Gravitational Fields QP1

1 The Moon takes 27.3 days to make one complete orbit of the Earth.

(a) (i) Show that the orbital angular velocity of the Moon is about 3×10^{-6} rad s^{-1}.

(2)

(ii) Calculate the radius of the Moon's orbit.

mass of Earth = 6.4×10^{24} kg

(4)

Radius = ...

(b) The Moon is gradually moving further away from the Earth because of the action of tides.

(i) State and explain how this increasing distance affects the moon's orbital period.

(2)

(ii) In 200 years the radius of the Moon's orbit is predicted to increase by 8 m.

Calculate the rate of increase of the radius of the orbit in cm per year.

(1)

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Rate of increase = ... cm per year

*(iii) In practice, the rate of increase of the orbital radius due to tidal action will not have been constant. Suggest why this rate of change might have been different in the very distant past.

(3)

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(Total for Question 1 = 12 marks)

2 (a) Derive an expression for the gravitational field strength g at a distance r from the centre of a mass M.

(2)

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(b) Use your expression to calculate g at the surface of the Earth.

mass of Earth $M_E = 5.97 \times 10^{24}$ kg
radius of Earth $r_E = 6.38 \times 10^{6}$ m

(1)

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g = ...

(Total for Question 2 = 3 marks)

3 In a physics lesson a student learns that the Earth is 81 times more massive than the Moon. Searching the Internet, she is surprised to discover that the gravitational field strength at the surface of the Earth is only 6 times greater than that at the surface of the Moon.

Use the above data to compare the radius of the Earth with that of the Moon.

(3)

(Total for Question 3 = 3 marks)

4 Communications satellites were first proposed in 1945 by the science fiction author Arthur C. Clarke. In an article published in the magazine Wireless World he asked whether rocket stations could give worldwide radio coverage.

In the article Clarke states:

"There are an infinite number of possible stable orbits, circular and elliptical, in which a rocket would remain if the initial conditions were correct. A velocity of 8 km s^{-1} applies only to the closest possible orbit, one just outside the atmosphere, and the period of revolution would be about 90 minutes. As the radius of the orbit increases the velocity decreases, since gravity is diminishing and less centrifugal force is needed to balance it."

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(a) State what is meant in the article by the phrase "gravity is diminishing", and criticise the statement that "less centrifugal force is needed to balance (the satellite)".

(3)

(b) (i) By deriving an appropriate equation, show that the orbital speed of the satellite decreases as the radius of orbit increases.

(3)

(ii) By deriving an appropriate equation, show that the orbital period of a satellite increases as the orbital speed decreases.

(2)

(c) The period T of a satellite in a circular orbit is given by the equation

$$T = \frac{4\pi^2 r^3}{GM}$$

where r is the radius of orbit and M is the mass of the Earth.

Calculate the period of a satellite in an orbit 4.0×10^5 m above the surface of the Earth.

mass of the Earth = 5.98×10^{24} kg

radius of the Earth = 6.36×10^6 m

(2)

Period of satellite = ...

(d) After a time the radius of the satellite's orbit will start to decrease due to the resistive forces acting on the satellite from the atmosphere. As this happens the satellite speeds up.

Describe the energy changes occurring as the radius of the orbit decreases.

(2)

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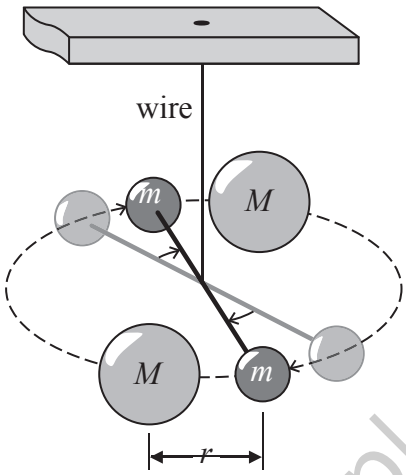
(Total for Question 4 = 12 marks)

5 In the 18th century Henry Cavendish devised an experiment to determine the average density of the Earth. This involved the first laboratory determination of the universal gravitational constant G.

A light horizontal rod with a small metal sphere at each end was hung from a fixed point by a very thin wire. Two large lead spheres were then brought close to the small spheres causing the rod to oscillate and then settle into a new position of equilibrium.



(a) In a modern version of the experiment the following data was obtained:

mass of large lead sphere $M = 160$ kg

mass of small sphere $m = 0.75$ kg

distance $r = 0.23$ m

gravitational force between adjacent large and small spheres $F = 1.5 \times 10^{-7}$ N.

Use this data to calculate a value for G.

(2)

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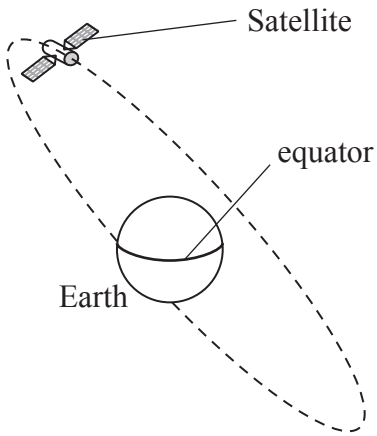
$G =$ ..... $Nm^2\ kg^{-2}$

6 The Global Positioning System (GPS) is a network of satellites orbiting the Earth. The satellites are arranged in six different orbital planes at a height of 20 200 km above the Earth's surface. Wherever you are, at least four GPS satellites are 'visible' at any time. The diagram shows a single satellite.



(a) Show that the GPS satellites take about 40 000 s (12 hours) to complete one orbit about the Earth.

mass of the Earth $M_E = 6.0 \times 10^{24}$ kg

radius of the Earth $R_E = 6400$ km

(4)

(b) Communications satellites are placed in orbit with an orbital time of 24 hours.

Explain why it is essential for communications satellites to be in such an orbit.

(2)

(c) State how the orbit of a GPS satellite differs from that of a communications satellite.

(2)

(Total for Question 6 = 8 marks)