1)

1	a	i	force per unit mass ✓ a vector quantity ✓	2	Accept force on 1 kg (or a unit mass).
1	a	ii	force on body of mass m is given by $F = \frac{GMm}{(R+h)^2}$ ✓ gravitational field strength $g\left(= \frac{F}{m}\right) = \frac{GM}{(R+h)^2}$ ✓	2	For both marks to be awarded, correct symbols must be used for *M* and *m*.
1	b	i	$F\left(= \frac{GMm}{(R+h)^2}\right) = \frac{6.67\times10^{-11}\times5.98\times10^{24}\times2520}{((6.37\times10^6)+(1.39\times10^7))^2}$ ✓ $= 2.45 \times 10^3$ (N) ✓ to **3SF** ✓	3	1st mark: all substituted numbers must be to at least 3SF. If 1.39×10^7 is used as the complete denominator, treat as AE with ECF available. 3rd mark: **SF mark is independent**.
1	b	ii	$F = m\omega^2(R+h)$ gives $\omega^2 = \frac{2450}{2520\times2.03\times10^7}$ ✓ from which $\omega = 2.19 \times 10^{-4}$ (rad s^{-1}) ✓ time period $T\left(= \frac{2\pi}{\omega}\right) = \frac{2\pi}{2.19\times10^{-4}}$ **or** $= 2.87 \times 10^4$ s ✓ [**or** $F = \frac{mv^2}{R+h}$ gives $v^2 = \frac{2.45\times10^3\times((6.37\times10^6)+(13.9\times10^6))}{2520}$ ✓ from which $v = 4.40 \times 10^3$ (m s^{-1}) ✓ time period $T\left(= \frac{2\pi(R+h)}{v}\right) = \frac{2\pi\times2.03\times10^7}{4.40\times10^3}$ **or** $= 2.87 \times 10^4$ s ✓] [**or** $T^2 = \frac{4\pi^2(R+h)^3}{GM}$ ✓ $= \frac{4\pi^2((6.37\times10^6)+(13.9\times10^6))^3}{6.67\times10^{-11}\times5.98\times10^{24}}$ ✓ gives time period $T = 2.87 \times 10^4$s ✓] $= \frac{2.87\times10^4}{3600} = 7.97$ (hours) ✓ number of transits in 1 day $= \frac{24}{7.97} = 3.01$ (≈ 3) ✓	5	Allow ECF from wrong *F* value in (b)(i) but mark to max 4 (because final answer won't agree with value to be *shown*). First 3 marks are for determining time period (or frequency). Last 2 marks are for relating this to the number of transits. Determination of $f = 3.46 \times 10^{-5}$ (s^{-1}) is equivalent to finding *T* by any of the methods.
1	c		acceptable use ✓ satisfactory explanation ✓ e.g. monitoring weather **or** surveillance: whole Earth may be scanned **or** Earth rotates under orbit **or** information can be updated regularly **or** communications: limited by intermittent contact **or** gps: several satellites needed to fix position on Earth	2	Any reference to equatorial satellite should be awarded 0 marks.

2)

a		work done (**or** energy required) per unit mass ✓ in moving a mass from infinity to the point ✓	2

b	i	ΔV (= –1.3 – (–62.6)) = 61.3 (MJ kg^{-1}) ✓ energy required (= $m\Delta V$) = $1.2 \times 10^4 \times 61.3 \times 10^6$ = 7.4×10^{11} (J) ✓ to **2SF** only ✓	3

b	ii	beyond **X**, gravitational potential decreases as Moon is approached [**or** gravitational field (or force) of Moon will now attract the probe] ✓	1

b	iii	distance from Earth to Sun » distance from Earth to Moon ✓ <u>change in</u> V_{sun} (**or** in g_{sun}) over Earth to Moon distance is negligible ✓ value of V_{sun} (**or** g_{sun}) is not (significantly) changed by relative positions of E+M ✓	max 2

c		**The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.** The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria. **High Level (Good to excellent): 5 or 6 marks** The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.	Max 6

The candidate discusses the forces of attraction due to the Earth and due to the Moon, appreciates that they act in opposite directions, and that the former is generally much greater than the latter.
The candidate discusses the resultant gravitational field between E and M, understands that there is a 'neutral' point at which the resultant field strength is zero and that this point is much closer to M than E. It is recognised that this point has to be passed for the journey to be completed in either direction.
There is a discussion of gravitational potential, in which it is pointed out that the resultant potential rises to a maximum at the neutral point. There is a reference to the much greater amount of work that has to be done on the spacecraft to reach this point from E than from M.

Intermediate Level (Modest to adequate): 3 or 4 marks
The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The candidate discusses the forces of attraction due to the Earth and the Moon, and appreciates either that they act in opposite directions, or that the former is much greater than the latter. There is a relevant discussion of field strength or potential. The significance of the neutral point may not be appreciated. The candidate is likely to make some reference to the work that has to be done on the spacecraft.

Low Level (Poor to limited): 1 or 2 marks
The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.
The candidate has some understanding of the forces that act during the journey but makes very limited references to the significance of the variation of the gravitational field. Discussions of gravitational potential and/or work done are likely to be superficial and may be absent.

The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences in this case.

Gravitational forces
- The spacecraft experiences gravitational attractions to both the Earth and the Moon during its journey.
- These forces pull in opposite directions on the spacecraft.
- Because E is much more massive than M, for most of the outward journey the force towards E is greater than that towards M.
- Only in the later stages of the outward journey is the

		resultant force directed towards M. • On the return journey the resultant force is predominantly towards E. **Gravitational field strength** • During the outward journey E's gravitational field becomes weaker and M's becomes stronger. • The resultant field is the vector sum of those due to E and M separately. • A point (X) is reached at which these two component fields are equal and opposite, giving zero resultant. • X is much closer to M than to E. • Once X has been passed, the spacecraft will be attracted to M by M's gravitational field. • On the return journey the spacecraft will 'fall' to E once it is beyond X. **Gravitational potential** • The gravitational potential due E increases (i.e. becomes less negative) as the spacecraft moves away from E. • The resultant gravitational potential is the (scalar) sum of those due to E and M separately. • At X the gravitational potential reaches a maximum value before decreasing as M is approached. • In order to reach M on the outward journey, the spacecraft has to be given at least enough energy to reach X, and vice-versa for the return. • Much more work is needed to move the spacecraft from E to X than from M to X, since a larger force has to be overcome over a larger distance.	

3)

(a)		force of attraction between two point masses (or particles) ✓ proportional to product of masses ✓ inversely proportional to square of distance between them ✓ **[alternatively** quoting an equation, $F = \frac{GM_1M_2}{r^2}$ with all terms defined ✓ reference to point masses (or particles) **or** r is distance between centres ✓ F identified as an attractive force ✓]	**max 2**
(b)	(i)	mass of larger sphere $M_L (= \frac{4}{3}\pi r^3 \rho) = \frac{4}{3}\pi \times (0.100)^3 \times 11.3 \times 10^3$ ✓ = 47(.3) (kg) ✓ **[alternatively** use of $M \propto r^3$ gives $\frac{M_L}{0.74} = \left(\frac{100}{25}\right)^3$ ✓ (= 64) and $M_L = 64 \times 0.74 = 47(.4)$ (kg) ✓]	**2**
(b)	(ii)	gravitational force F $\left(= \frac{GM_L.M_S}{x^2}\right) = \frac{6.67 \times 10^{-11} \times 47.3 \times 0.74}{0.125^2}$ ✓ $= 1.5 \times 10^{-7}$ (N) ✓	**2**
(c)		for the spheres, mass ∝ volume (or ∝ r^3, or $M = \frac{4}{3}\pi r^3 \rho$) ✓ mass of either sphere would be 8 × greater (378 kg, 5.91 kg) ✓ this would make the force 64 × greater ✓ but separation would be doubled causing force to be 4 × smaller ✓ net effect would be to make the force (64/4) = 16 × greater ✓ (ie 2.38×10^{-6} N)	**max 4**
		Total	**10**

4)

a	i	$\left(T \propto r^{3/2} \text{ or } \frac{T_E}{T_P} = \left(\frac{r_E}{r_P}\right)^{3/2} \text{ gives}\right) \quad \frac{60 \times 24}{105} = \left(\frac{r_E}{7370}\right)^{3/2}$ ✓ from which $\frac{r_E}{7370} = \left(\frac{60 \times 24}{105}\right)^{2/3} = 5.73$ and r_E (= 5.73 × 7370) = 42 200 (km) ✓ height above surface = 42 200 – 6370 = 35 800 or 35 900 (km) ✓ answer to **3SF** only ✓ [**or** Newton's law approach for 1st two marks: $\left(\frac{GMm}{r^2} = m\omega^2 r \text{ and } \omega = \frac{2\pi}{T}\right)$ give $r^3 \left(= \frac{GMT^2}{4\pi^2}\right)$ $\therefore r_E^3 = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times (24 \times 60 \times 60)^2}{4\pi^2}$ ✓ (=7.54 × 10^{22}) from which r_E = 42 200 (km) ✓]	4	Full solution derived from Newton's law of gravitation is acceptable for all 4 marks. For 3rd mark, final answer **must** be expressed in km. **3SF** mark is independent.

a	ii	centripetal force ($=m\omega^2 r$) = $\frac{650\times 4\pi^2 \times 7.37\times 10^6}{(105\times 60)^2}$ ✓ = 4800 (4760) (N) ✓ [or centripetal force $\left(=\frac{mv^2}{r}\right)$ and $v=\frac{2\pi r}{T}=\frac{2\pi\times 7.37\times 10^6}{105\times 60}$ gives v = 7350 (m s^{-1}) and centripetal force = $\frac{650\times 7350^2}{7.37\times 10^6}$ ✓ = 4800 (4760) (N) ✓] [or centripetal force $\left(=\frac{GMm}{r^2}\right)=\frac{6.67\times 10^{-11}\times 5.98\times 10^{24}\times 650}{(7.37\times 10^6)^2}$ ✓ = 4800 (4770) (N) ✓]	2	If **both** T and r values for the **geosynchronous** satellite are substituted, award 0 marks for (ii). If only **one** correct T or r value for the **polar** satellite is substituted, mark (ii) to max 1.
b		**The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.** The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria. **High Level (Good to excellent): 5 or 6 marks** The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question. *The candidate gives a comprehensive comparison of the principal features of the satellite orbits and explains the consequences for the uses of the two types of satellites. There are clear statements showing good understanding of why the polar satellite is suitable for monitoring, and of why the geosynchronous satellite is useful for communications.* **Intermediate Level (Modest to adequate): 3 or 4 marks** The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate. *The candidate's comparison of the principal features of the orbits is less complete and the consequences for the uses of satellites in them are less well understood. The candidate has an acceptable appreciation of why the polar satellite is suitable for monitoring, and of why the geosynchronous satellite is useful for communications.* **Low Level (Poor to limited): 1 or 2 marks** The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.	max 6	**Four** aspects must be considered in a high level answer:- Features of polar orbit. Features of geosynchronous orbit. Why polar orbit is suitable for monitoring. Why geosynchronous orbit is suitable for communication.

		The candidate has a much weaker knowledge of the principal features of the orbits and very limited knowledge of consequences for the uses of satellites in them. Understanding of why the polar satellite is suitable for monitoring, and why the geosynchronous satellite is suitable for communications, is limited or absent. **The explanation expected in a competent answer should include a coherent selection of the following points.** ***Low polar orbit*** • Orbital period is a few hours • Earth rotates relative to the orbit • Many orbits with different radii and periods are possible • Orbit height is less than geosynchronous satellite • Speed is greater than that of geosynchronous satellite • Satellite scans the whole surface of the Earth • Applications: surveillance of conditions/installations on Earth, mapping, weather observations, environmental monitoring • Gives access to every point on Earth's surface every day • Can collect data from regions inaccessible to man • Contact with transmitting/receiving aerial is intermittent • Aerial is likely to need a tracking facility • Lower signal strength required than that for geosynchronous satellite ***Geosynchronous orbit above Equator*** • Orbital period matches Earth's rotational period exactly • Satellite maintains same position relative to Earth • Only one particular orbit radius is possible • Travels west to east above Equator (in same direction as Earth's rotation) • Orbit height is greater than polar orbit satellite • Speed is less than that of polar orbiting satellite • Scans a restricted (and fixed) area of the Earth's surface only • Applications: telecommunications generally, cable and satellite TV, radio, digital information, etc. • Satellite is in continuous contact with transmitting/receiving aerial • Aerial can be in a fixed position		

5)

(a)	(i)	relationship between them is $E_p = mV$ (allow $\Delta E_p = m\Delta V$) [or V is energy per unit mass (or per kg)] ✓	1
(a)	(ii)	value of E_p is doubled ✓ value of V is unchanged ✓	2
(b)	(i)	use of $V = -\frac{GM}{r}$ gives $r_A = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{12.0 \times 10^6}$ ✓ $= 3.3(2) \times 10^7$ (m) ✓	2
(b)	(ii)	since $V \propto (-)\frac{1}{r}\left(or\ \frac{r_A}{r_B} = \frac{V_B}{V_A} = \frac{36.0}{12.0} = 3\right)$ $r_B = \frac{3.32 \times 10^7 m}{3}$ ✓ (which is ≈ 1.1×10^4 km)	1
(b)	(iii)	centripetal acceleration $g_B = \frac{GM}{{r_B}^2} = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(1.11 \times 10^7)^2}$ ✓ [allow use of 1.1×10^7 m from (b) (ii)] = 3.2 (m s^{-2}) ✓ [**alternatively**, since $g_B = (-)\frac{V_B}{V_a}$, $g_B = \frac{36.0 \times 10^6}{1.11 \times 10^7}$ ✓ = 3.2 (m s^{-2}) ✓]	2
(b)	(iv)	use of $\Delta E_p = m\Delta V$ gives $\Delta E_p = 330 \times (-12.0 - (-36.0)) \times 10^6$ ✓ (which is 7.9×10^9 J or ≈ 8 GJ)	1
(c)		g is not constant over the distance involved (**or** g decreases as height increases **or** work done per metre decreases as height increases **or** field is radial and/or not uniform) ✓	1
		Total	**10**