Q1. (a) Explain what is meant by the *gravitational potential* at a point in a gravitational field.

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(2)

(b) Use the following data to calculate the gravitational potential at the surface of the Moon.

mass of Earth = 81 × mass of Moon
radius of Earth = 3.7 × radius of Moon
gravitational potential at surface of the Earth = –63 MJ kg^{-1}

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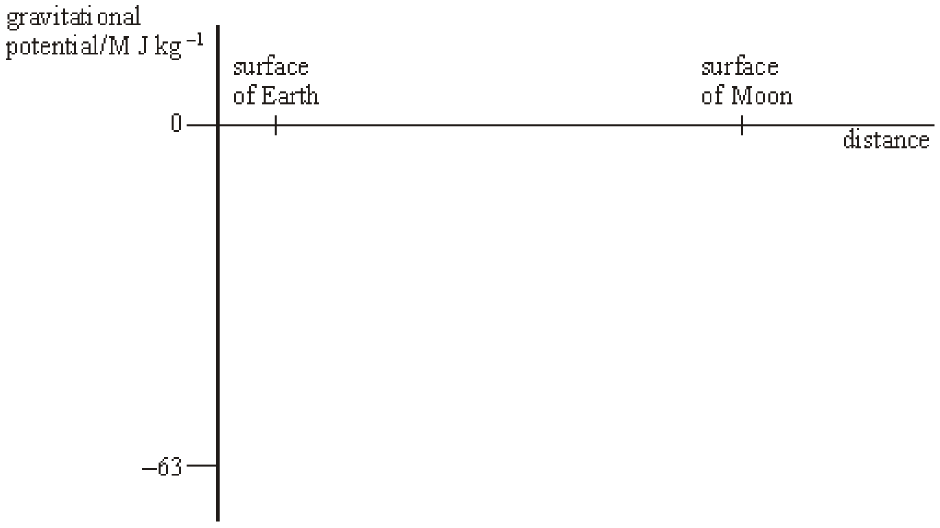
(3)

(c) Sketch a graph on the axes below to indicate how the gravitational potential varies with distance along a line outwards from the surface of the Earth to the surface of the Moon.



(3)
(Total 8 marks)

Q2. (a) State Newton's law of gravitation.

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(2)

(b) In 1798 Cavendish investigated Newton's law by measuring the gravitational force between two unequal uniform lead spheres. The radius of the larger sphere was 100 mm and that of the smaller sphere was 25 mm.

(i) The mass of the smaller sphere was 0.74 kg. Show that the mass of the larger sphere was about 47 kg.

density of lead = 11.3×10^3 kg m^{-3}

(2)

(ii) Calculate the gravitational force between the spheres when their surfaces were in contact.

answer = ... N

(2)

(c) Modifications, such as increasing the size of each sphere to produce a greater force between them, were considered in order to improve the accuracy of Cavendish's experiment. Describe and explain the effect on the calculations in part (b) of doubling the radius of both spheres.

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(4)
(Total 10 marks)

Q3. (a) Artificial satellites are used to monitor weather conditions on Earth, for surveillance and for communications. Such satellites may be placed in a *geo-synchronous* orbit or in a low polar orbit.

Describe the properties of the geo-synchronous orbit and the advantages it offers when a satellite is used for communications.

You may be awarded marks for the quality of written communication in your answer.

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(3)

(b) A satellite of mass m travels at angular speed ω in a circular orbit at a height h above the surface of a planet of mass M and radius R.

(i) Using these symbols, give an equation that relates the gravitational force on the satellite to the centripetal force.

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(ii) Use your equation from part (b)(i) to show that the orbital period, T, of the satellite is given by

$$T^2 = \frac{4\pi^2 (R+h)^3}{GM}$$

....

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....

(iii) Explain why the period of a satellite in orbit around the Earth cannot be less than 85 minutes. Your answer should include a calculation to justify this value.

mass of the Earth = 6.00×10^{24} kg

kg radius of the Earth = 6.40×10^{6} m

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(6)

(c) Describe and explain what happens to the speed of a satellite when it moves to an orbit that is closer to the Earth.

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(2)
(Total 11 marks)

Q4. Communications satellites are usually placed in a *geo-synchronous* orbit.

(a) State two features of a geo-synchronous orbit.

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(2)

(b) The mass of the Earth 6.00×10^{24} kg and its mean radius is 6.40×10^{6} m.

(i) Show that the radius of a geo-synchronous orbit must be 4.23×10^{7} m,

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(ii) Calculate the increase in potential energy of a satellite of 750 kg when it is raised from the Earth's surface into a geo-synchronous orbit.

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(6)

(c) Satellites in orbits nearer the Earth than geo-synchronous satellites may be used in the future to track road vehicles.

(i) State and explain **one** reason why geo-synchronous satellites would not be suitable for such a purpose.

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(ii) Give **two** points you would make in arguing for or against tracking road vehicles. Explain your answers.

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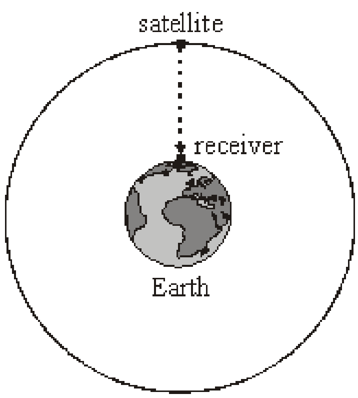
(4)
(Total 12 marks)

Q5. The Global Positioning System (GPS) is a system of satellites that transmit radio signals which can be used to locate the position of a receiver anywhere on Earth.



(a) A receiver at sea level detects a signal from a satellite in a circular orbit when it is passing directly overhead a hown in the diagram above

(i) The microwave signal is received 68 ms after it was transmitted from the satellite. Calculate the height of the satellite.

....

....

(ii) Show that the gravitational field strength of the Earth at the position of the satellite is $0.56\ \text{N kg}^{-1}$.

mass of the Earth	=	6.0×10^{24} kg
mean radius of the Earth	=	6400 km

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(4)

(b) For the satellite in this orbit, calculate

(i) its speed,

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(ii) its time period.

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(5)
(Total 9 marks)

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

2

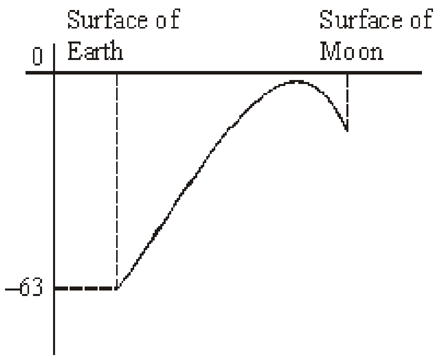
(b) $V_E = -\frac{GM_E}{R_E}$ and $V_M = -\frac{GM_M}{R_M}$ **(1)**

$V_M = -G \times \frac{M_E}{81} \times \frac{3.7}{R_E} = \frac{3.7}{81} V_E$ **(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 $\left(= \frac{GM_L M_S}{x^2}\right) = \frac{6.67\times10^{-11}\times47.3\times0.74}{0.125^2}$ **(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) $G\frac{Mm}{(R+h)^2} = mw^2(R+h)$ **(1)**

use of $w = \frac{2\pi}{T}$ **(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 = 42.3×10^3 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 × 5.31 × 10^{7}) = 3.98 ×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 × 10^{8} × 68 × 10^{-3}) = 2.0(4) × 10^{7} m **(1)**

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

r (= 6.4 × 10^{6} + 2.04 × 10^{7}) = 2.68 × 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]