CAMBRIDGE INTERNATIONAL A LEVEL • PHYSICS 9702

Topical Questions

Unit 13: Gravitation

Past Papers 2021 – 2025

QUESTION PAPER 19 Questions

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Question 1

(a) Define *gravitational potential*.

.....

.....

..... [2]

(b) The Earth E and the Moon M can both be considered as isolated point masses at their centres. The mass of the Earth is 5.98×10^{24} kg and the mass of the Moon is 7.35×10^{22} kg. The Earth and the Moon are separated by a distance of 3.84×10^{8} m, as shown in Fig. 2.1.

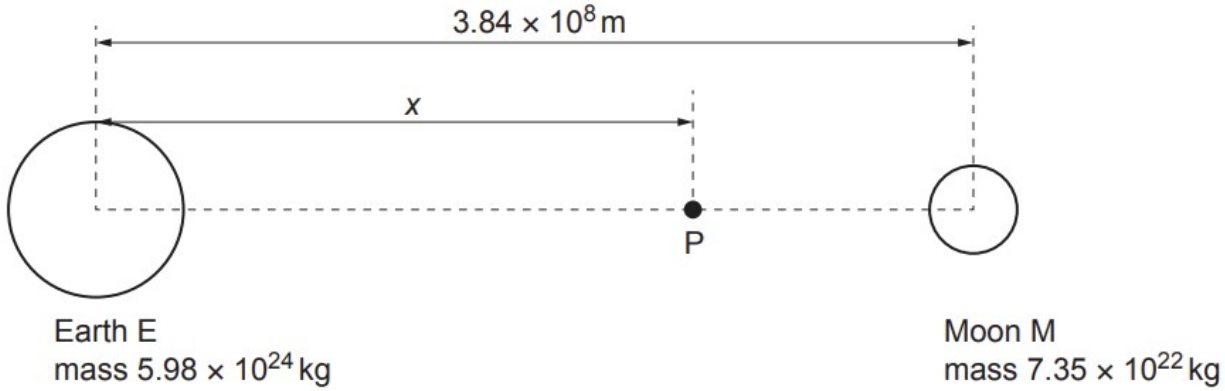


Fig. 2.1 (not to scale)

P is a point, on the line joining the centres of E and M, where the resultant gravitational field strength is zero. Point P is at a distance x from the centre of the Earth.

P is a point, on the line joining the centres of E and M, where the resultant gravitational field strength is zero. Point P is at a distance x from the centre of the Earth.

(i) Explain how it is possible for the gravitational field strength to be zero despite the presence of two large masses nearby.

.....

.....

..... [2]

(ii) Show that x is approximately 3.5×10^8 m.

[2]

(iii) Calculate the gravitational potential ϕ at point P.

ϕ = ... $J\,kg^{-1}$ [3]

[Total: 9]

Question 2

(a) State the relationship between gravitational potential and gravitational field strength.

.....

.....

..... [2]

(b) A moon of mass M and radius R orbits a planet of mass $3M$ and radius $2R$. At a particular time, the distance between their centres is D, as shown in Fig. 2.1.

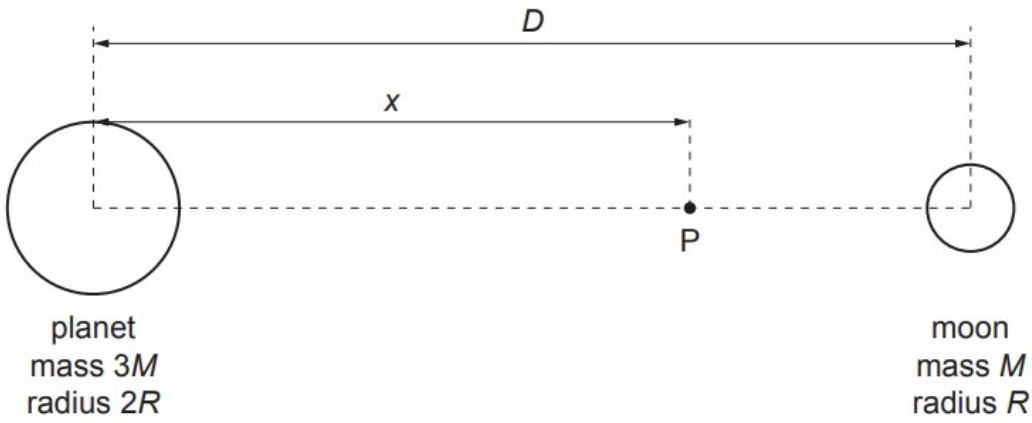


Fig. 2.1

Point P is a point along the line between the centres of the planet and the moon, at a variable distance x from the centre of the planet.

The variation with x of the gravitational potential ϕ at point P, for points between the planet and the moon, is shown in Fig. 2.2.

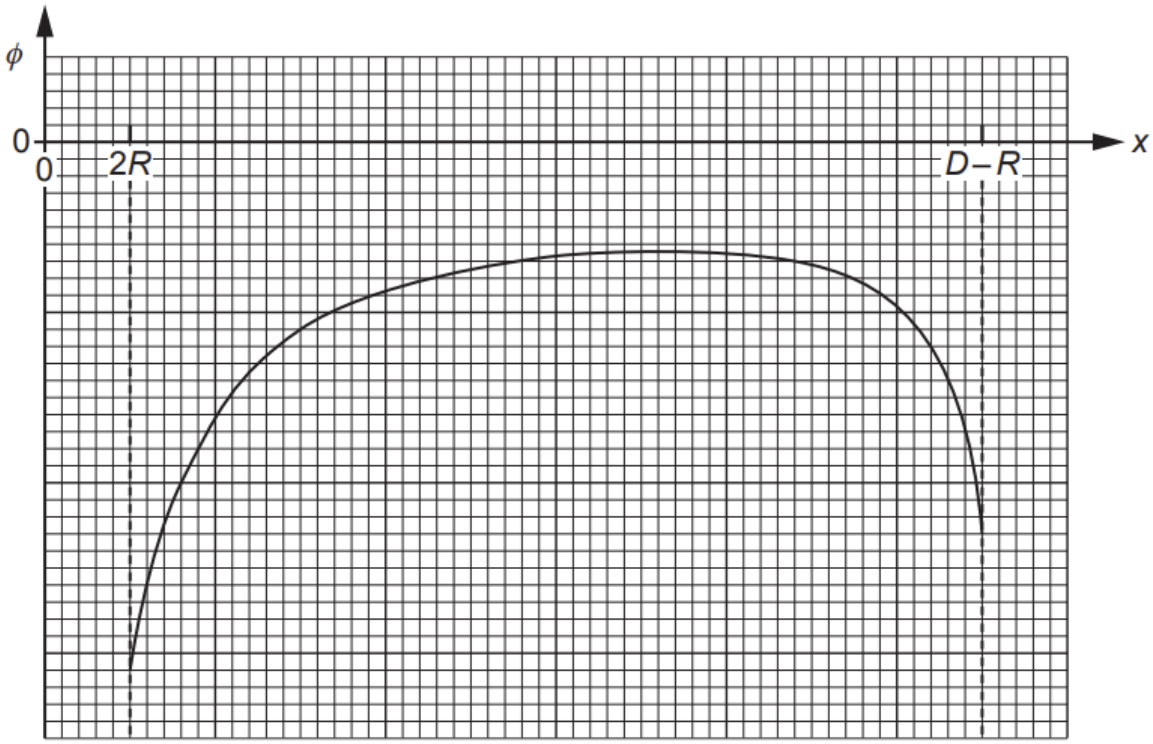


Fig. 2.2

(i) Explain why ϕ is negative throughout the entire range $x = 2R$ to $x = D - R$.

.....

.....

.....

..... [3]

(ii) One of the features of Fig. 2.2 is that ϕ is negative throughout.

Describe **two** other features of Fig. 2.2.

1. .....

.....

2. .....

.....

[2]

(iii) On Fig. 2.3, sketch the variation with x of the gravitational field strength g at point P between $x = 2R$ and $x = D - R$.

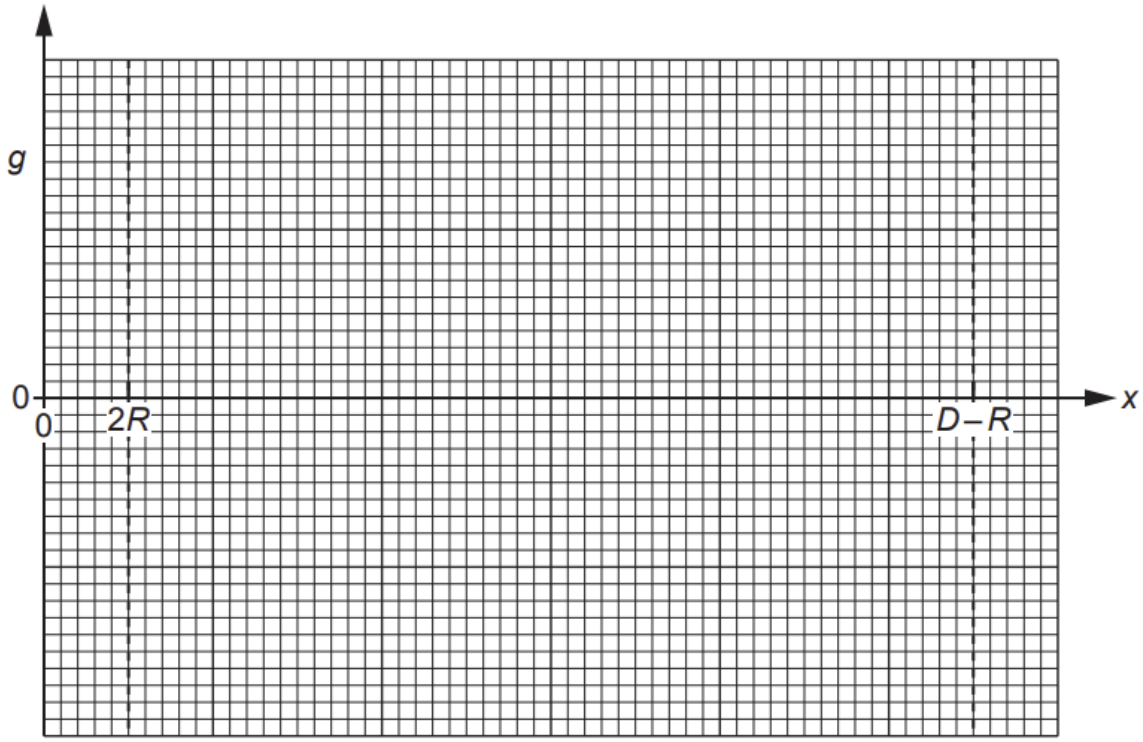


Fig. 2.3

[3]

[Total: 10]

Question 3

The Earth may be assumed to be an isolated uniform sphere with its mass of 6.0×10^{24} kg concentrated at its centre.

A satellite of mass 1200 kg is in a circular orbit about the Earth in the Earth's gravitational field. The period of the orbit is 94 minutes.

(a) Define *gravitational field strength*.

.....

..... [1]

(b) Calculate the radius of the orbit of the satellite.

radius = ... m [3]

(c) Rockets on the satellite are fired so that the satellite enters a different circular orbit that has a period of 150 minutes. The change in the mass of the satellite may be assumed to be negligible.

(i) Show that the radius of the new orbit is 9.4×10^6 m.

[2]

(ii) State, with a reason, whether the gravitational potential energy of the satellite increases or decreases.

.....

..... [1]

(iii) Determine the magnitude of the change in the gravitational potential energy of the satellite.

change in potential energy = ... J [3]

[Total: 10]

Question 4

(a) Define *gravitational field strength*.

.....

..... [1]

(b) An isolated planet is a uniform sphere of radius 3.39×10^6 m. Its mass of 6.42×10^{23} kg may be considered to be a point mass concentrated at its centre. The planet rotates about its axis with a period of 24.6 hours.

For an object resting on the surface of the planet at the equator, calculate, to three significant figures:

(i) the gravitational field strength

field strength = ... $N\,kg^{-1}$ [2]

(ii) the centripetal acceleration

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

(iii) the force per unit mass exerted on the object by the surface of the planet.

force per unit mass = ... $N\,kg^{-1}$ [1]

[Total: 6]

Question 5

(a) State Newton's law of gravitation.

.....

.....

..... [2]

(b) Planets have been observed orbiting a star in another solar system. Measurements are made of the orbital radius r and the time period T of each of these planets.

The variation with R^3 of T^2 is shown in Fig. 1.1.

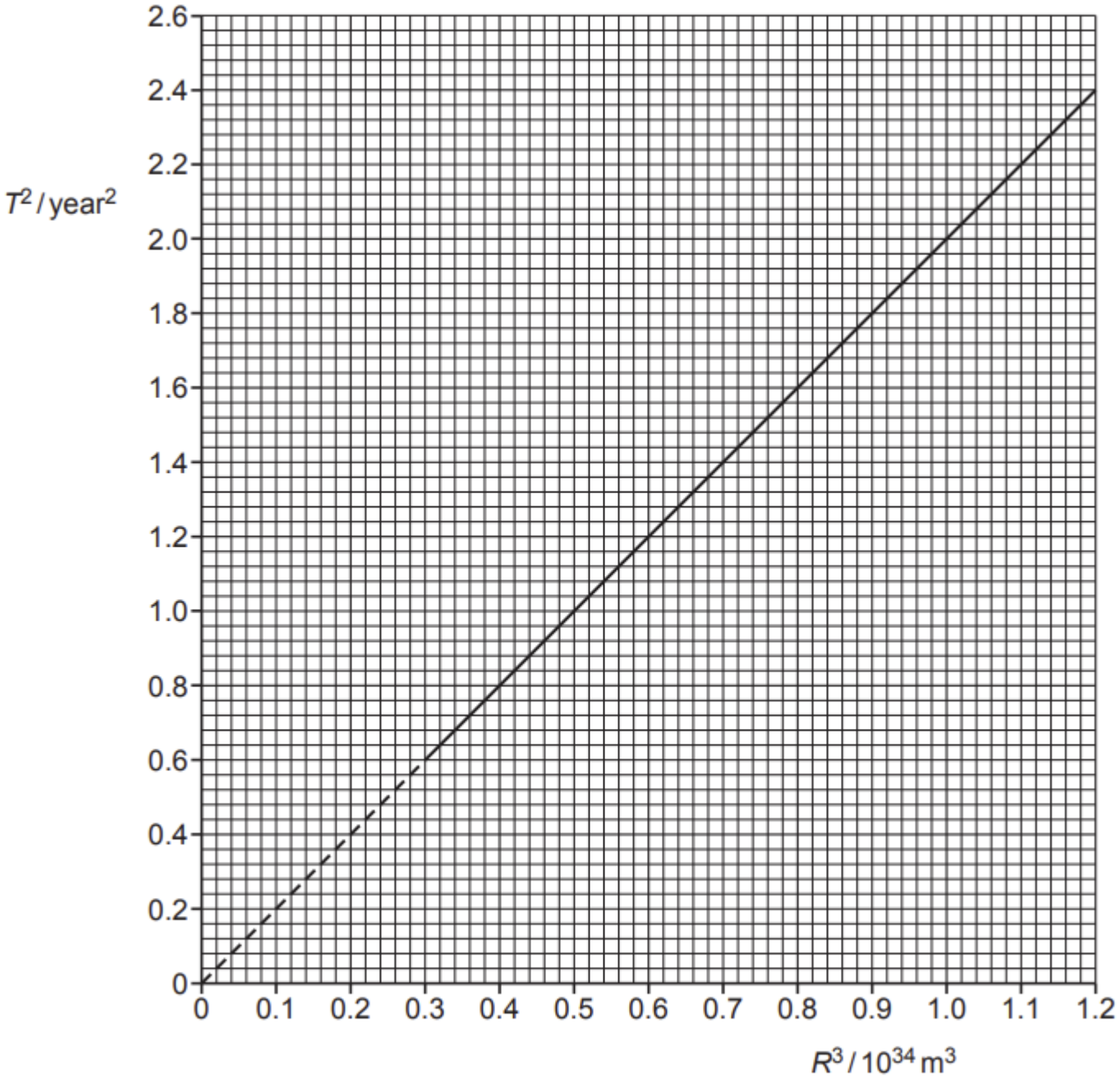

T^2 / year^2
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
R^3 / 10^{34} m^3

Fig. 1.1

The relationship between T and R is given by

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

where G is the gravitational constant and M is the mass of the star.

Determine the mass M.

M = ... kg [3]

(c) A rock of mass m is also in orbit around the star in **(b)**. The radius of the orbit is r.

(i) Explain why the gravitational potential energy of the rock is negative.

.....

.....

.....

..... [3]

(ii) Show that the kinetic energy E_k of the rock is given by

$$E_k = \frac{GMm}{2r}.$$

[2]

(iii) Use the expression in **(c)(ii)** to derive an expression for the total energy of the rock.

[2]

[Total: 12]

Question 6

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

.....

.....

..... [2]

(ii) Use Newton's law of gravitation to show that the gravitational field strength g at a distance r away from a point mass M is given by

$$g = \frac{GM}{r^2}.$$

[2]

(b) The Earth has a mass of 5.98×10^{24} kg and a radius of 6.37×10^{6} m.
The Moon has a mass of 7.35×10^{22} kg and a radius of 1.74×10^{6} m.
The Earth and the Moon can both be considered as point masses at their centres. Their centres are a distance of 3.84×10^{8} m apart.

(i) Show that the gravitational field strength at the surface of the Moon due to the mass of the Moon is $1.62\,\text{N kg}^{-1}$.

[1]

(ii) Explain why there is a point X on the line between the centres of the Earth and the Moon where the resultant gravitational field strength due to the Earth and the Moon is zero.

.....

.....

..... [2]

(iii) Calculate the distance x of point X from the centre of the Moon.

x = ... m [3]

[Total: 10]

Question 7

(a) (i) Define gravitational potential at a point.

.....

.....

..... [2]

(ii) Starting from the equation for the gravitational potential due to a point mass, show that the gravitational potential energy E_P of a point mass m at a distance r from another point mass M is given by

$$E_P = -\frac{GMm}{r}$$

where G is the gravitational constant.

[1]

(b) Fig. 1.1 shows the path of a comet of mass 2.20×10^{14} kg as it passes around a star of mass 1.99×10^{30} kg.

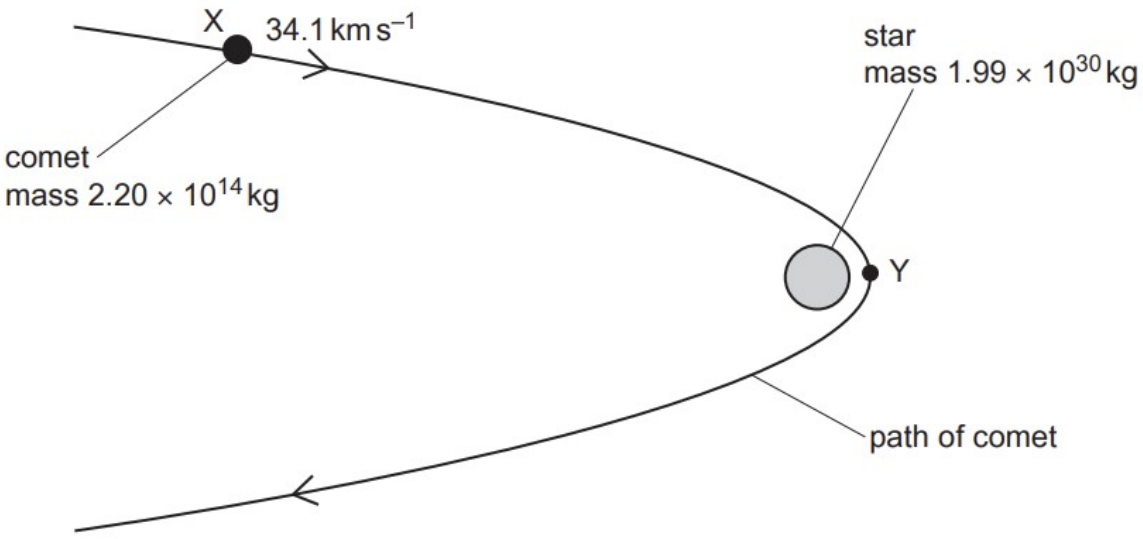


Fig. 1.1 (not to scale)

At point X, the comet is 8.44×10^{11} m from the centre of the star and is moving at a speed of 34.1 km s^{-1}.

At point Y, the comet passes its point of closest approach to the star. At this point, the comet is a distance of 6.38×10^{10} m from the centre of the star.

Both the comet and the star can be considered as point masses at their centres.

(i) Calculate the magnitude of the change in the gravitational potential energy ΔE_P of the comet as it moves from position X to position Y.

ΔE_P = ... J [2]

(ii) State, with a reason, whether the change in gravitational potential energy in **(b)(i)** is an increase or a decrease.

.....

..... [1]

(iii) Use your answer in **(b)(i)** to determine the speed, in $km\,s^{-1}$, of the comet at point Y.

speed = ... $km\,s^{-1}$ [3]

(c) A second comet passes point X with the same speed as the comet in **(b)** and travelling in the same direction. This comet is gradually losing mass. The mass of this comet when it passes point X is the same as the mass of the comet in **(b)**.

Suggest, with a reason, how the path of the second comet compares with the path shown in Fig. 1.1.

.....

..... [1]

[Total: 10]

Question 8

(a) The point P in Fig. 1.1 represents a point mass.

On Fig. 1.1, draw lines to represent the gravitational field around P.



Fig. 1.1

[2]

(b) A moon is in circular orbit around a planet.

Explain why the path of the moon is circular.

.....

.....

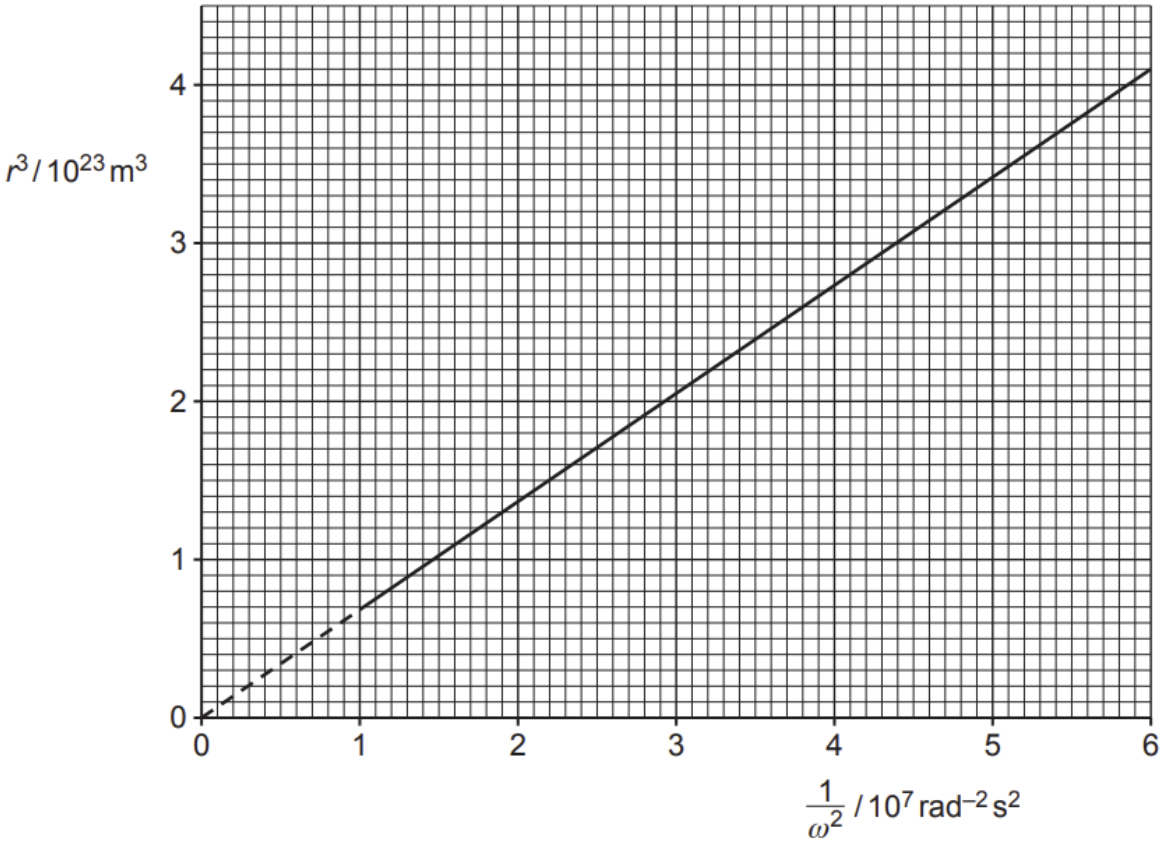
.....

..... [2]

(c) Many moons are in circular orbit about a planet.

The angular velocity of a moon is ω when the orbit of the moon has a radius r about the planet.

Fig. 1.2 shows the variation of r^3 with $1/\omega^2$ for these moons.



(i) Show that the mass M of the planet is given by the expression

$$M = \frac{\text{gradient}}{G}$$

where G is the gravitational constant.

[2]

(ii) Use Fig. 1.2 and the expression in **(c)(i)** to show that the mass M of the planet is 1.0×10^{26} kg.

[1]

(iii) Determine the speed of a moon in orbit around the planet with an orbital radius of 1.2×10^{8} m.

speed = ... $m\,s^{-1}$ [3]

[Total: 10]

Question 9

(a) State the equation for the gravitational force F between two point masses m_1 and m_2 that are separated by a distance r. State the meaning of any other symbols you use.

[2]

(b) A satellite is in a circular orbit of radius R around a planet of mass M.

Show that the period T of the orbit is given by

$$T^2 = kR^3$$

where k is a constant that depends on the value of M. Explain your reasoning.

[3]

(c) A satellite is in a circular orbit around the Earth with a period of 24 hours. The mass of the Earth is 6.0×10^{24} kg.

(i) Calculate the radius of the orbit.

radius = ... m [2]

(ii) State the **two** other conditions that must be met for the orbit to be geostationary.

1 .....

.....

2 .....

.....

[2]

[Total: 9]

Question 10

(a) Define gravitational field.

.....

..... [1]

(b) A spherical planet can be considered as a point mass at its centre.

(i) On Fig. 1.1, draw gravitational field lines outside the planet to represent the gravitational field due to the planet.

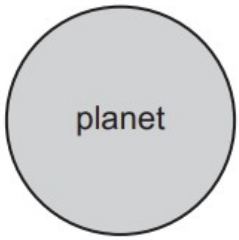


Fig. 1.1

[2]

(ii) A satellite is in a circular orbit around the planet.

Explain, with reference to your answer in **(b)(i)**, why the path of the satellite is circular.

.....

.....

..... [2]

(c) An object rests on the surface of the Earth at the Equator.
The radius of the Earth is 6.4×10^6 m.

(i) Determine the centripetal acceleration of the object.

centripetal acceleration = ... $m\,s^{-2}$ [3]

(ii) Describe how the two forces acting on the object give rise to this centripetal acceleration.
You may draw a diagram if you wish.

.....

.....

..... [2]

[Total: 10]

Question 11

(a) (i) Define gravitational field.

.....

..... [1]

(ii) Define electric field.

.....

..... [1]

(iii) State **one** similarity and **one** difference between the gravitational potential due to a point mass and the electric potential due to a point charge.

similarity: .....

.....

difference: .....

.....

[2]

(b) An isolated uniform conducting sphere has mass M and charge Q.
The gravitational field strength at the surface of the sphere is g.
The electric field strength at the surface of the sphere is E.

(i) Show that

$$\frac{M}{Q} = \alpha \frac{g}{E}$$

where α is a constant.

[3]

(ii) Show that the numerical value of α is $1.35 \times 10^{20}\,\text{kg}^2\,\text{C}^{-2}$.

[1]

(c) Assume that the Earth is a uniform conducting sphere of mass 5.98×10^{24} kg.
The surface of the Earth carries a charge of -4.80×10^{5} C that is evenly distributed.

(i) Use the information in **(b)** to determine the electric field strength at the surface of the Earth. Give a unit with your answer.

electric field strength = ... unit ..... [2]

(ii) State how the direction of the electric field at the surface of the Earth compares with the direction of the gravitational field.

..... [1]

[Total: 11]

Question 12

(a) State Newton's law of gravitation.

.....

.....

..... [2]

(b) A satellite is in a circular orbit around a planet. The radius of the orbit is R and the period of the orbit is T. The planet is a uniform sphere.

Use Newton's law of gravitation to show that R and T are related by

$$4\pi^2R^3 = GMT^2$$

where M is the mass of the planet and G is the gravitational constant.

[2]

(c) The Earth may be considered to be a uniform sphere of mass 5.98×10^{24} kg and radius 6.37×10^6 m.

A geostationary satellite is in orbit around the Earth.

Use the expression in **(b)** to determine the height of the satellite above the Earth's surface.

height = ... m [3]

(d) Another satellite is in a circular orbit around the Earth with the same orbital radius and period as the satellite in **(c)**.

(i) Calculate the angular speed of the satellite in this orbit. Give a unit with your answer.

angular speed = ... unit ..... [2]

(ii) Despite having the same orbital period, the orbit of this satellite is not geostationary.

Suggest **two** ways in which the orbit of this satellite could be different from the orbit of the satellite in **(c)**.

1 .....

.....

2 .....

.....

[2]

[Total: 11]

Question 13

(a) Define gravitational potential at a point.

.....

.....

..... [2]

(b) Artemis is a spherical planet that may be assumed to be isolated in space. The variation with distance x from the centre of Artemis of the gravitational potential ϕ is shown in Fig. 1.1.

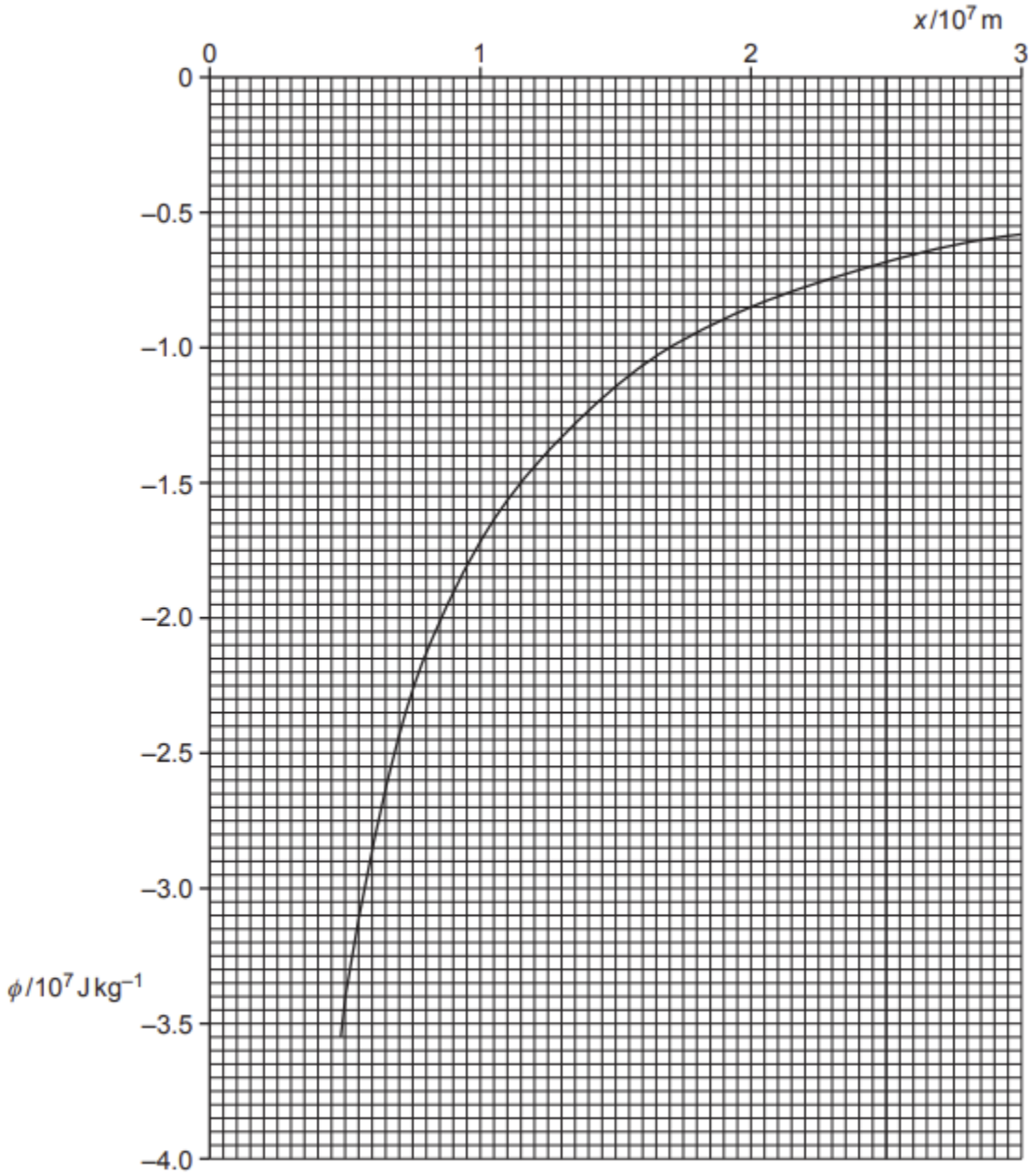


Fig. 1.1

(i) The radius of Artemis is 4800 km.

Determine the value of ϕ on the surface of Artemis.

ϕ = ... $J\,kg^{-1}$ [1]

(ii) Show that the mass of Artemis is 2.55×10^{24} kg.

[1]

(iii) Calculate the gravitational field strength g on the surface of Artemis.

g = ... $N\,kg^{-1}$ [2]

(iv) A satellite is in an orbit at a fixed position above a point on the surface of Artemis. The satellite is located above the equator of Artemis at a height above the surface where the gravitational potential is $-0.65 \times 10^{7}\,J\,kg^{-1}$.

Calculate the period, in hours, of rotation of Artemis.

period = ... hours [4]

(c) State **one** similarity and **one** difference between gravitational potential due to a point mass and electric potential due to a point charge.

similarity .....

.....

difference .....

.....

[2]

[Total: 12]

Question 14

(a) (i) State what is indicated by the direction of the gravitational field line at a point in a gravitational field.

.....

..... [1]

(ii) Explain, with reference to gravitational field lines, why the gravitational field near the surface of the Earth is approximately constant for small changes in height.

.....

.....

..... [2]

(b) A large isolated uniform sphere has mass *M* and radius *R*.

Point P lies on a straight line passing through the centre of the sphere, at a variable displacement *x* from the centre, as shown in Fig. 1.1.

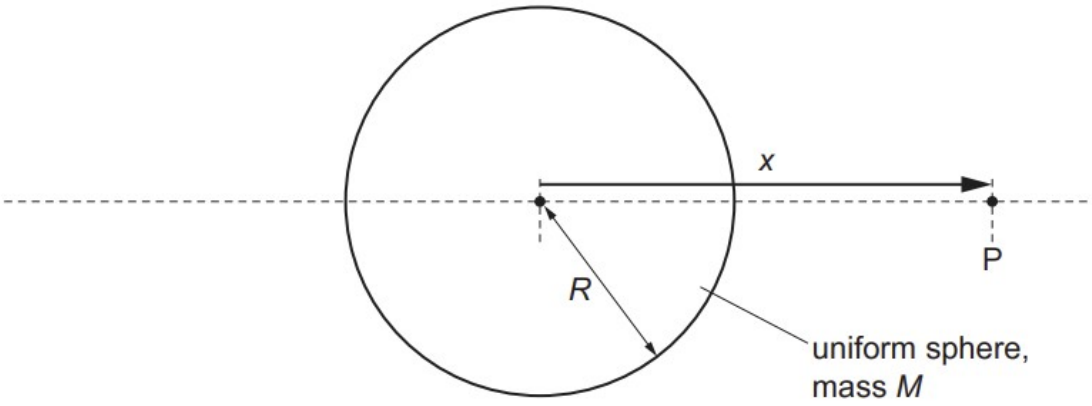


Fig. 1.1

Fig. 1.2 shows the variation with x of the gravitational field g at point P due to the sphere for the values of x for which P is inside the sphere.

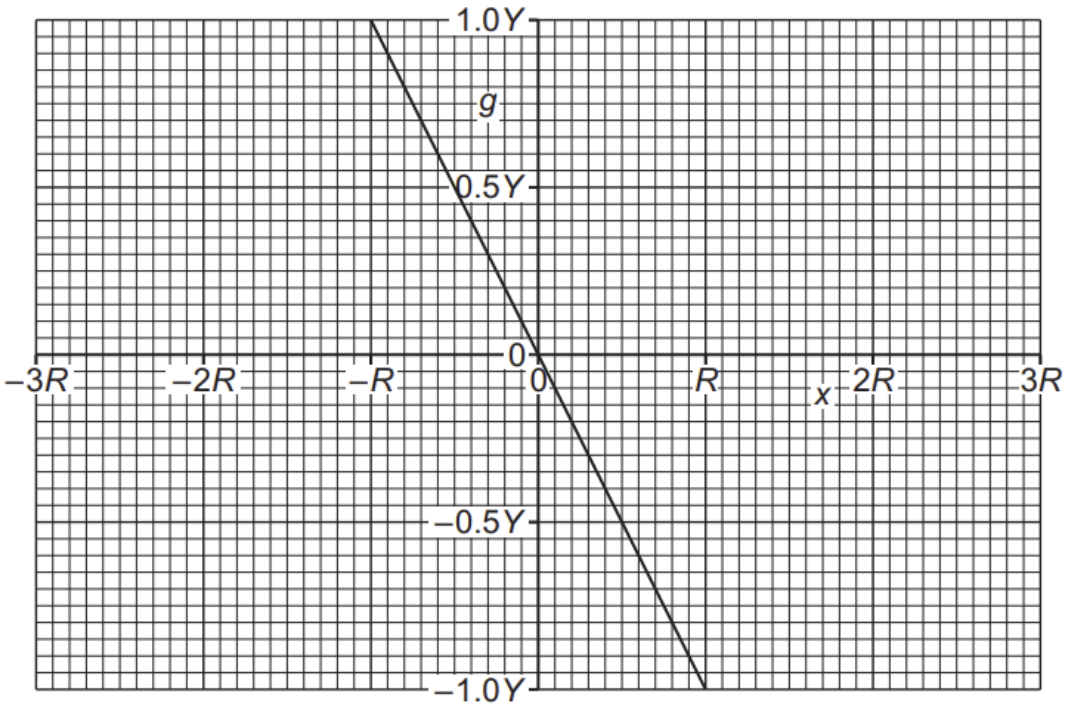


Fig. 1.2

The magnitude of the gravitational field at the surface of the sphere is Y.

(i) Determine an expression for Y in terms of M and R. Identify any other symbols that you use.

[2]

(ii) Explain why, at the surface of the sphere, g always has the opposite sign to x.

.....

.....

..... [2]

(iii) Complete Fig. 1.2 to show the variation of g with x for values of x, up to $\pm 3R$, for which point P is outside the sphere. [3]

[Total: 10]

Question 15

(a) (i) Define gravitational potential at a point.

.....

.....

..... [2]

(ii) The Moon may be considered to be an isolated uniform sphere of mass 7.3×10^{22} kg and radius 1.7×10^{6} m.

Calculate the gravitational potential at the surface of the Moon. Give a unit with your answer.

gravitational potential = ... unit ..... [2]

(b) An isolated uniform spherical planet has gravitational potential ϕ at its surface.

A particle of mass m is projected vertically upwards from the surface. The particle is given just enough kinetic energy to travel to an infinite distance away from the planet, escaping from the gravitational pull of the planet, without any additional work being done on it.

(i) Determine an expression, in terms of m and ϕ, for the gravitational potential energy E_P of the particle at the surface of the planet.

E_P = ... [1]

(ii) Show that the speed v at which the particle is projected upwards from the surface of the planet is given by

$$v = \sqrt{-2\phi}.$$

[2]

(c) A particle is moving upwards at the surface of the Moon.

Use your answer in **(a)(ii)** and the expression in **(b)(ii)** to determine the minimum speed of this particle that will result in it escaping from the gravitational pull of the Moon.

speed = ... $m\,s^{-1}$ [1]

(d) Hydrogen may be assumed to be an ideal gas.
The mass of a hydrogen molecule is 3.34×10^{-27} kg.

Calculate the root-mean-square (r.m.s.) speed of a hydrogen molecule in hydrogen gas that is at a temperature of 400 K.

r.m.s. speed = ... $m\,s^{-1}$ [3]

(e) The surface of the Moon reaches temperatures of approximately 400 K when in direct sunlight.

Use your answers in **(c)** and **(d)** to suggest a reason why the Moon does not have an atmosphere consisting of hydrogen.

.....

..... [1]

[Total: 12]

Question 16

(a) Define gravitational potential at a point.

.....

.....

..... [2]

(b) A satellite X, of mass *M*, orbits a planet at a constant distance 4*R* from the centre of the planet, as shown in Fig. 1.1.

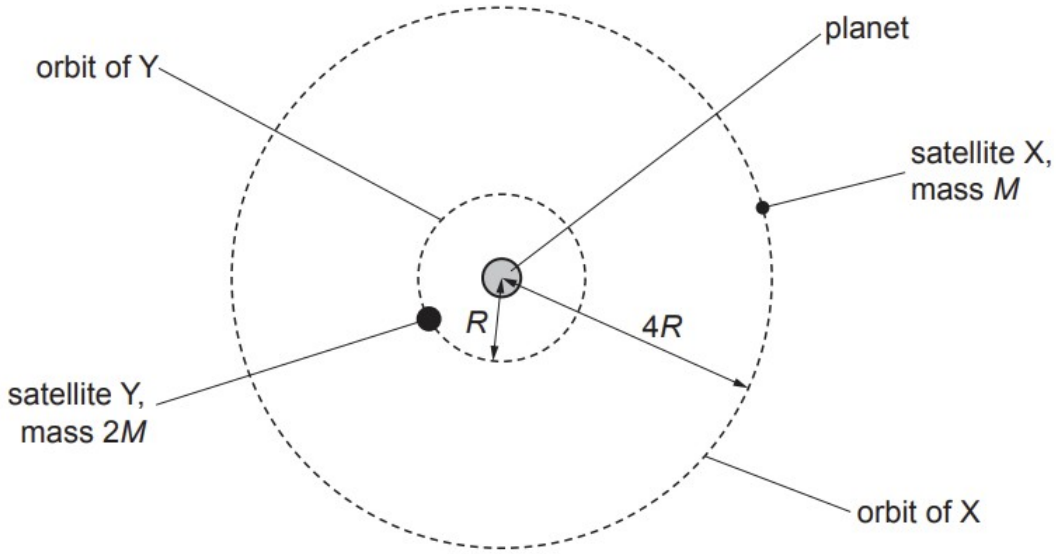


Fig. 1.1 (not to scale)

A second satellite Y, of mass $2M$, orbits the planet with orbital radius R.

The gravitational potential at X due to the planet is $-\Phi$. The planet is a uniform sphere.

(i) Explain why the gravitational potential at X is negative.

.....

.....

..... [2]

(ii) State an expression, in terms of Φ, for the gravitational potential at Y due to the planet.

gravitational potential = ... [2]

(iii) Complete Table 1.1 by giving expressions, in terms of some or all of M, R and Φ, for the quantities indicated for each of the satellites X and Y.

Table 1.1

	satellite X	satellite Y
gravitational field strength at satellite due to planet		
gravitational potential energy of satellite		

[4]

[Total: 10]

Question 17

(a) Explain why the gravitational potential near to a point mass is negative.

.....

.....

.....

..... [2]

(b) A planet may be assumed to be a uniform sphere. It has gravitational potential ϕ at distance r from the centre of the planet.

The variation with $\frac{1}{r}$ of ϕ is shown in Fig. 1.1.

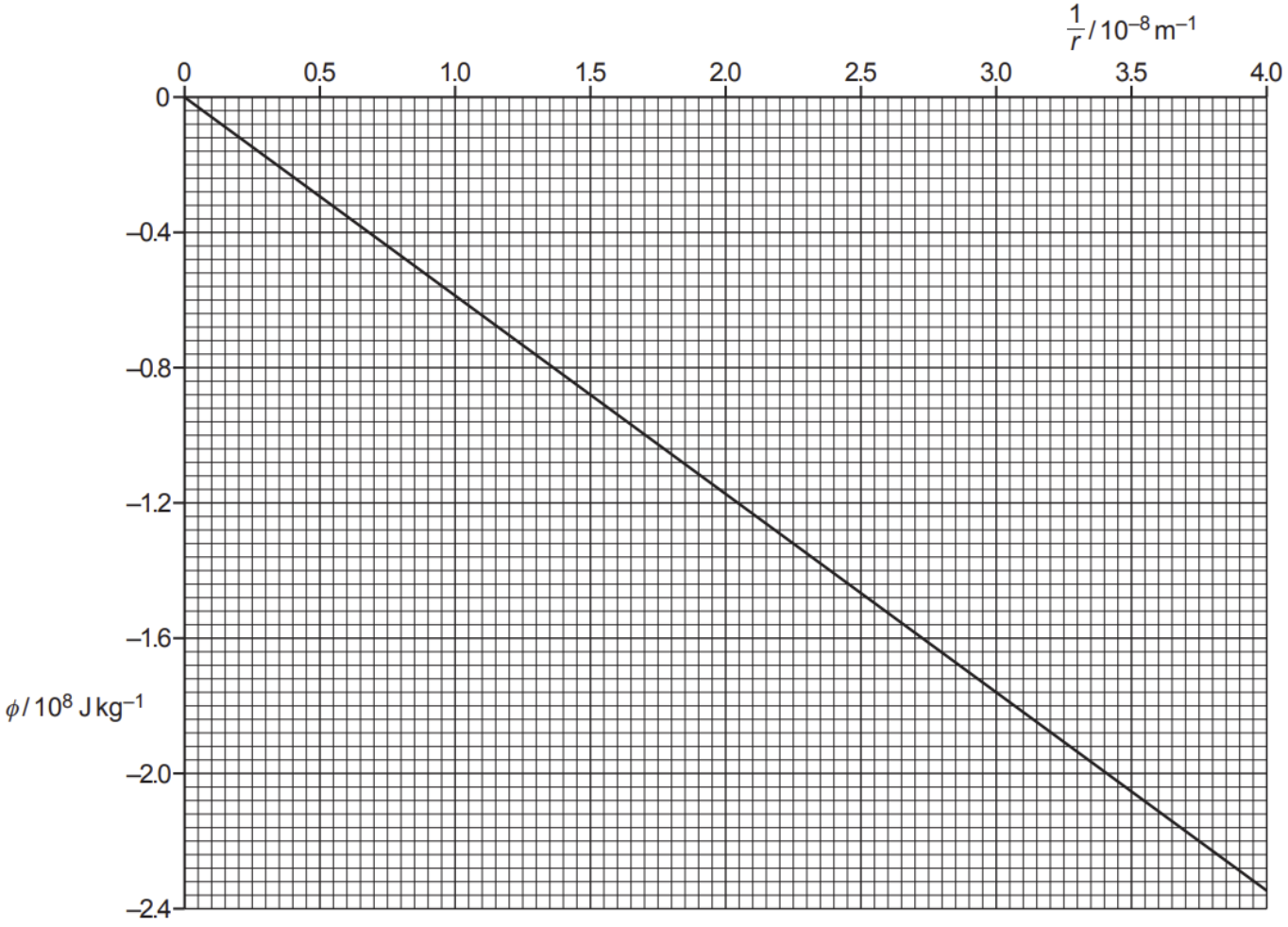


Fig. 1.1

(i) Show that the mass of the planet is 8.8×10^{25} kg.

[2]

(ii) The period of rotation of the planet is 0.72 Earth days.

A satellite in orbit around the planet remains above the same point on the surface of the planet.

Use the mass of the planet in **(b)(i)** to determine the radius R of the orbit of the satellite.

R = ... m [3]

(iii) The speed of the satellite in **(b)(ii)** is 8400 m s^{-1}. The mass of the satellite is 1200 kg.

Determine the additional energy required to move the satellite from its orbit to infinity.

energy required = ... J [3]

[Total: 10]

Question 18

(a) State Newton's law of gravitation.

.....

.....

..... [2]

(b) A planet may be considered as a uniform sphere.

A satellite is in circular orbit of period T around the planet at a height h above the surface. The height of the orbit can be adjusted by use of the satellite's rocket engines.

Fig. 1.1 shows the variation with h of $T^{\frac{2}{3}}$.

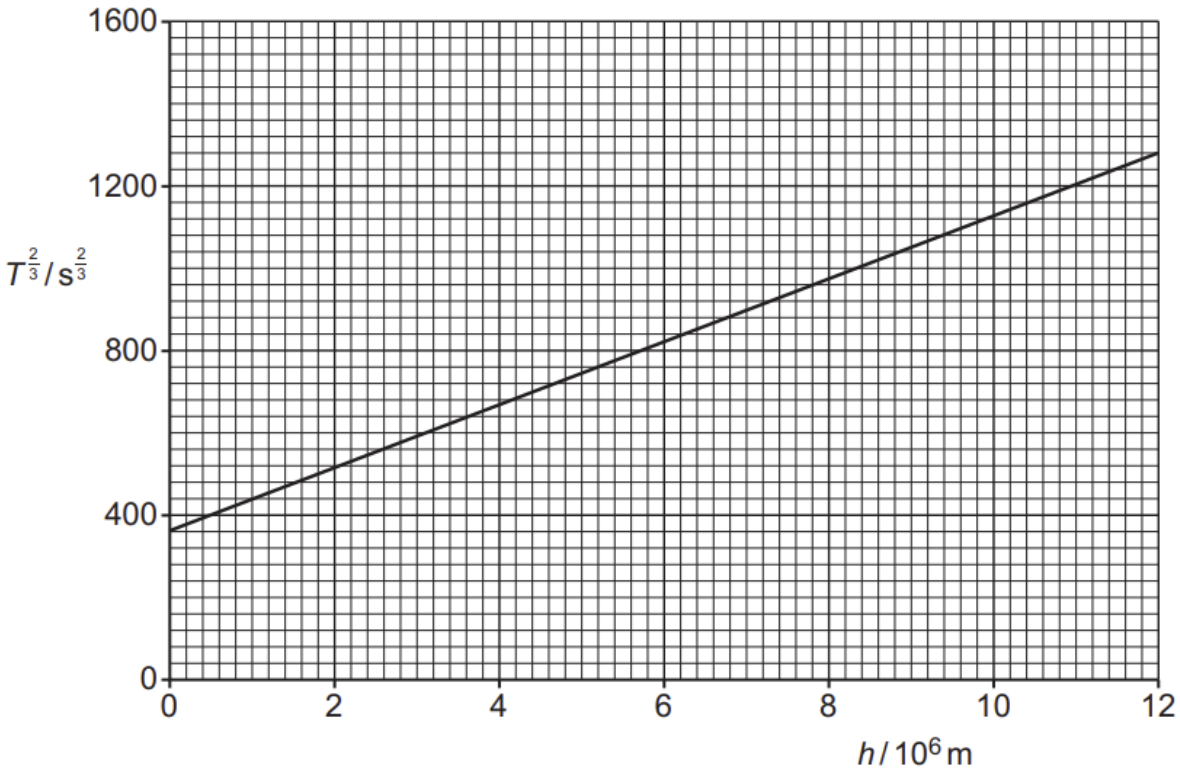


Fig. 1.1

(i) By reference to forces, explain why the orbit of the satellite is circular.

.....

.....

..... [2]

(ii) Use Newton's law of gravitation to show that h and T are related by

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

where G is the gravitational constant and A and B are constants that depend on the properties of the planet.

[3]

(iii) Use the gradient and intercept of the line in Fig. 1.1 to determine values for A and B. Give units with your answers.

A = ... unit .....

B = ... unit .....

[5]

[Total: 12]

Question 19

The Sun may be considered as a uniform sphere with a mass of 1.99×10^{30} kg and a surface temperature of 5780 K.

A probe with a mass of 2.63 kg moves in a straight line towards the Sun.
When it is at a distance x from the centre of the Sun, the probe measures the gravitational field strength g due to the Sun and the radiant flux intensity F of radiation from the Sun.

(a) Define gravitational field.

.....

..... [1]

(b) For the position of the probe where $x = 1.47 \times 10^{11}$ m:

(i) calculate g

g = ... N kg^{-1} [2]

(ii) determine the gravitational potential energy E_P of the probe.

E_P = ... J [2]

(c) **(i)** Show that, for any particular value of x, the numerical values of g and F are related by

$$g = \frac{4\pi GM}{L} F$$

where M is the mass of the Sun, L is the luminosity of the Sun and G is the gravitational constant.

[3]

(ii) Fig. 2.1 shows the variation of g with F.

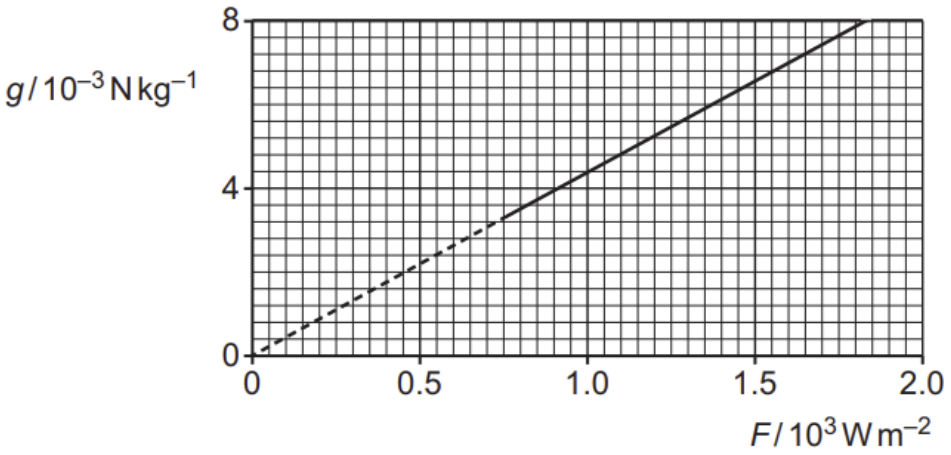


Fig. 2.1

Determine a value for the luminosity L of the Sun. Give a unit with your answer.

L = ... unit ..... [2]

(iii) Use your answer in **(c)(ii)** to determine the radius r of the Sun.

r = ... m [2]

[Total: 12]