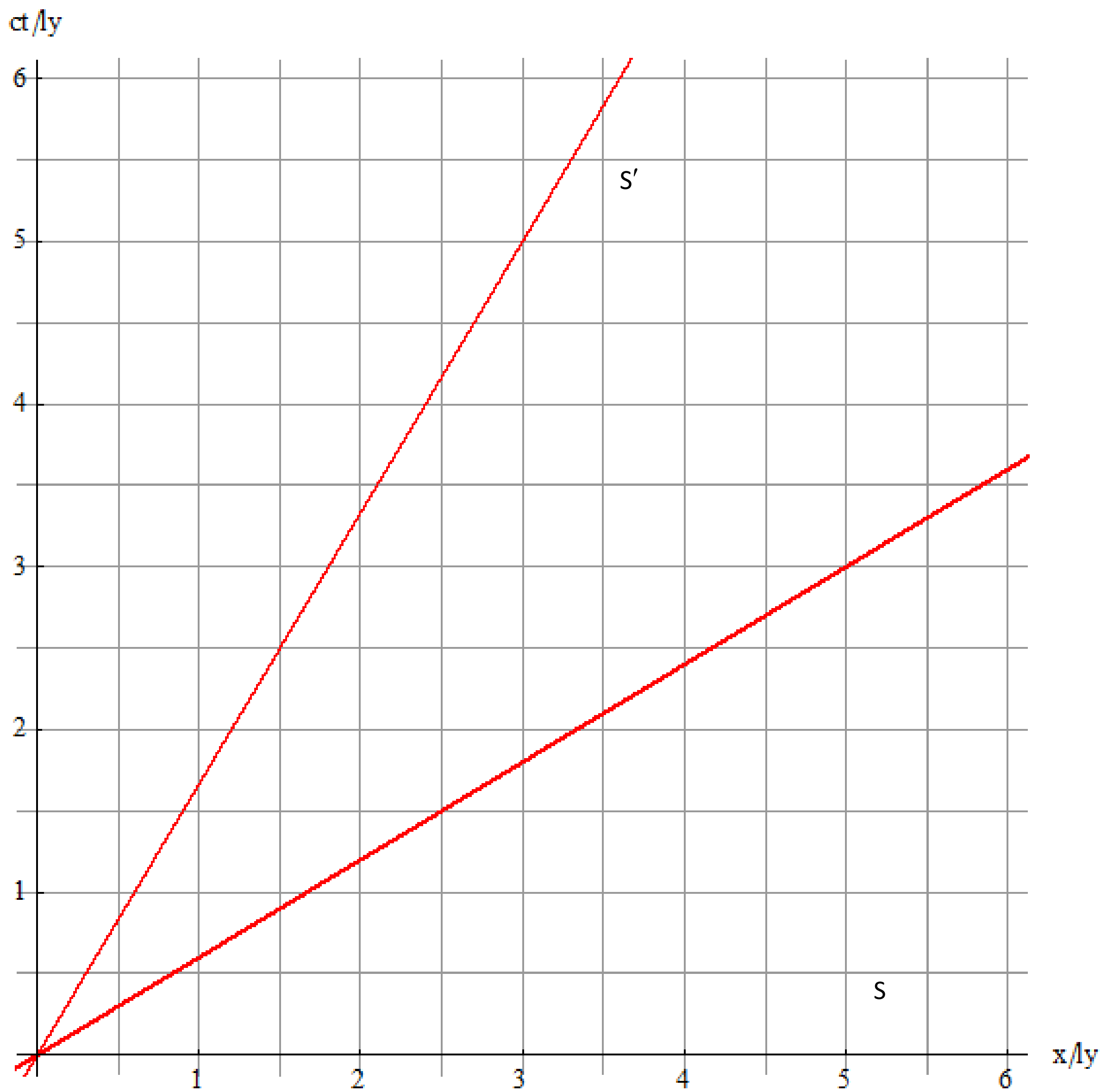
………

………

K.A. Tsokos

Q2 [5 marks]

The diagram shows the space-time axes of two inertial frames S and S′.



(a) Show that speed of S′ relative to frame S is 0.60 c. [1]

……

……

(b) S′ is moving towards a space station a distance 3.0 ly from the origin of S as measured by S. The space station is at rest relative to S.

(i) Draw the worldline of the space station. [1]

(ii) State the time it will take S' to reach the space station according to S clocks. [1]

………

………

(iii) Determine the travel time according to S'. [2]

………

………

………

………

Q3 [11 marks]

(a) Discuss how the Rutherford-Geiger-Marsden scattering experiment led to the conclusion of the existence of an atomic nucleus. [2]

………

………

………

………

(b) A plutonium ($^{239}_{94}Pu$) nucleus decays by alpha decay into a nucleus of uranium (U).

(i) State the reaction equation for this decay. [2]

………

………

………

………

(ii) The following binding energies per nucleon are available:

Plutonium	7.5603 MeV
Uranium	7.5909 MeV
Helium	7.0739 MeV

Estimate the energy released. [2]

....

....

....

....

(iii) The binding energy per nucleon for uranium is larger than that for plutonium. Explain this observation. [2]

....

....

....

....

(c) Large stable nuclei have more neutrons than protons. Explain this observation. [3]

....

....

....

....

....

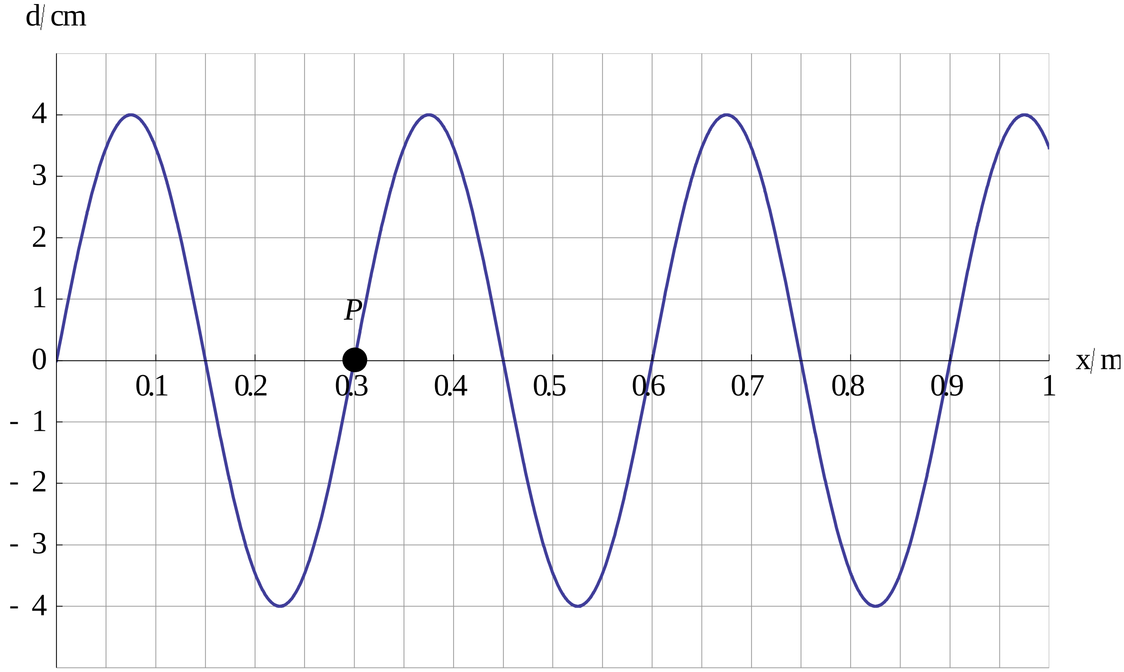
....

K.A. Tsokos

Q4 [10 marks]

(a) Distinguish between a transverse and a longitudinal wave. [2]

(b) The graph shows, at t = 0, the variation with distance of the displacement of particles in a medium in which a transverse wave of frequency 250 Hz is travelling to the right.



A particle P in the medium has been marked.

(i) Calculate the speed of the wave. [2]

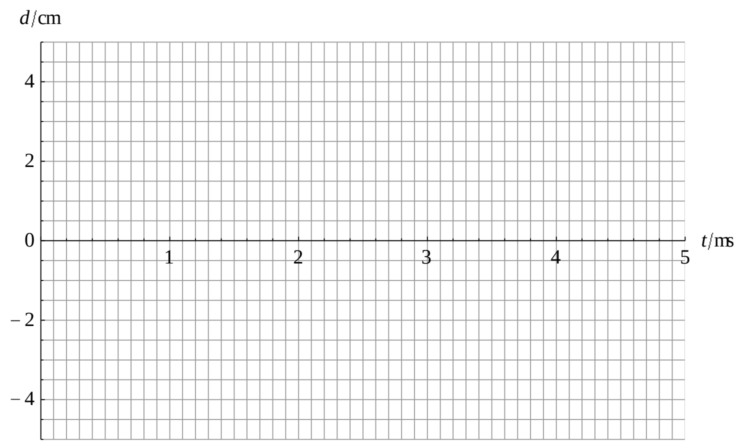
....

....

....

....

(ii) Draw a graph to show the variation with time *t* of the displacement of P. [2]



(iii) State the equation giving the displacement of P in the form $x = x_0 \sin(\omega t + \phi)$ where x_0, ω and ϕ are to be determined. [2]

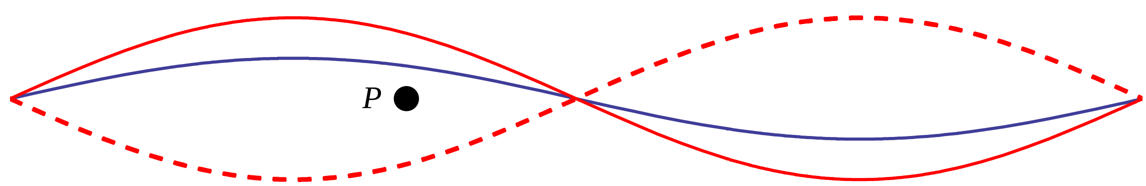
....

....

....

....

(c) A standing wave is formed on a string with both ends fixed. The solid line represents the wave at $t = 0$ and the dashed line at $t = T/2$ where T is the period. The blue line represents the wave at $t = \frac{T}{8}$.



The marked point shows the **equilibrium** position of a point P on the string.

At $t = \frac{T}{8}$ draw

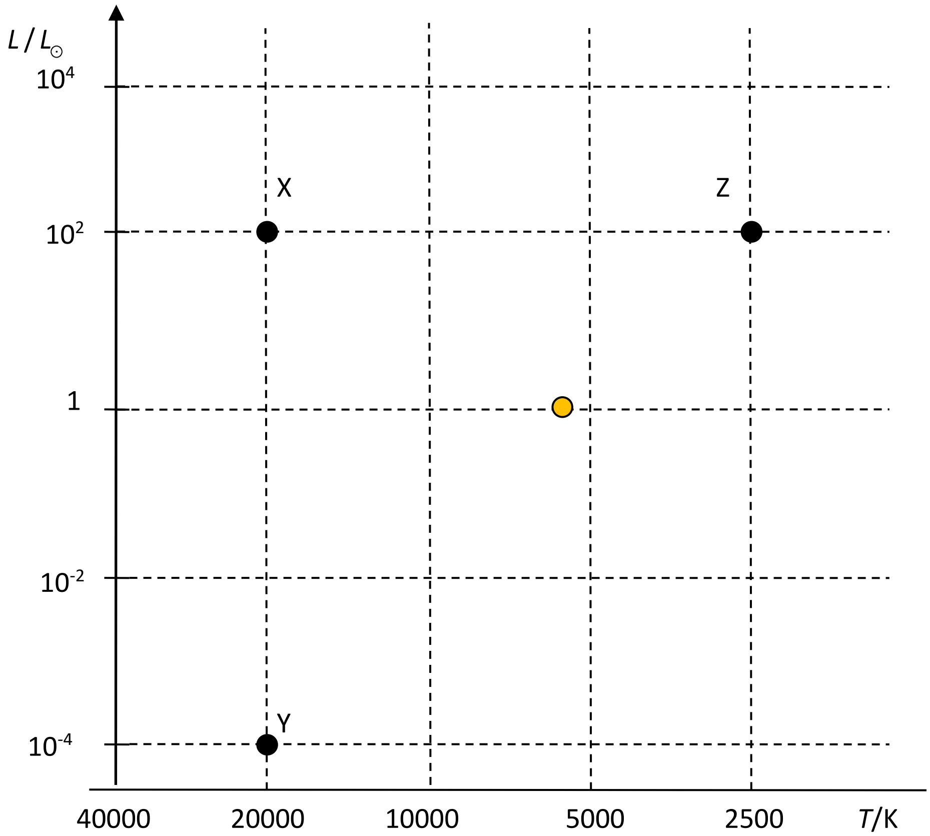
(i) a point to indicate the position of P. [1]

(ii) an arrow to indicate the velocity of P. [1]

K.A. Tsokos

Q5 [7 marks]

The HR diagram shows the Sun and three other stars X, Y and Z.



(a) X is much hotter than Z yet X and Z have the same luminosity. Explain this observation. [2]

(b) Calculate the ratio $\frac{R_Z}{R_Y}$ of the radius of Z to that of Y. [3]

(c) Gravitational pressure tends to make stars contract. X and Y are both stable stars. State how X and of Y manage to oppose their gravitational pressures.

(i) X [1]

....

....

(ii) Y [1]

....

....

K.A. Tsokos

Q6 [5 marks]

Two parallel plates are oppositely charged. The potential difference between the plates is 240 V and their separation is 2.0 cm.

(a) Draw the electric field lines for this arrangement. [2]

(b) Calculate the electric field strength between the plates. [1]

………

………

(c) A proton is placed on the positively charged plate and is then released. The experiment is repeated with the proton replaced by an alpha particle.

Calculate the ratio $\frac{v_p}{v_\alpha}$ of the speed of the proton to that of the alpha particle when the particles reach the negative plate. [2]

………

………

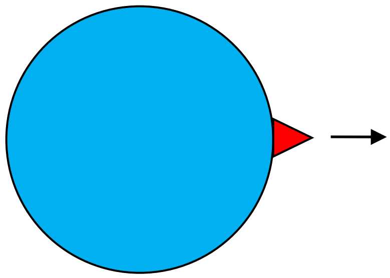
………

………

K.A. Tsokos

Q7 [7 marks]

A probe is launched from the surface of a planet with a speed that is half the escape speed.



(a) Outline what is meant by escape speed. [1]

………

………

(b) Determine in terms of the radius of the planet, *R*, the maximum distance from the center of the planet reached by the probe. [3]

………

………

………

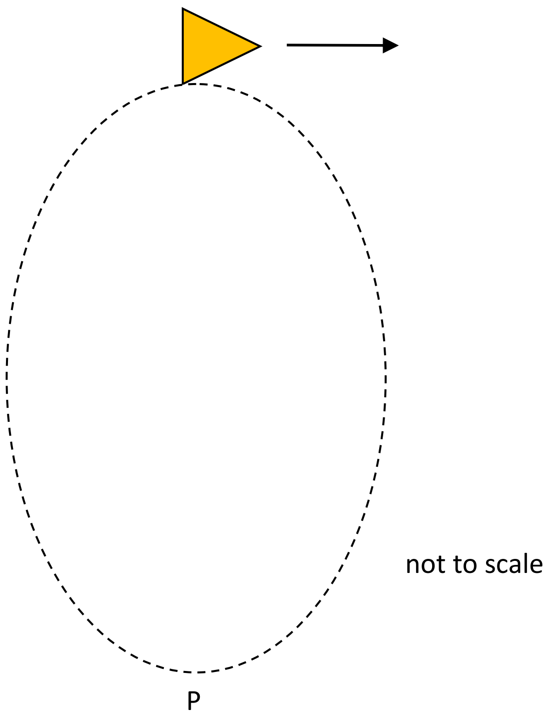
………

………

………

K.A. Tsokos

(c) Another probe is launched from the surface of another planet. The diagram shows the probe at the instant of launch and the elliptical orbit followed by the probe.



(i) On the diagram draw a dot to indicate a possible centre of the planet. [1]

(ii) Discuss how the speed of the probe at position P compares with the launch speed. [2]

....

....

....

....

K.A. Tsokos

Q8 [20 marks]

(a) A container of fixed volume holds 7.0 mol of helium (${}^{4}_{2}He$) at pressure 3.0×10^{5} Pa and temperature 270 K. The volume of a helium atom is about 3×10^{-30} m^3.

Calculate

(i) the total volume of the molecules in the container, [2]

....

....

....

....

(ii) the volume of the container, [2]

....

....

....

....

(iii) the total mass of the helium gas. [1]

....

....

(b) State and explain, by reference to the kinetic model of gases, why it is reasonable to consider helium in this container to behave as an ideal gas. [2]

....

....

....

....

(c) The gas in (a) is heated at constant volume from a pressure of 3.0×10^5 Pa and temperature 270 K to a pressure of 5.0×10^5 Pa. Calculate the new temperature of the gas. [2]

....

....

....

....

(d) Draw a line on the *P*-*V* diagram to represent the change in (c). [1]

(e)

(i) Show that the change in the internal energy of helium is about 16 kJ. [1]

....

....

(ii) Estimate the specific heat capacity of helium. [2]

....

....

....

....

(f) The emission spectrum of helium contains photons of energy 1.86 eV. Show that the wavelength of these photons is 667 nm. [2]

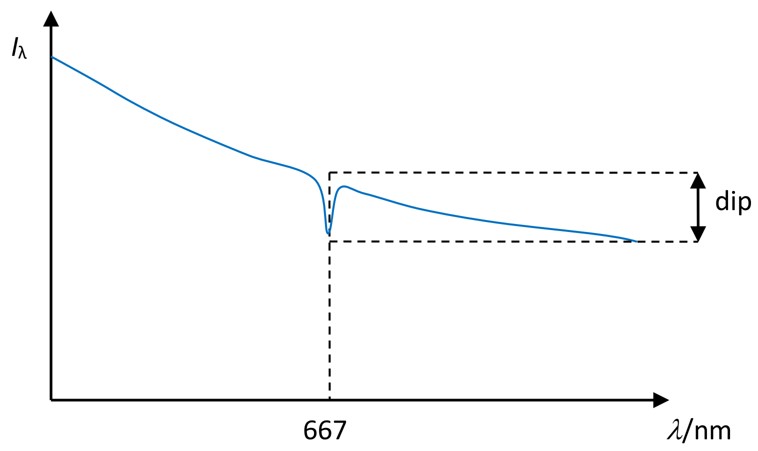
....

....

....

....

(g) The graph shows the variation of the intensity per unit wavelength I_λ of the black body radiation emitted by the Sun for wavelengths near 667 nm.



The curve shows a dip at a wavelength of 667 nm.

(i) Outline what is meant by black body radiation. [2]

....

....

....

....

(ii) Explain why the presence of the dip is evidence that the Sun contains helium. [3]

………

………

………

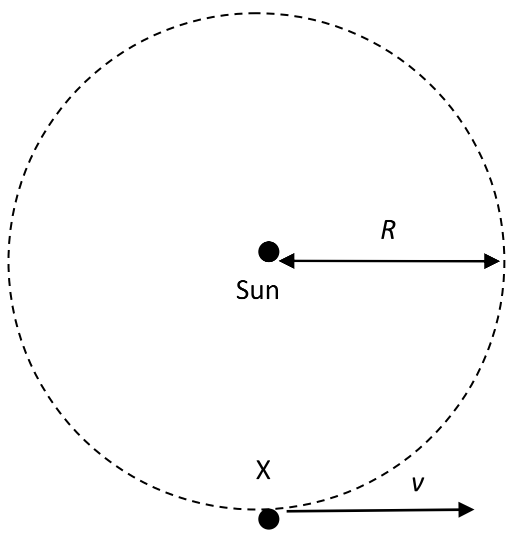
………

………

………

Q9 [20 marks]

The Earth orbits the Sun in a circular orbit of radius $R = 1.5\text{x}10^{11}$ m.



(a) Show that the speed v of the Earth around the Sun is about 30 km s^{-1}. [2]

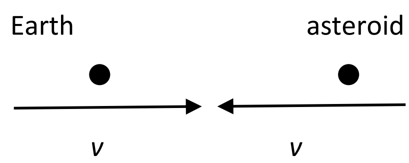
………

………

………

………

(b) An asteroid collides with the Earth in a head on collision when the Earth is at X. The asteroid gets embedded into Earth. The asteroid moves with the same speed as the Earth.



(i) Show that the speed u of the Earth-asteroid system immediately after the collision is given by

$$u = v\frac{M-m}{M+m}$$

where M is the mass of the Earth and m the mass of the asteroid. [1]

....

....

(ii) The asteroid impacts the Earth with a kinetic energy of 2×10^{25} J. Show that the mass of the asteroid is about 10^{16} kg. [2]

....

....

....

....

(c) The mass of Earth is $M = 6.0\times10^{24}$ kg. Assume that the orbit of the Earth stays circular after the collision.

(i) Suggest, with a reason, whether the new orbit radius of Earth will increase or decrease. [2]

....

....

....

....

K.A. Tsokos

(ii) Predict whether the change in (c) (i) is significant. [1]

……

……

(d) Assume that all the kinetic energy of the asteroid in (b) (ii) goes into vaporizing rocks around the impact point. Ignore any thermal energy that will go into the asteroid itself.

The following data are available for rocks at the point of impact:

Temperature of rocks	300 K
Solid rock specific heat capacity	$850 \text{ Jkg}^{-1}\text{K}^{-1}$
Molten rock specific heat capacity	$1450 \text{ Jkg}^{-1}\text{K}^{-1}$
Melting temperature of rocks	1700 K
Specific latent heat of fusion of rocks	$1.6\times10^{5} \text{ Jkg}^{-1}$
Boiling temperature of rocks	2600 K
Specific latent heat of vaporization of rocks	$1.1\times10^{7} \text{ Jkg}^{-1}$

(i) Estimate the mass of rocks that will be vaporized. [3]

……

……

……

……

……

……

(ii) Suggest whether the actual mass of rocks vaporized will be larger or smaller than the estimate in (i). [2]

………

………

………

………

(iii) The density of rock is $2800\,\text{kg}\,\text{m}^{-3}$. Assume, for simplicity, that the shape of the crater formed by the impact of the asteroid is a cube. Estimate, in km, the side of the cube. [2]

………

………

………

………

(e) Tektites are small spheres of rock and glass formed when molten rock solidifies. Argon is produced when potassium ($^{40}_{19}\text{K}$) in the rocks decays after absorbing an electron:

$^{40}_{19}\text{K} + e^{-} \rightarrow {}^{\square}_{\square}\text{Ar} + \nu$.

(i) State the proton and nucleon numbers of argon. [2]

………

………

………

………

K.A. Tsokos

(ii) The half-life of potassium is 1.2×10^{10} yr . Tektites from a crater formed by an asteroid impact contain 0.996 of the potassium contained in tektites formed now. Determine the time of impact. [3]

....

....

....

....

....

....

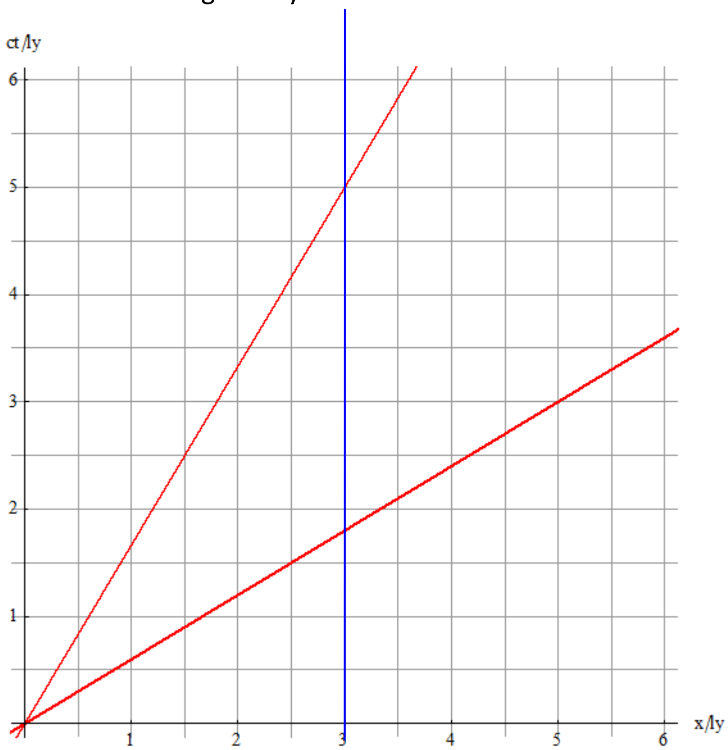
END OF EXAM

K.A. Tsokos

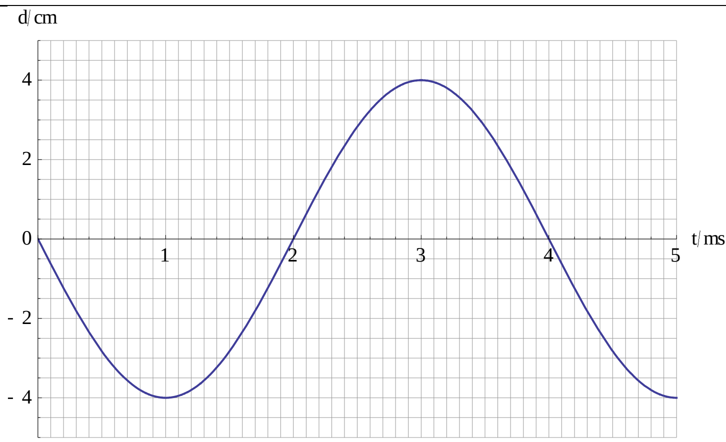
Markscheme

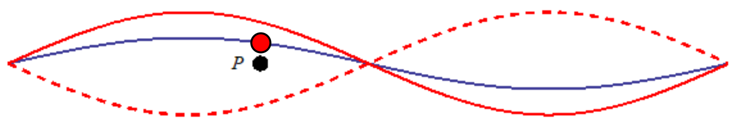
1				
a		$\frac{16}{2.0}=8.0\text{ ms}^{-2}$ ✓		[1]
b		Impulse = area = 32 N s✓ $2\times v-2\times(-4)=32\Rightarrow v=12\text{ ms}^{-1}$ ✓ Change in KE: $\frac{1}{2}\times2\times12^2-\frac{1}{2}\times2\times(-4)^2=128\text{ J}$ ✓ Average power: $\frac{128}{4}=32\text{ W}$ ✓ ***OR*** Impulse = area = 32 N s✓ $2\times v-2\times(-4)=32\Rightarrow v=12\text{ ms}^{-1}$ ✓ $\overline{P}=\overline{F}\frac{u+v}{2}$ ✓ $\overline{P}=8.0\times\frac{-4.0+12}{2}=32\text{ W}$ ✓		[4]

K.A. Tsokos

2				
a		$\frac{3.0}{5.0} = 0.60c$ ✓		[1]
b	i	Vertical line through 3.0 ly✓ 		[1]
b	ii	5.0 years read from graph at intersection point✓ ***OR*** $\frac{3.0\text{ ly}}{0.60c} = 5.0\text{ yr}$ ✓		[1]
b	iii	$\gamma = \frac{5}{4}$ ✓ $\Delta t' = \gamma(\Delta t - \frac{v}{c^2}\Delta x) = \frac{5}{4} \times (5.0 - \frac{0.60c}{c^2} \times 3.0\text{ly}) = 4.0\text{ yr}$ ✓ ***OR*** $\gamma = \frac{5}{4}$ ✓ $\Delta t' = \frac{5.0}{\gamma} = 4.0\text{ yr}$ ✓ ***OR*** $\gamma = \frac{5}{4}$ ✓ $\Delta t' = \frac{\frac{3.0}{1.25}}{0.60c} = \frac{2.4\text{ ly}}{0.60c} = 4.0\text{ yr}$ ✓		[2]

3				
a		A very small percentage of the incident alpha particles were scattered at very large scattering angles✓ 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	${}^{239}_{94}\text{Pu} \rightarrow {}^{235}_{92}\text{U} + {}^{4}_{2}\alpha$ Correct numbers for U✓		[2]
b	ii	$235\times7.5909+4\times7.0739-239\times7.5603$ ✓ 5.25 MeV✓		[2]
b	iii	Binding energy per nucleon is a measure of the stability of a nucleus✓ And uranium is more stable than plutonium✓		[2]
c		Protons tend to break a nucleus apart because the electric force is repulsive✓ Putting extra neutrons means average distance between protons increases and so tendency to split decreases✓ And neutrons contribute to bonding through the strong nuclear force✓		[3]

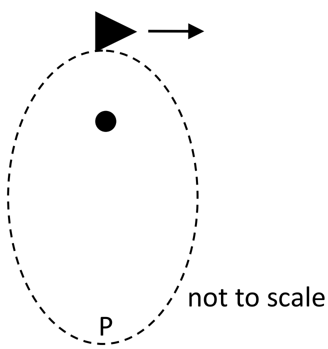
4				
a		In a transverse wave the displacement is at right angles to the direction of energy transfer✓ In a longitudinal wave the displacement is parallel to the direction of energy transfer ✓		[2]
b	i	$\lambda=0.30$ m ✓ $v=f\lambda=250\times0.30=75\text{ms}^{-1}$ ✓		[2]
b	ii	 Correct shape✓ Correct period✓		[2]

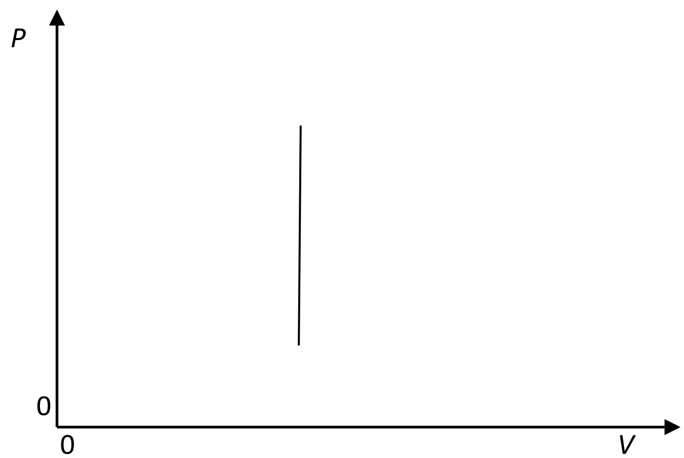
b	iii	$y=-4\sin(500\pi t)$ ✓ $y=4\sin(500\pi t+\pi)$ ✓		[2]
c	i	 ✓		[1]
c	ii	 ✓		[1]

5				
a		Luminosity also depends on area✓ Star Z has a much larger area than X✓		[2]
b	i	$\frac{L_Z}{L_Y}=\frac{4\pi\sigma R_Z^2 T_Z^4}{4\pi\sigma R_Y^2 T_Y^4}=10^6$ ✓ $\frac{R_Z}{R_Y}=\sqrt{10^6\times\frac{20000^4}{2500^4}}$ ✓ $\frac{R_Z}{R_Y}=6.4\times10^4$ ✓		[3]
c	i	X: by radiation pressure caused by fusion reactions✓		[1]
c	ii	Y: by electron degeneracy pressure✓		[1]

6				
a		Uniform lines from left to right in the interior✓ Edge effects✓		[2]
b		$E=\frac{V}{d}=\frac{240}{2.0\times10^{-2}}=1.2\times10^4\ \text{NC}^{-1}$ ✓		[1]
c		$qV=\frac{1}{2}mv^2\Rightarrow v=\sqrt{\frac{2qV}{m}}$ ✓ $\frac{v_p}{v_\alpha}=\sqrt{\frac{q_p m_\alpha}{q_\alpha m_p}}=\sqrt{\frac{1}{2}\times4}=\sqrt{2}$ ✓		[2]

K.A. Tsokos

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

8				
a	i	$N = 7.0\times 6.02\times 10^{23} = 4.2\times 10^{24}$ ✓ $4.2\times 10^{24}\times 3.0\times 10^{-30} = 1.3\times 10^{-5}\ \text{m}^3$ ✓		[2]
a	ii	$V = \frac{RnT}{P}$ ✓ $V = \frac{8.31\times 7.0\times 270}{3.0\times 10^{5}} = 5.2\times 10^{-2}\ \text{m}^3$ ✓		[2]
a	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 ✓ 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		$\frac{P_1}{T_1} = \frac{P_2}{T_2} \Rightarrow T_2 = T_1\times \frac{P_2}{P_1}$ ✓ $T_2 = 270\times \frac{5.0}{3.0} = 450$ K ✓		[2]
d		 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]
e	ii	Realization that $Q = \Delta U$ ✓ $c = \frac{Q}{m\Delta T} = \frac{15705}{0.028\times (450-270)} = 3.1\times 10^{3}\ \text{J kg}^{-1}\ \text{K}^{-1}$ ✓		[2]
f		$E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E}$ ✓ $\lambda = \frac{1.24\times 10^{-6}}{1.86} = 666.6 \approx 667$ nm ✓		[2]
g	i	[2] max from Electromagnetic radiation with an infinite rage of wavelengths✓		[2] max

		With a peak determined by temperature ✓ Radiation emitted by a body at some finite kelvin temperature ✓ Radiation with an intensity proportional to the 4th power of the kelvin temperature✓		
g	ii	Helium has energy levels separated by 1.86 eV✓ This energy difference is unique to helium✓ The dip implies that photons of this energy are absorbed «by electrons in helium atoms in the outer layers of the Sun which then make a transition between the 2 levels» ✓		[3]

9				
a		$v=\frac{2\pi R}{T}=\frac{2\pi\times 1.5\times 10^{11}}{365\times 24\times 60\times 60}$ ✓ $v=2.99\times 10^{4}\approx 3.0\times 10^{4}\ \text{ms}^{-1}=30\ \text{kms}^{-1}$ ✓		[2]
b	i	$Mv-mv=(M+m)u$ ✓ Result follows		[1]
b	ii	$m=\frac{2\times 2\times 10^{25}}{(2.99\times 10^{4})^{2}}$ ✓ $m=4.47\times 10^{16}\ \text{kg}$ ✓		[2]
c	i	$R=\frac{GM_{\odot}}{u^{2}}$ ✓ $u < v$ so R increases✓		[2]
c	ii	The mass of the asteroid is much smaller than that of earth so change in R is not significant✓ (For the aficionados! $u^{2}=\frac{GM_{\odot}}{R'}\Rightarrow R'=\frac{GM_{\odot}}{\left(\frac{M-m}{M+m}v\right)^{2}}=\frac{GM_{\odot}(M+m)^{2}}{v^{2}(M-m)^{2}}=\frac{GM_{\odot}}{v^{2}}\frac{M^{2}(1+\frac{m}{M})^{2}}{M^{2}(1-\frac{m}{M})^{2}}$ $R'=\frac{GM_{\odot}}{v^{2}}\times\frac{(1+\frac{m}{M})^{2}}{(1-\frac{m}{M})^{2}}=R\frac{(1+\frac{m}{M})^{2}}{(1-\frac{m}{M})^{2}}$ From Math HL we know that $\frac{(1+\frac{m}{M})^{2}}{(1-\frac{m}{M})^{2}}\approx(1+\frac{2m}{M})(1+\frac{2m}{M})\approx 1+\frac{4m}{M}$ Hence the change in orbit radius is an increase of $\Delta R\approx R\times\frac{4m}{M}\approx 1.5\times 10^{11}\times 4\times\frac{5\times 10^{16}}{6\times 10^{24}}\approx 5\ \text{km}$ and so insignificant.)		[1]
d	i	Thermal energy needed		[3]

		$M\times 850\times(1700-300)+M\times 1.6\times 10^{5}+M\times 1450\times(2600-1700)+M\times 1.1\times 10^{7}$ ✓ $=M\times 1.3655\times 10^{7}$ ✓ $M=\dfrac{2\times 10^{25}}{1.3655\times 10^{7}}=1.46\times 10^{18}\approx 1.5\times 10^{18}$ kg ✓		
d	ii	Smaller✓ Some of the kinetic energy will go as thermal energy in the asteroid and the surrounding air✓		[2]
d	iii	Volume of rocks vaporized is $\dfrac{1.46\times 10^{18}}{2800}=5.21\times 10^{14}$ m^3 ✓ Side of cube $(5.21\times 10^{14})^{1/3}=8\times 10^{4}$ m ≈ 80 km ✓		[2]
e	i	Z = 18 ✓ A = 40✓		[2]
e	ii	Decay constant is $\dfrac{\ln 2}{1.2\times 10^{10}}=5.78\times 10^{-11}$ yr^{-1} ✓ $0.996=e^{-5.78\times 10^{-11}\times t}$ ✓ $t=6.9\times 10^{7}$ yr ≈ 69 million years ✓		[3]