Question Number	Answer	Mark
1	See $g = \frac{GM}{r^2}$ **(1)** Correct substitution into $g = \frac{GM}{r^2}$ **(1)** $r_E/r_m = 3.7$ **(1)** (Correct inverse ratio i.e. $r_m/r_E = 0.27$, scores full marks) <u>Example of calculation</u> $g_E = \frac{GM_E}{r_E^2} \qquad g_m = \frac{GM_m}{r_m^2}$ $\therefore \frac{g_E}{g_m} = \frac{GM_E/r_E^2}{GM_m/r_m^2} = \frac{M_E}{M_m} \times \frac{r_m^2}{r_E^2}$ $\therefore 6 = 81 \times \frac{r_m^2}{r_E^2}$ $\therefore \frac{r_E}{r_m} = \sqrt{\frac{81}{6}} = 3.67 \approx 3.7$	3
	Total for question	**3**

Question Number	Answer	Mark
2(a)	The weight of the moon **Or** the gravitational force of the Earth (on the moon) **(1)** The (mass of the Earth and) speed/velocity of the moon **(1)**	**2**
2(b)	A centripetal / unbalanced force is needed (because the water is moving in a circular path) **(1)** **Max 2** At the highest point the (unbalanced) force is weight of water plus reaction from bucket **(1)** Idea that the minimum force needed (towards the centre of the circle) is the weight of the water **(1)** Minimum velocity where $\frac{mv_{min}^2}{r} = mg$ **Or** $v_{min}^2 = rg$ **(1)** [Credit may be given for a diagram with appropriate annotations]	**Max 3**
	Total for question	**5**

Question Number	Answer	Mark
3(a)(i)	Use of $\omega=2\pi/T$ (1) $\omega = 2.66 \times 10^{-6}$ (rad s^{-1}) (1 <u>Example of calculation</u> $\omega = \frac{2\pi}{T} = \frac{2\pi}{27.3 \times 24 \times 3600\text{s}} = 2.66 \times 10^{-6}\,(\text{rad})\text{s}^{-1}$	2
3(a)(ii)	See $(F =)\frac{Gm_1m_2}{r^2}$ (1) Evidence that gravitational force equated to centripetal force (1) Correct substitution [e.c.f.] (1) $r = 3.92 \times 10^8$ m (1) If show that value is used, $r = 3.62 \times 10^8$ m <u>Example of calculation</u> $\frac{GMm}{r^2} = m\omega^2 r$ $r^3 = \frac{GM}{\omega^2}$ $\therefore r = \sqrt[3]{\frac{6.67\times10^{-11}\,\text{Nm}^2\text{kg}^{-2}\times6.4\times10^{24}\,\text{kg}}{(2.66\times10^{-6}\,\text{s}^{-1})^2}} = 3.92\times10^8$ m	4
3(b)(i)	Max **two** from: ♦ Gravitational force on moon is reduced (1) ♦ (Therefore) ω or v is decreased (1) ♦ (Hence) the orbital time increases (1) ♦ Valid reference to Kepler's law: $T^2 \propto r^3$ (1)	Max 2
3(b)(ii)	Rate of increase = 4 (cm per year) (1) <u>Example of calculation</u> Rate of increase = 800 cm / 200 yr = 4 cm yr^{-1}	1
3(b)(iii)*	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Answers based on expanding universe/galaxies/stars do not gain credit Idea that in the past the moon was closer OR the gravitational pull would have been larger (1) In the past the tidal effects would have been greater/stronger (1) The rate of change of orbital radius would have been greater (1)	3
	Total for question	**12**

Question Number	Answer		Mark
*4	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Gravitational fields are regions in which a mass experiences a force due to its mass Electric fields are regions in which a charge experiences a force due to its charge Both types of field have an infinite range In each type of field the force varies as an inverse square The force between masses is always attractive whereas the force between charges can be attractive or repulsive **Or** electric fields can cancel or reinforce but gravitational fields always reinforce one another The force between (unit) charges at a given separation is much stronger than the force between (unit) masses at the same separation	 **(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	**6**
	Total for question		**6**

Question Number	Answer		Mark
5(a)(i)	See $F = GMm/r^2$ Equated to mg to give required expression **Or** use of g = F/m	**(1)** **(1)**	 **2**
5(a)(ii)	Use of $g = \omega^2 r$ OR $g = v^2/r$ Use of $\omega = 2\pi/T$ OR $v = 2\pi r/T$ Correct algebra leading to expression given <u>Example of calculation:</u> $\omega^2 r = \frac{GM}{r^2}$ $\left(\frac{2\pi}{T}\right)^2 = \frac{GM}{r^3}$ $r^3 = \frac{GMT^2}{4\pi^2}$	**(1)** **(1)** **(1)**	 **3**
5(a)(iii)	See T = 24 hours T converted into s $r = 4.2 \times 10^7$ m <u>Example of calculation:</u> $T = 24 \times 60 \times 60$ s = 86 400 s $r^3 = \frac{GMT^2}{4\pi^2} = \frac{6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times 6.0 \times 10^{24}\ \text{kg} \times (86400\ \text{s})^2}{4\pi^2} = 7.57 \times 10^{22}\ \text{m}^3$ $r = \sqrt[3]{7.57 \times 10^{22}\ \text{m}^3} = 4.23 \times 10^7\ \text{m}$	**(1)** **(1)** **(1)**	 **3**
5(b)	The satellite must rotate with the Earth **Or** the satellite must be in a geosynchronous orbit **Or** any non-equatorial orbit would cause the satellite to move N-S		 **1**
	Total for question		**9**

Question Number	Answer		Mark
6(a)	See (unbalanced force), $F = \frac{Gm_1m_2}{r^2}$	**(1)**	
	Apply N2 with $a = v^2/r$ **Or** Equate F with mv^2/r **Or** Equate F with $m\omega^2r$	**(1)**	
	Use of $T = 2\pi r/v$ **Or** $T = 2\pi/\omega$ T = 43000 (s)	**(1)** **(1)**	
	Or At height of satellite orbit, use $g = GM/r^2$ Use $g = a = \omega^2 r$ **Or** $g = a = v^2/r$ Use of $T = 2\pi r/v$ **Or** $T = 2\pi/\omega$ T = 43000 (s)	**(1)** **(1)** **(1)** **(1)**	**4**
	[First 3 marks can be obtained from use of $T = 2\pi\sqrt{\frac{r^3}{GM}}$] [If reverse show that to calculate h = 18 900 km, then max 3 marks] <u>Example of calculation:</u> $\frac{GMm}{r^2} = \frac{mv^2}{r}$ $v = \sqrt{\frac{GM}{r}}$ r = (20200 + 6400) km = 2.66 × 10^7 m $v = \sqrt{\frac{6.67\times10^{-11}\ \mathrm{N\,m^2\,kg^{-2}} \times 6.0\times10^{24}\ \mathrm{kg}}{2.66\times10^{7}\ \mathrm{m}}} = 3.88\times10^{3}\ \mathrm{m\,s^{-1}}$ $T = \frac{2\pi\times2.66\times10^{7}\ \mathrm{m}}{3.88\times10^{3}\ \mathrm{m\,s^{-1}}} = 43100\,\mathrm{s}$		
6(b)	Communications satellites must be in the same position in sky at all times **Or** communications satellites must be in a geostationary orbit	**(1)**	
	(So) communications satellites must rotate at the same rate as the Earth **Or** communications satellites must have same angular velocity as the Earth **Or** communications satellites must have same period as the Earth **Or** communications satellites must be in geosynchronous orbits	**(1)**	**2**
6(c)	The radius of the GPS satellite orbit is smaller	**(1)**	

	The orbit of the communications satellite must be in an equatorial plane **(1)** [Converse accepted for both marks. Do not credit references to velocity or period]	**2**
	Total for question	**8**