M1. (a) work done/energy change (against the field) per unit mass **(1)**
when moved from infinity to the point **(1)**

2

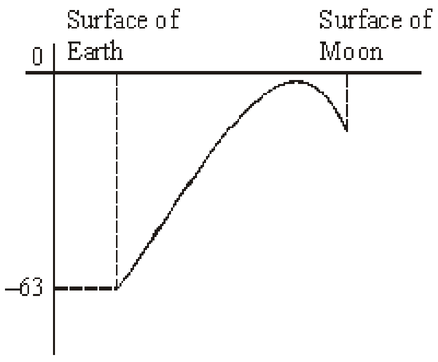
(b) $V_E = -\frac{GM_E}{R_E}$ and $V_M = -\frac{GM_M}{R_M}$ **(1)**

$V_M = -G \times \frac{M_E}{81} \times \frac{3.7}{R_E} = \frac{3.7}{81} V_E$ **(1)**

$= 4.57 \times 10^{-2} \times (-63) = -2.9$ MJ kg^{-1} **(1)** (2.88 MJ kg^{-1})

3

(c)



limiting values ($-63, -V_M$) on correctly curving line **(1)**
rises to value close to but below zero **(1)**
falls to Moon **(1)**
from point much closer to M than E **(1)**

max 3

[8]

M2. (a) force of attraction between two point masses (or particles) **(1)**

proportional to product of masses **(1)**

inversely proportional to square of distance between them **(1)**

[**alternatively**

quoting an equation, $F = \frac{GM_1M_2}{r^2}$ with all terms defined **(1)**

reference to point masses (or particles) **or** *r* is distance between centres **(1)**

F identified as an attractive force **(1)**]

max 2

(b) (i) mass of larger sphere M_L (= $\frac{4}{3}\pi r^3\rho$) = $\frac{4}{3}$ π × (0.100)^3 × 11.3 × 10^3 **(1)**
= 47(.3) (kg) **(1)**

[**alternatively**

use of $M \propto r^3$ gives $\frac{M_L}{0.74} = \left(\frac{100}{25}\right)^3$ **(1)** (= 64)
and M_L = 64 × 0.74 = 47(.4) (kg) **(1)**]

2

(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)**
= 1.5 × 10^{-7} (N) **(1)**

2

(c) for the spheres, mass ∝ volume (or ∝ r^3, or $M = \frac{4}{3}\pi r^3\rho$) **(1)**

mass of either sphere would be 8 × greater (378 kg, 5.91 kg) **(1)**

this would make the force 64 × greater **(1)**

but separation would be doubled causing force to be 4 × smaller **(1)**

net effect would be to make the force (64/4) = 16 × greater **(1)**
(ie 2.38 × 10^{-6} N)

max 4

[10]

M3. (a) orbits (westwards) over Equator **(1)**

maintains a fixed position relative to surface of Earth **(1)**

period is 24 hrs (1 day) or same as for Earth's rotation **(1)**

offers uninterrupted communication between transmitter and receiver **(1)**

steerable dish not necessary **(1)**

Max 3

(b) (i) $G\frac{Mm}{(R+h)^2} = m\omega^2(R+h)$ **(1)**

use of $\omega = \frac{2\pi}{T}$ **(1)**

(ii) gives $\frac{GM}{(R+h)^3} = \frac{4\pi^2}{T^2}$, hence result **(1)**

(iii) limiting case is orbit at zero height i.e. h = 0 **(1)**

$T^2 = \left(\frac{4\pi^2 R^3}{GM}\right) = \frac{4\pi^2 \times (6.4\times10^6)^3}{6.67\times10^{-11}\times6.0\times10^{24}}$ **(1)**

T = 5090 s **(1)** (= 85 min)

6

(c) speed increases **(1)**

loses potential energy but gains kinetic energy **(1)**

[or because $v^2 \propto \frac{1}{r}$ from $\frac{GMm}{r^2} = \frac{mv^2}{r}$]

[or because satellite must travel faster to stop it falling inwards when gravitational force increases]

2

[11]

M4. (a) period is 24 hours (or equal to period of Earth's rotation) **(1)**

remains in fixed position relative to surface of Earth **(1)**

equatorial orbit **(1)**

same *angular* speed as Earth (or equatorial surface) **(1)**

max 2

(b) (i) $\frac{GMm}{r^2} = m\omega^2 r$ **(1)**

$T = \frac{2\pi}{\omega}$ **(1)**

$r\left(=\frac{GMT^2}{4\pi^2}\right) = \left(\frac{6.7\times10^{-11}\times6.0\times10^{24}\times(24\times3600)^2}{4\pi^2}\right)^{1/3}$ **(1)**

(gives $r = 42.3\times10^3$ km)

(ii) $\Delta V = GM\left(\frac{1}{R} - \frac{1}{r}\right)$ **(1)**

$= 6.67 \times 10^{-11} \times 6 \times 10^{24} \times \left(\frac{1}{6.4 \times 10^6} - \frac{1}{4.23 \times 10^7}\right)$

$= 5.31 \times 10^7$ (J kg^{-1}) **(1)**

$\Delta E_P = m\Delta V$ ($= 750 \times 5.31 \times 10^7$) $= 3.98 \times 10^{10}$ J **(1)**

(allow ecf for value of ΔV)

6

(c) (i) signal would be too weak at large distance **(1)**

(or large aerial needed to detect/transmit signal, or any other acceptable reason)

the signal spreads out more the further it travels **(1)**

(ii) **for** road pricing would reduce congestion

stolen vehicles can be tracked and recovered

uninsured/unlicensed vehicles can be apprehended

against road pricing would increase cost of motoring

possibility of state surveillance/invasion of privacy

(1)(1) any 2 valid points (must be for both for **or** against)

4

[12]

M5. (a) (i) h ($= ct$) ($= 3.0 \times 10^8 \times 68 \times 10^{-3}$) $= 2.0(4) \times 10^7$ m **(1)**

(ii) $g = (-)\frac{GM}{r^2}$ **(1)**

r ($= 6.4 \times 10^6 + 2.04 \times 10^7$) $= 2.68 \times 10^7$ (m) **(1)**

(allow C.E. for value of h from (i) for first two marks, but not 3rd)

$g = \frac{6.67 \times 10^{-11} \times 6.0 \times 10^{24}}{(2.68 \times 10^7)^2}$ **(1)** ($= 0.56$ N kg^{-1})

4

(b) (i) $g = \frac{v^2}{r}$ **(1)**

$v = [0.56 \times (2.68 \times 10^7)]^{½}$ **(1)**

$= 3.9 \times 10^3$ m s^{-1} **(1)** (3.87×10^3 m s^{-1})

(allow C.E. for value of *r* from a(ii))

[or $v^2 = \frac{GM}{r} =$ **(1)**

$$v = \left(\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{2.68 \times 10^7}\right)^{1/2}$$ **(1)**

$= 3.9 \times 10^3$ m s^{-1} **(1)**]

(ii) $T\left(= \frac{2\pi r}{v}\right) = \frac{2\pi \times 2.68 \times 10^7}{3.87 \times 10^3}$ **(1)**

$= 4.3(5) \times 10^4$ s **(1)** (12.**(1)** hours)

(use of $v = 3.9 \times 10^3$ gives $T = 4.3$**(1)** $\times 10^4$ s = 12.0 hours)

(allow C.E. for value of *v* from (I)

[alternative for (b):

(i) $v\left(\frac{2\pi r}{T}\right) = \frac{2\pi \times 2.68 \times 10^7}{4.36 \times 10^4}$ **(1)**

$= 3.8(6) \times 10^3$ m s^{-1} **(1)**]

(allow C.E. for value of *r* from (a)(ii) and value of *T*)

(ii) $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$ **(1)**

$\left(= \frac{4\pi^2}{6.67 \times 10^{-11} \times 6.0 \times 10^{24}} \times (2.68 \times 10^7)^3\right) = (1.90 \times 10^9$ **(s^2) (1)**

$T = 4.3(6) \times 10^4$ s **(1)**

5

[9]