

1

Read the following passage and answer the questions that follow

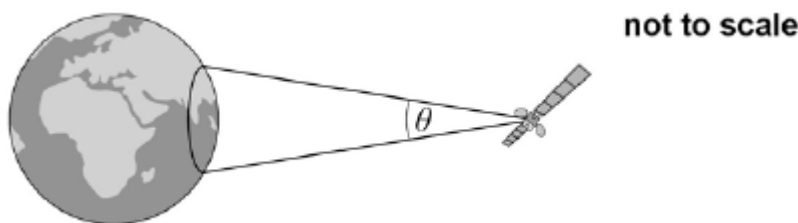
Satellites used for telecommunications are usually in geostationary orbits. Using suitable dishes to transmit the signals, communication over most of the Earth's surface is possible at all times using only 3 satellites.

Satellites used for meteorological observations and observations of the Earth's surface are usually in low Earth orbits. Polar orbits, in which the satellite passes over the North and South Poles of the Earth, are often used.

5

One such satellite orbits at a height of about 12 000 km above the Earth's surface circling the Earth at an angular speed of $2.5 \times 10^{-4} \text{ rad s}^{-1}$. The microwave signals from the satellite are transmitted using a dish and can only be received within a limited area, as shown in the image below.

10



The signal of wavelength λ is transmitted in a cone of angular width θ , in radian, given by

$$\theta = \frac{\lambda}{d}$$

where d is the diameter of the dish.

The satellite transmits a signal at a frequency of 1100 MHz using a 1.7 m diameter dish. As this satellite orbits the Earth, the area over which a signal can be received moves. There is a maximum time for which a signal can be picked up by a receiving station on Earth.

15

- (a) Describe **two** essential features of the orbit needed for the satellite to appear geostationary.

(2)

- (b) Calculate the time taken, in s, for the satellite mentioned in line 7 in the passage to complete one orbit around the Earth.

time taken = _____ s

(1)

- (c) Show that at a distance of 12 000 km from the satellite the beam has a width of 1900 km.

(3)

- (d) The satellite is in a polar orbit and passes directly over a stationary receiver at the South Pole.

Show that the receiver can remain in contact with the satellite for no more than about 20 minutes each orbit.

radius of the Earth = 6400 km

maximum time = _____ minute

(3)

- (e) The same satellite is moved into a higher orbit.

Discuss, with reasons, how this affects the signal strength and contact time for the receiver at the South Pole.

(4)

(Total 13 marks)

2

A geosynchronous satellite is in a constant radius orbit around the Earth. The Earth has a mass of 6.0×10^{24} kg and a radius of 6.4×10^6 m.

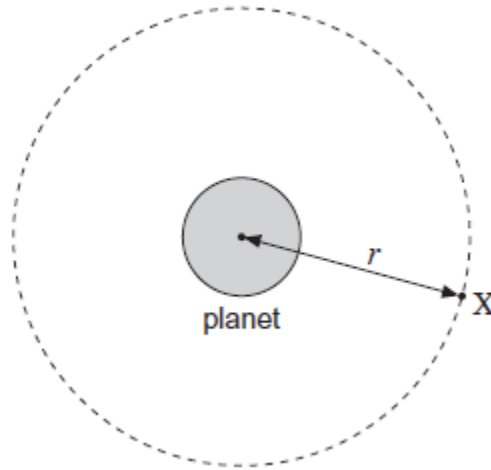
What is the height of the satellite above the Earth's surface?

- A 1.3×10^7 m
- B 3.6×10^7 m
- C 4.2×10^7 m
- D 4.8×10^7 m

(Total 1 mark)

3

A satellite X is in a circular orbit of radius r about the centre of a spherical planet of mass M .



Which line, **A** to **D**, in the table gives correct expressions for the centripetal acceleration a and the speed v of the satellite?

	Centripetal acceleration a	Speed v
A	$\frac{GM}{2r}$	$\sqrt{\frac{GM}{2r}}$
B	$\frac{GM}{2r}$	$\sqrt{\frac{GM}{r}}$
C	$\frac{GM}{r^2}$	$\sqrt{\frac{GM}{2r}}$
D	$\frac{GM}{r^2}$	$\sqrt{\frac{GM}{r}}$

(Total 1 mark)

4

A satellite orbiting the Earth moves to an orbit which is closer to the Earth.

Which line, **A** to **D**, in the table shows correctly what happens to the speed of the satellite and to the time it takes for one orbit of the Earth?

	Speed of satellite	Time For One Orbit Of Earth
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

(Total 1 mark)

5

- (a) Explain why astronauts in an orbiting space vehicle experience the sensation of weightlessness.

(2)

- (b) A space vehicle has a mass of 16 800 kg and is in orbit 900 km above the surface of the Earth.

mass of the Earth = 5.97×10^{24} kg

radius of the Earth = 6.38×10^6 m

- (i) Show that the orbital speed of the vehicle is approximately 7400 m s^{-1} .

(4)

- (ii) The space vehicle moves from the orbit 900 km above the Earth's surface to an orbit 400 km above the Earth's surface where the orbital speed is 7700 m s^{-1} .

Calculate the total change that occurs in the energy of the space vehicle.
Assume that the vehicle remains outside the atmosphere after the change of orbit.
Use the value of 7400 m s^{-1} for the speed in the initial orbit.

change in energy _____ J

(4)

(Total 10 marks)

6

- (a) (i) State what is meant by the term **escape velocity**.

(1)

- (ii) Show that the escape velocity, v , at the Earth's surface is given by $v = \sqrt{\frac{2GM}{R}}$

where M is the mass of the Earth
and R is the radius of the Earth.

(2)

- (iii) The escape velocity at the Moon's surface is $2.37 \times 10^3 \text{ m s}^{-1}$ and the radius of the Moon is $1.74 \times 10^6 \text{ m}$.

Determine the mean density of the Moon.

mean density _____ kg m^{-3}

(2)

- (b) State **two** reasons why rockets launched from the Earth's surface do **not** need to achieve escape velocity to reach their orbit.

(2)

(Total 7 marks)

7

- (a) (i) Define gravitational field strength and state whether it is a scalar or vector quantity.

(2)

- (ii) A mass m is at a height h above the surface of a planet of mass M and radius R . The gravitational field strength at height h is g . By considering the gravitational force acting on mass m , derive an equation from Newton's law of gravitation to express g in terms of M , R , h and the gravitational constant G .

(2)

- (b) (i) A satellite of mass 2520 kg is at a height of 1.39×10^7 m above the surface of the Earth. Calculate the gravitational force of the Earth attracting the satellite.
Give your answer to an appropriate number of significant figures.

force attracting satellite _____ N

(3)

- (ii) The satellite in part (i) is in a circular polar orbit. Show that the satellite would travel around the Earth three times every 24 hours.

(5)

- (c) State and explain **one** possible use for the satellite travelling in the orbit in part (ii).

(2)

(Total 14 marks)

8

Two satellites P and Q, of equal mass, orbit the Earth at radii R and $2R$ respectively. Which one of the following statements is correct?

- A P has less kinetic energy and more potential energy than Q.
- B P has less kinetic energy and less potential energy than Q.
- C P has more kinetic energy and less potential energy than Q.
- D P has more kinetic energy and more potential energy than Q.

(Total 1 mark)

9

The Earth moves around the Sun in a circular orbit with a radius of 1.5×10^8 km. What is the Earth's approximate speed?

- A $1.5 \times 10^3 \text{ms}^{-1}$
- B $5.0 \times 10^3 \text{ms}^{-1}$
- C $1.0 \times 10^4 \text{ms}^{-1}$
- D $3.0 \times 10^4 \text{ms}^{-1}$

(Total 1 mark)

10

Two satellites, P and Q, of the same mass, are in circular orbits around the Earth. The radius of the orbit of Q is three times that of P. Which one of the following statements is correct?

- A The kinetic energy of P is greater than that of Q.
- B The weight of P is three times that of Q.
- C The time period of P is greater than that of Q.
- D The speed of P is three times that of Q.

(Total 1 mark)

11

(a) Explain why the mass of an object is constant but its weight may change.

- (b) The table gives the gravitational potentials, V , at three different distances, r , from the centre of the Earth.

distance from centre of Earth r / km	gravitational potential $V / 10^7 \text{ J kg}^{-1}$
7500	-5.36
12500	-3.22
22500	-1.79

- (i) Explain why the gravitational potential at a point in a gravitational field is negative.

(2)

- (ii) Show that the data in the table are consistent with $V \propto r^{-1}$.

(3)

- (iii) A satellite of mass 450 kg is moved from an orbit of radius 7500 km around the Earth to an orbit of radius 12 500 km.

Use data from the table to show that the potential energy of the satellite increases, by about 10 GJ.

(2)

- (c) The kinetic energy of a 450 kg satellite orbiting the Earth with a radius of 7500 km is 12 GJ.

- (i) Calculate the kinetic energy of the 450 kg satellite when it is in an orbit of radius 12 500 km.

mass of the Earth = 6.0×10^{24} kg

kinetic energy _____ GJ

(4)

- (ii) Calculate the change in kinetic energy of the satellite when it moves into the higher orbit.

change in kinetic energy _____ GJ

(1)

- (iii) Calculate the **total** energy that has to be supplied to move the 450 kg satellite from an orbit of radius 7500 km to an orbit of radius 12 500 km.

total energy _____ GJ

(1)

(Total 16 marks)

12

The Hubble space telescope was launched in 1990 into a circular orbit near to the Earth. It travels around the Earth once every 97 minutes.

- (a) Calculate the angular speed of the Hubble telescope, stating an appropriate unit.

answer = _____

(3)

- (b) (i) Calculate the radius of the orbit of the Hubble telescope.

answer = _____ m

(3)

- (ii) The mass of the Hubble telescope is 1.1×10^4 kg. Calculate the magnitude of the centripetal force that acts on it.

answer = _____ N

(2)

(Total 8 marks)

13

As a comet orbits the Sun the distance between the comet and the Sun continually changes. As the comet moves towards the Sun this distance reaches a minimum value.

Which one of the following statements is **incorrect** as the comet approaches this minimum distance?

- A The potential energy of the comet increases.
- B The gravitational force acting on the comet increases.
- C The direction of the gravitational force acting on the comet changes.
- D The kinetic energy of the comet increases.

(Total 1 mark)

14

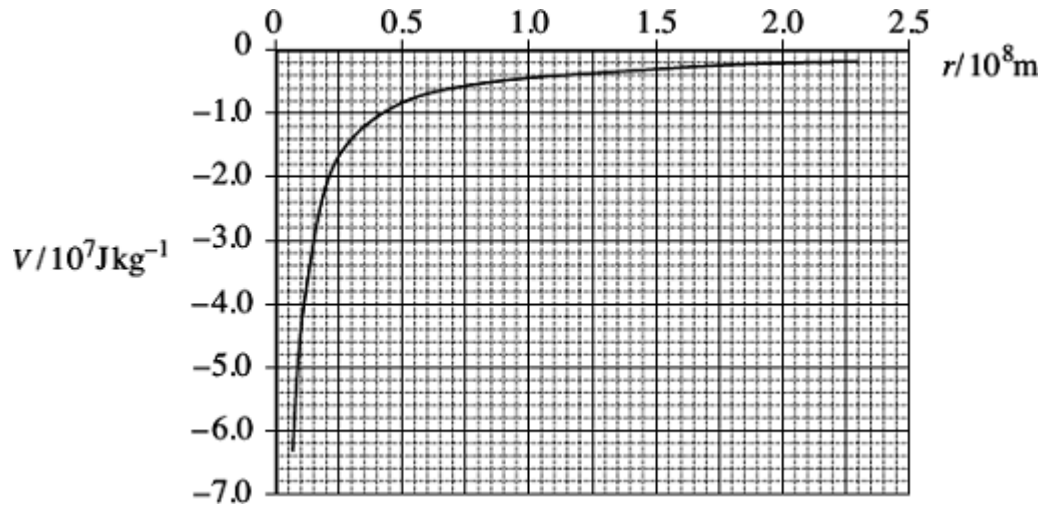
A satellite of mass m travels in a circular orbit of radius r around a planet of mass M . Which one of the following expressions gives the angular speed of the satellite?

- A $\sqrt{GMr}$
- B $\sqrt{Gmr}$
- C $\sqrt{\frac{Gm}{r^3}}$
- D $\sqrt{\frac{GM}{r^3}}$

(Total 1 mark)

15

The figure below shows the variation of gravitational potential, V , with distance from the centre of the Earth, r . The radius of the Earth is 6.4×10^6 m.



- (a) Explain why the V values are negative.

(3)

- (b) Use data from the graph to show that the mass of the Earth is approximately 6×10^{24} kg.

(3)

- (c) (i) Calculate the work done in raising a satellite of mass 2100 kg from the surface of the Earth to a height of 850 km above the surface of the Earth.

work done _____ J

(3)

- (ii) Calculate the change in the kinetic energy of the satellite when it moves from its 850 km orbit to one at a height of 700 km above the Earth's surface. Make it clear whether the change in kinetic energy is an increase or decrease.

kinetic energy change _____ J

(4)

- (iii) Without performing any further calculations explain how the change in kinetic energy relates to the change of the potential energy when the satellite's orbit alters as in part (c)(ii).

(2)

(Total 15 marks)

16

An artificial satellite of mass m is in a stable circular orbit of radius r around a planet of mass M . Which one of the following expressions gives the speed of the satellite?
 G is the universal gravitational constant.

A $\left(\frac{Gm}{r}\right)^{\frac{1}{2}}$

B $\left(\frac{GM}{r}\right)^{\frac{1}{2}}$

C $\frac{Gm}{r}$

D $\left(\frac{Gm}{r}\right)^{\frac{3}{2}}$

(Total 1 mark)

17

(a) State, in words, Newton's law of gravitation.

(3)

(b) By considering the centripetal force which acts on a planet in a circular orbit, show that $T^2 \propto R^3$, where T is the time taken for one orbit around the Sun and R is the radius of the orbit.

(3)

(c) The Earth's orbit is of mean radius 1.50×10^{11} m and the Earth's year is 365 days long.

(i) The mean radius of the orbit of Mercury is 5.79×10^{10} m. Calculate the length of Mercury's year.

(ii) Neptune orbits the Sun once every 165 Earth years.

Calculate the ratio $\frac{\text{distance from Sun to Neptune}}{\text{distance from Sun to Earth}}$.

(4)

(Total 10 marks)

18

(a) (i) State the relationship between the *gravitational potential energy*, E_p , and the *gravitational potential*, V , for a body of mass m placed in a gravitational field.

(1)

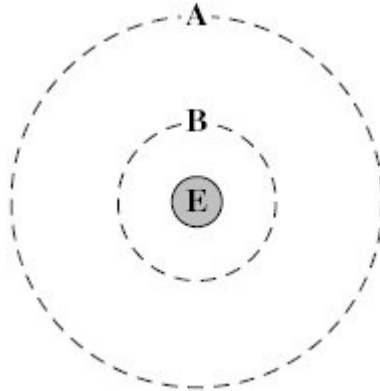
- (ii) What is the effect, if any, on the values of E_p and V if the mass m is doubled?

value of E_p _____

value of V _____

(2)

(b)



The diagram above shows two of the orbits, **A** and **B**, that could be occupied by a satellite in circular orbit around the Earth, **E**.

The gravitational potential due to the Earth of each of these orbits is:

orbit **A** $- 12.0 \text{ MJ kg}^{-1}$

orbit **B** $- 36.0 \text{ MJ kg}^{-1}$.

- (i) Calculate the radius, from the centre of the Earth, of orbit **A**.

answer = _____ m

(2)

- (ii) Show that the radius of orbit **B** is approximately $1.1 \times 10^4 \text{ km}$.

(1)

- (iii) Calculate the centripetal acceleration of a satellite in orbit **B**.

answer = _____ m s^{-2}

(2)

- (iv) Show that the gravitational potential energy of a 330 kg satellite decreases by about 8 GJ when it moves from orbit **A** to orbit **B**.

(1)

- (c) Explain why it is not possible to use the equation $\Delta E_p = mg\Delta h$ when determining the change in the gravitational potential energy of a satellite as it moves between these orbits.

(1)

(Total 10 marks)

19

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

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

(2)

(b) Given that the mass of the Earth is 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,

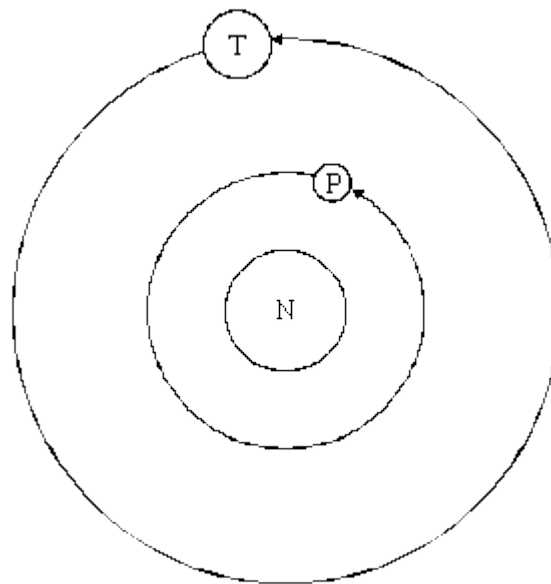
(ii) calculate the increase in potential energy of a satellite of mass 750 kg when it is raised from the Earth's surface into a geo-synchronous orbit.

(6)

(Total 8 marks)

20

The diagram below (not to scale) shows the planet Neptune (N) with its two largest moons, Triton (T) and Proteus (P). Triton has an orbital radius of 3.55×10^8 m and that of Proteus is 1.18×10^8 m. The orbits are assumed to be circular.



- (a) Explain why the velocity of each moon varies whilst its orbital speed remains constant.

(1)

- (b) Write down an equation that shows how Neptune's gravitational attraction provides the centripetal force required to hold Triton in its orbit. Hence show that it is unnecessary to know the mass of Triton in order to find its angular speed.

(3)

- (c) Show that $\frac{\text{the orbital period of Triton}}{\text{the orbital period of Proteus}}$ is approximately 5.2.

(4)

(Total 8 marks)

21

Satellites N and F have the same mass and move in circular orbits about the same planet. N is the nearer satellite and F is the more distant. Which one of the following is smaller for N than for F?

- A gravitational force on the satellite
- B speed
- C kinetic energy
- D time for one orbit

(Total 1 mark)

22

A satellite is in orbit at a height h above the surface of a planet of mass M and radius R . What is the velocity of the satellite?

- A $\sqrt{\frac{GM(R+h)}{R}}$
- B $\frac{\sqrt{GM(R+h)}}{R}$
- C $\sqrt{\frac{GM}{(R+h)}}$
- D $\frac{\sqrt{GM}}{(R+h)}$

(Total 1 mark)

23

What is the angular speed of a satellite in a geo-synchronous orbit around the Earth?

- A $7.3 \times 10^{-5} \text{ rad s}^{-1}$
- B $2.6 \times 10^{-1} \text{ rad s}^{-1}$
- C 24 rad s^{-1}
- D $5.0 \times 10^6 \text{ rad s}^{-1}$

(Total 1 mark)

Mark schemes

1

- (a) Equatorial orbit ✓

Moving west to east ✓

Period 24 hours ✓

ANY TWO

2

(b) $T \left(= \frac{2\pi}{\omega} = \frac{2\pi}{2.5(4) \times 10^{-4}} \right) = 2.5 \times 10^4 \text{ s } \checkmark$

1

(c) $\lambda \left(= \frac{c}{f} = \frac{3.0 \times 10^8}{1100 \times 10^6} \right) = 0.27 \text{ (3)m } \checkmark$

$\theta \left(= \frac{\lambda}{d} = \frac{0.27(3)}{1.7} \right) = 0.16(1) \text{ rad} = 92^\circ \checkmark$

(linear) width = $D\theta = 12000 \text{ km } 0.16(1) \text{ rad } = 1.9(3) \times 10^3 \text{ km } \checkmark$

3

(d) Angle subtended by beam at Earth's centre

$$= \text{beam width} / \text{Earth's radius} = 1.9(3) \times 10^3 / 6400 \text{ } \checkmark$$

$$0.30 \text{ rad (or } 17^\circ) \checkmark$$

$$\text{Time taken} = \alpha / \omega = 0.30 / 2.5(4) \times 10^{-4} = 1.18 \times 10^3 \text{ s}$$

$$= 20 \text{ mins } \checkmark$$

Alternative:

$$\text{Speed of point on surface directly below satellite} = \omega R$$

$$= 2.5(4) \times 10^{-4} \times 6400 \times 10^3 \text{)}$$

$$= 1.63 \times 10^3 \text{ m s}^{-1} \checkmark$$

$$\text{Time taken} = \text{width} / \text{speed}$$

$$= 1.93 \times 10^6 \text{ m} / 1.63 \times 10^3 \text{ m s}^{-1} \checkmark$$

$$= 1.18 \times 10^3 \text{ s}$$

$$(\text{accept } 1.2 \times 10^3 \text{ s or } 20 \text{ mins}) \checkmark$$

or

$$\text{Satellite has to move through angle of } 1900 / 6400 \text{ radian} = 0.29 \text{ rad} \checkmark$$

$$\text{Fraction of one orbit} = 0.30 / 2 \times 3.14 \checkmark$$

$$\text{Time} = 0.048 \times 2.5 \times 10^4 = 1.19 \times 10^3 \text{ s} \checkmark$$

$$\text{Time} = \frac{17}{360} \times 2.5 \times 10^4 = 1.18 \times 10^3 \text{ s}$$

or

$$\text{Circumference of Earth} = 2\pi \times 6370 \checkmark$$

$$= 40023 \text{ km}$$

$$\text{Width of beam at surface} = 1920 \text{ km } \checkmark$$

$$\text{Time} = \frac{1920}{40023} \times 2.48 \times 10^4$$

$$= 1180 \text{ s} = 19.6 \text{ min } \checkmark$$

3

(e) Signal would be weaker $\checkmark$ (as distance it travels is greater)

Energy spread over wider area/intensity decreases with increase of distance $\checkmark$

Signal received for longer (each orbit) $\checkmark$

Beam width increases with satellite height/satellite moves at lower angular speed $\checkmark$

4

[13]

3

D

[1]

4

C

[1]

5

- (a) Idea that both astronaut and vehicle are travelling at same (orbital) speed or have the same (centripetal) acceleration / are in freefall

Not falling at the same speed

B1

No (normal) reaction (between astronaut and vehicle)

B1

2

- (b) (i) Equates centripetal force with gravitational force using appropriate formulae

E.g. $\frac{GMm}{r^2} = \frac{mv^2}{r}$ or $mr\omega^2$

B1

Correct substitution seen e.g. $v^2 = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{\text{any value of radius}}$

B1

(Radius of) 7.28×10^6 seen or $6.38 \times 10^6 + 0.9 \times 10^6$

B1

7396 (m s^{-1}) to at least 4 sf

Or $v^2 = 5.47 \times 10^7$ seen

B1

4

(ii) $\Delta PE = 6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1.68 \times 10^4 (1 / (7.28 \times 10^6) - 1 / (6.78 \times 10^6))$

C1

$$-6.8 \times 10^{10} \text{ J}$$

C1

$$\Delta KE = 0.5 \times 1.68 \times 10^4 \times (7700^2 - 7400^2) = 3.81 \times 10^{10} \text{ J}$$

C1

$$\Delta KE - \Delta PE = (-) 2.99 \times 10^{10} \text{ (J)}$$

A1

OR

Total energy in original orbit shown to be $(-)GMm / 2r$
or $mv^2 / 2 - GMm / r$

C1

Initial energy

$$= -6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1.68 \times 10^4 / (2 \times 7.28 \times 10^6)$$

$$= 4.59 \times 10^{11}$$

C1

Final energy

$$= -6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1.68 \times 10^4 / (2 \times 6.78 \times 10^6)$$

$$= 4.93 \times 10^{11}$$

$$3.4 \times 10^{10} \text{ (J)}$$

Condone power of 10 error for C marks

A1

4

[10]

6

- (a) (i) (Minimum) Speed (given at the Earth's surface) that will allow an object to leave / escape the (Earth's) gravitational field (with no further energy input)

Not gravity

Condone gravitational pull / attraction

B1

1

(ii) $\frac{1}{2}mv^2 = \frac{GMm}{r}$

B1

Evidence of correct manipulation

At least one other step before answer

B1

2

- (iii) Substitutes data and obtains $M = 7.33 \times 10^{22}(\text{kg})$
or
Volume = $(1.33 \times 3.14 \times (1.74 \times 10^6)^3 \text{ or } 2.2 \times 10^{19}$

$$\text{or } \rho = \frac{3v^2}{8\pi Gr^2}$$

C1

3300 (kg m⁻³)

A1

2

- (b) (Not given all their KE at Earth's surface) energy continually added in flight / continuous thrust provided / can use fuel (continuously)

B1

Less energy needed to achieve orbit than to escape from Earth's gravitational field / it is not leaving the gravitational field

B1

2

[7]

7

- (a) (i) force per unit mass ✓
a vector quantity ✓

Accept force on 1 kg (or a unit mass).

2

(ii) force on body of mass m is given by $F = \frac{GMm}{(R+h)^2}$ ✓

gravitational field strength $g\left(= \frac{F}{m}\right) = \frac{GM}{(R+h)^2}$ ✓

For both marks to be awarded, correct symbols must be used for M and m .

2

(b) (i) $F\left(= \frac{GMm}{(R+h)^2}\right) = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times 2520}{((6.37 \times 10^6) + (1.39 \times 10^7))^2}$ ✓

$= 2.45 \times 10^3 \text{ (N)}$ ✓ to **3SF** ✓

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.***

3

$$(ii) \quad F = m\omega^2 (R + h) \text{ gives } \omega^2 = \frac{2450}{2520 \times 2.03 \times 10^7} \checkmark$$

$$\text{from which } \omega = 2.19 \times 10^{-4} \text{ (rad s}^{-1}\text{)} \checkmark$$

$$\text{time period } T \left(= \frac{2\pi}{\omega} \right) = \frac{2\pi}{2.19 \times 10^{-4}} \quad \text{or} = 2.87 \times 10^4 \text{ s } \checkmark$$

$$[\text{or } F = \frac{mv^2}{R+h} \text{ gives } v^2 = \frac{2.45 \times 10^3 \times ((6.37 \times 10^6) + (13.9 \times 10^6))}{2520} \checkmark$$

$$\text{from which } v = 4.40 \times 10^3 \text{ (m s}^{-1}\text{)} \checkmark$$

$$\text{time period } T \left(= \frac{2\pi(R+h)}{v} \right) = \frac{2\pi \times 2.03 \times 10^7}{4.40 \times 10^3} \quad \text{or} = 2.87 \times 10^4 \text{ s } \checkmark]$$

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

$$= \frac{4\pi^2 ((6.37 \times 10^6) + (13.9 \times 10^6))^3}{6.67 \times 10^{-11} \times 5.98 \times 10^{24}} \checkmark$$

$$\text{gives time period } T = 2.87 \times 10^4 \text{ s } \checkmark]$$

$$= \frac{2.87 \times 10^4}{3600} = 7.97 \text{ (hours)} \checkmark$$

$$\text{number of transits in 1 day} = \frac{24}{7.97} = 3.01 \text{ (} \approx 3 \text{)} \checkmark$$

Allow ECF from wrong F value in (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 $f = 3.46 \times 10^{-5} \text{ (s}^{-1}\text{)}$ is equivalent to finding T by any of the methods.

5

(c) acceptable use $\checkmark$

satisfactory explanation $\checkmark$

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

Any reference to equatorial satellite should be awarded 0 marks.

2

[14]

9	D			[1]
10	A			[1]
11	(a)	mass depends only on the amount of matter present owtte	B1	
		weight is force between body and Earth/depends on g/mg /gravitational field strength or answers in terms of Newton's gravitational law	B1	
		g (etc) varies at different points on and above the Earth or is different on different planets etc	B1	
				3
	(b)	(i) reference is 'infinity' where potential is 0	B1	
		energy has to be put in/work has to be done to move mass to infinity or a bodies energy/PE decreases as a body moves from infinity towards the Earth	B1	
				2
		(ii) need to show V_r to be constant, clear from algebra or final statement	B1	
		two sets of data used correctly	B1	
		all three sets of data used correctly (4.02, 4.025, 4.028)	B1	
				3
		(iii) energy change per kg = $(5.36 - 3.22) \times 10^7$ (J)	B1	
		total change = $963\ (960) \times 10^7$ J	B1	
				2

(c) (i) $GMm/r^2 = mv^2/r$ or $v = (GM/r)$

C1

$$v^2 = 3.2 \times 10^7 \text{ m}^2 \text{ s}^{-2} \text{ or } v = 5670 \text{ ms}^{-1}$$

C1

use of $KE = \frac{1}{2} mv^2$ using their v

C1

7.2 GJ

A1

4

(ii) KE changes by 4.8 GJ (allow ecf, 12 – their ci)

B1

1

(iii) total energy (supplied) = (4.8) GJ (cnao)

(allow 5.2 GJ using 10 GJ for change in E_p)
(allow variations due to rounding off if physics is correct in previous parts)

B1

1

[16]

12

(a) $\omega \left(= \frac{2\pi}{T} \right) = \frac{2\pi}{97 \times 60}$ [or $\omega \left(= \frac{360}{T} \right) = \frac{360}{97 \times 60}$]

$$= 1.1 \times 10^{-3} (1.08 \times 10^{-3}) \text{ (1)} [= 6.2 (6.19) \times 10^{-2}]$$

$$\text{rad s}^{-1} [\text{accept s}^{-1}] \text{ (1)} \quad [\text{degree s}^{-1}]$$

3

(b) (i) $\frac{GMm}{r^2} = m\omega^2 r$ or $r^3 = \frac{GM}{\omega^2}$ (1)

$$\text{gives } r^3 = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(1.08 \times 10^{-3})^2} \text{ (1)}$$

$$\therefore r = 6.99 \times 10^6 \text{ (m)} \text{ (1)}$$

3

$$(ii) \quad F (= m\omega^2 r) = 1.1 \times 10^4 \times (1.08 \times 10^{-3})^2 \times 6.99 \times 10^6 \text{ (1)}$$

$$= 9.0 \times 10^4 \text{ (8.97} \times 10^4 \text{) (N) (1)}$$

$$[\text{or } F \left(= \frac{GMm}{r^2} \right) = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times 1.1 \times 10^4}{(6.99 \times 10^6)^2} \text{ (1)}$$

$$= 9.0 \times 10^4 \text{ (8.98} \times 10^4 \text{) (N) (1)]}$$

2

[8]

13

A

[1]

14

D

[1]

15

(a) work done per unit mass in bringing object from infinity to point

B1

potential at infinity zero by definition

B1

work has been done by the field so potential at all points closer than infinity negative

B1

3

(b) use of point on graph allow within $\pm$ small square

C1

substitution into $V = -\frac{GM}{r}$

C1

range from 590 – 6.90×10^{24} (kg)

A1

3

(c) (i) $\Delta E_p = -\frac{GMm}{R_E + h} + \frac{GMm}{R_E}$

C1

addition of radius of Earth to give 7.25×10^6 (m)

C1

1.54×10^{10} (J)

A1

3

(ii) equates $\frac{mv^2}{r}$ and $G \frac{mM}{r^2}$

C1

to give $\Delta E_K = G \frac{mM}{2} \left(\frac{1}{r_1} - \frac{1}{r_2} \right)$

C1

1.25×10^9 J

A1

positive or increase

B1

4

(iii) (lower altitude so) gpe decreases ke increases

C1

loss of gpe is twice gain in ke

A1

2

[15]

16

B

[1]

17

- (a) attractive **force** between point masses **(1)**
 proportional to (product of) the masses **(1)**
 inversely proportional to square of separation/distance apart **(1)**

3

$$(b) \quad m\omega^2 R = (-)\frac{GMm}{R^2} \left(\text{or } = \frac{mv^2}{R} \right) \quad (1)$$

$$(\text{use of } T = \frac{2\pi}{\omega} \text{ gives}) \quad \frac{4\pi^2}{T^2} = \frac{GM}{R^3} \quad (1)$$

G and M are constants, hence $T^2 \propto R^3$ (1)

3

$$(c) \quad (i) \quad (\text{use of } T^2 \propto R^3 \text{ gives}) \quad \frac{365^2}{(1.50 \times 10^{11})^3} = \frac{T_m^2}{(5.79 \times 10^{10})^3} \quad (1)$$

$$T_m = 87(.5) \text{ days} \quad (1)$$

$$(ii) \quad \frac{1^2}{(1.50 \times 10^{11})^3} = \frac{165^2}{R_N^3} \quad (1) \text{ (gives } R_N = 4.52 \times 10^{12} \text{ m)}$$

$$\text{ratio} = \frac{4.51 \times 10^{12}}{1.50 \times 10^{11}} = 30(.1) \quad (1)$$

4

[10]

18

(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)

1

(ii) value of E_p is doubled (1)

value of V is unchanged (1)

2

$$(b) \quad (i) \quad \text{use of } V = -\frac{GM}{r} \text{ gives } r_A = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{12.0 \times 10^6} \quad (1)$$

$$= 3.3(2) \times 10^7 \text{ (m)} \quad (1)$$

2

$$(ii) \quad \text{since } V \propto (-)\frac{1}{r} \left(\text{or } \frac{r_A}{r_B} = \frac{v_B}{v_A} = \frac{36.0}{12.0} = 3 \right) r_B = \frac{3.32 \times 10^7 \text{ m}}{3} \quad (1)$$

(which is $\approx 1.1 \times 10^4 \text{ km}$)

1

(iii) centripetal acceleration $g_B = \frac{GM}{r_B^2} = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(1.11 \times 10^7)^2}$ **(1)**

[allow use of 1.1×10^7 m from (b)(ii)]

$= 3.2 \text{ (m s}^{-2}\text{)} \text{ (1)}$

[**alternatively**, since $g_B = (-)\frac{v_B}{v_a}, g_B = \frac{36.0 \times 10^6}{1.11 \times 10^7}$ **(1)**

$= 3.2 \text{ (m s}^{-2}\text{)} \text{ (1)}$

2

(iv) use of $\Delta E_p = m\Delta V$ gives $\Delta E_p = 330 \times (-12.0 - (-36.0)) \times 10^6$ **(1)**

(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)**

1

[10]

19

(a) period = 24 hours or equals 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)**

$r \left(= \frac{GMT^2}{4\pi^2} \right)^{1/3} = \left(\frac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times (24 \times 3600)^2}{4\pi^2} \right)^{1/3}$ **(1)**

(gives $r = 42.3 \times 10^3$ km)

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

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

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

$$\Delta E_p = m\Delta V (= 750 \times 5.31 \times 10^7) = 3.98 \times 10^{10} \text{ J} \quad (1)$$

(allow C.E. for value of ΔV)

[alternatives:

$$\text{calculation of } \frac{GM}{R} (6.25 \times 10^7) \text{ or } \frac{GM}{r} (9.46 \times 10^6) \quad (1)$$

$$\text{or calculation of } \frac{GMm}{R} (4.69 \times 10^{10}) \text{ or } \frac{GMm}{r} (7.10 \times 10^9) \quad (1)$$

calculation of both potential energy values (1)

subtraction of values or use of $m\Delta V$ with correct answer (1)]

6

[8]

20

(a) direction changing, velocity vector

B1

1

(b) Newton's law equation

M1

centripetal force equation

M1

cancel mass of Triton

A1

3

(c) $\omega = 2\pi f$ or $\omega = 2\pi/T$

M1

$$\omega^2 r^3 = \text{constant or } \omega^2 = \frac{GM}{r^3}$$

M1

$$\frac{T_T^2}{T_P^2} = \frac{r_T^3}{r_P^3} \text{ or statement of Kepler III for B3}$$

$$\frac{T_T}{T_P} = \sqrt{\frac{(3.55 \times 10^8)^3}{(1.18 \times 10^8)^3}} = 5.2(2)$$

M1

4

[8]

21

D

[1]

22

C

[1]

23

A

[1]