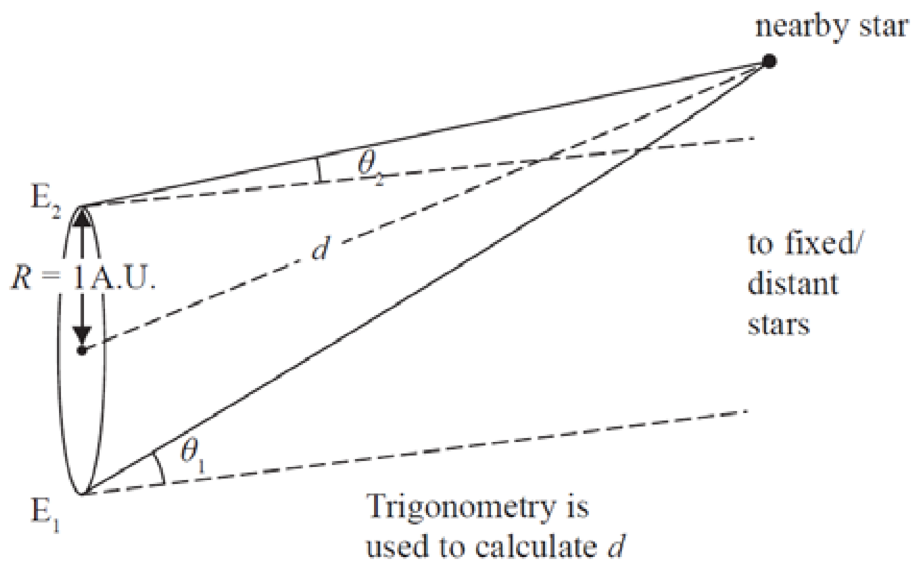
Unit 5: Thermodynamics, Radiation, Oscillations and Cosmology - Mark scheme

Question number	Answer	Mark
1	B	1
2	D	1
3	B	1
4	C	1
5	D	1
6	C	1
7	D	1
8	A	1
9	D	1
10	B	1

Question number	Answer		Mark
11	• The star is viewed from two positions at 6-month intervals **Or** The star is viewed from opposite ends of the Earth's orbit diameter about the Sun • The change in angular position of the star against backdrop of fixed stars is measured • Trigonometry is used to calculate the distance (to the star) [Do not accept Pythagoras] **Or** The diameter/radius of the Earth's orbit about the Sun must be known **Or** The distance to the Sun is 1AU Full marks may be obtained from a suitably annotated diagram, e.g.  [Accept the symmetrical diagram seen in many textbooks]	(1) (1) (1)	3
	Total for Question 11		3

Question number	Answer		Mark
12(a)	• Use of $\Delta E = mc\Delta\theta$ • Use of $P = \frac{\Delta W}{\Delta t}$ • Time taken = 130 s <u>Example of calculation</u> ΔE = 3 × 0.325 kg × 4190 J kg^{-1} K^{-1} × (100 − 8.5)K=373 800 J $\Delta t = \dfrac{373\ 800\ \text{J}}{2.80 \times 10^{3}\ \text{W}} = 134\ \text{s}$	(1) (1) (1)	**3**
12(b)	• Use of $\Delta E = L\Delta m$ • Difference between power input and useful power calculated • Rate of thermal energy transfer to surroundings = 340 W <u>Example of calculation</u> $\dfrac{\Delta E}{\Delta t} = 2.26 \times 10^{6}\ \text{J kg}^{-1} \times \dfrac{0.136\ \text{kg}}{125\ \text{s}} = 2460\ \text{W}$ Rate of thermal energy transfer to surroundings = 2800 W – 2460 W = 340 W	(1) (1) (1)	**3**
	Total for Question 12		**6**

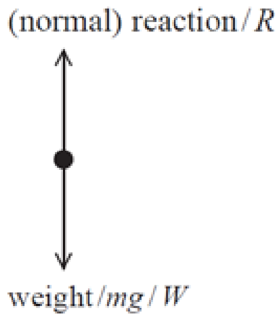
Question number	Answer		Mark
13(a)	• α correct (1) • Th correct (1) $^{238}_{92}\text{U} \rightarrow \ ^{234}_{90}\text{Th} + \ ^{4}_{2}\alpha$	(1) (1)	**2**
13(b)(i)	• Use of $A = -\lambda N$ • Use of $\lambda = \frac{ln2}{t_{1/2}}$ • N = 7.47 × 10^{18} <u>Example of calculation</u> $\lambda = \dfrac{\ln 2}{1.41 \times 10^{17}\ \text{s}} = 4.91 \times 10^{-18}\ \text{s}^{-1}$ $36.7\ \text{s}^{-1} = -4.91 \times 10^{-18}\ \text{s}^{-1} \times N$ $\therefore N = \dfrac{36.7\ \text{s}^{-1}}{4.91 \times 10^{-18}\ \text{s}^{-1}} = 7.47 \times 10^{18}$	(1) (1) (1)	**3**

Question number	Answer	Mark
13(b)(ii)	• The decay products are radioactive **Or** the background radiation should be subtracted from the recorded count rate (1)	1
	Total for Question 13	6

Question number	Answer	Mark
14(a)	• Use of $pV = NkT$ (1) • Conversion of temperature from ºC to K (1) • $N = 3.82 \times 10^{23}$ (1) <u>Example of calculation</u> $N = \dfrac{1.10 \times 10^5 \text{Pa} \times 0.0142 \text{ m}^3}{1.38 \times 10^{-23} \text{J K}^{-1} \times (23.5+273)\text{K}} = 3.82 \times 10^{23}$	3
14(b)	If the temperature of the helium gas is increased then • The pressure exerted by the helium inside the balloon increases (1) • (so the volume of the balloon will increase) until the pressure exerted by the helium equals the external air pressure (1)	2
	Total for Question 14	5

Question number	Answer	Mark
15(a)	**The binding energy is:** • The energy released when the nucleons come together to form the nucleus **Or** The energy required to split the nucleus up into its component nucleons (1)	1
15(b)(i)	• Calculation of mass difference in kg (1) • Use of $\Delta E = c^2 \Delta m$ (1) • Conversion from kg into MeV (1) • ΔE = 8.5 MeV (1) <u>Example of calculation</u> $\Delta m = (1.00728 + [2 \times 1.00867] - 3.01551)\text{u} \times 1.66 \times 10^{-27}\text{kg}$ $\therefore \Delta m = 1.51 \times 10^{-29}$ kg $\Delta E = (3 \times 10^{8}\text{m s}^{-1})^{2} \times 1.51 \times 10^{-29}\text{kg} = 1.36 \times 10^{-12}\text{J}$ $\Delta E = \frac{1.36 \times 10^{-12}\text{J}}{1.6 \times 10^{-13}\text{J MeV}^{-1}} = 8.49$ MeV	4
15(b)(ii)	• When massive nuclei undergo fusion the binding energy per nucleon decreases (1) • Hence energy must be supplied in order for fusion to proceed (1)	2
	Total for Question 15	7

Question number	Answer	Mark
16(a)	• Use of $L = 4\pi r^2 \sigma T^4$ (1) • r = 6.9×10^8 m (1) <u>Example of calculation</u> $r = \sqrt{\frac{3.85 \times 10^{26}\text{W}}{4\pi \times 5.67 \times 10^{-8}\text{W m}^{-2}\text{ K}^{-4} \times (5800)^4}} = 6.91 \times 10^{8}\text{m}$	2
16(b)	• Use of $I = \frac{L}{4\pi d^2}$ (1) • Use of fraction dissipated (1) • Use of efficiency= $\frac{\text{useful power out}}{\text{total power input}}$ (1) • Use of $I = \frac{P}{A}$ (1) • P = 56 MW (1) <u>Example of calculation</u> $I = \frac{3.85 \times 10^{26}\text{W}}{4\pi \times (1.50 \times 10^{11}\text{m})^2} = 1360\text{ W m}^{-2}$ $P = 1360\text{ W m}^{-2} \times (1-0.25) \times 0.22 \times 250\,000\text{ m}^2 = 5.61 \times 10^7\text{ W}$	5
	Total for Question 16	7

Question number	Answer		Mark
17(a)	Resonance	(1)	**1**
17(b)	• Use of $f = \frac{n}{t}$ • Use of $\omega = 2\pi f$ • Use of $a = -\omega^2 x$ • a = 14 m s^{-2} <u>Example of calculation</u> $f = \frac{38}{60\text{ s}} = 0.633\text{ s}^{-1}$ $\omega = 2\pi \times 0.633\text{ s}^{-1} = 3.98\text{ rad s}^{-1}$ $a = -\left(3.98\text{ rad s}^{-1}\right)^2 \times 0.90\text{ m} = 14.3\text{ m s}^{-2}$	(1) (1) (1) (1)	**4**
17(c)(i)	• Both forces drawn and labelled <u>Example of diagram</u> 	(1)	**1**
17(c)(ii)	• There must always be an acceleration towards the equilibrium position **Or** there must always be a resultant force towards the equilibrium position • (Applying Newton's 2^{nd} law) W – R = ma so R = W – ma • If $a \geq g$, then $R = 0$ and so car will lose contact with the road	(1) (1) (1)	**3**
	Total for Question 17		**9**

<table>
<tr><th>Question number</th><th>Answer</th><th>Mark</th></tr>
<tr><td>18(a)</td><td>

The fan in the toy pushes the air molecules downwards (1)
According to Newton’s 3rd law, toy is pushed upwards by the air molecules (1)
The upward force balances the weight of the toy (1)

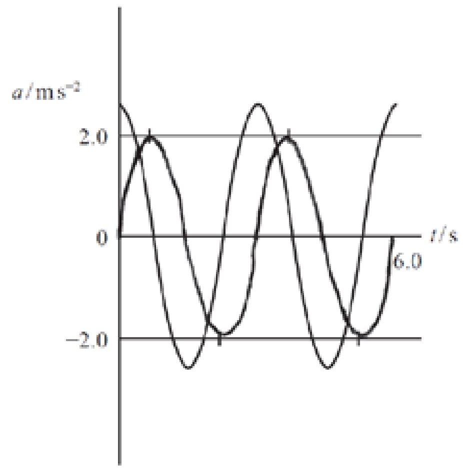
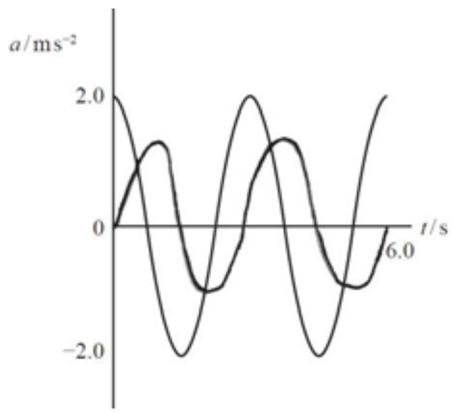
</td><td>3</td></tr>
<tr><td>18(b)</td><td>
This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.
<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5–4</td><td>3</td></tr>
<tr><td>3–2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
The following table shows how the marks should be awarded for structure and lines of reasoning.
<table>
<tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr>
<tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr>
</table>
Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning

Indicative content

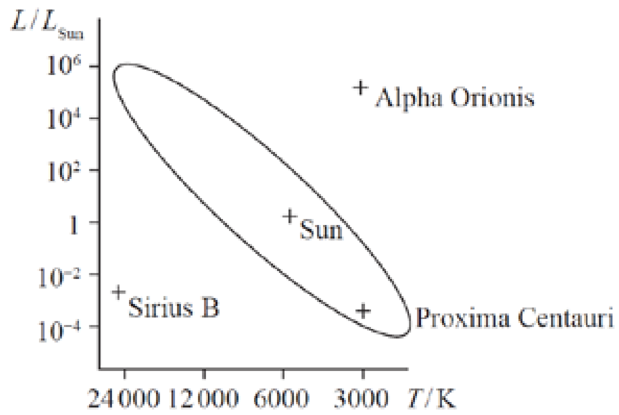
applying Newton’s 3rd law, toy A exerts a force on toy B and vice versa
forces equal in magnitude and opposite in direction
forces act for same time
$F\Delta t_A = - F\Delta t_B$
applying Newton’s 2nd law $F\Delta t = \Delta p$
total momentum change = 0, so momentum conserved
Or Δp for one toy = $-\Delta p$ for the other toy, so momentum is conserved

</td><td>6</td></tr>
<tr><td></td><td>Total for Question 18</td><td>9</td></tr>
</table>

Question number	Answer	Mark
19(a)	For simple harmonic motion the acceleration of the tyre is: • directly proportional to displacement from equilibrium position (1) • always acting towards the equilibrium position **Or** idea that acceleration is in the opposite direction to displacement (1) [Accept definition in terms of force]	2
19(b)(i)	• Use of $\omega = \frac{2\pi}{T}$ with T = 3 s (1) • Use of $a = -\omega^2 x$ (1) • A = 0.46 m (1) <u>Example of calculation</u> $\omega = \frac{2\pi}{6.0 \text{ s}/2} = 2.09 \text{ rad s}^{-1}$ $A = \frac{2 \text{ m s}^{-2}}{(2.09 \text{ rad s}^{-1})^2} = 0.456 \text{ m}$	3
19(b)(ii)	• Use of $v = A\omega \sin \omega t$ (1) • $v = 0.95 \text{ m s}^{-1}$ (allow e.c.f. ω and A from b(i)) (1) <u>Example of calculation</u> $v = 0.456 \text{ m} \times 2.09 \text{ rad s}^{-1} = 0.953 \text{ m s}^{-1}$	2

Question number	Answer	Mark
19(b)(iii)	• Sine curve drawn with correct shape and time period of 3 s (1) • Constant amplitude [any size] (MP2 dependent upon MP1) (1) Examples of graphs:  This graph has been carefully sketched, with construction lines and positions of maxima and minima marked before making the freehand graph sketch.  This graph has been sketched without the aid of construction lines. Positions of maxima and minima have not been marked. The maxima are slightly displaced from their correct positions, although the shape is generally good and the amplitude is constant.	**2**
	Total for Question 19	**9**

Question number	Answer	Mark
20(a)(i)	• States $F = \frac{GMm}{r^2}$ (1) • $mg = \frac{GMm}{r^2}$ leading to $g = \frac{GM}{r^2}$ (1)	**2**
20(a)(ii)	• $g = \frac{GM}{r^2}$ combined with $a = r\omega^2$ **Or** $F = \frac{GMm}{r^2}$ combined with $F = mr\omega^2$ (1) (accept equations in terms of *v* or *ω*) • Use of $\omega = \frac{2\pi}{T}$ **Or** $v = \frac{2\pi r}{T}$ (1) • Maths to show $T^2 = \frac{4\pi^2 r^3}{GM}$ (1) • π, *G* and *M* identified as being constant, so $T^2 \propto r^3$ (1) <u>Example of derivation</u> $\frac{GM}{r^2} = r\omega^2 = r\left(\frac{2\pi}{T}\right)^2$ $\therefore \frac{GM}{r^2} = \frac{4\pi^2 r}{T^2}$ $\therefore T^2 = \frac{4\pi^2 r^3}{GM}$ $\therefore T^2 \propto r^3$	**4**
20(b)(i)	• $T = 24$ hours for a geostationary orbit (1) • Use of $T^2 \propto r^3$ (1) • $h = 3.5 \times 10^7$ m (1) <u>Example of calculation</u> $\frac{T_1^2}{T_2^2} = \frac{r_1^3}{r_2^3}$ $\therefore r_2 = \sqrt[3]{\frac{(24 \times 60\ \text{min})^2}{(88\ \text{min})^2}} \times 6.4 \times 10^6\text{m} = 4.13 \times 10^7\text{m}$ $\therefore h = 4.13 \times 10^7\text{m} - 6.4 \times 10^6\text{m} = 3.49 \times 10^7\text{m}$	**3**
20(b)(ii)	• Idea that there must be a common axis of rotation for the satellite and the Earth **Or** the plane of the satellite's orbit must be at right angles to the spin axis of the Earth (1)	**1**
	Total for Question 20	**10**

Question number	Answer		Mark
21(a)(i)	• A main sequence star is fusing/burning hydrogen in its core	(1)	**1**
21(a)(i)	• Diagonal region from top left to bottom right to include the Sun and Proxima Centauri <u>Example of diagram</u> 	(1)	**1**
21(b)(i)	• Alpha Orionis and Proxima Centauri both have a surface temperature of about 3000 K • So according to Wien's law ($\lambda_{max}T = 2.9 \times 10^{-3}$) both will emit em-radiation that peaks in the same region of the spectrum • Alpha Orionis has a much greater luminosity than Proxima Centauri • According to Stefan's law ($L = 4\pi r^2 \sigma T^4$) so Alpha Orionis must have a much larger radius than Proxima Centauri hence the statement is not valid	(1) (1) (1) (1)	**4**
21(b)(ii)	• Sirius B is off the main sequence, has a much higher surface temperature but about the same luminosity as Proxima Centauri • So hydrogen fusion has ceased in the core of Sirius B whereas it hasn't for Proxima Centauri • Since Sirius B is much hotter but about the same luminosity this means it must have a much smaller radius than Proxima Centauri	(1) (1) (1)	**3**
	Total for Question 21		**9**