Question Number	Answer		Mark
16(a)(i)	Use of $F = \frac{GMm}{r^2}$ **with** $F = m\omega^2 r$	(1)	
	Re-arrangement with $\omega = \frac{2\pi}{T}$ to obtain $T^2 = \frac{(2\pi)^2}{GM} r^3$	(1)	
	Statement that G, M (and π) are constants, so $T^2 \propto r^3$ (dependent upon MP2)	(1)	
	OR		
	Use of $F = \frac{GMm}{r^2}$ **with** $F = \frac{mv^2}{r}$	(1)	
	Re-arrangement with $v = \frac{2\pi r}{T}$ to obtain $T^2 = \frac{(2\pi)^2}{GM} r^3$	(1)	
	Statement that G, M (and π) are constants, so $T^2 \propto r^3$ (dependent upon MP2)	(1)	**3**
	<u>Example of calculation</u> $\frac{GMm}{r^2} = m\omega^2 r$ $\frac{GM}{r^2} = \left(\frac{2\pi}{T}\right)^2 r$ $T^2 = \frac{(2\pi)^2}{GM} r^3$ $\therefore T^2 \propto r^3$		

16(a)(ii)	Use of $T^2 \propto r^3$ T_J = 142 months (11.9 years) Use of $\omega = \frac{\theta}{t}$ and $\omega = \frac{2\pi}{T}$ Calculation of time elapsed for planets to be in opposition Time between opposition is 13.1 months, with an appropriate conclusion (dependent upon MP4) <u>Example of calculation</u> $\left(\frac{T_J}{T_E}\right)^2 = \left(\frac{r_J}{r_E}\right)^3$ $\left(\frac{T_J}{1\text{ year}}\right)^2 = \left(\frac{7.8 \times 10^{11}\text{ m}}{1.5 \times 10^{11}\text{ m}}\right)^3$ $T_J = 12\text{ months} \times \sqrt{\left(\frac{7.8 \times 10^{11}\text{ m}}{1.5 \times 10^{11}\text{ m}}\right)^3} = 142\text{ months}$ At the next opposition Earth will have done one more orbit than Jupiter plus whatever fraction of an orbit Jupiter has completed. If t is the time to next opposition, both planets will have the same angular displacement, so equating $\theta = 2\pi\, t/T$ for both planets where for Earth the time is (t -12). $\frac{2\pi\text{ rad }(t-12)\text{ month}}{12\text{ month}} = \frac{2\pi\text{ rad } t}{142\text{ month}}\ \therefore t = 13.1\text{ month}$	(1) (1) (1) (1) (1)	5
16(b)	Use of $V = (-)\frac{GM}{r}$ Use of $\Delta V \times m$ $\Delta E_{grav} = 3.3 \times 10^{34}$ J <u>Example of calculation</u> $\Delta V = -GM\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$ $\Delta V = -6.67 \times 10^{-11}\text{ N m}^2\text{ kg}^{-2} \times 2.0 \times 10^{30}\text{kg} \times \left(\frac{1}{8.2 \times 10^{11}\text{ m}} - \frac{1}{7.4 \times 10^{11}\text{ m}}\right)$ $\Delta V = 1.76 \times 10^7\text{ J kg}^{-1}$ $\therefore \Delta E_{grav} = 1.76 \times 10^7\text{ J kg}^{-1} \times 1.9 \times 10^{27}\text{ kg} = 3.34 \times 10^{34}\text{ J}$	(1) (1) (1)	3
	Total for question 16		**11**