Question	Type 1 (explanatory) or Type 2 (problem)	B Evidence	A Evidence
1(i)	2	Place the origin at M_1. Then take moments about M_1; this gives $(M_1 + M_2)r = M_2D$	
1(ii)	2		

Question	Typical evidence that will be awarded one mark (if applicable)	Typical evidence that will be awarded two marks	
2(a)		$\frac{\pi}{T^2} = \frac{G\rho}{3}$ $T = \sqrt{\frac{3\pi}{G\rho}}$ Sufficient steps must be shown to award 2 marks.	2
2(b)		This is significantly less than 24 hours so the Earth is not close to disintegration.	2

Question	Typical evidence that will be awarded one mark (if applicable)	Typical evidence that will be awarded two marks	
2(c)	ONE reason provided.	BOTH reasons provided. One reason involves the difference in the distance from the centre of the Earth between the two positions due to the equatorial bulge – this leads to a variation in the gravitational field strength. The equator is further away from the centre of the Earth than the poles leading to a difference of about 0.05 m s^{-2}. The second reason is due to the rotation of the Earth. The person on the equator experiences a centripetal acceleration. Given that the scales read the normal (or reaction) force N, in this case $N = m(g–a_c)$. Therefore there is a slight reduction (of the order of the first effect).	2

Question	Evidence	1-4 marks	5-6 marks	7-8 marks
3(a)(i)	The centre of mass will continue in the same direction regardless of the explosion. There is no external force applied to alter the motion of the centre of mass.	Shows some understanding of at least one of the following aspects of the physics of the situation outlined – for example centre of mass, momentum, acceleration, energy considerations.	Shows clear understanding of some relevant aspects of the physics of the situation outlined—for example centre of mass, momentum, acceleration, energy considerations.	Shows insight in relation to all relevant aspects of the physics of the situation outlined.
(ii)	Assume a spherical asteroid. Take $r = 0.725 \times 10^6$ m (half the "diameter" of Texas).Mass of the asteroid = $4/3\ \pi\ r^3\ \rho$ $= 4.8 \times 10^{21}$ kg Mass of each half $= 2.4 \times 10^{21}$ kg Assume all of the bomb energy is converted into KE of the lumps in the y direction – velocity (v) in the y direction given by $\frac{1}{2}mv^2 = E$ (assume half the E_k goes to each lump) $0.5 \times 2.4 \times 10^{21}\ v^2 = 2.5 \times 10^{18}$ $v = 0.046$ m s^{-1} In 4 hours, 4 × 3600 s, the y distance moving by each half will be 657 m (700 m) The distance needed to be moved is much larger than this so we are doomed!			
(iii)	Assume that both halves are spherical The radius of each spherical lump is given by $r^3 = \frac{3M}{4\partial\rho}$ $= \frac{3\times2.4\times10^{21}}{4\partial\times3000}$ $r = 0.58\times10^6$ m Force of gravitational attraction between the two lumps $F = \frac{GmM}{r^2}$ $F = \frac{6.67\times10^{-11}\times2.4\times10^{21}\times2.4\times10^{21}}{1.33\times10^{12}}$ $F = 2.9\times10^{20}$ This force will cause the two lumps to accelerate towards each other $a = \frac{F}{m}$ $a = \frac{2.9\times10^{20}}{2.4\times10^{21}}$ $a = 0.12\,\text{ms}^{-2}$ This is 12 cm s^{-2}. The maximum speed of separation from the blast is only 4.6 cm s^{-1}. In other words the self gravitation would almost immediately overwhelm the force from the blast and bring the asteroid back together. The asteroid might "heave" but it would not split apart.			

Question	Evidence	1-4 marks	5-6 marks	7-8 marks
4 (a)	Surrounded on all sides by equal quantities of mass all the gravitational forces will balance and sum to zero.	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems. AND/OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems. AND/OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics.
(b)	$mg = \frac{GMm}{r^2}$ $M = \rho V = \rho \frac{4}{3}\pi r^3$ $g = G\rho \frac{4}{3}\pi r$			
(c)	The gravitational attraction from a point mass decreases according to $1/r^2$, where r is the distance from the point mass. The Earth can be regarded as a point mass, with all of its mass in the centre.			
(d)	The Earth has not got uniform density. The outer layers of low density material do not produce the expected fall off in field strength as we descend because we are simultaneously approaching the core region of much higher density. The two effects cancel out, producing a region of uniform field strength. The core region is of uniform density.			

Question number	Acceptable answers	Additional guidance	Mark
5(a)	A description that makes reference to the following points: • g is directly proportional to r up to R_0 **(1)** • and then g decreases with increasing r **(1)** • where g is proportional to the inverse of the square of r **(1)**		**3**
(b)	• Force on object = mg (local g) **(1)** • Force is proportional to displacement **(1)** • Force acts in the opposite direction to the displacement **(1)** • Therefore we can say $F = -kx$, so the condition for SHM is met and the prediction is correct **(1)**		**4**
(c)(i)	**Either** • When $x = R_0$, $F = GMm/R_0^2$ **(1)** • $F = GMmR_0/R_0^3$ so $k = m\omega^2 = GMm/R_0^3$ **(1)** • Use of $T=2\pi/\omega$ **(1)** • $T^2 = 4\pi^2/\omega^2 = 4\pi^2 R_0^3/GM$ So $T = 2\pi\sqrt{(R_o^3/GM)}$ **(1)** **OR** • From graph $F=-(g/R_o)r$ **(1)** • From which $\omega = \sqrt{(g/R_0)}$ **(1)** • Use of $T=2\pi/\omega$ **(1)** • So $T = 2\pi\sqrt{(R_o/g)}$ **(1)**		**4**

Question number	Acceptable answers	Additional guidance	Mark
(c)(ii)	**Either** Centripetal force = $mv^2/R_0 = GMm/R_0^2$ **(1)** • $4\pi^2 R_0^2/ T^2R_0 = GM/R_0^2$ **(1)** • $T^2 = 4\pi^2/\omega^2 = 4\pi^2 R_0^3/GM$ So $T = 2\pi\sqrt{(R_o^3 /GM)}$ **(1)** **OR** • $mg = mv^2/R_0 = m\,\omega^2R_0$ **(1)** • So $\omega = \sqrt{(g/R_0)}$ **(1)** • $T = 2\pi/\omega = 2\pi\sqrt{(R_0/g)}$ **(1)**		**3**

(Total for Question 5 = 14 marks)

Qno.6

Various approaches:

(a) $g \; \alpha \; \frac{1}{r^2}$ therefore $g\,r^2 = \text{constant}$ ✓

$6{,}400^2 \times 9.81 = 6{,}700^2 \times g'$ mark for use of 6,700 value ✓

$g' = \left(\frac{6{,}400}{6{,}700}\right)^2 \times 9.81$ mark for $\left(\frac{6{,}400}{6{,}700}\right)^2$ term ✓

$= 8.95 \text{ m s}^{-2}$

Reduced by 8.8 % full marks for correct answer

[3]

(b) $g' = \left(\frac{6{,}400}{406{,}400}\right)^2 \times 9.81$ 400,000 acceptable ✓

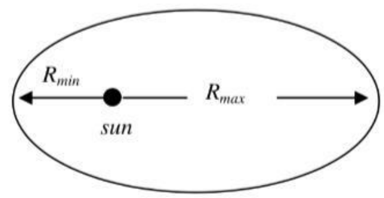
$= (2.4 - 2.5) \times 10^{-3} \text{ m s}^{-2} = 2.4 - 2.5 \text{ mm s}^{-2}$ ✓

[2]

[Q2: 5 marks]

Qno.7

(a)



✓

(b) $T^2 = \mathrm{k}\, R^3$ ✓

$$R = \frac{(R_{\min} + R_{\max})}{2}$$ ✓

(c) $1^2 = \mathrm{k}\ 1^3$

$\mathrm{k} = 1\ \mathrm{year}^2\ \mathrm{AU}^{-3}$ ✓

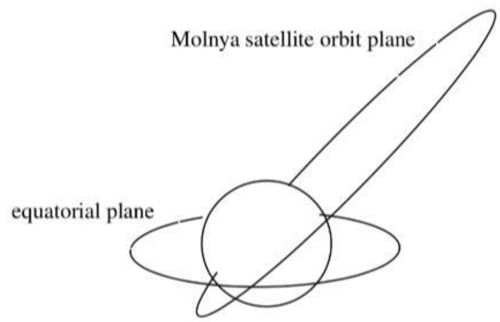
(d) $75.3^2 = 1 \times R^3$ giving $R = 17.8$ AU ✓

(e) $17.8 = \frac{1}{2}(0.585 + R_{\max})$

$R_{\max} = 35.1$ AU ✓

(f) The speed is slower at the distant point ✓
Total mechanical energy is constant ✓
Increase of gravitational pe accompanied by loss of ke. ✓

(g) The satellite is in a highly elliptical orbit ✓
(with the centre of the earth at one focus) not centred on the earth ✓
plane of the ellipse tilted at a large angle ✓
with respect to the plane of the equator.



(h) At the furthest point of the orbit, when the satellite is moving slowest / spends more time (✓), the region below the satellite is Russia or the USA

[Q5: 13 marks]

Qno.8

Field increases as $1/r^2$. So calculation is

$$\frac{B_1}{B_2} = \frac{R_2^2}{R_1^2}$$

$$\frac{10^{-2}}{B_2} = \frac{(10)^2}{(1.4\times10^6)^2}$$

$$B_2 = 10^{-2}\times10^{-2}\times1.96\times10^{12}$$

$$B_2 = 2.0\times10^8\,\text{T}$$

Right idea ✓, numbers substituted ✓✓, answer ✓

(4 marks)

Qno.9

a) R α $V^{1/3}$ so that the ratio $\frac{R_{final}}{R_{initial}} = \sqrt[3]{\frac{1}{10^{15}}} = \frac{1}{10^5}$ (3)

b) $\Omega_{initial} R^2_{initial} = \Omega_{final} R^2_{final}$

and $\Omega_{final} = 3.6\text{x}10^4$ radians/second

and T=0.17 ms (3)

c) R^2 decreases by a factor 10^{10}

and so B increases by 10^{10} to a final field strength of 10^8 T (2)

d) Assume that the star remains spherical so that R describes its radius. Equate gravitational field strength with the centripetal acceleration at the equator.

$$\frac{v^2_{max}}{R} = \frac{GM}{R^2} \quad with \ v_{max} = \frac{2\pi r}{T_{min}} \Rightarrow T_{min} = \frac{2\pi}{\sqrt{G}} \frac{R^{\frac{3}{2}}}{M^{\frac{1}{2}}}$$

which evaluates to give T_{min}=0.46 seconds (much longer period than the answer to part (b)) (4)

e) The initial BE is that for the two stars summed together. The factor relating the initial and final stars is the mass; the masses add whereas the radii do not.

$$BE_{initial} = k_1 \frac{GM^2_{initial}}{R_{initial}} \times 2 \quad with \ R_{initial} M^{\frac{1}{3}}_{initial} = k_2$$

giving

$$BE_{initial} = k_1 \frac{GM^{2+\frac{1}{3}}_{initial}}{k_2} \times 2$$

after collision

$$BE_{final} = k_1 \frac{GM^{2+\frac{1}{3}}_{final}}{k_2}$$

with $M_{final} = 2 \times M_{initial}$

hence

$$\frac{BE_{final}}{BE_{initial}} = \frac{M^{\frac{7}{3}}_{final}}{2M^{\frac{7}{3}}_{initial}}$$

$$= \frac{1}{2} \times 2^{\frac{7}{3}} = 2.52$$ (4)

Qno.10

a)

$$f = {}^{c}/_{\lambda}$$
$$f = 5.46 \times 10^{14}\ \text{Hz}$$ ✓

$$E_{\text{ph}} = h\,{}^{c}/_{\lambda} = hf$$
$$E_{\text{ph}} = 3.6 \times 10^{-19}\ \text{J}$$ ✓

Given that $n_{\text{E}} = 3.6 \times 10^{21}\ \text{m}^{-2}\ \text{s}^{-1}$

Inverse square law result: $\frac{n_{\text{J}}}{N_{\text{E}}} = \frac{R_{\text{E}}^2}{R_{\text{J}}^2} = \frac{150^2}{780^2}$ so that $n_{\text{J}} = \frac{n_E}{5.2^2}$ ✓

$$n_{\text{J}} = 1.3 \times 10^{20}\ \text{m}^{-2}\ \text{s}^{-1}$$ ✓

(Not needed, but $n_{\text{J}}E_{ph} = 48\ \text{W m}^{-2}$ and $n_{\text{E}}E_{ph} = 1300\ \text{W m}^{-2}$)

At Jupiter the force on the satellite is $F_{av} \times A$ which is $m_{sat} \times a$ ✓
(the question assumes that the gravitational force on the satellite is negligible for this mass)

Thus

$$m_{sat} \times a = F_{av} \times A = \frac{2n_{\text{J}}E_{ph}A}{c}$$ ✓

rearranging

$$A = \frac{m_{sat}ac}{2n_{\text{J}}E_{ph}}$$

$$A = 0.56 \times 10^6\ \text{m}^2$$ ✓
$$(A = 750 \times 750\ \text{m}^2)$$

(There may be some small rounding errors in the values in the calculation. These are not critical)

Individual intermediate values may not be calculated, but if the subsequent value is obtained then credit should be given.

[7]

b) The gravitational force of attraction of the Sun increases with the mass of the satellite. ✓

(The light pressure on the sail does not depend on the mass of the satellite.)

Or: with five times the mass, the gravitational pull will be similar in strength to the light pressure.

Closer to the Sun, the light pressure increases (as $1/r^2$), but so does the pull of gravity. (owtte) ✓

[2]

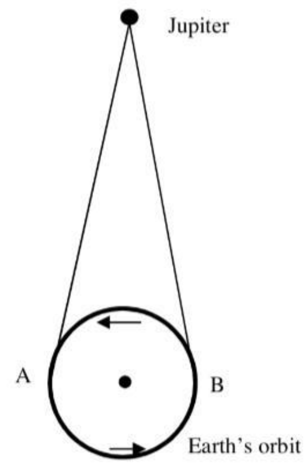
Total 9

Qno.11

Question 11.

a) Clear labelled diagram ✓
The variations from the mean are greatest at points A and B. (as the Earth is moving away from and towards Jupiter).
The two points must be labeled not inferred ✓

[2]



b) The speed of the Earth, $v = 29\,900\ \text{m s}^{-1}$ ✓

In 42 hours 28 min 42 s the Earth has travelled 4.57×10^9 m ✓

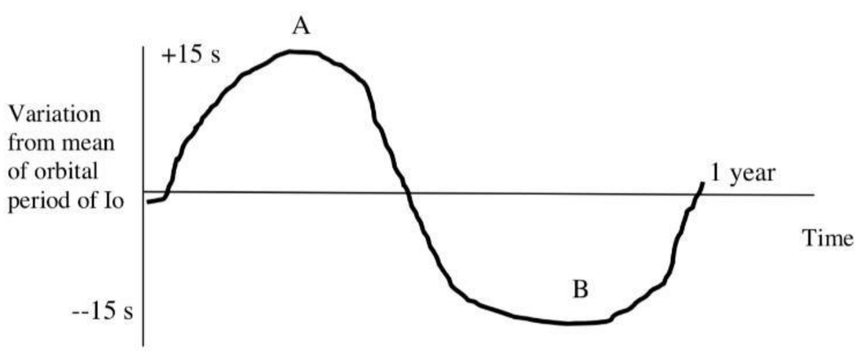
So the light has to travel this distance extra, taking 15 seconds, giving

$$c = \frac{4.57 \times 10^9}{15} = 3.0 \times 10^8\ \text{s}$$

✓

[3]

c) Need sine/cosine curve (i.e. up down aspect), and **A** and **B** marked. ✓



[1]

Total 6

Qno.12

A

Qno.13

Intensity is power/area $10^{-20} \times 1.4 \times 10^{3}$ (✓) $= \frac{100}{4\pi r^2}$ (✓)

$$r^2 = \frac{100}{4\pi}\frac{1}{10^{-20}\times1.4\times10^{3}}$$ ✓

$r = 7.5 \times 10^{8}$ m (8×10^{8} m) ✓

answer with an order of magnitude correct gains the mark

Total 4

Qno.9

D