Question			Answer	Marks	Guidance
1	(a)		(gravitational) force ∝ $\frac{\text{[mass 1] [mass 2]}}{\text{[separation (of masses)]}^2}$	B1	**Allow:** equation in symbols if symbols are defined **Allow:** equality **Not** radius
	(b)		Use of $F = \frac{GMm}{R^2}$ AND $F = \frac{mv^2}{R}$ $v = \frac{2\pi R}{T}$ $\frac{GM}{R^2} = \frac{1}{R}\left(\frac{(2\pi R)}{T}\right)^2$ $R^3 = \frac{GM}{4\pi^2}T^2$ *OR* $R^3 \propto T^2$	B1 B1 B1 A1	**Ignore** signs **Allow:** equation with cancelling shown This mark is for some evidence of substitution and manipulation **Allow:** subject must be either R^3 or T^2 **Allow:** Max 1 mark for bald statement of $R^3 = \frac{GM}{4\pi^2}T^2$ without proof
	(c)	(i)	Graph is a straight line / has constant gradient and passes through the origin	B1	
		(ii)	gradient of graph $= \frac{GM}{4\pi^2} = \frac{15\times10^{34}}{4.5\times10^{16}} = \left(3.3\times10^{18}\right)$ $M = \frac{4\pi^2\times3.3\times10^{18}}{6.67\times10^{-11}}$ $M = 1.97\times10^{30}$ (kg)	C1 C1 A1	**Allow:** ± half small square on reading off points on line **Note** 2 possible POT error in this equation would give max 1 out 3 with FT. **Allow:** use of a point read from straight line substituted into Kepler's equation **Allow:** FT from their gradient value. 2.0×10^n where $n \neq 30$ scores **max** 2 out of 3 marks
			Total	**9**	

Question			Answer	Marks	Guidance
2	(a)		Spaceship is (always vertically) above the same point on (the surface of the Earth/ planet) (AW)	B1	**Allow:** Spaceship must orbit the equator with a period of 24 h/ 1 day **and** must have the same direction of rotation as Earth / planet (AW) **Not :** same point in sky
	(b)	(i)	Centre of spaceship's orbit must coincide with the centre of mass of Benzar **OR** orbit must be equatorial (AW) Velocity of spaceship must be parallel to the velocity of a point on the surface of Benzar. **OR** Spaceship must orbit in the same direction as Benzar rotates (AW)	B1 B1	S Pole is on axis of rotation (radius of orbit is zero) Spacecraft must be stationary /not orbiting planet / spinning on its axis OR Spacecraft will only pass over S Pole once in each orbit
		(ii)	$R^3 = \frac{GT^2M}{4\pi^2}$ $R^3 = \frac{6.67\times10^{-11}\times(1.2\times10^5)^2\times8.9\times10^{25}}{4\pi^2}$ $R = 1.3\times10^8$ (m)	C1 C1 A1	Must have R or R^3 as subject Mark is for substitution Answer to 3 sf is 1.29×10^8 (m)
			Total	6	

Question			Answer	Marks	Guidance
3	(a)	(i)	Diagram showing **at least 4 radial** lines outside Earth, appearing to meet at centre of Earth (as judged by eye – in a square containing letters **a** and **r** of label) **AND** **at least 4 arrows** directed towards the Earth	B1	**Do not** award this mark if any arrow is in wrong direction. **Allow**: line(s) to continue inside the Earth
		(ii)	Any **two** from the following: • Field lines are **parallel** to each other • Field lines are equally/evenly/uniformly/constantly spaced (AW) • Field lines are **perpendicular / vertical** / **right angles** (to surface of the Earth)	B1 B1	**Note: vertical**, **parallel**, **perpendicular** /**right angles** wherever used to be spelled correctly .
	(b)	(i)	$g = \frac{GM}{R^2}$ $g = \frac{6.67\times10^{-11}\times5.7\times10^{26}}{(6\times10^7)^2}$ $g = 11\quad(\text{N kg}^{-1})$	C1 A1	**Note:** Mark is for substitution Answer is 10.6 (N kg^{-1}) to 3 sf Ignore sign
		(ii)1	$\frac{mv^2}{r} = \frac{GMm}{r^2}$ or $v^2 = \frac{GM}{r}$ $v^2 = \frac{6.67\times10^{-11}\times5.7\times10^{26}}{5.3\times10^8}\quad(= 7.17\times10^7)$ $v = 8.5\times10^3\quad(\text{m s}^{-1})$	C1 C1 A1	Allow $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$ **and** $v = \frac{2\pi r}{T}$ Expected value for $T = 3.93 \times 10^5$ s **Note:** Mark is for substitution Answer is 8470 (m s^{-1}) to 3 sf **Note:** Using • mass of Rhea (2.3×10^{21}) gives v = 17 (m s^{-1}) • g from b(i) in $v = \sqrt{gr}$ gives $v = 7.5 \times 10^4$ [correct value of g at Rhea's orbit is 0.135 N kg^{-1}] Both score max 1 mark for use of correct formula
		(ii)2	$E_k = \frac{1}{2}\times2.3\times10^{21}\times7.17\times10^7$ $E_k = 8.2\times10^{28}\quad$ (J)	B1	Possible **ecf** for v from **(ii)1** **Note:** Using v = 17 gives $E_k = 3.3 \times 10^{23}$ (J) Using $v = 7.5 \times 10^4$ gives $E_k = 6.5 \times 10^{30}$ (J) Using b(ii)1 to 2sf gives $E_k = 8.3 \times 10^{28}$ (J)
			Total	**9**	

Question			Answer	Marks	Guidance
4	(a)	(i)	Force between two (point) masses is proportional to the product of masses and inversely proportional to the square of the distance between them	B1 B1	**Not:** radius **Allow:** $F = GMm/r^2$ B1 **All** symbols defined B1
		(ii)	Force per (unit) mass	B1	**Allow:** $g = F/m$ with symbols defined
	(b)	(i)	$v = \frac{2\pi R}{T}$ $v = \frac{2\pi \times 1.2 \times 10^9}{16 \times 86400}$ $v = 5.5 \times 10^3$ (ms^{-1})	C1 A1	**Note:** Answer to 3 sf is 5.45 x 10^3 **Allow:** 1 mark for 4.7 x 10^8 not converting days to s **Allow:** 1 mark for 5.5 not converting km to m
		(ii)	$m_T \frac{v^2}{r} = \frac{GM_S m_T}{r^2}$ $M_S = \frac{v^2 r}{G}$ $M_S = \frac{(5.45 \times 10^3)^2 \times 1.2 \times 10^9}{6.67 \times 10^{-11}}$ $M = 5.3 \times 10^{26}$ (kg)	C1 C1 A1	**Allow:** alternative method using Kepler's third law Possible ECF from b(i) **Note :** An answer of 5.3 x 10^{26} (or 5.4 x 10^{26}) **without substitution shown** scores 2 marks since this is a '**show'** question. **Note:** Use of 5.5 x 10^3 gives 5.4 x 10^{26} (kg)
	(c)		Reference to $T^2 = (4\pi^2 /GM)\, r^3$ OR $T^2 \propto r^3$ $\frac{T_R}{T_T} = \sqrt{\frac{r_R^3}{r_T^3}}$ OR $\frac{T_R}{T_T} = \left(\frac{r_R}{r_T}\right)^{\frac{3}{2}}$	B1 B1	**Not:** $\left(\frac{T_R}{T_T}\right)^2 = \left(\frac{r_R}{r_T}\right)^3$
			Total	**10**	

5	Expected Answers	Marks	Additional guidance
(a)	Force per unit mass (at a point in a gravitational field).	B1	Accept $g = F/m$ if F and m are identified
(b)(i)	Recognition that inverse square law needs to be verified: e.g. $g \propto 1/r^2$ hence gr^2 = constant $\Rightarrow$ 9.8 x 6400^2 = 4.0 x 10^8 (or 4 x 10^{14}) AND 2.7 x 10^{-3} x (3.8 x $10^5)^2$ = 3.9 x 10^8 (or 3.9 x 10^{14}) (n.b values in brackets correspond to radius in metres) Any appropriate comment consistent with the calculations e.g. values are close enough (to verify the relationship).	B1 B1 B1	Do not accept a bare $g = GM/r^2$ unless G and M are stated as constants or following calculations shows this. They must use values in table and do both calculations for this mark **Allow** other valid approaches e.g. g ratio compared to $1/r^2$ ratio (3630 and 3530) OR (2.75 x 10^{-4} , 2.84 x 10^{-4} ,)
(b)(ii)	($mg = GmM / r^2 \Rightarrow M = gr^2$ / G) M = 9.81 x (6.4 x $10^6)^2$ / 6.67 x 10^{-11} M = 6.024 x 10^{24} kg	 C1 A1	(this formula is given on data sheet) Correct substitution into formula **Allow** 6.018 x 10^{24} this is for g = 9.8 and allow any value between 6.0 x 10^{24} and 6.03 x 10^{24} but not 6x 10^{24} Also **allow** data for the moon to be used i.e M_E = 2.7x10^{-3} x 3.8 x 10^8 / 6.67 x 10^{-11} = 5.846 x 10^{24} kg ≈ 6 x 10^{24} kg
(b)(iii)	volume = $(4/3)\pi r^3 = (4/3)\pi$ (6.4 x $10^6)^3$ (= 1.10x10^{21} m^3) $\rho = M/V$ = 6.0 x 10^{24} / 1.10 x 10^{21} = 5500 (5464)(kg m^{-3})	C1 A1	mark for correct substitution e.g. 6.4 x 10^6 (in m) used and not 6.4 x ^{3} (km) **allow** ecf from b(ii) for cand's value of M but no ecf for wrong volume <u>formula</u> If r = 6.4 x10^3 is used V = 1.1 x10^{12} $\Rightarrow$ ρ = 5.5x 10^{12} and scores 1 mark
	Total	**8**	