(ii) When the car is travelling along a ridged concrete road at a speed of $20\,\mathrm{m\,s^{-1}}$ the driver notices that the car bounces significantly. The ridges in the road are equally spaced 6.2 m apart.

1 Calculate the frequency f of the bounce.

f = ... Hz **[1]**

2 State and explain the phenomenon which is occurring.

....

....

....

....

.... **[3]**

[Total: 15]

24

(a) Define *simple harmonic motion*.

....

....

.... **[2]**

(b) Fig. 2.1(a) shows a simple pendulum suspended from point **P** with the bob at the amplitude of its swing. A student knocks the bob at this instant causing the bob to rotate in a horizontal circle as shown in Fig. 2.1(b).

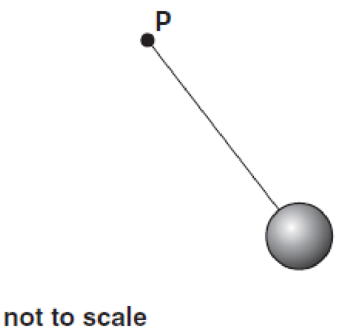


Fig. 2.1(a)

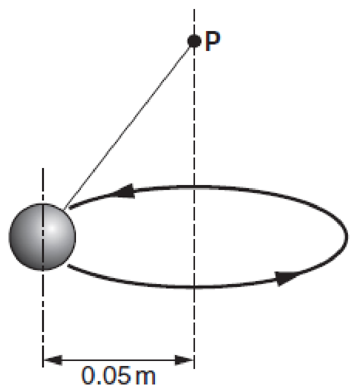


Fig. 2.1(b)

Draw and label arrows on Fig. 2.1(b) to represent the forces acting on the bob. **[2]**

(c) Fig. 2.2 shows a graph of the displacement of the bob against time when it is oscillating as a simple pendulum.

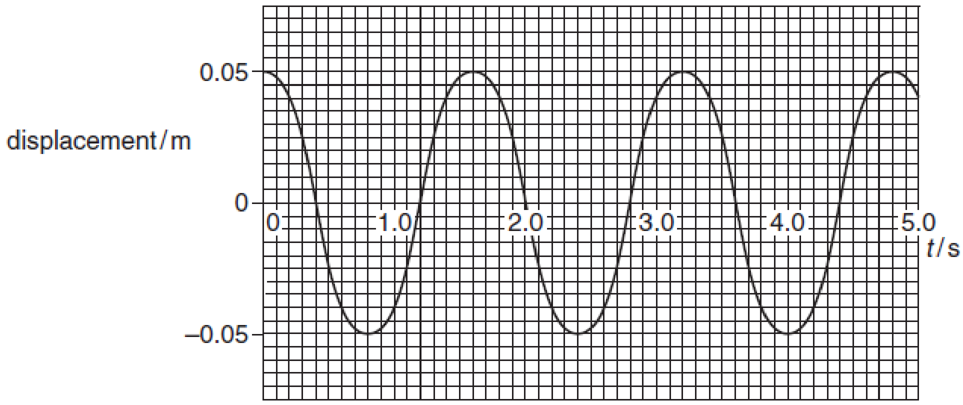


Fig. 2.2

The frequency f of oscillation is related to the length l of the pendulum by the formula

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{l}}\ .$$

Use data from Fig. 2.2 to determine

(i) the length l of the pendulum

l = ... m **[3]**

(ii) the maximum acceleration a of the bob.

a = ... $m\,s^{-2}$ **[2]**

(d) Explain why the circular motion of the conical pendulum has the same frequency as the simple pendulum.

....

....

....

....

....

....

.... **[3]**

[Total: 12]

3 This question is about orbits around the Sun.

(a) The gravitational force of the Sun, mass M, provides the centripetal force which holds the Earth in a near circular orbit of radius R.

By considering the Earth as an isolated planet moving in a circular orbit show that its speed v is given by the equation $v = \sqrt{\frac{GM}{R}}$.

[3]

(b) A space observatory to monitor activity on the surface of the Sun has been placed in a circular orbit, which is 1% smaller than the orbit of the Earth, as shown in Fig. 3.1.

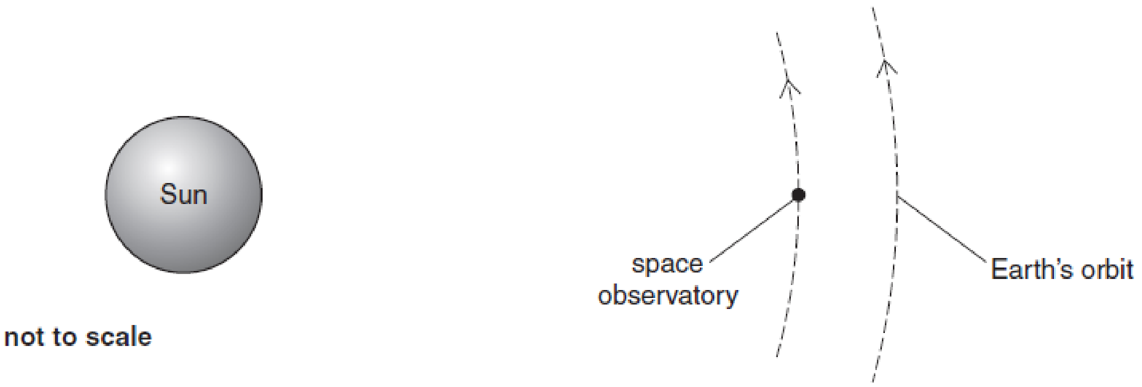


Fig. 3.1

Explain why the equation of part **(a)** predicts that the observatory should orbit the Sun in less than one year.

....

....

....

.... **[2]**

(c) Fig. 3.2 shows the special case where the Earth and observatory are positioned so that both orbit the Sun in exactly one year.

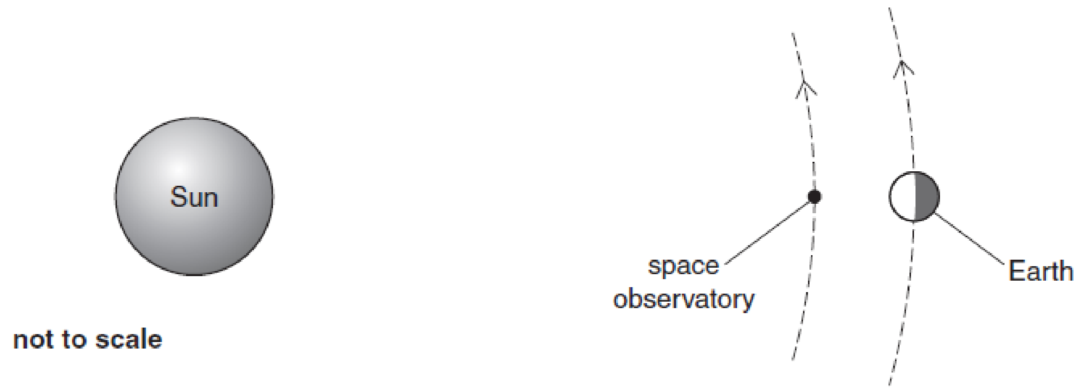


Fig. 3.2

(i) Explain why in this special case the speed of the observatory must be less than the speed of the Earth.

....

....

.... **[1]**

(ii) Draw labelled arrows on Fig. 3.2 to show the directions of the gravitational forces acting on the observatory. Indicate, by length of arrow, which force is larger. **[1]**

(iii) Explain how it is possible for the observatory to have an orbital period of one year. Suggest why this is convenient.

....

....

....

....

....

....

.... **[3]**

[Total: 10]

2 Fig. 2.1 shows a graph of the variation of the gravitational field strength g of the Earth with distance r from its centre.

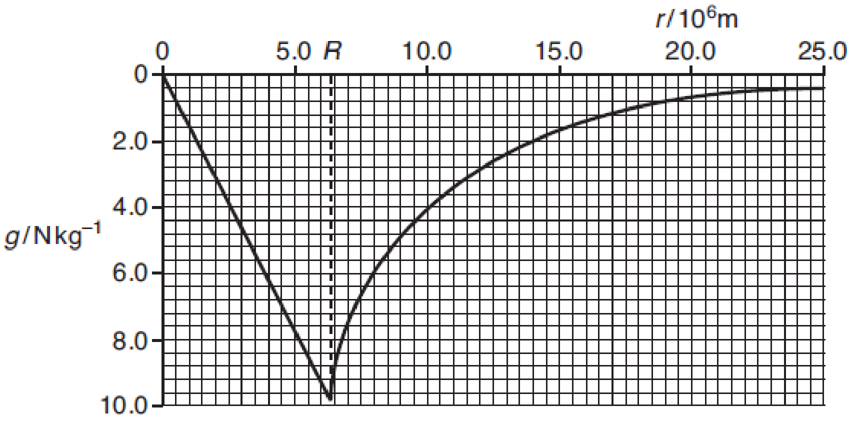


Fig. 2.1

(a) **(i)** Define the gravitational field strength at a point.

....

.... **[1]**

(ii) Write down an algebraic expression for the gravitational field strength g at the surface of the Earth in terms of the mass M and the radius R of the Earth and the universal gravitational constant G.

[1]

(iii) Use data from Fig. 2.1 and the value of G to show that the mass of the Earth is 6.0×10^{24} kg.

[2]

(iv) State which feature of the graph in Fig. 2.1 indicates that the gravitational field strength at a point below the surface of the Earth, assumed to be of uniform density, is directly proportional to the distance from the centre of the Earth.

....

.... **[1]**

(v) Calculate the **two** distances from the centre of the Earth at which $g = 0.098\,\mathrm{N\,kg^{-1}}$.
Explain how you arrived at your answers.

distance 1 = ... m

....

....

.... **[2]**

distance 2 = ... m

....

....

.... **[2]**

(b) A spacecraft on a journey from the Earth to the Moon has no resultant gravitational pull from the Earth and the Moon when it has travelled to a point 0.9 of the distance between their centres. Calculate the mass of the Moon, using the value for the mass of the Earth in **(a)(iii)**.

mass = ... kg **[3]**

[Total: 12]

27

A mass oscillates on the end of a spring in simple harmonic motion. The graph of the acceleration a of the mass against its displacement x from its equilibrium position is shown in Fig. 4.1.

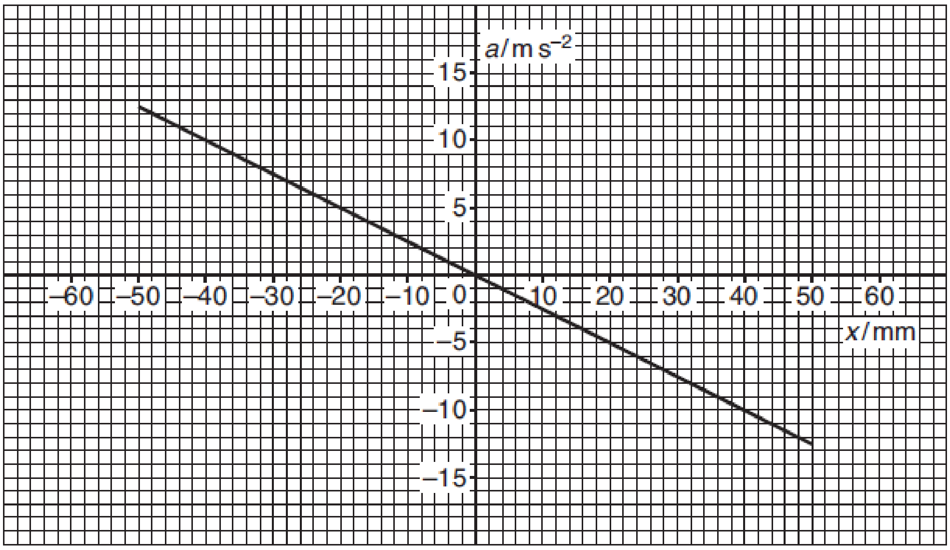


Fig. 4.1

(a) **(i)** Define *simple harmonic motion.*

....

....

.... **[2]**

(ii) Explain how the graph shows that the object is oscillating in simple harmonic motion.

....

....

.... **[2]**

(b) Use data from the graph

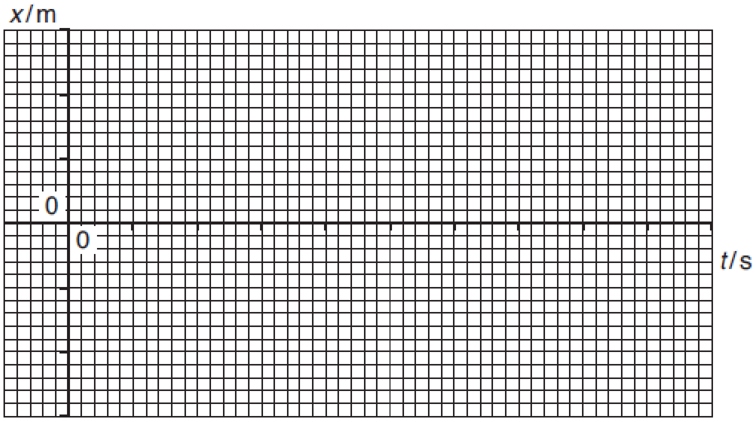
(i) to find the amplitude of the motion

amplitude = ... m **[1]**

(ii) to show that the period of oscillation is about 0.4 s.

[3]

(c) **(i)** The mass is released at time $t = 0$ at displacement $x = 0.050$ m. Draw a graph on the axes of Fig. 4.2 of the displacement of the mass until $t = 1.0$ s. Add scales to both axes.



[3]

Fig. 4.2

(ii) State a displacement and time at which the system has maximum kinetic energy.

displacement .... m

time .... s **[2]**

[Total: 13]

28 **(a)** State Newton's law of Gravitation.

[1]

(b) Show that the radius r of the circular orbit of a planet around the Sun is given by

$$r = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$$

where M is the mass of the Sun and T is the orbital period of the planet.

[4]

(c) Venus has an orbital period of 0.62 years. Calculate the mean radius of its orbit about the Sun. Mass of Sun = 2.0×10^{30} kg.

mean radius = ... m [3]

[Total : 8]

29

Triton, a moon of Neptune, has an orbital period of 5.88 days and its mean distance from Neptune is 3.55×10^5 km. Proteus, another moon of Neptune, is observed to orbit Neptune with a period of 1.12 days.
Calculate the mean distance of Proteus from Neptune.

distance = ... km [3]

30 The period and average orbital radius of two Earth-orbiting research satellites are given in Fig. 2.1.

satellite	period / h	orbital radius / km
A	1.63	7010
B	48.1	67100

Fig. 2.1

(i) Satellite **B** has the larger orbital radius. Using Newton's law of gravitation, explain why the satellites have such different periods.

....

....

....

.... [2]

(ii) Using data from Fig. 2.1, calculate the average orbital radius for a satellite with a period of 57.2 hours.

radius = ...km [3]

31 Astronomers are searching for planets which orbit distant stars. The planets are not visible from the Earth. Their existence is revealed by the star's motion which causes a shift in the wavelength of the light it emits.
A large planet **P** is shown orbiting a star **S** in Fig. 2.1. Both the star and the planet rotate about their common centre of mass **C**.

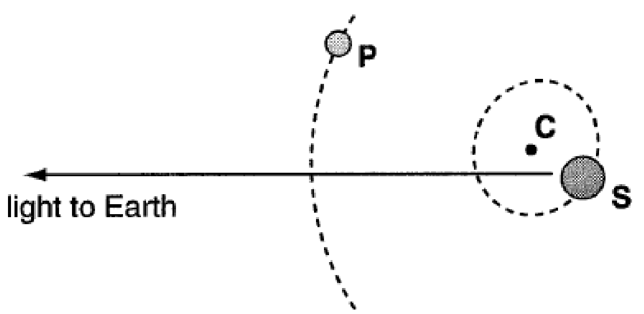


Fig. 2.1

(vi) The mass M of the star is estimated to be 4×10^{30} kg. Calculate the radius of the planet's orbit using the relationship below.

$$r = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$$

radius = ...m [2]

32

The elliptical path of a planet **P** which orbits a star is shown in plan view in Fig. 2.1. The period of the orbit is 80 years. The planet's current position and direction of motion are shown.

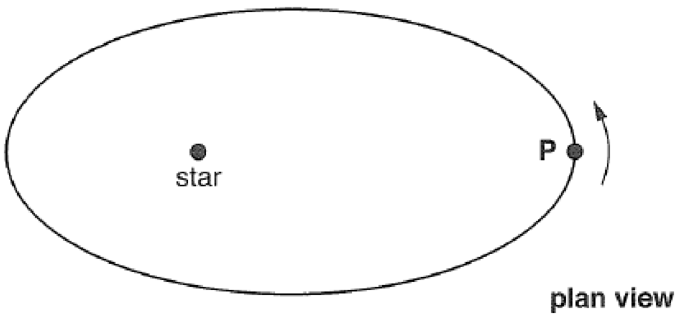


Fig. 2.1

(b) A second planet orbiting the same star has an average orbital radius of $0.4 \times$ the average orbital radius of **P**. What is its orbital period?

period = ... years [3]

33

Newton first showed that the gravitational force F between two bodies of mass m_1 and m_2 a distance r apart is given by

$$F = \frac{Gm_1 m_2}{r^2}.$$

(a) (i) A satellite of mass m_s moving with velocity v is in circular orbit about the Earth, of mass m_e.

By considering an expression for centripetal force show that the velocity of the satellite is given by

$$v^2 = \frac{Gm_e}{r}.$$

[1]

(ii) Hence show that the relationship between T, the period of the satellite, and r, the radius of its orbit is given by

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

[2]

(b) The Global Positioning System (GPS) uses 24 satellites. They each orbit the Earth with a period of 11h 58min. Calculate the average orbital radius of the satellites.

mass of the Earth, $m_e = 5.98 \times 10^{24}$ kg

radius = ... m [3]

34 **(a)** State Newton's law of gravitation, explaining any symbols used.

....

....

....

.... [1]

(c) The average orbital velocity of the Sun within the Galaxy is $230\,\text{km}\,\text{s}^{-1}$. Assuming the orbit is circular with radius of 2.6×10^{17} km calculate the mass of that part of the Galaxy which is bounded by the Sun's orbit.

Treat the Sun and inner part of the Galaxy as point masses.

mass = ... kg [4]

35 Kepler's third law states that the square of the orbital period of a planet is proportional to the cube of its average distance from the Sun.

(b) A Low Earth Orbit (LEO) satellite is one which has a relatively small orbital radius.
The table in Fig. 2.1 shows the period T and average orbital radius r for some LEO satellites.

$T\,/\,10^3\,\text{s}$	$r\,/\,10^6\,\text{m}$	$T^2\,/\,10^7\,\text{s}^2$	$r^3\,/\,10^{20}\,\text{m}^3$
6.3	7.4	4.0	4.05
6.7	7.7	4.5	4.57
7.0	7.9	4.9	4.93
7.2	8.1	5.2	
7.6	8.4	5.9	

Fig. 2.1

(i) Complete the final column of Fig. 2.1 by calculating r^3. **[1]**

(ii) Plot a graph of T^2 against r^3 on the axes of Fig. 2.2. Draw the best straight line through the points. **[2]**

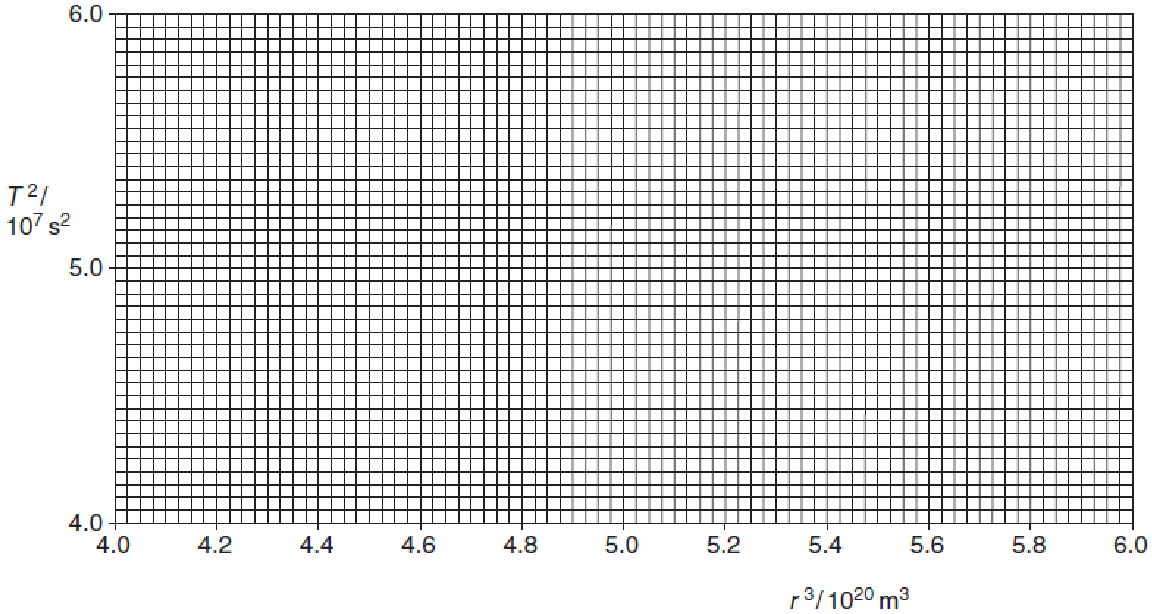


Fig. 2.2

The relationship between T and r is given by

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

where M is the mass of the Earth.

(iii) Use your graph to calculate a value for M, showing all your working.

M = ... kg **[2]**

(v) State and explain how, if at all, the gradient of the graph changes if the satellites were orbiting the planet Jupiter, not the Earth?

....

....

....

.... **[2]**