1 **(a)** Write a word equation which states Newton's law of gravitation.

....

....

.... **[1]**

(b) A planet of mass *m* moves in a circular orbit of radius *r* about a star of mass *M*. The planet has an orbital period *T*.

Use your knowledge of circular motion and Newton's law of gravitation to derive Kepler's third law.

[4]

(c) The star HD10180 in the constellation Hydrus is notable for its large planetary system. The period *T* and the mean orbital radius *r* for HD10180's planets have been deduced from recent observations. Fig. 4.1 has been constructed using these data.

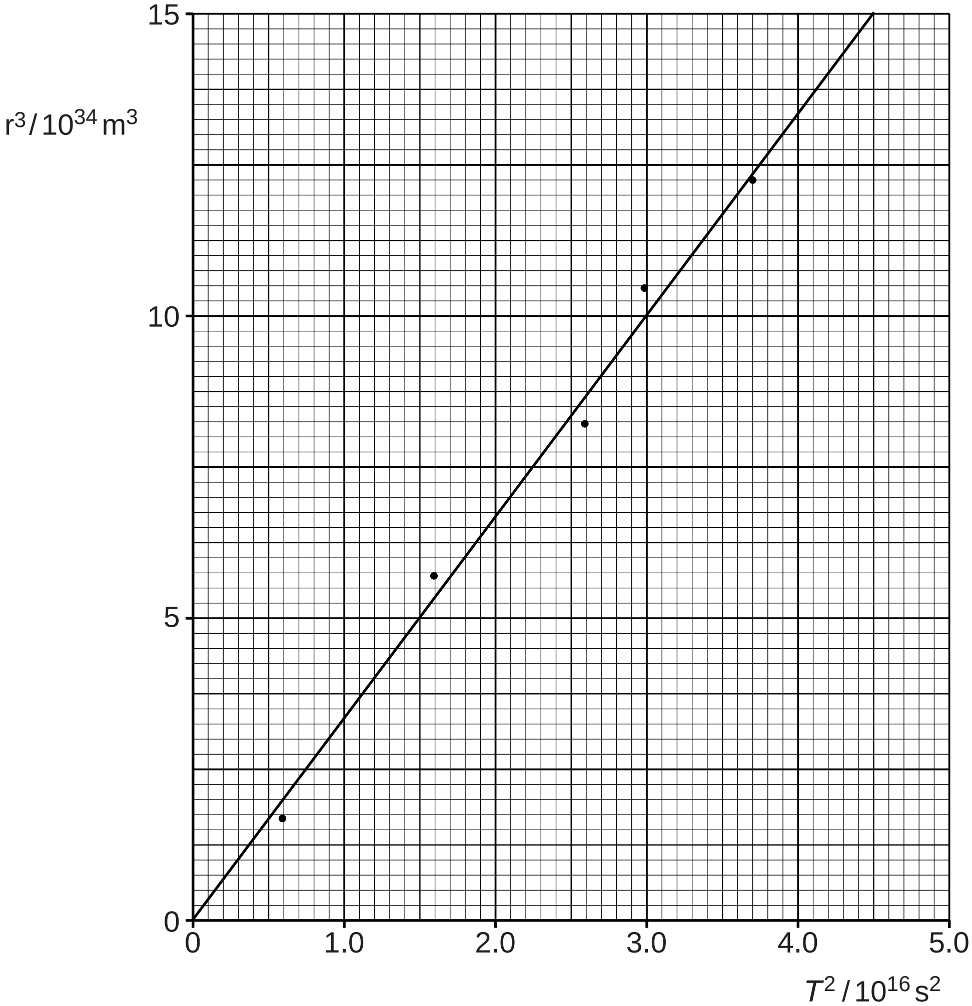

Fig. 4.1

(i) State what features of Fig. 4.1 support the view that Kepler's third law may be applied to this system.

....

....

.... **[1]**

(ii) Use Fig. 4.1 to determine the mass of the star HD10180.

mass = ... kg **[3]**

2 **(a)** State what is meant by the term *geostationary orbit*.

....

....

.... **[1]**

(b) In a science fiction movie, a spaceship approaches a planet called Benzar.
Benzar has a period of rotation of 1.2×10^5 s.
The captain of the spaceship orders the crew to "enter a stationary orbit over the South Pole of Benzar".

(i) Use your knowledge of physics to explain why it is impossible to follow these orders.

....

....

....

....

.... **[2]**

(ii) Benzar has mass 8.9×10^{25} kg.
Calculate the radius of the possible stationary orbit for a spaceship circling Benzar.

radius = ... m **[3]**

[Total: 6]

3 **(a)** Fig. 2.1 shows the Earth in space.

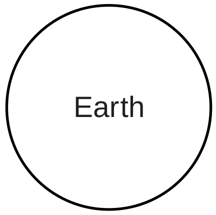

Fig. 2.1

(i) Draw lines on Fig. 2.1 to show the shape and direction of the gravitational field of the Earth. **[1]**

(ii) The gravitational field strength, g, is uniform close to the Earth's surface. Describe the pattern of gravitational field lines close to the surface of the Earth.

In your answer you should use appropriate technical terms spelled correctly.

....

....

....

.... **[2]**

(b) The planet Saturn has mass 5.7×10^{26} kg and radius 6.0×10^{7} m.

(i) Calculate the gravitational field strength g_s at Saturn's surface.

g_s = ... $N\,kg^{-1}$ **[2]**

(ii) Saturn's second-largest moon, Rhea, has orbital radius 5.3×10^8 m and mass 2.3×10^{21} kg.
Calculate for Rhea

1 its orbital speed *v*

v = ... $m\,s^{-1}$ **[3]**

2 its kinetic energy.

kinetic energy = ... J **[1]**

[Total: 9]

4 **(a)** **(i)** State Newton's law of gravitation.

....

....

.... **[2]**

(ii) Define *gravitational field strength, g*.

....

.... **[1]**

(b) Titan, a moon of Saturn, has a circular orbit of radius 1.2×10^{6} km. The orbital period of Titan is 16 Earth days.

(i) Calculate the speed of Titan in its orbit.

speed = ……………… m s^{-1} **[2]**

(ii) Show that the mass of Saturn is about 5×10^{26} kg.

[3]

(c) Rhea is another moon of Saturn with a smaller orbital radius than Titan.
Determine the ratio

$$\frac{\text{orbital period } T_R \text{ of Rhea}}{\text{orbital period } T_T \text{ of Titan}}$$ in terms of their orbital radii r_R, and r_T.

ratio = …………………… **[2]**

[Total: 10]

5 **(a)** Define *gravitational field strength*.

....

.... **[1]**

(b) The table shows, in modern units, information that was known to physicists at the time of Isaac Newton.

position	distance r from centre of the Earth / km	gravitational field strength g due to the Earth / N kg^{-1}
surface of Earth	6.4×10^3	9.8
Moon's orbit	3.8×10^5	2.7×10^{-3}

Use the information provided in the table to

(i) state a relationship between the gravitational field strength g and the distance r and verify this relationship

....

.... **[3]**

(ii) show that the mass of the Earth is about 6×10^{24} kg

[2]

(iii) determine the mean density of the Earth.

density = ... kg m^{-3} **[2]**

[Total: 8]

1 **(a)** Fig. 2.1 shows an aeroplane flying in a horizontal circle at constant speed. The weight of the aeroplane is *W* and *L* is the lift force acting at right angles to the wings.

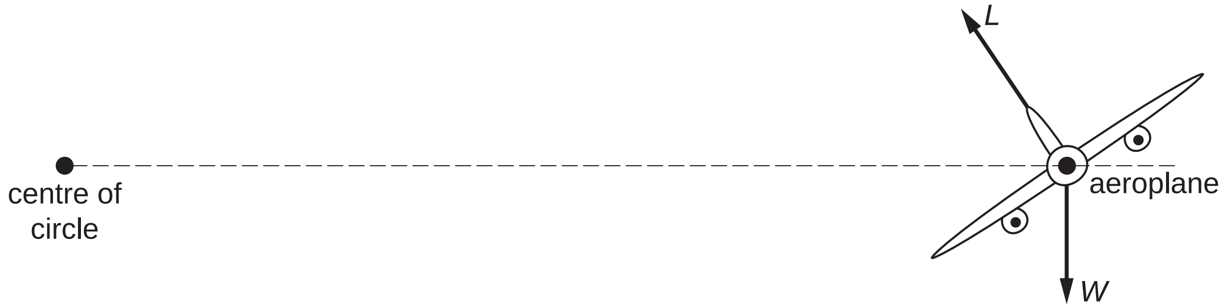

Fig. 2.1

(i) Explain how the lift force *L* maintains the aeroplane flying in a **horizontal** circle.

....

....

....

.... **[2]**

(ii) The aeroplane of mass 1.2×10^5 kg is flying in a horizontal circle of radius 2.0 km.

The centripetal force acting on the aeroplane is 1.8×10^6 N. Calculate the speed of the aeroplane.

speed = ... $m s^{-1}$ **[2]**

(b) Fig. 2.2 shows a satellite orbiting the Earth at a constant speed *v*. The radius of the orbit is *r*.

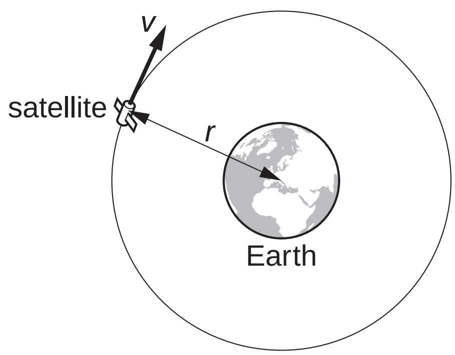

Fig. 2.2

Show that the orbital period T of the satellite is given by the equation

$$T^2 = \frac{4\pi^2 r^3}{GM}$$

where M is the mass of the Earth and G is the gravitational constant.

[3]

(c) The satellites used in television communication systems are usually placed in geostationary orbits.

In your answer, you should use appropriate technical words spelled correctly.

(i) State two features of geostationary orbits.

1. ....

....

2. ....

.... **[2]**

(ii) Calculate the radius of orbit of a geostationary satellite.

The mass of the Earth is 6.0×10^{24} kg.

radius = ... m **[3]**

[Total: 12]

2 A satellite orbits the Earth in a circular path 800 km above the Earth's **surface**. At the orbit of the satellite the gravitational field strength is 7.7 N kg^{-1}. The radius of the Earth is 6400 km.

(a) Calculate

(i) the orbital speed of the satellite

orbital speed = ... m s^{-1} **[3]**

(ii) the period of the orbit of the satellite.

period = ... s **[2]**

(b) The orbit of the satellite passes over the Earth's poles.

(i) Show that the satellite makes about 14 orbits around the Earth in 24 hours.

[1]

(ii) The cameras on board the satellite continually photograph a strip of the Earth's surface, of width 3000 km, directly below the satellite. Determine, with an appropriate calculation, whether the satellite can photograph the whole of the Earth's surface in 24 hours. State your conclusion.

....

....

.... **[3]**

(c) Suggest a practical use of such a satellite.

....

.... **[1]**

[Total: 10]

3 **(a)** State, in words, Newton's law of gravitation.

....

....

.... **[1]**

(b) Fig. 3.1 shows the circular orbits of two of Jupiter's moons: Adrastea, **A**, and Megaclite, **M**.

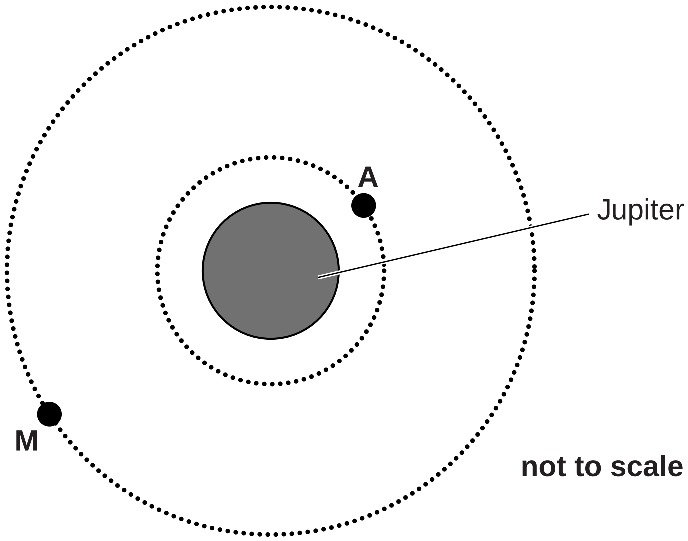

Fig. 3.1

Use the following data in the calculations below.

orbital radius of **A** = 1.3×10^{8} m
orbital period of **A** = 7.2 hours
gravitational field strength at orbit of **A** = 7.5 N kg^{-1}
orbital radius of **M** = 2.4×10^{10} m

Calculate

(i) the mass of Jupiter

mass = ... kg **[3]**

(ii) the gravitational field strength at the orbit of **M**

gravitational field strength = ... $N\,kg^{-1}$ **[2]**

(iii) the orbital period of **M**.

orbital period = ... hours **[3]**

[Total: 9]

4 **(a)** **(i)** State the name given to satellites that orbit the Earth, with a period of 1 day, above the equator.

You should use the appropriate technical term spelled correctly.

.... **[1]**

(ii) Explain why these satellites orbit above the equator.

....

.... **[1]**

(iii) For companies who provide a satellite TV service, suggest the main advantage of using this type of satellite.

....

.... **[1]**

(iv) The mass of the Earth is 6.0×10^{24} kg. Show that the radius of the orbit of a satellite with an orbital period of 1 day is about 4×10^{7} m.

[3]

(b) **(i)** State Kepler's third law.

....

.... **[1]**

(ii) The Moon orbits the Earth with a period of 27.3 days. Use the information given in **(a)(iv)** to calculate the following ratio:

$$\frac{\text{distance of the Moon from the Earth's centre}}{\text{distance of the satellite from the Earth's centre}}$$

ratio = ... **[2]**

[Total: 9]

5 **(a)** **(i)** State, in terms of force, the conditions necessary for an object to move in a circular path at constant speed.

....

.... **[1]**

(ii) Explain why this object is accelerating. State the direction of the acceleration.

....

.... **[2]**

(b) A satellite moves in a circular orbit around the Earth at a constant speed of $3700\,m\,s^{-1}$.

The mass M of the Earth is 6.0×10^{24} kg.

Calculate the radius of this orbit.

radius = ... m **[4]**

(c) In order to move the satellite in **(b)** into a new smaller orbit, a decelerating force is applied for a brief period of time.

(i) Suggest how the decelerating force could be applied.

....

.... **[1]**

(ii) The radius of this new orbit is 2.0×10^{7} m. Calculate the speed of the satellite in this orbit.

speed = ... $m\,s^{-1}$ **[2]**

[Total: 10]

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 <u>through the origin</u>	B1	
		(ii)	$\text{gradient of graph} = \frac{GM}{4\pi^2} = \frac{15\times10^{34}}{4.5\times10^{16}} = \left(3.3\times10^{18}\right)$ $M = \frac{4\pi^2\times3.3\times10^{18}}{6.67\times10^{-11}}$ $M = 1.97\times10^{30}$ (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 x 10^n where n ≠ 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 R³ as subject Mark is for substitution Answer to 3 sf is 1.29 x 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	$E_k = \frac{1}{2}\times2.3\times10^{21}\times7.17\times10^7$ $E_k = 8.2\times10^{28}$ (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 formula 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**	

Question	Expected Answers	Marks	Additional guidance
1 (a) (i)	Horizontal <u>component</u> of **L** provides the centripetal force (WTTE) Vertical <u>component</u> of **L** balances the weight (WTTE)	B1 B1	
(a) (	$F = mv^2/r$ correct rearranged into $v = \sqrt{(Fr/m)}$ $v = \sqrt{(1.8 \text{x} 10^6 \text{ x} 2000/1.2 \text{x} 10^5)}$ = **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 $T^2 = \dfrac{4\pi^2 r^3}{GM}$	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)	**Equatorial** orbit (WTTE) (<u>QWC mark</u>) Period is 24h/1day/same as Earth **OR** moves from West to East (WTTE)	B1 B1	QWC <u>equatorial</u> or <u>equator</u> must be spelled correctly
(c) (	Correct rearrangement of $T^2 = (4\pi^2 r^3/GM)$ to give $r^3 = T^2GM/4\pi^2$ correct sub. $r^3 = \{6.67 \text{ x} 10^{-11} \text{ x } 6.0 \text{ x } 10^{24} \text{ x } (8.64 \text{x} 10^4)^2\}/4\pi^2 = 7.57 \text{x} 10^{22}$ r = $\mathbf{4.23 \text{ x } 10^7}$ **m** (or 4.2 or 4.3 x 10^7)	C1 C1 A1	(1 day = 8.64 x10^4s 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 x 10^6 m.
	Total	12	

Question			Answer	Marks	Guidance
2	(a)	(i)	$g = \frac{v^2}{r}$ or $v^2 = \frac{GM}{r}$ $v = \sqrt{gr}$ $v = \sqrt{7.7 \times 7.2 \times 10^6}$ $v = 7400$ (m s^{-1})	C1 C1 A1	Correct formula in any form **Allow:** use of *a* for *g* 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** **Note:** Answer to 3 sf is 7450 (m s^{-1})
		(ii)	$T = \frac{2\pi r}{v}$ $T = \frac{2\pi \times 7.2 \times 10^6}{7450}$ = 6100 (s) $T^2 = \frac{4\pi^2 r^3}{GM}$ $T^2 = \frac{4\pi^2 (7.2 \times 10^6)^3}{6.67 \times 10^{-11} \times 6 \times 10^{24}}$ T = 6100 (s)	C1 A1	**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 **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 = $2\pi r$ $\frac{\text{equatorial circumference}}{\text{width of photograph}} = \frac{2\pi \times 6400}{3000} = 13.4$ (But each orbit crosses the equator twice hence) number of orbits = 6.7 This is fewer than 14 orbits so whole of Earth's surface can be photographed (AW)	C1 C1 A1 A0	**Allow**: Circumference = $2\pi r$ (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) min width to be photographed = ½ x 2872 = 1400 km (A1) < 3000 km so all of Earth's surface can be photographed in one day (A0)

Question			Answer	Marks	Guidance
	(c)		suitable example: eg weather / spy / surveying / mapping / GPS	B1	**Ignore** TV / radio / communications
			Total	**10**	

Question			Answer	Marks	Guidance
3	(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)	$mg = \frac{GmM_J}{r^2}$	C1	**Allow:** formula with m cancelled
			$M_J \left(= \frac{gr^2}{G} \right) = \frac{7.5 \times (1.3 \times 10^8)^2}{6.67 \times 10^{-11}}$	C1	**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
			M_J = 1.9 x 10^{27} (kg)	A1	
		(ii)	$\frac{g_M}{g_A} = \frac{r_A^2}{r_M^2}$		**Allow:** use of $g = \frac{GM_J}{r^2}$ with possible ecf for M_J from (b)(i)
			$\frac{g_M}{7.5} = \frac{(1.3 \times 10^8)^2}{(2.4 \times 10^{10})^2}$	C1	$g_M = \frac{(6.67 \times 10^{-11}) \times (1.9 \times 10^{27})}{(2.4 \times 10^{10})^2}$ **Note:** mark is for substitution
			g_M = 2.2 x 10^{-4} (N kg^{-1})	A1	g_M = 2.2 x 10^{-4} (N kg^{-1})
		(iii)	$T^2 \propto r^3$ OR T^2/r^3 = constant (= $4\pi^2/GM_J$)	C1	**Allow:** possible ecf for M_J from b(i) **Allow:** use of other **c**orrect formulae
			$\frac{T_M^2}{7.2^2} = \frac{(2.4 \times 10^{10})^3}{(1.3 \times 10^8)^3}$	C1	**Note:** mark is for substitution
			T_M = 1.8 x10^4 (hours)	A1	**Note** using times in seconds gives T_M = 6.49 x10^7 (s) scores 2 marks
			Total	**9**	

Question			Answer	Marks	Guidance
4	(a)	(	**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 $T^2 = (4\pi^2/GM)r^3$ $r^3 = T^2\ (GM/4\pi^2)$ $r^3 = (8.64 \times 10^4)^2\ (6.67 \times 10^{-11} \times 6.0 \times 10^{24} / 4\pi^2)$ any subject $(= 7.56 \times 10^{22})$ $r = 4.2 \times 10^7$ (m) $r \approx 4 \times 10^7$ (m)	C1 C1 A1 A0	**Allow**: Full credit if candidate assumes r = 4×10^7 and shows T is approx 1 day. 1 day = 8.64×10^4 s G = 6.67×10^{-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**	

Question	Expected Answers	Marks	Additional guidance
5(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 $v^2/r = GM/r^2$ $v^2 = GM/r \Rightarrow r = GM/v^2$ $r = 6.67 \times 10^{-11} \times 6 \times 10^{24} / 3700^2$ r = $\mathbf{2.92 \times 10^7}$ 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 $v = \sqrt{(6.67\times10^{-11}\times6 \times 10^{24})/2\times10^7}$ new $v = \sqrt{(3700^2 \times 2.94/2)}$ = **4500** m s^{-1} (4473)	C1 A1	
	Total	**10**	