1)

Question			Answer	Marks	Guidance
	(a)		Force is proportional to the product of the masses and inversely proportional to the square of their separation (AW)	B1	**Allow:** $F = \frac{GmM}{r^2}$ with **all** symbols defined.
	(b)	(i)	$mg = \frac{GmM_J}{r^2}$ $M_J\left(=\frac{gr^2}{G}\right) = \frac{7.5 \times (1.3 \times 10^8)^2}{6.67 \times 10^{-11}}$ $M_J = 1.9 \times 10^{27}$ (kg)	C1 C1 A1	**Allow:** formula with m cancelled **Allow:** use of $T^2 = \frac{4\pi^2 r^3}{GM_J} \Rightarrow M_J = \frac{4\pi^2 (1.3 \times 10^8)^3}{6.67 \times 10^{-11} \times (7.2 \times 60^2)^2}$ **Note:** mark is for substitution with any subject
		(ii)	$\frac{g_M}{g_A} = \frac{r_A^2}{r_M^2}$ $\frac{g_M}{7.5} = \frac{(1.3 \times 10^8)^2}{(2.4 \times 10^{10})^2}$ $g_M = 2.2 \times 10^{-4}$ (N kg^{-1})	C1 A1	**Allow:** use of $g = \frac{GM_J}{r^2}$ with possible ecf for M_J from (b)(i) $g_M = \frac{(6.67 \times 10^{-11}) \times (1.9 \times 10^{27})}{(2.4 \times 10^{10})^2}$ **Note:** mark is for substitution $g_M = 2.2 \times 10^{-4}$ (N kg^{-1})
		(iii)	$T^2 \propto r^3$ OR T^2/r^3 = constant ($= 4\pi^2/GM_J$) $\frac{T_M^2}{7.2^2} = \frac{(2.4 \times 10^{10})^3}{(1.3 \times 10^8)^3}$ $T_M = 1.8 \times 10^4$ (hours)	C1 C1 A1	**Allow:** possible ecf for M_J from b(i) **Allow:** use of other correct formulae **Note:** mark is for substitution **Note** using times in seconds gives $T_M = 6.49 \times 10^7$ (s) scores 2 marks
			Total	**9**	

2)

	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 $\Rightarrow 9.8 \times 6400^2 = 4.0 \times 10^8$ (or 4×10^{14}) AND $2.7 \times 10^{-3} \times (3.8 \times 10^5)^2 = 3.9 \times 10^8$ (or 3.9×10^{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 (2.75×10^{-4} , 2.84×10^{-4} ,)
(b)(ii)	($mg = GmM / r^2 \Rightarrow M = gr^2$ / G) $M = 9.81 \times (6.4 \times 10^6)^2 / 6.67 \times 10^{-11}$ $M = 6.024 \times 10^{24}$ kg	C1 A1	(this formula is given on data sheet) Correct substitution into formula **Allow** 6.018×10^{24} this is for $g = 9.8$ and allow any value between 6.0×10^{24} and 6.03×10^{24} but not 6×10^{24} Also **allow** data for the moon to be used i.e $M_E = 2.7 \times 10^{-3} \times 3.8 \times 10^8 / 6.67 \times 10^{-11} = 5.846 \times 10^{24}$ kg $\approx 6 \times 10^{24}$ kg
(b)(iii)	volume = $(4/3)\pi r^3 = (4/3)\pi\ (6.4 \times 10^6)^3$ (= 1.10×10^{21} m^3) $\rho = M/V = 6.0 \times 10^{24} / 1.10 \times 10^{21} = 5500$ (5464)(kg m^{-3})	C1 A1	mark for correct substitution e.g. 6.4×10^6 (in m) used and not 6.4×10^3 (km) **allow** ecf from b(ii) for cand's value of M but no ecf for wrong volume formula If $r = 6.4 \times 10^3$ is used $V = 1.1 \times 10^{12} \Rightarrow \rho = 5.5 \times 10^{12}$ and scores 1 mark
	Total	**8**	

3)

Question			Answer	Marks	Guidance
	(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)	$v = \frac{2\pi R}{T}$ $v = \frac{2\pi \times 1.2\times10^9}{16\times86400}$ $v = 5.5\times10^3$ (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)	$m_T\frac{v^2}{r} = \frac{GM_S m_T}{r^2}$ $M_S = \frac{v^2 r}{G}$ $M_S = \frac{(5.45\times10^3)^2\times1.2\times10^9}{6.67\times10^{-11}}$ $M = 5.3\times10^{26}$ (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**	

4)

Question			Answer	Marks	Guidance
	(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)**	$g = \frac{GM}{R^2}$ $g = \frac{6.67\times10^{-11}\times5.7\times10^{26}}{(6\times10^7)^2}$ $g = 11$ (Nkg^{-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 $v^2 = \frac{GM}{r}$ $v^2 = \frac{6.67\times10^{-11}\times5.7\times10^{26}}{5.3\times10^8}$ $(= 7.17\times10^7)$ $v = 8.5\times10^3$ (ms^{-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 x 10^5 s **Note:** Mark is for substitution Answer is 8470 (m s^{-1}) to 3 sf **Note:** Using • mass of Rhea (2.3 x 10^{21}) gives v = 17 (m s^{-1}) • g from b(i) in $v = \sqrt{gr}$ gives v = 7.5 x 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	$E_k = \frac{1}{2}\times2.3\times10^{21}\times7.17\times10^7$ $E_k = 8.2\times10^{28}$ (J)	B1	Possible **ecf** for v from **(ii)1** **Note:** Using v = 17 gives E_k = 3.3 x 10^{23} (J) Using v = 7.5 x 10^4 gives E_k = 6.5 x 10^{30} (J) Using b(ii)1 to 2sf gives E_k = 8.3 x 10^{28} (J)
			Total	**9**	

5)

Question			Answer	Marks	Guidance
	(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	

6)

Question			Answer	Marks	Guidance
	(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 $= \frac{GM}{4\pi^2} = \frac{15\times10^{34}}{4.5\times10^{16}} = (3.3\times10^{18})$ $M = \frac{4\pi^2\times3.3\times10^{18}}{6.67\times10^{-11}}$ $M = 1.97\times10^{30}$ (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**	

7)

Question	Expected Answers	Marks	Additional guidance
(a) (i)	Horizontal component of **L** provides the centripetal force (WTTE) Vertical component of **L** balances the weight (WTTE)	B1 B1	
(a) (ii)	$F = mv^2/r$ correct rearranged into $v = \sqrt{(Fr/m)}$ $v = \sqrt{(1.8\times10^6 \times 2000/1.2\times10^5)}$ = **173** m s^{-1} (or 170)	C1 A1	Allow correct substitution of values into $F = mv^2/r$ for C1 mark
(b)	$mv^2/r = GMm/r^2$ $T = 2\pi r/v$ Correct manipulation of equations to give $T^2 = \frac{4\pi^2 r^3}{GM}$	B1 M1 A1	Do not allow a bare $v^2 = GM/r$ for the first mark – we need to see where this has come from.
(c) (i)	**Equatorial** orbit (WTTE) (QWC mark) Period is 24h/1day/same as Earth **OR** moves from West to East (WTTE)	B1 B1	QWC equatorial or equator must be spelled correctly
(c) (ii)	Correct rearrangement of $T^2 = (4\pi^2 r^3/GM)$ to give $r^3 = T^2GM/4\pi^2$ correct sub. $r^3 = \{6.67\times10^{-11} \times 6.0\times10^{24} \times (8.64\times10^4)^2\}/4\pi^2 = 7.57\times10^{22}$ r = **4.23 x 10^7 m** (or 4.2 or 4.3 x 10^7)	C1 C1 A1	(1 day = 8.64×10^4s is given on the data sheet). For those who use $g = GM/r^2$ with g = 9.81 award 1 mark for r= 6.4×10^6 m.
	Total	12	

8)

Question	Expected Answers	Marks	Additional guidance
(a)(i)	resultant OR net OR overall force acts (on object) perpendicular to the velocity OR towards the centre of the circle	B1	Ignore any reference to "centripetal force"
(a)(ii)	velocity OR direction is always changing acceleration is in direction of force OR is towards the centre/perp. to velocity	B1 B1	Allow a (resultant) force is acting (hence there is an acceleration))
(b)	centripetal force OR $mv^2/r = GMm/r^2$ OR $v^2/r = GM/r^2$ $v^2 = GM/r \Rightarrow r = GM/v^2$ $r = 6.67\times10^{-11} \times 6\times10^{24} / 3700^2$ r = **2.92 x 10^7** m	C1 C1 C1 A1	
(c)(i)	Any mass ejected in the same direction as the satellite (WTTE)	B1	Idea of rocket motor pushing against direction of motion of satellite.
(c)(ii)	v^2r = constant OR $v^2 = GM/r$ OR $v = \sqrt{\{(6.67\times10^{-11} \times 6\times10^{24})/2\times10^7\}}$ new $v = \sqrt{(3700^2 \times 2.94/2)}$ = **4500** m s^{-1} (4473)	C1 A1	
	Total	**10**	

9)

Question			Answer	Marks	Guidance
	(a)	(i)	**geostationary** or **synchronous** ✐**The term geostationary** or **synchronous to be included and spelled correctly to gain the B1 mark**	B1	**Must use tick or cross on Scoris to show if the mark is awarded**
		(ii)	So that they stay: above the same point (at all times) at same point in the sky	B1	**Allow**: travel at same (angular) speed / period and same direction as the Earth
		(iii)	Dish can be fixed to point in one (specific) direction/ Dish does not have to track the satellite (across the sky)	B1	**Allow**: Receiver / aerial for dish
		(iv)	Select from data sheet $T^2 = (4\pi^2/GM)r^3$ $r^3 = T^2 (GM/4\pi^2)$ $r^3 = (8.64\times10^4)^2 (6.67\times10^{-11} \times 6.0\times10^{24} / 4\pi^2)$ any subject $(= 7.56\times10^{22})$ $r = 4.2\times10^7$ (m) $r \approx 4\times10^7$ (m)	C1 C1 A1 A0	**Allow**: Full credit if candidate assumes $r = 4\times10^7$ and shows T is approx 1 day. 1 day = 8.64×10^4 s $G = 6.67\times10^{-11}$ N m^2 kg^{-2} Mark for radius can only be awarded if suitable working is shown
	(b)	(i)	The cube of the planets distance (from the Sun) divided by the square of the (orbital) period is the same (for all planets) (WTTE)	B1	**Allow**: radius for distance., **Allow**: $T^2 \propto r^3$ or r^3/T^2 = constant provided T and r are identified
		(ii)	$\text{ratio}^3 = \left(\frac{27.3}{1}\right)^2$ ratio = $(27.3)^{2/3}$ ratio = 9.1	C1 A1	**Allow:** 1 mark for correct value of distance of Moon from Earth's centre 3.8×10^8(m) **Note**: Full credit for 4×10^7 (m) used from (a)(iv)
			Total	9	

10)

Question			Answer		Marks	Guidance
2	(a)	(i)	$g = \frac{v^2}{r}$ or $v^2 = \frac{GM}{r}$		C1	Correct formula in any form **Allow**: use of *a* for *g*
			$v = \sqrt{gr}$ $v = \sqrt{7.7 \times 7.2 \times 10^6}$		C1	Mark is for substitution (**Note** Mass of Earth is 6.0 x 10^{24} kg) **Any use of r = 800 km is WP scores 0/3**
			$v = 7400$ (m s^{-1})		A1	**Note:** Answer to 3 sf is 7450 (m s^{-1})
		(ii)	$T = \frac{2\pi r}{v}$ $T = \frac{2\pi \times 7.2 \times 10^6}{7450}$	$T^2 = \frac{4\pi^2 r^3}{GM}$ $T^2 = \frac{4\pi^2 (7.2 \times 10^6)^3}{6.67 \times 10^{-11} \times 6 \times 10^{24}}$	C1	**Allow**: possible ecf for *v* from (a)(i) **No ecf** for use of *r* = 6.4 x 10^6 again or use of r = 800 km Both score 0/2
			= 6100 (s)	T = 6100 (s)	A1	**Note:** Answer to 3 sf using v = 7400 is 6110 (s) Answer to 3 sf using v = 7450 is 6070 (s)
	(b)	(i)	Number of orbits = $\frac{24 \times 3600}{6080}$ (= 14.2) ≈ 14		B1	**Allow** any correct method **Allow** ora **No ecf** from a(ii)
		(ii)	Circumference = $2\pi r$		C1	**Allow**: Circumference = $2\pi r$ (C1)
			$\frac{\text{equatorial circumference}}{\text{width of photograph}} = \frac{2\pi \times 6400}{3000} = 13.4$		C1	length of equator covered per orbit = 2π x 6.4 x 10^3/14 (C1) (= 2872)
			(But each orbit crosses the equator twice hence) number of orbits = 6.7		A1	(But each orbit crosses the equator twice hence) min width to be photographed = ½ x 2872 = 1400 km (A1)
			This is fewer than 14 orbits so whole of Earth's surface can be photographed (AW)		A0	< 3000 km so all of Earth's surface can be photographed in one day (A0)
	(c)		suitable example: eg weather / spy / surveying / mapping / GPS		B1	**Ignore** TV / radio / communications
			Total		**10**	