CAMBRIDGE INTERNATIONAL AS & A LEVEL PHYSICS · 9702

PHYSICS



EXAM QUESTION PACK

13 GRAVITATIONAL FIELDS

SCORE	PERCENTAGE
/	%

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Chapter 2

Gravitational fields

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4. 9702_s20_qp_41 Q: 1

(a) State what is meant by a *gravitational force*.

.....

..... [1]

(b) A binary star system consists of two stars S_1 and S_2, each in a circular orbit.

The orbit of each star in the system has a period of rotation T.

Observations of the binary star from Earth are represented in Fig. 1.1.

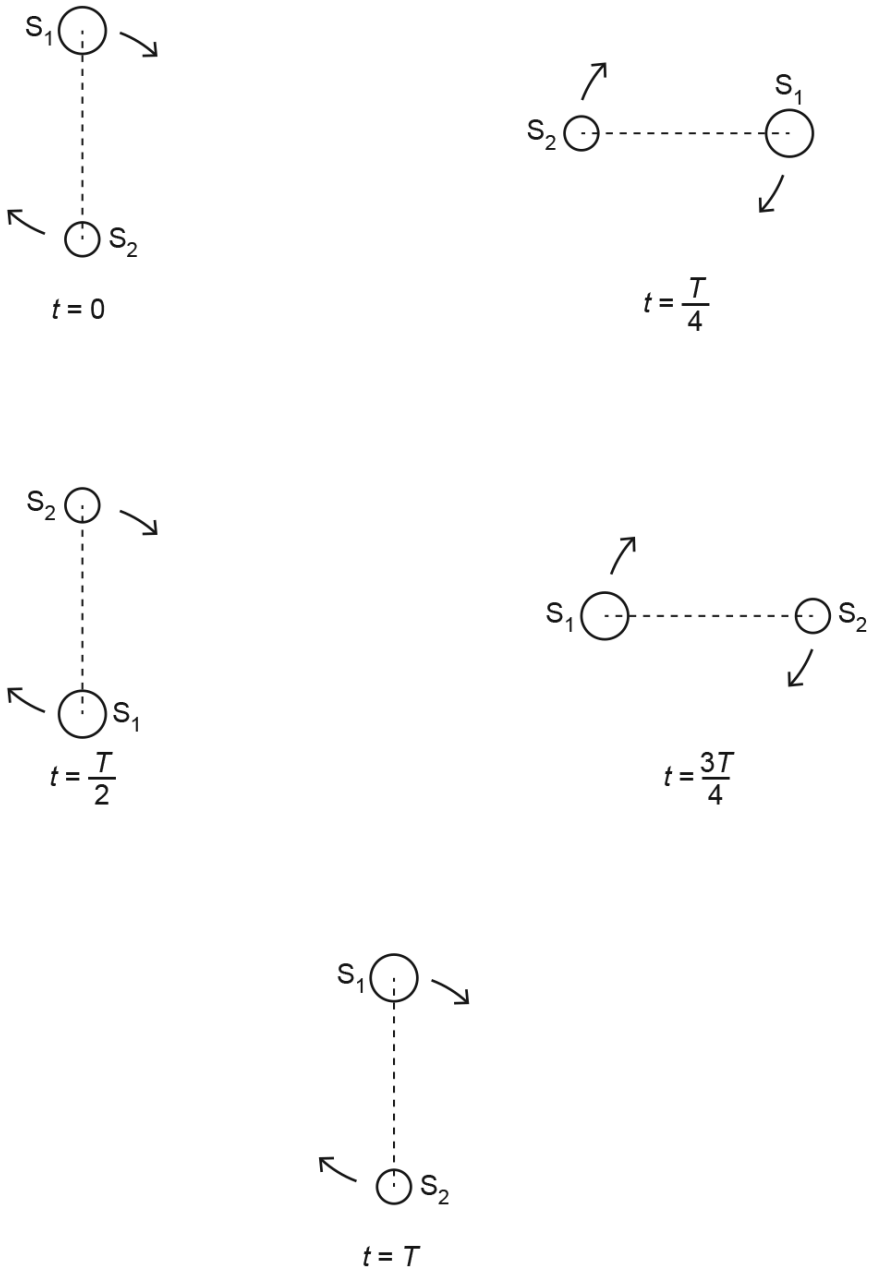


Fig. 1.1 (not to scale)

Observed from Earth, the angular separation of the centres of S_1 and S_2 is 1.2×10^{-5} rad. The distance of the binary star system from Earth is 1.5×10^{17} m.

Show that the separation d of the centres of S_1 and S_2 is 1.8×10^{12} m.

[1]

(c) The stars S_1 and S_2 rotate with the same angular velocity ω about a point P, as illustrated in Fig. 1.2.

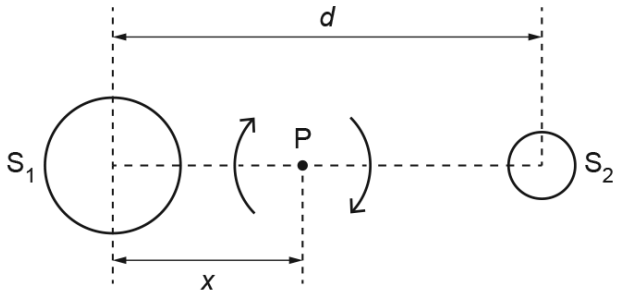


Fig. 1.2 (not to scale)

Point P is at a distance x from the centre of star S_1.
The period of rotation of the stars is 44.2 years.

(i) Calculate the angular velocity ω.

ω = ... rad s^{-1} [2]

(ii) By considering the forces acting on the two stars, show that the ratio of the masses of the stars is given by

$$\frac{\text{mass of } S_1}{\text{mass of } S_2} = \frac{d - x}{x}.$$

[2]

(iii) The mass M_1 of star S_1 is given by the expression

$$GM_1 = d^2(d - x)\omega^2$$

where G is the gravitational constant.

The ratio in **(ii)** is found to be 1.5.

Use data from **(b)** and your answer in **(c)(i)** to determine the mass M_1.

M_1 = ... kg [3]

[Total: 9]

5. 9702_s20_qp_43 Q: 1

(a) State what is meant by a *gravitational force*.

.....

..... [1]

(b) A binary star system consists of two stars S_1 and S_2, each in a circular orbit.

The orbit of each star in the system has a period of rotation T.

Observations of the binary star from Earth are represented in Fig. 1.1.

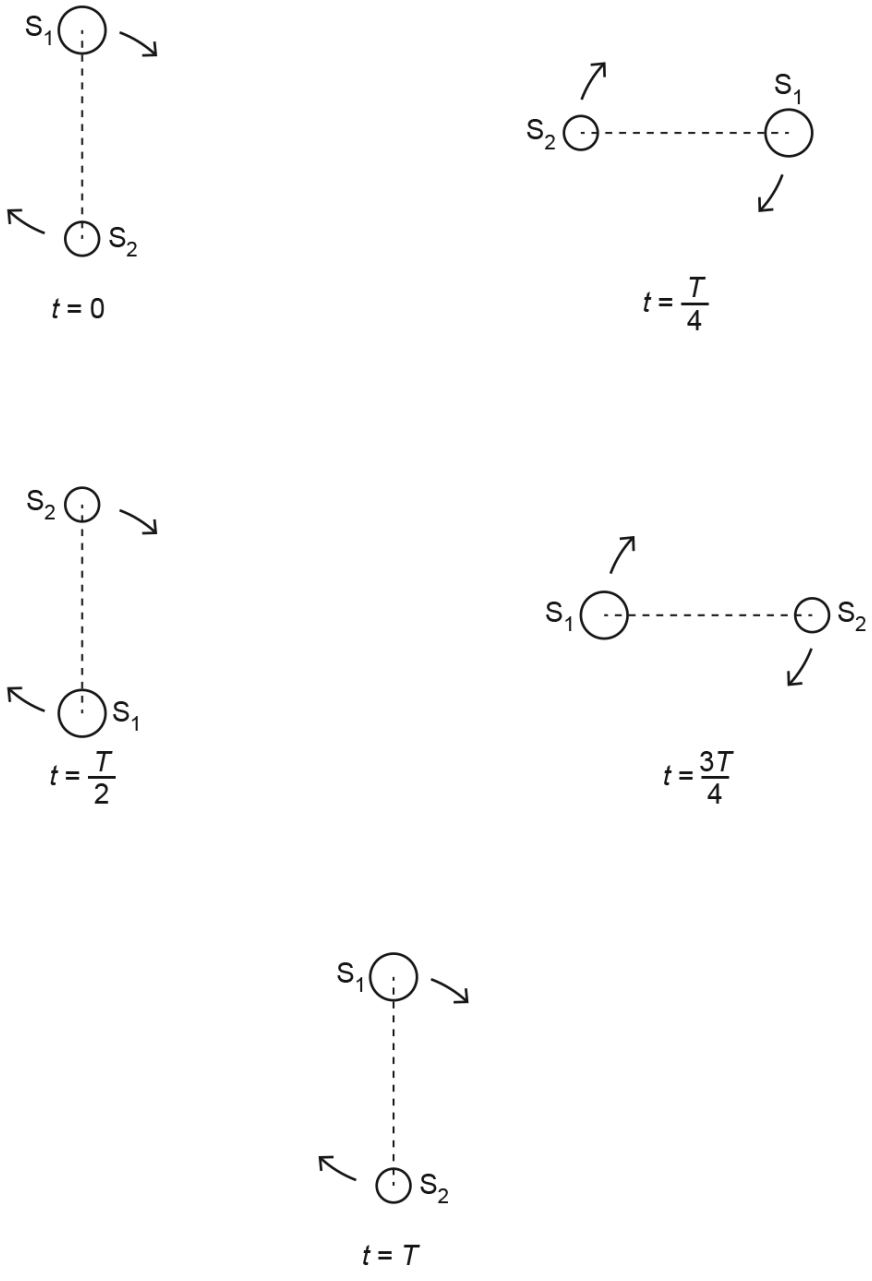


Fig. 1.1 (not to scale)

Observed from Earth, the angular separation of the centres of S_1 and S_2 is 1.2×10^{-5} rad. The distance of the binary star system from Earth is 1.5×10^{17} m.

Show that the separation d of the centres of S_1 and S_2 is 1.8×10^{12} m.

[1]

(c) The stars S_1 and S_2 rotate with the same angular velocity ω about a point P, as illustrated in Fig. 1.2.

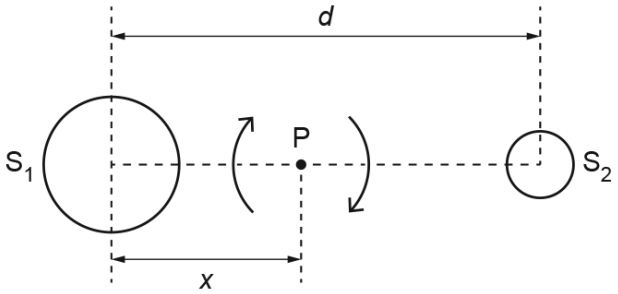


Fig. 1.2 (not to scale)

Point P is at a distance x from the centre of star S_1.
The period of rotation of the stars is 44.2 years.

(i) Calculate the angular velocity ω.

ω = ... rad s^{-1} [2]

(ii) By considering the forces acting on the two stars, show that the ratio of the masses of the stars is given by

$$\frac{\text{mass of } S_1}{\text{mass of } S_2} = \frac{d - x}{x}.$$

[2]

(iii) The mass M_1 of star S_1 is given by the expression

$$GM_1 = d^2(d - x)\omega^2$$

where G is the gravitational constant.

The ratio in **(ii)** is found to be 1.5.

Use data from **(b)** and your answer in **(c)(i)** to determine the mass M_1.

M_1 = ... kg [3]

[Total: 9]

6. 9702_w19_qp_41 Q: 1

(a) State Newton's law of gravitation.

.....

.....

..... [2]

(b) A geostationary satellite orbits the Earth. The orbit of the satellite is circular and the period of the orbit is 24 hours.

(i) State **two** other features of this orbit.

1. .....

.....

2. .....

.....

[2]

(ii) The radius of the orbit of the satellite is 4.23×10^4 km.

Determine a value for the mass of the Earth. Explain your working.

mass = ... kg [4]

[Total: 8]

7. 9702_w19_qp_42 Q: 1

(a) State Newton's law of gravitation.

.....

.....

..... [2]

(b) The astronomer Johannes Kepler showed that the period T of rotation of a planet about the Sun is related to its mean distance R from the centre of the Sun by the expression

$$\frac{R^3}{T^2} = k$$

where k is a constant.

Use Newton's law to show that, for planets in circular orbits about the Sun of mass M, the constant k is given by

$$k = \frac{GM}{4\pi^2}$$

where G is the gravitational constant. Explain your working.

[4]

(c) A satellite is in a circular orbit about Mars.
The radius of the orbit of the satellite is 4.38×10^6 m. The orbital period is 2.44 hours.

Use the expressions in **(b)** to calculate a value for the mass of Mars.

mass = ... kg [2]

[Total: 8]

8. 9702_w19_qp_43 Q: 1

(a) State Newton's law of gravitation.

.....

.....

..... [2]

(b) A geostationary satellite orbits the Earth. The orbit of the satellite is circular and the period of the orbit is 24 hours.

(i) State **two** other features of this orbit.

1. .....

.....

2. .....

.....

[2]

(ii) The radius of the orbit of the satellite is 4.23×10^4 km.

Determine a value for the mass of the Earth. Explain your working.

mass = ... kg [4]

[Total: 8]

9. 9702_s18_qp_41 Q: 1

(a) State Newton's law of gravitation.

.....

.....

.....

.....[2]

(b) A distant star is orbited by several planets. Each planet has a circular orbit with a different radius.

(i) Each planet orbits at constant speed.
Explain whether the planets are in equilibrium.

.....

.....

.....[1]

(ii) The radius of the orbit of a planet is R and the orbital period is T.

Data for some of the planets are given in Fig. 1.1.

planet	R/m	T^2/s^2
c	9.6×10^{10}	2.5×10^{11}
e	4.0×10^{11}	1.8×10^{13}
g	2.1×10^{12}	2.6×10^{15}

Fig. 1.1

The relationship between R and T is given by the expression

$$R^3 = kT^2.$$

1. Show that the constant k is given by the expression

$$k = \frac{GM}{4\pi^2}$$

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

[3]

2. Use data from Fig. 1.1 for the three planets and the expression for k to calculate the mass M of the star.

M = ...kg [3]

[Total: 9]

10. 9702_s18_qp_43 Q: 1

(a) State Newton's law of gravitation.

.....

.....

.....

.....[2]

(b) A distant star is orbited by several planets. Each planet has a circular orbit with a different radius.

(i) Each planet orbits at constant speed.
Explain whether the planets are in equilibrium.

.....

.....

.....[1]

(ii) The radius of the orbit of a planet is R and the orbital period is T.

Data for some of the planets are given in Fig. 1.1.

planet	R/m	T^2/s^2
c	9.6×10^{10}	2.5×10^{11}
e	4.0×10^{11}	1.8×10^{13}
g	2.1×10^{12}	2.6×10^{15}

Fig. 1.1

The relationship between R and T is given by the expression

$$R^3 = kT^2.$$

1. Show that the constant k is given by the expression

$$k = \frac{GM}{4\pi^2}$$

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

[3]

2. Use data from Fig. 1.1 for the three planets and the expression for k to calculate the mass M of the star.

$M =$ .....kg [3]

[Total: 9]

11. 9702_s17_qp_43 Q: 1

(a) Explain how a satellite may be in a circular orbit around a planet.

.....

.....

.....[2]

(b) The Earth and the Moon may be considered to be uniform spheres that are isolated in space. The Earth has radius R and mean density ρ. The Moon, mass m, is in a circular orbit about the Earth with radius nR, as illustrated in Fig. 1.1.

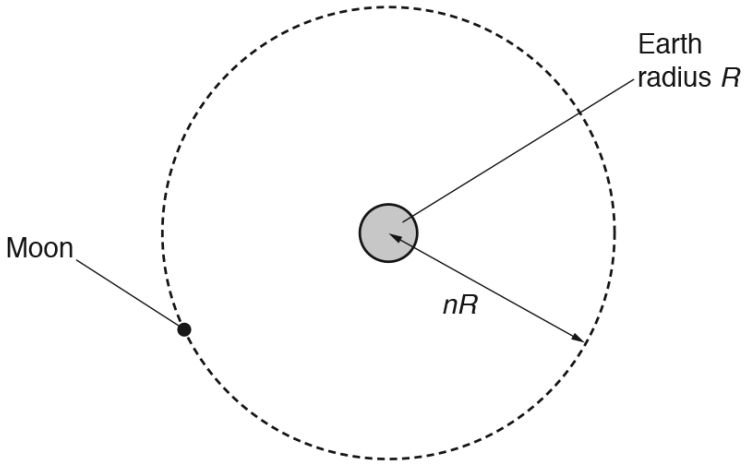


Fig. 1.1

The Moon makes one complete orbit of the Earth in time T.
Show that the mean density ρ of the Earth is given by the expression

$$\rho = \frac{3\pi n^3}{GT^2}.$$

[4]

(c) The radius R of the Earth is 6.38×10^3 km and the distance between the centre of the Earth and the centre of the Moon is 3.84×10^5 km.
The period T of the orbit of the Moon about the Earth is 27.3 days.
Use the expression in **(b)** to calculate ρ.

$\rho =$ ..... kg m^{-3} [3]

[Total: 9]

---

12. 9702_w17_qp_42 Q: 1

(a) State Newton's law of gravitation.

.....

.....

.....[2]

(b) The planet Jupiter and one of its moons, Io, may be considered to be uniform spheres that are isolated in space.
Jupiter has radius R and mean density ρ.
Io has mass m and is in a circular orbit about Jupiter with radius nR, as illustrated in Fig. 1.1.

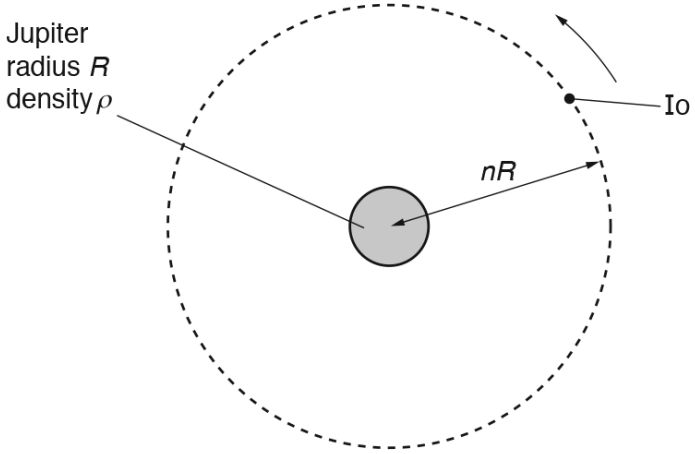


Fig. 1.1

The time for Io to complete one orbit of Jupiter is T.

Show that the time T is related to the mean density ρ of Jupiter by the expression

$$\rho T^2 = \frac{3\pi n^3}{G}$$

where G is the gravitational constant.

[4]

(c) **(i)** The radius R of Jupiter is 7.15×10^4 km and the distance between the centres of Jupiter and Io is 4.32×10^5 km.
The period T of the orbit of Io is 42.5 hours.

Calculate the mean density ρ of Jupiter.

$\rho =$ ..... kg m^{-3} [3]

(ii) The Earth has a mean density of $5.5 \times 10^3\,\text{kg m}^{-3}$. It is said to be a planet made of rock.
By reference to your answer in **(i)**, comment on the possible composition of Jupiter.

.....

.....[1]

[Total: 10]

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13. 9702_w16_qp_41 Q: 1

A satellite is in a circular orbit of radius r about the Earth of mass M, as illustrated in Fig. 1.1.

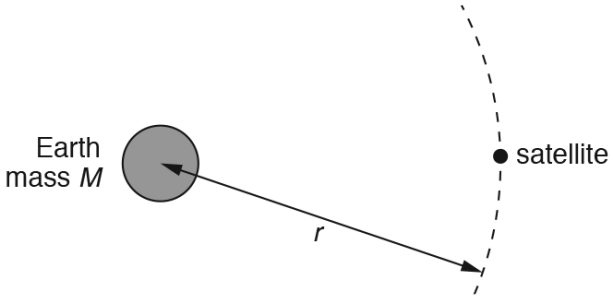


Fig. 1.1

The mass of the Earth may be assumed to be concentrated at its centre.

(a) Show that the period T of the orbit of the satellite is given by the expression

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

where G is the gravitational constant. Explain your working.

[3]

(b) **(i)** A satellite in geostationary orbit appears to remain above the same point on the Earth and has a period of 24 hours.
State two other features of a *geostationary* orbit.

1. .....

.....

2. .....

.....

[2]

(ii) The mass M of the Earth is 6.0×10^{24} kg.
Use the expression in **(a)** to determine the radius of a geostationary orbit.

radius = ... m [2]

(c) A global positioning system (GPS) satellite orbits the Earth at a height of 2.0×10^{4} km above the Earth's surface.
The radius of the Earth is 6.4×10^{3} km.

Use your answer in **(b)(ii)** and the expression

$$T^2 \propto r^3$$

to calculate, in hours, the period of the orbit of this satellite.

period = ... hours [2]

[Total: 9]

14. 9702_w16_qp_43 Q: 1

A satellite is in a circular orbit of radius r about the Earth of mass M, as illustrated in Fig. 1.1.

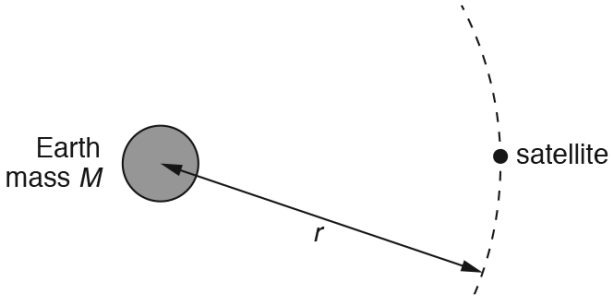


Fig. 1.1

The mass of the Earth may be assumed to be concentrated at its centre.

(a) Show that the period T of the orbit of the satellite is given by the expression

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

where G is the gravitational constant. Explain your working.

[3]

(b) **(i)** A satellite in geostationary orbit appears to remain above the same point on the Earth and has a period of 24 hours.
State two other features of a *geostationary* orbit.

1. .....

.....

2. .....

.....

[2]

(ii) The mass M of the Earth is 6.0×10^{24} kg.
Use the expression in **(a)** to determine the radius of a geostationary orbit.

radius = ... m [2]

(c) A global positioning system (GPS) satellite orbits the Earth at a height of 2.0×10^{4} km above the Earth's surface.
The radius of the Earth is 6.4×10^{3} km.

Use your answer in **(b)(ii)** and the expression

$$T^2 \propto r^3$$

to calculate, in hours, the period of the orbit of this satellite.

period = ... hours [2]

[Total: 9]

15. 9702_s21_qp_42 Q: 1

(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]

16. 9702_s19_qp_42 Q: 1

(a) Two point masses are separated by a distance x in a vacuum.
State an expression for the force F between the two masses M and m.
State the name of any other symbol used.

.....

.....

.....[1]

(b) A small sphere S is attached to one end of a rod, as shown in Fig. 1.1.

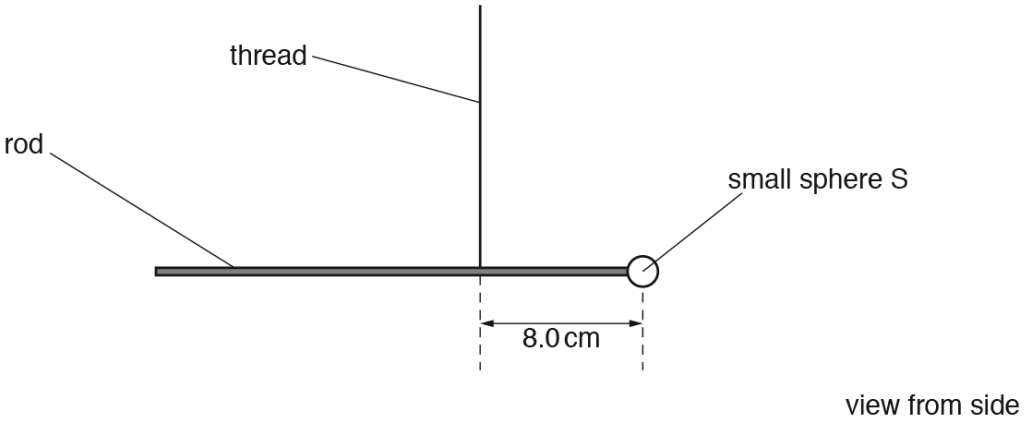


Fig. 1.1 (not to scale)

The rod hangs from a vertical thread and is horizontal.
The distance from the centre of sphere S to the thread is 8.0 cm.

A large sphere L is placed near to sphere S, as shown in Fig. 1.2.

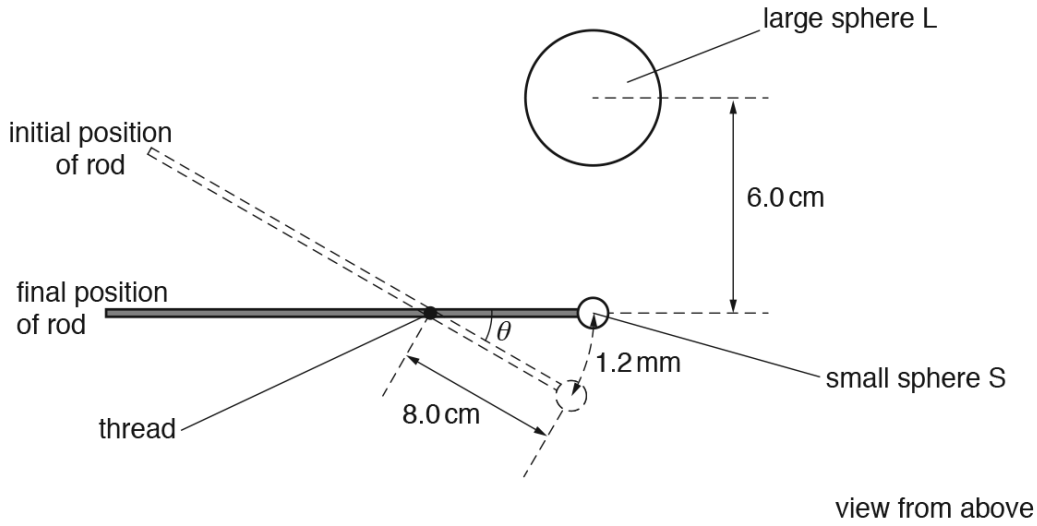


Fig. 1.2 (not to scale)

There is a force of attraction between spheres S and L, causing sphere S to move through a distance of 1.2 mm.
The line joining the centres of S and L is normal to the rod.

(i) Show that the angle θ through which the rod rotates is 1.5×10^{-2} rad.

[1]

(ii) The rotation of the rod causes the thread to twist.
The torque T (in N m) required to twist the thread through an angle β (in rad) is given by

$$T = 9.3 \times 10^{-10} \times \beta.$$

Calculate the torque in the thread when sphere L is positioned as shown in Fig. 1.2.

torque = ... N m [1]

(c) The distance between the centres of spheres S and L is 6.0 cm.
The mass of sphere S is 7.5 g and the mass of sphere L is 1.3 kg.

(i) By equating the torque in **(b)(ii)** to the moment about the thread produced by gravitational attraction between the spheres, calculate a value for the gravitational constant.

gravitational constant = ... $N m^2 kg^{-2}$ [3]

(ii) Suggest why the total force between the spheres may not be equal to the force calculated using Newton's law of gravitation.

.....

.....[1]

[Total: 7]

---

17. 9702_m18_qp_42 Q: 1

(a) **(i)** State what is meant by a line of force in a gravitational field.

.....

.....

.....[1]

(ii) By reference to the pattern of the lines of gravitational force near to the surface of the Earth, explain why the acceleration of free fall near to the Earth's surface is approximately constant.

.....

.....

.....

.....

.....[3]

(b) The Moon may be considered to be a uniform sphere that is isolated in space. It has radius 1.74×10^3 km and mass 7.35×10^{22} kg.

(i) Calculate the gravitational field strength at the Moon's surface.

gravitational field strength = ... N kg^{-1} [2]

(ii) A satellite is in a circular orbit about the Moon at a height of 320 km above its surface.

Calculate the time for the satellite to complete one orbit of the Moon.

time = ... s [3]

[Total: 9]

18. 9702_s18_qp_42 Q: 1

(a) **(i)** A gravitational field may be represented by lines of gravitational force.
State what is meant by a *line of gravitational force*.

.....

.....

.....[1]

(ii) By reference to lines of gravitational force near to the surface of the Earth, explain why the gravitational field strength g close to the Earth's surface is approximately constant.

.....

.....

.....

.....

.....

.....[3]

(b) The Moon may be considered to be a uniform sphere of diameter 3.4×10^3 km and mass 7.4×10^{22} kg. The Moon has no atmosphere.

During a collision of the Moon with a meteorite, a rock is thrown vertically up from the surface of the Moon with a speed of $2.8\,\text{km}\,\text{s}^{-1}$.

Assuming that the Moon is isolated in space, determine whether the rock will travel out into distant space or return to the Moon's surface.

[4]

[Total: 8]

19. 9702_w18_qp_42 Q: 1

(a) **(i)** State what is meant by *gravitational field strength*.

.....

.....

.....[1]

(ii) Explain why, at the surface of a planet, gravitational field strength is numerically equal to the acceleration of free fall.

.....

.....

.....[1]

(b) An isolated uniform spherical planet has radius R.
The acceleration of free fall at the surface of the planet is g.

On Fig. 1.1, sketch a graph to show the variation of the acceleration of free fall with distance x from the centre of the planet for values of x in the range $x = R$ to $x = 4R$.

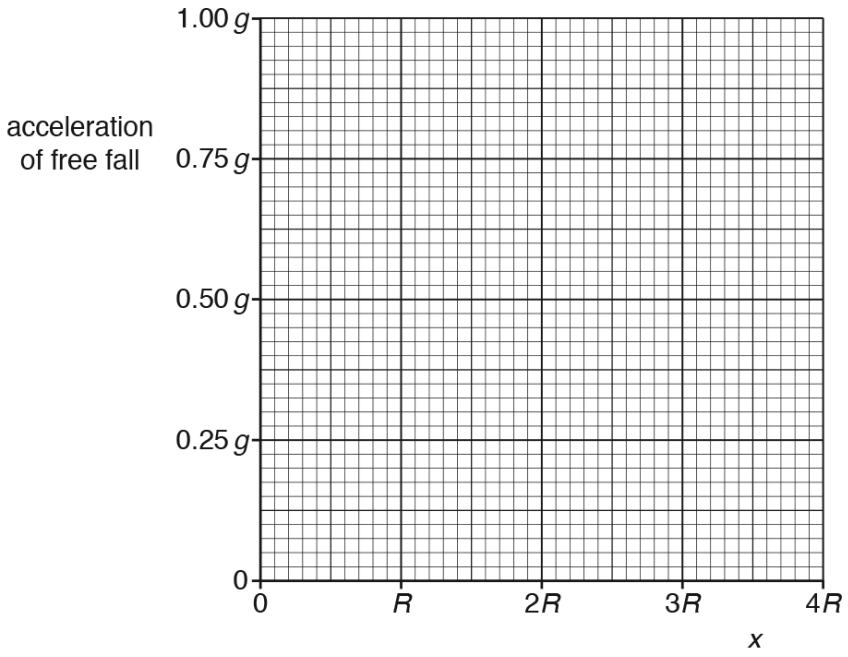


Fig. 1.1

[3]

(c) The planet in **(b)** has radius R equal to 3.4×10^3 km and mean density 4.0×10^3 kg m^{-3}.

Calculate the acceleration of free fall at a height R above its surface.

acceleration of free fall = ... m s^{-2} [3]

[Total: 8]

---

20. 9702_s17_qp_41 Q: 1

(a) Explain how a satellite may be in a circular orbit around a planet.

.....

.....

.....[2]

(b) The Earth and the Moon may be considered to be uniform spheres that are isolated in space. The Earth has radius R and mean density ρ. The Moon, mass m, is in a circular orbit about the Earth with radius nR, as illustrated in Fig. 1.1.

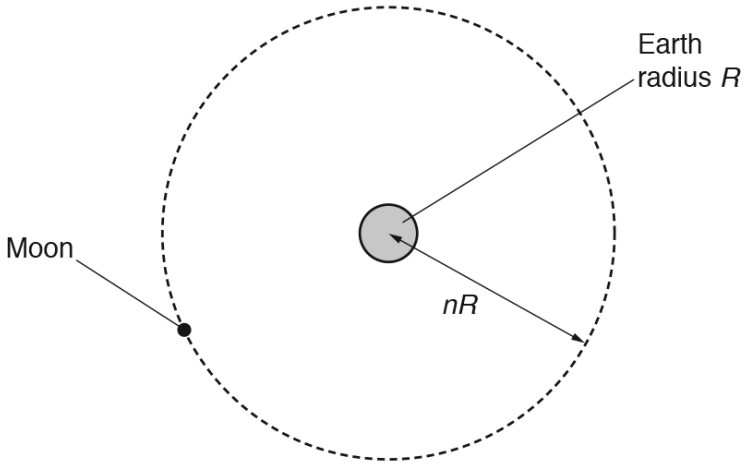


Fig. 1.1

The Moon makes one complete orbit of the Earth in time T.
Show that the mean density ρ of the Earth is given by the expression

$$\rho = \frac{3\pi n^3}{GT^2}.$$

[4]

(c) The radius R of the Earth is 6.38×10^3 km and the distance between the centre of the Earth and the centre of the Moon is 3.84×10^5 km.
The period T of the orbit of the Moon about the Earth is 27.3 days.
Use the expression in **(b)** to calculate ρ.

ρ = ... kg m^{-3} [3]

[Total: 9]

---

21. 9702_s17_qp_42 Q: 1

(a) Define *gravitational field strength*.

.....

.....[1]

(b) The mass of a spherical comet of radius 3.6 km is approximately 1.0×10^{13} kg.

(i) Assuming that the comet has constant density, calculate the gravitational field strength on the surface of the comet.

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

(ii) A probe having a weight of 960 N on Earth lands on the comet.
Using your answer in **(i)**, determine the weight of the probe on the surface of the comet.

weight = ... N [2]

(c) A second comet has a length of approximately 4.5 km and a width of approximately 2.6 km. Its outline is illustrated in Fig. 1.1.

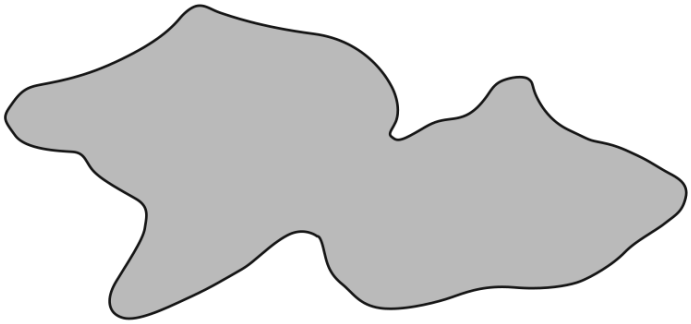


Fig. 1.1

Suggest one similarity and one difference between the gravitational fields at the surface of this comet and at the surface of the comet in **(b)**.

similarity: .....

.....

difference: .....

.....

[2]

[Total: 7]

22. 9702_w17_qp_41 Q: 3

(a) Define *gravitational field strength*.

.....

..... [1]

(b) Explain why, for changes in vertical position of a point mass near the Earth's surface, the gravitational field strength may be considered to be constant.

.....

.....

.....

..... [2]

(c) The orbit of the Earth about the Sun is approximately circular with a radius of 1.5×10^8 km. The time period of the orbit is 365 days.

Determine a value for the mass M of the Sun. Explain your working.

M = ... kg [5]

[Total: 8]

23. 9702_w17_qp_43 Q: 3

(a) Define *gravitational field strength*.

.....

..... [1]

(b) Explain why, for changes in vertical position of a point mass near the Earth's surface, the gravitational field strength may be considered to be constant.

.....

.....

.....

..... [2]

(c) The orbit of the Earth about the Sun is approximately circular with a radius of 1.5×10^8 km. The time period of the orbit is 365 days.

Determine a value for the mass M of the Sun. Explain your working.

$M =$ ..... kg [5]

[Total: 8]

24. 9702_m16_qp_42 Q: 1

(a) State Newton's law of gravitation.

.....

.....

.....

.....[2]

(b) A satellite of mass m has a circular orbit of radius r about a planet of mass M. It may be assumed that the planet and the satellite are uniform spheres that are isolated in space.

Show that the linear speed v of the satellite is given by the expression

$$v = \sqrt{\frac{GM}{r}}$$

where G is the gravitational constant.
Explain your working.

[2]

(c) Two moons A and B have circular orbits about a planet, as illustrated in Fig. 1.1.

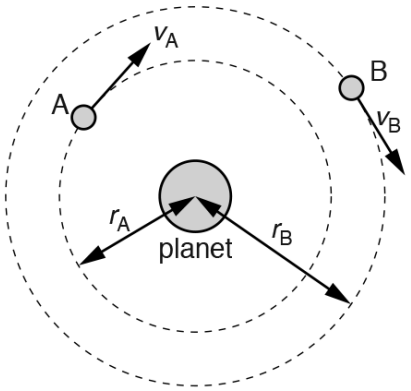


Fig. 1.1 (not to scale)

Moon A has an orbital radius r_A of 1.3×10^8 m, linear speed v_A and orbital period T_A.
Moon B has an orbital radius r_B of 2.2×10^{10} m, linear speed v_B and orbital period T_B.

(i) Determine the ratio

1. $\frac{v_A}{v_B}$,

ratio = ...[2]

2. $\frac{T_A}{T_B}$.

ratio = ...[3]

(ii) The planet spins about its own axis with angular speed $1.7 \times 10^{-4}\,\text{rad}\,\text{s}^{-1}$.
Moon A is always above the same point on the planet's surface.

Determine the orbital period T_B of moon B.

T_B = ...s [2]

[Total: 11]

---

25. 9702_w16_qp_42 Q: 1

(a) Define *gravitational field strength*.

.....

.....[1]

(b) The nearest star to the Sun is Proxima Centauri.
This star has a mass of 2.5×10^{29} kg and is a distance of 4.0×10^{13} km from the Sun.
The Sun has a mass of 2.0×10^{30} kg.

(i) State why Proxima Centauri may be assumed to be a point mass when viewed from the Sun.

.....

.....[1]

(ii) Calculate

1. the gravitational field strength due to Proxima Centauri at a distance of 4.0×10^{13} km,

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

2. the gravitational force of attraction between the Sun and Proxima Centauri.

force = ... N [2]

(c) Suggest quantitatively why it may be assumed that the Sun is isolated in space from other stars.

.....

.....

.....[2]

[Total: 8]

---

26. 9702_m21_qp_42 Q: 1

(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.

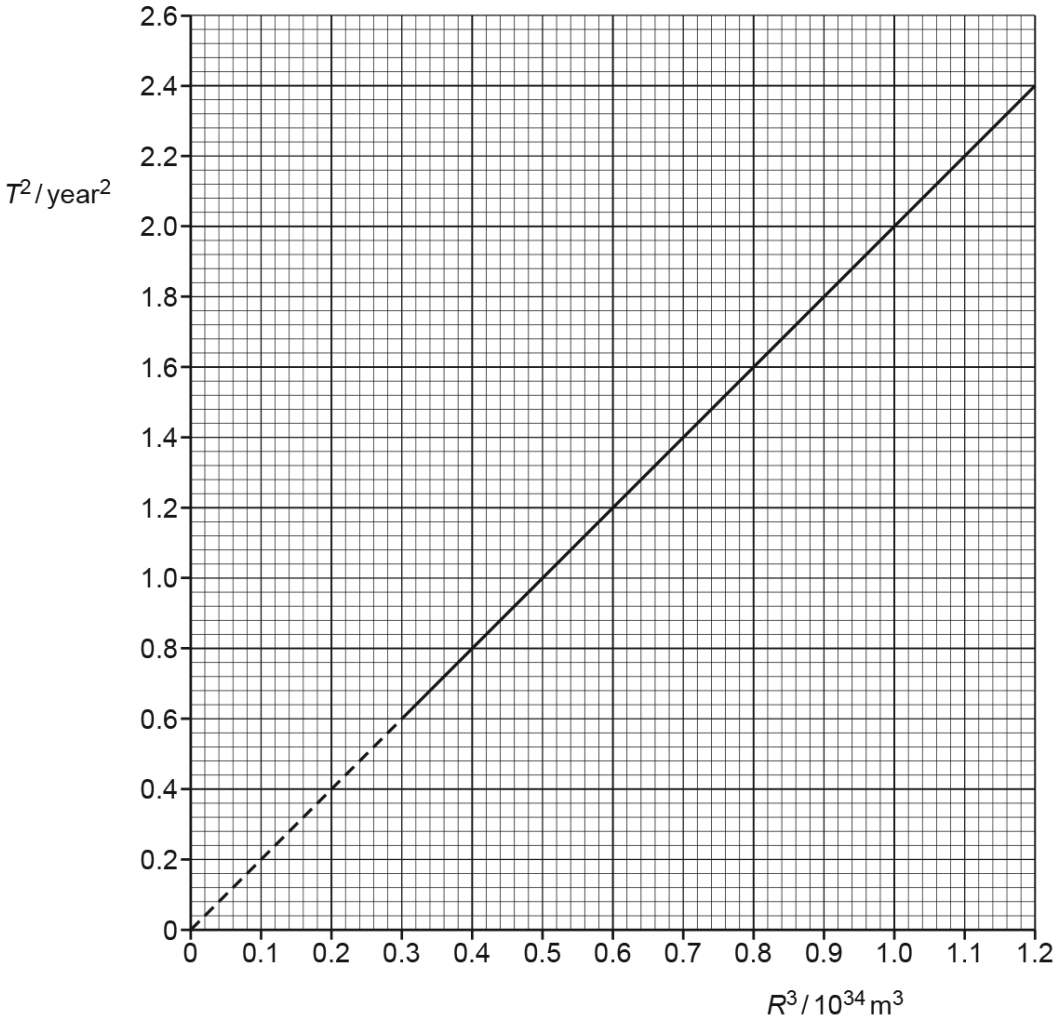


Fig. 1.1

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]

27. 9702_s21_qp_41 Q: 1

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]

---

28. 9702_s21_qp_43 Q: 1

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]

---

29. 9702_w21_qp_41 Q: 2

(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.

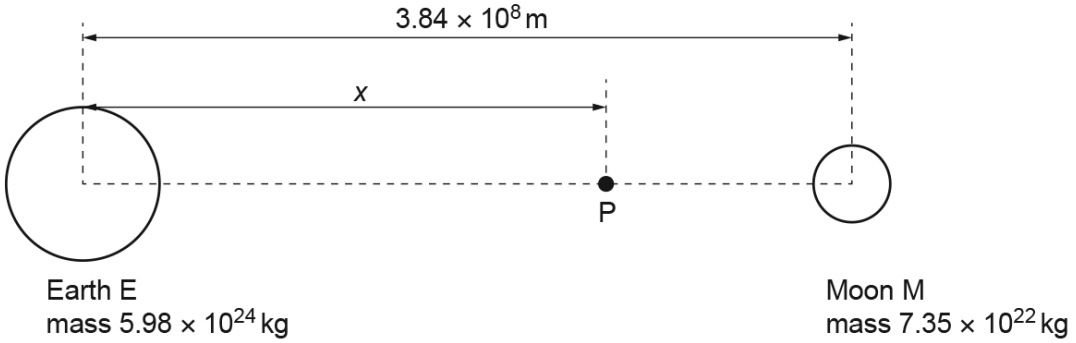


Fig. 2.1 (not to scale)

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.

(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]

---

30. 9702_w21_qp_42 Q: 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.

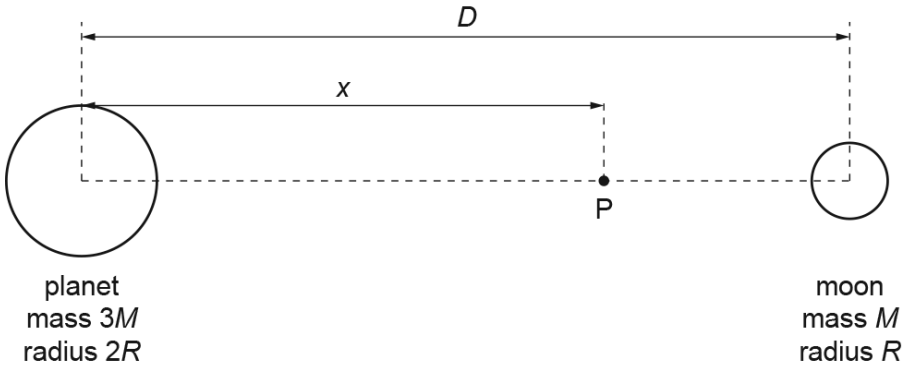


Fig. 2.1

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.

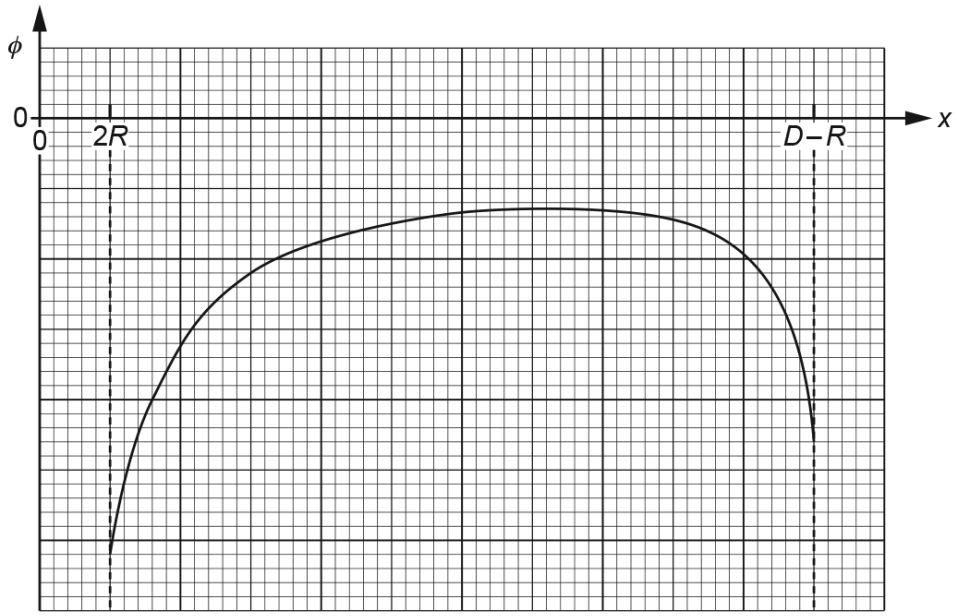


Fig. 2.2

(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 $x = D - R$.

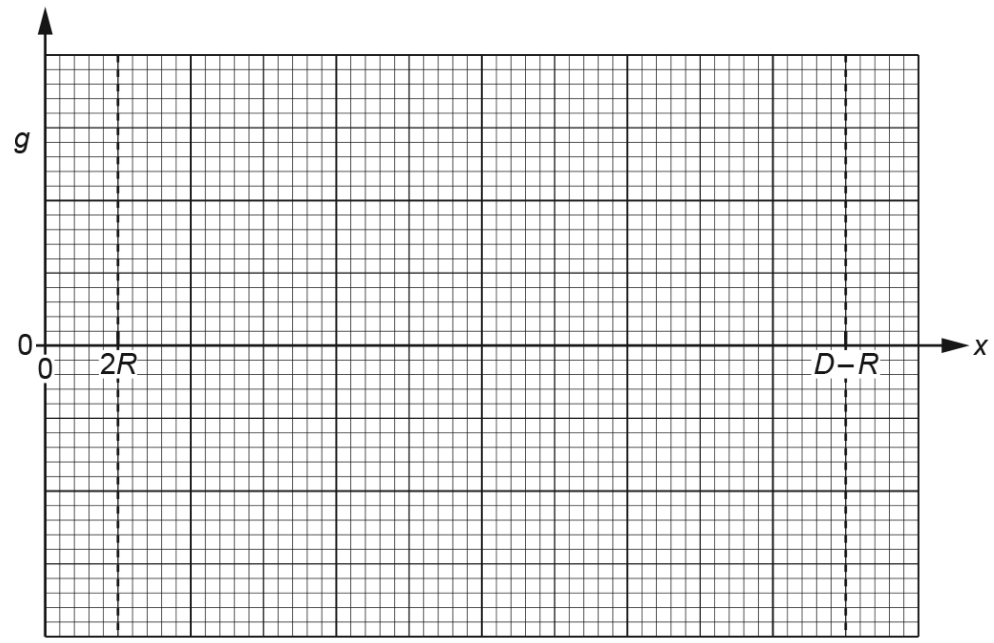


Fig. 2.3

[3]

[Total: 10]

31. 9702_w21_qp_43 Q: 2

(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.

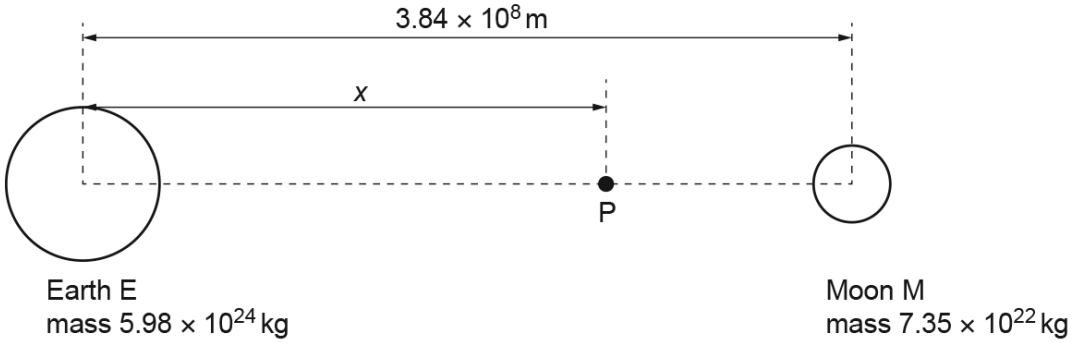


Fig. 2.1 (not to scale)

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.

(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]

---

32. 9702_m20_qp_42 Q: 1

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

.....

.....

..... [2]

(b) TESS is a satellite of mass 360 kg in a circular orbit about the Earth as shown in Fig. 1.1.

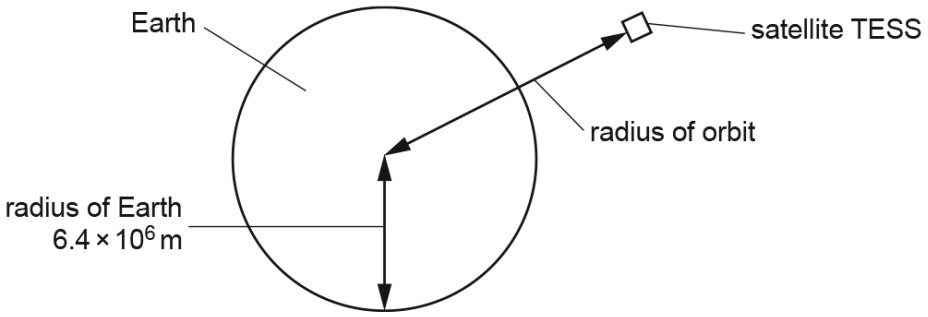


Fig. 1.1 (not to scale)

The radius of the Earth is 6.4×10^6 m and the mass of the Earth, considered to be a point mass at its centre, is 6.0×10^{24} kg.

(i) It takes TESS 13.7 days to orbit the Earth.

Show that the radius of orbit of TESS is 2.4×10^8 m.

[3]

(ii) Calculate the change in gravitational potential energy between TESS in orbit and TESS on a launch pad on the surface of the Earth.

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

(iii) Use the information in **(b)(i)** to calculate the ratio:

$$\frac{\text{gravitational field strength on surface of Earth}}{\text{gravitational field strength at location of TESS in orbit}}.$$

ratio = ... [2]

[Total: 10]

---

33. 9702_s20_qp_42 Q: 1

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

.....

.....

..... [2]

(b) An isolated solid sphere of radius r may be assumed to have its mass M concentrated at its centre. The magnitude of the gravitational potential at the surface of the sphere is ϕ.

On Fig. 1.1, show the variation of the gravitational potential with distance d from the centre of the sphere for values of d from $d = r$ to $d = 4r$.

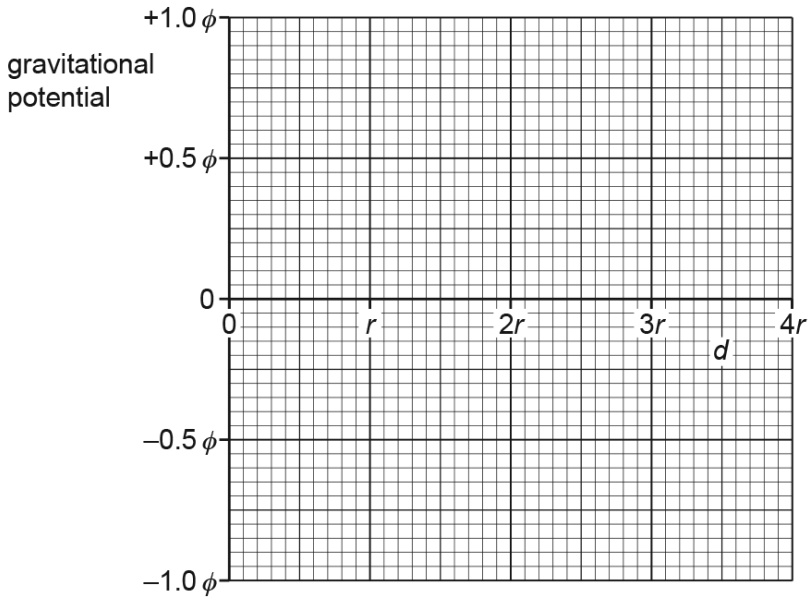


Fig. 1.1

[3]

(c) The sphere in **(b)** is a planet with radius r of 6.4×10^6 m and mass M of 6.0×10^{24} kg. The planet has no atmosphere.

A rock of mass 3.4×10^3 kg moves directly towards the planet. Its distance from the centre of the planet changes from $4r$ to $3r$.

(i) Calculate the change in gravitational potential energy of the rock.

change = ... J [3]

(ii) Explain whether the rock's speed increases, decreases or stays the same.

.....

..... [2]

[Total: 10]

---

34. 9702_m19_qp_42 Q: 1

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

.....

.....

..... [2]

(ii) Use your answer in **(i)** to explain why the gravitational potential near an isolated mass is always negative.

.....

.....

.....

.....

.....

..... [3]

(b) A spherical planet has mass 6.00×10^{24} kg and radius 6.40×10^{6} m.
The planet may be assumed to be isolated in space with its mass concentrated at its centre.

A satellite of mass 340 kg is in a circular orbit about the planet at a height 9.00×10^{5} m above its surface.

For the satellite:

(i) show that its orbital speed is $7.4 \times 10^{3}\,\text{m s}^{-1}$

[2]

(ii) calculate its gravitational potential energy.

energy = ... J [3]

(c) Rockets on the satellite are fired for a short time. The satellite's orbit is now closer to the surface of the planet.

State and explain the change, if any, in the kinetic energy of the satellite.

.....

.....

.....

..... [2]

[Total: 12]

---

35. 9702_s19_qp_41 Q: 1

(a) Two point masses are isolated in space and are separated by a distance x.

State an expression relating the gravitational force F between the two masses to the magnitudes M and m of the masses. State the name of any other symbol used.

.....

.....

..... [1]

(b) A spacecraft is to be put into a circular orbit about a spherical planet.

The planet may be considered to be isolated in space. The mass of the planet, assumed to be concentrated at its centre, is 7.5×10^{23} kg. The radius of the planet is 3.4×10^{6} m.

(i) The spacecraft is to orbit the planet at a height of 2.4×10^{5} m above the surface of the planet. At this altitude, there is no atmosphere.

Show that the speed of the spacecraft in its orbit is $3.7 \times 10^{3}\,\text{m s}^{-1}$.

[2]

(ii) One possible path of the spacecraft as it approaches the planet is shown in Fig. 1.1.

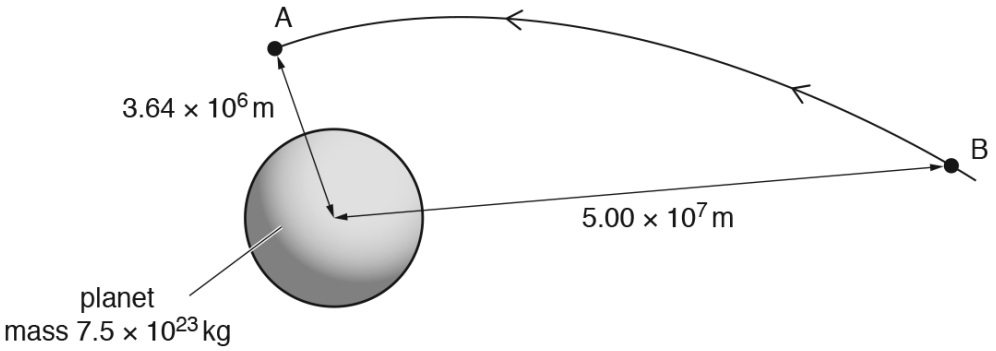


Fig. 1.1 (not to scale)

The spacecraft enters the orbit at point A with speed $3.7 \times 10^3\,m\,s^{-1}$.

At point B, a distance of 5.00×10^7 m from the centre of the planet, the spacecraft has a speed of $4.1 \times 10^3\,m\,s^{-1}$. The mass of the spacecraft is 650 kg.

For the spacecraft moving from point B to point A, show that the change in gravitational potential energy of the spacecraft is 8.3×10^9 J.

[3]

(c) By considering changes in gravitational potential energy and in kinetic energy of the spacecraft, determine whether the total energy of the spacecraft increases or decreases in moving from point B to point A. A numerical answer is not required.

.....

.....

.....

..... [2]

[Total: 8]

36. 9702_s19_qp_43 Q: 1

(a) Two point masses are isolated in space and are separated by a distance x.

State an expression relating the gravitational force F between the two masses to the magnitudes M and m of the masses. State the name of any other symbol used.

.....

.....

..... [1]

(b) A spacecraft is to be put into a circular orbit about a spherical planet.

The planet may be considered to be isolated in space. The mass of the planet, assumed to be concentrated at its centre, is 7.5×10^{23} kg. The radius of the planet is 3.4×10^{6} m.

(i) The spacecraft is to orbit the planet at a height of 2.4×10^{5} m above the surface of the planet. At this altitude, there is no atmosphere.

Show that the speed of the spacecraft in its orbit is $3.7 \times 10^{3}\,\text{m s}^{-1}$.

[2]

(ii) One possible path of the spacecraft as it approaches the planet is shown in Fig. 1.1.

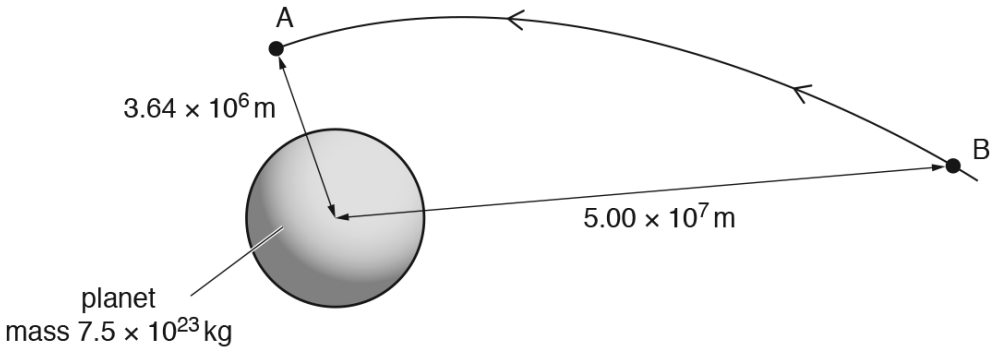


Fig. 1.1 (not to scale)

The spacecraft enters the orbit at point A with speed $3.7 \times 10^3\,m\,s^{-1}$.

At point B, a distance of 5.00×10^7 m from the centre of the planet, the spacecraft has a speed of $4.1 \times 10^3\,m\,s^{-1}$. The mass of the spacecraft is 650 kg.

For the spacecraft moving from point B to point A, show that the change in gravitational potential energy of the spacecraft is 8.3×10^9 J.

[3]

(c) By considering changes in gravitational potential energy and in kinetic energy of the spacecraft, determine whether the total energy of the spacecraft increases or decreases in moving from point B to point A. A numerical answer is not required.

.....

.....

.....

..... [2]

[Total: 8]

37. 9702_w18_qp_41 Q: 1

(a) **(i)** State what is meant by *gravitational potential* at a point.

.....

.....

.....[2]

(ii) Suggest why, for small changes in height near the Earth's surface, gravitational potential is approximately constant.

.....

.....

.....

.....[2]

(b) The Moon may be considered to be a uniform sphere with a diameter of 3.5×10^3 km and a mass of 7.4×10^{22} kg.

A meteor strikes the Moon and, during the collision, a rock is sent off from the surface of the Moon with an initial speed v.

Assuming that the Moon is isolated in space, determine the minimum speed of the rock such that it does not return to the Moon's surface. Explain your working.

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

[Total: 7]

38. 9702_w18_qp_43 Q: 1

(a) (i) State what is meant by *gravitational potential* at a point.

.....

.....

.....[2]

(ii) Suggest why, for small changes in height near the Earth's surface, gravitational potential is approximately constant.

.....

.....

.....

.....[2]

(b) The Moon may be considered to be a uniform sphere with a diameter of 3.5×10^3 km and a mass of 7.4×10^{22} kg.

A meteor strikes the Moon and, during the collision, a rock is sent off from the surface of the Moon with an initial speed v.

Assuming that the Moon is isolated in space, determine the minimum speed of the rock such that it does not return to the Moon's surface. Explain your working.

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

[Total: 7]

39. 9702_m17_qp_42 Q: 1

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

.....

.....

.....[2]

(b) A rocket is launched from the surface of a planet and moves along a radial path, as shown in Fig. 1.1.

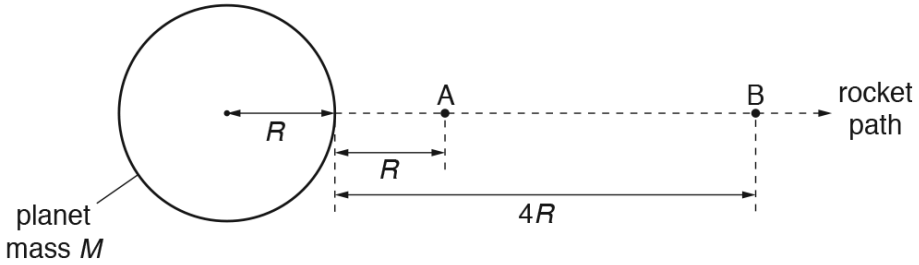


Fig. 1.1

The planet may be considered to be an isolated sphere of radius R with all of its mass M concentrated at its centre. Point A is a distance R from the surface of the planet. Point B is a distance $4R$ from the surface.

(i) Show that the difference in gravitational potential $\Delta\phi$ between points A and B is given by the expression

$$\Delta\phi = \frac{3GM}{10R}$$

where G is the gravitational constant.

[1]

(ii) The rocket motor is switched off at point A. During the journey from A to B, the rocket has a constant mass of 4.7×10^4 kg and its kinetic energy changes from 1.70 TJ to 0.88 TJ.

For the planet, the product GM is $4.0 \times 10^{14}\,\text{N m}^2\,\text{kg}^{-1}$. It may be assumed that resistive forces to the motion of the rocket are negligible.

Use the expression in **(b)(i)** to determine the distance from A to B.

distance = ...m [3]

[Total: 6]

Q1.

1 (a) Define gravitational potential.

.....

..... [2]

(b) Explain why values of gravitational potential near to an isolated mass are all negative.

.....

.....

..... [3]

(c) The Earth may be assumed to be an isolated sphere of radius 6.4×10^3 km with its mass of 6.0×10^{24} kg concentrated at its centre. An object is projected vertically from the surface of the Earth so that it reaches an altitude of 1.3×10^4 km.

Calculate, for this object,

(i) the change in gravitational potential,

change in potential = ... $J\,kg^{-1}$

(ii) the speed of projection from the Earth's surface, assuming air resistance is negligible.

speed = ... $m\,s^{-1}$
[5]

(d) Suggest why the equation

$$v^2 = u^2 + 2as$$

is not appropriate for the calculation in **(c)(ii)**.

.....

..... [1]

Q2.

Use

3 A binary star consists of two stars that orbit about a fixed point C, as shown in Fig. 3.1.

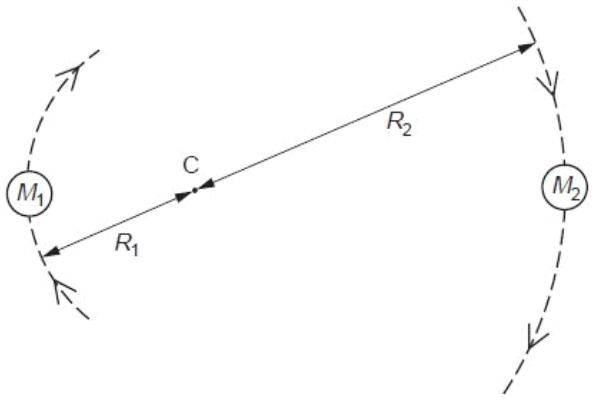


Fig. 3.1

The star of mass M_1 has a circular orbit of radius R_1 and the star of mass M_2 has a circular orbit of radius R_2. Both stars have the same angular speed ω, about C.

(a) State the formula, in terms of G, M_1, M_2, R_1, R_2 and ω for

(i) the gravitational force between the two stars,

.....

(ii) the centripetal force on the star of mass M_1.

.....

[2]

(b) The stars orbit each other in a time of 1.26×10^8 s (4.0 years). Calculate the angular speed ω for each star.

angular speed = ... rad s^{-1} [2]

(c) **(i)** Show that the ratio of the masses of the stars is given by the expression

$$\frac{M_1}{M_2} = \frac{R_2}{R_1}.$$

[2]

(ii) The ratio $\frac{M_1}{M_2}$ is equal to 3.0 and the separation of the stars is 3.2×10^{11} m.

Calculate the radii R_1 and R_2.

R_1 = ... m

R_2 = ... m

[2]

(d) **(i)** By equating the expressions you have given in **(a)** and using the data calculated in **(b)** and **(c)**, determine the mass of one of the stars.

mass of star = ... kg

(ii) State whether the answer in **(i)** is for the more massive or for the less massive star.

.....

[4]

Q3.

1 The orbit of the Earth, mass 6.0×10^{24} kg, may be assumed to be a circle of radius 1.5×10^{11} m with the Sun at its centre, as illustrated in Fig. 1.1.

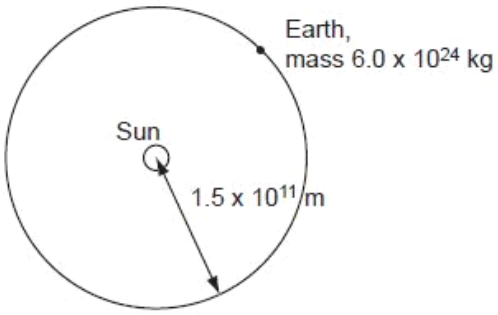


Fig. 1.1

The time taken for one orbit is 3.2×10^{7} s.

(a) Calculate

(i) the magnitude of the angular velocity of the Earth about the Sun,

angular velocity = ... rad s^{-1} [2]

(ii) the magnitude of the centripetal force acting on the Earth.

force = ... N [2]

(b) **(i)** State the origin of the centripetal force calculated in **(a)(ii)**.

.....

.....[1]

(ii) Determine the mass of the Sun.

mass = ... kg [3]

Q4.

1 The Earth may be considered to be a uniform sphere with its mass M concentrated at its centre.

A satellite of mass m orbits the Earth such that the radius of the circular orbit is r.

(a) Show that the linear speed v of the satellite is given by the expression

$$v = \sqrt{\left(\frac{GM}{r}\right)}.$$

[2]

(b) For this satellite, write down expressions, in terms of G, M, m and r, for

(i) its kinetic energy,

kinetic energy = ... [1]

(ii) its gravitational potential energy,

potential energy = ... [1]

(iii) its total energy.

total energy = ... [2]

(c) The total energy of the satellite gradually decreases.

State and explain the effect of this decrease on

(i) the radius r of the orbit,

.....

.....

..... [2]

(ii) the linear speed v of the satellite.

.....

.....

..... [2]

Q5.

1 **(a)** Explain what is meant by a *gravitational field*.

.....

..... [1]

(b) A spherical planet has mass M and radius R. The planet may be considered to have all its mass concentrated at its centre.
A rocket is launched from the surface of the planet such that the rocket moves radially away from the planet. The rocket engines are stopped when the rocket is at a height R above the surface of the planet, as shown in Fig. 1.1.

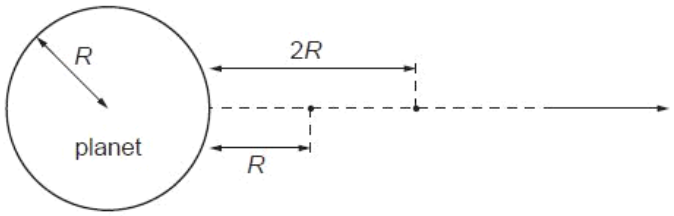


Fig. 1.1

The mass of the rocket, after its engines have been stopped, is m.

(i) Show that, for the rocket to travel from a height R to a height $2R$ above the planet's surface, the change ΔE_P in the magnitude of the gravitational potential energy of the rocket is given by the expression

$$\Delta E_P = \frac{GMm}{6R}.$$

[2]

(ii) During the ascent from a height R to a height $2R$, the speed of the rocket changes from $7600\,m\,s^{-1}$ to $7320\,m\,s^{-1}$. Show that, in SI units, the change ΔE_K in the kinetic energy of the rocket is given by the expression

$$\Delta E_K = (2.09 \times 10^6)m.$$

[1]

(c) The planet has a radius of 3.40×10^6 m.

(i) Use the expressions in **(b)** to determine a value for the mass M of the planet.

M = ... kg [2]

(ii) State one assumption made in the determination in **(i).**

.....

..... [1]

Q6.

1 **(a)** Define *gravitational field strength*.

.....

..... [1]

(b) A spherical planet has diameter 1.2×10^4 km. The gravitational field strength at the surface of the planet is $8.6\,N\,kg^{-1}$.
The planet may be assumed to be isolated in space and to have its mass concentrated at its centre.
Calculate the mass of the planet.

mass = ... kg [3]

(c) The gravitational potential at a point X above the surface of the planet in **(b)** is $-5.3 \times 10^7\,J\,kg^{-1}$.
For point Y above the surface of the planet, the gravitational potential is $-6.8 \times 10^7\,J\,kg^{-1}$.

(i) State, with a reason, whether point X or point Y is nearer to the planet.

.....

.....

..... [2]

(ii) A rock falls radially from rest towards the planet from one point to the other.
Calculate the final speed of the rock.

speed = ... $m\,s^{-1}$ [2]

Q7.

1 **(a)** Define *gravitational potential* at a point.

.....

.....

..... [2]

(b) The Earth may be considered to be an isolated sphere of radius R with its mass concentrated at its centre.
The variation of the gravitational potential ϕ with distance x from the centre of the Earth is shown in Fig. 1.1.

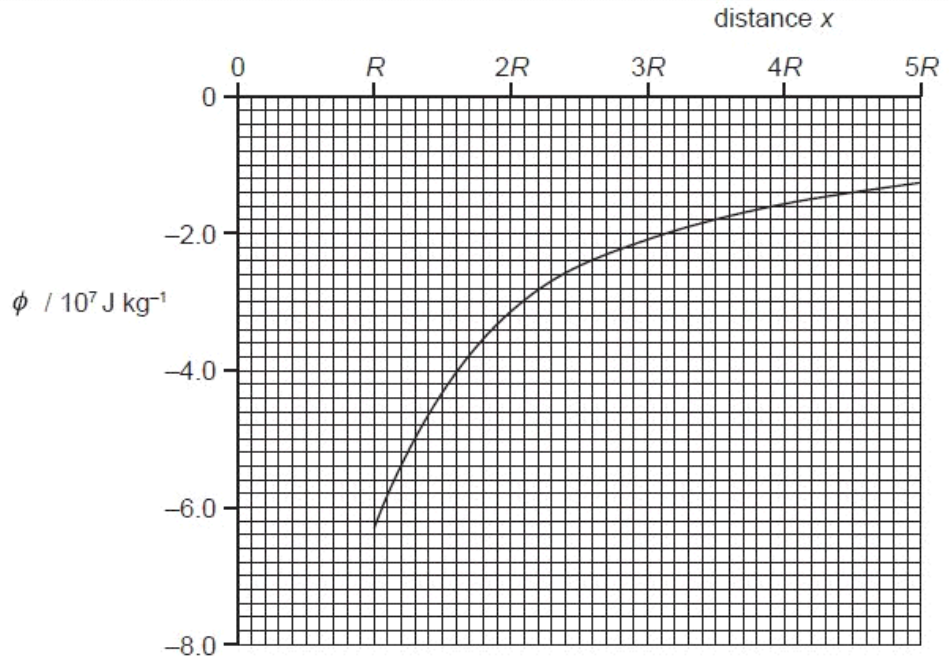


Fig. 1.1

The radius R of the Earth is 6.4×10^6 m.

(i) By considering the gravitational potential at the Earth's surface, determine a value for the mass of the Earth.

mass = ... kg [3]

(ii) A meteorite is at rest at infinity. The meteorite travels from infinity towards the Earth.

Calculate the speed of the meteorite when it is at a distance of $2R$ above the Earth's surface. Explain your working.

speed = ... $m s^{-1}$ [4]

(iii) In practice, the Earth is not an isolated sphere because it is orbited by the Moon, as illustrated in Fig. 1.2.



Fig. 1.2 (not to scale)

The initial path of the meteorite is also shown.

Suggest two changes to the motion of the meteorite caused by the Moon.

1. .....

.....

2. .....

.....

[2]

Q8.

1 **(a)** Newton's law of gravitation applies to point masses.

(i) State Newton's law of gravitation.

.....

.....

.....[2]

(ii) Explain why, although the planets and the Sun are not point masses, the law also applies to planets orbiting the Sun.

.....

.....[1]

(b) Gravitational fields and electric fields show certain similarities and certain differences. State one aspect of gravitational and electric fields where there is

(i) a similarity,

.....

.....[1]

(ii) a difference.

.....

.....

.....[2]

Q9.

1 **(a)** State what is meant by a *field of force*.

.....

..... [1]

(b) Gravitational fields and electric fields are two examples of fields of force.
State one similarity and one difference between these two fields of force.

similarity: .....

.....

difference: .....

.....

.....

[3]

(c) Two protons are isolated in space. Their centres are separated by a distance R.
Each proton may be considered to be a point mass with point charge.
Determine the magnitude of the ratio

$$\frac{\text{force between protons due to electric field}}{\text{force between protons due to gravitational field}}.$$

ratio = ... [3]

Q10.

1 **(a)** Define *gravitational potential* at a point.

.....

..... [1]

(b) The gravitational potential ϕ at distance r from point mass M is given by the expression

$$\phi = -\frac{GM}{r}$$

where G is the gravitational constant.

Explain the significance of the negative sign in this expression.

.....

.....

..... [2]

(c) A spherical planet may be assumed to be an isolated point mass with its mass concentrated at its centre. A small mass m is moving near to, and normal to, the surface of the planet. The mass moves away from the planet through a short distance h.

State and explain why the change in gravitational potential energy ΔE_P of the mass is given by the expression

$$\Delta E_P = mgh$$

where g is the acceleration of free fall.

.....

.....

.....

.....

.....

..... [4]

(d) The planet in **(c)** has mass M and diameter 6.8×10^3 km. The product GM for this planet is $4.3 \times 10^{13}\,\text{N m}^2\text{kg}^{-1}$.

A rock, initially at rest a long distance from the planet, accelerates towards the planet. Assuming that the planet has negligible atmosphere, calculate the speed of the rock as it hits the surface of the planet.

For Examin Use

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

Q11.

1 **(a)** State Newton's law of gravitation.

.....

.....

.....[2]

(b) The Earth and the Moon may be considered to be isolated in space with their masses concentrated at their centres.
The orbit of the Moon around the Earth is circular with a radius of 3.84×10^5 km. The period of the orbit is 27.3 days.

Show that

(i) the angular speed of the Moon in its orbit around the Earth is $2.66 \times 10^{-6}\,\text{rad s}^{-1}$,

[1]

(ii) the mass of the Earth is 6.0×10^{24} kg.

[2]

(c) The mass of the Moon is 7.4×10^{22} kg.

(i) Using data from **(b)**, determine the gravitational force between the Earth and the Moon.

force = ... N [2]

(ii) Tidal action on the Earth's surface causes the radius of the orbit of the Moon to increase by 4.0 cm each year.

Use your answer in **(i)** to determine the change, in one year, of the gravitational potential energy of the Moon. Explain your working.

energy change = ... J [3]

Q12.

1 **(a)** State what is meant by a *gravitational field*.

.....

.....

.....[2]

(b) In the Solar System, the planets may be assumed to be in circular orbits about the Sun. Data for the radii of the orbits of the Earth and Jupiter about the Sun are given in Fig. 1.1.

	radius of orbit / km
Earth	1.50×10^8
Jupiter	7.78×10^8

Fig. 1.1

(i) State Newton's law of gravitation.

.....

.....

.....

.....[3]

(ii) Use Newton's law to determine the ratio

$$\frac{\text{gravitational field strength due to the Sun at orbit of Earth}}{\text{gravitational field strength due to the Sun at orbit of Jupiter}}.$$

ratio = ... [3]

(c) The orbital period of the Earth about the Sun is T.

(i) Use ideas about circular motion to show that the mass M of the Sun is given by

$$M = \frac{4\pi^2 R^3}{GT^2}$$

where R is the radius of the Earth's orbit about the Sun and G is the gravitational constant.
Explain your working.

[3]

(ii) The orbital period T of the Earth about the Sun is 3.16×10^7 s.
The radius of the Earth's orbit is given in Fig. 1.1.
Use the expression in **(i)** to determine the mass of the Sun.

mass = ... kg [2]

Q13.

1 **(a)** Explain what is meant by a *geostationary orbit*.

.....

.....

.....

..... [3]

(b) A satellite of mass m is in a circular orbit about a planet.
The mass M of the planet may be considered to be concentrated at its centre.
Show that the radius R of the orbit of the satellite is given by the expression

$$R^3 = \left(\frac{GMT^2}{4\pi^2}\right)$$

where T is the period of the orbit of the satellite and G is the gravitational constant.
Explain your working.

[4]

(c) The Earth has mass 6.0×10^{24} kg. Use the expression given in **(b)** to determine the radius of the geostationary orbit about the Earth.

radius = ... m [3]

Q14.

Use

4 If an object is projected vertically upwards from the surface of a planet at a fast enough speed, it can escape the planet's gravitational field. This means that the object can arrive at infinity where it has zero kinetic energy. The speed that is just enough for this to happen is known as the escape speed.

(a) (i) By equating the kinetic energy of the object at the planet's surface to its total gain of potential energy in going to infinity, show that the escape speed v is given by

$$v^2 = \frac{2GM}{R},$$

where R is the radius of the planet and M is its mass.

(ii) Hence show that

$$v^2 = 2Rg,$$

where g is the acceleration of free fall at the planet's surface.

[3]

Use

(b) The mean kinetic energy E_k of an atom of an ideal gas is given by

$$E_k = \frac{3}{2} kT,$$

where k is the Boltzmann constant and T is the thermodynamic temperature.

Using the equation in **(a)(ii)**, estimate the temperature at the Earth's surface such that helium atoms of mass 6.6×10^{-27} kg could escape to infinity.

You may assume that helium gas behaves as an ideal gas and that the radius of Earth is 6.4×10^{6} m.

temperature = ... K [4]

Q15.

1 **(a)** **(i)** On Fig. 1.1, draw lines to represent the gravitational field outside an isolated uniform sphere.

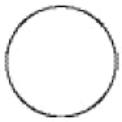


Fig. 1.1

(ii) A second sphere has the same mass but a smaller radius. Suggest what difference, if any, there is between the patterns of field lines for the two spheres.

.....

.....

[3]

(b) The Earth may be considered to be a uniform sphere of radius 6380 km with its mass of 5.98×10^{24} kg concentrated at its centre, as illustrated in Fig. 1.2.

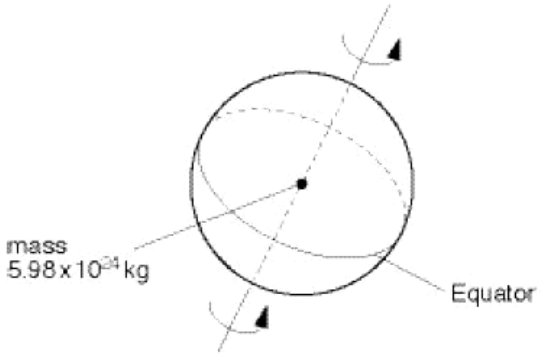


Fig. 1.2

A mass of 1.00 kg on the Equator rotates about the axis of the Earth with a period of 1.00 day (8.64×10^4 s).

Calculate, to three significant figures,

(i) the gravitational force F_G of attraction between the mass and the Earth,

F_G = ... N

(ii) the centripetal force F_C on the 1.00 kg mass,

F_C = ... N

(iii) the difference in magnitude of the forces.

difference = ... N

[6]

(c) By reference to your answers in **(b)**, suggest, with a reason, a value for the acceleration of free fall at the Equator.

.....

.....

..... [2]

Q16.

1 The Earth may be considered to be a sphere of radius 6.4×10^6 m with its mass of 6.0×10^{24} kg concentrated at its centre.
A satellite of mass 650 kg is to be launched from the Equator and put into geostationary orbit.

(a) Show that the radius of the geostationary orbit is 4.2×10^7 m.

[3]

(b) Determine the increase in gravitational potential energy of the satellite during its launch from the Earth's surface to the geostationary orbit.

energy = ... J [4]

(c) Suggest one advantage of launching satellites from the Equator in the direction of rotation of the Earth.

.....

.....[1]

Q17.

1 The definitions of electric potential and of gravitational potential at a point have some similarity.

(a) State one similarity between these two definitions.

.....

..... [1]

(b) Explain why values of gravitational potential are always negative whereas values of electric potential may be positive or negative.

.....

.....

.....

.....

..... [4]

q18.

4 A rocket is launched from the surface of the Earth.

Fig. 4.1 gives data for the speed of the rocket at two heights above the Earth's surface, after the rocket engine has been switched off.

height / m	speed / $m\,s^{-1}$
$h_1 = 19.9 \times 10^6$	$v_1 = 5370$
$h_2 = 22.7 \times 10^6$	$v_2 = 5090$

Fig. 4.1

The Earth may be assumed to be a uniform sphere of radius $R = 6.38 \times 10^6$ m, with its mass M concentrated at its centre. The rocket, after the engine has been switched off, has mass m.

(a) Write down an expression in terms of

(i) G, M, m, h_1, h_2 and R for the change in gravitational potential energy of the rocket,

..... [1]

(ii) m, v_1 and v_2 for the change in kinetic energy of the rocket.

..... [1]

(b) Using the expressions in **(a)**, determine a value for the mass M of the Earth.

M = ... kg [3]

Q19.

1 A spherical planet has mass M and radius R.
The planet may be assumed to be isolated in space and to have its mass concentrated at its centre.
The planet spins on its axis with angular speed ω, as illustrated in Fig. 1.1.

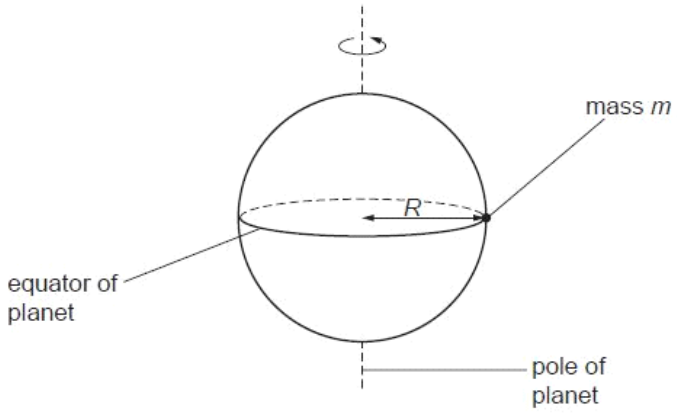


Fig. 1.1

A small object of mass m rests on the equator of the planet. The surface of the planet exerts a normal reaction force on the mass.

(a) State formulae, in terms of M, m, R and ω, for

(i) the gravitational force between the planet and the object,

.....[1]

(ii) the centripetal force required for circular motion of the small mass,

.....[1]

(iii) the normal reaction exerted by the planet on the mass.

.....[1]

(b) **(i)** Explain why the normal reaction on the mass will have different values at the equator and at the poles.

.....

.....

.....[2]

(ii) The radius of the planet is 6.4×10^6 m. It completes one revolution in 8.6×10^4 s. Calculate the magnitude of the centripetal acceleration at

1. the equator,

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

2. one of the poles.

acceleration = ...$m\,s^{-2}$ [1]

(c) Suggest two factors that could, in the case of a real planet, cause variations in the acceleration of free fall at its surface.

1. .....

.....

2. .....

.....

[2]

Q20.

1 **(a)** State Newton's law of gravitation.

.....

.....

..... [2]

(b) The Earth may be considered to be a uniform sphere of radius R equal to 6.4×10^6 m.

A satellite is in a geostationary orbit.

(i) Describe what is meant by a *geostationary orbit*.

.....

.....

.....

..... [3]

(ii) Show that the radius x of the geostationary orbit is given by the expression

$$gR^2 = x^3\omega^2$$

where g is the acceleration of free fall at the Earth's surface and ω is the angular speed of the satellite about the centre of the Earth.

[3]

(iii) Determine the radius x of the geostationary orbit.

radius = ... m [3]

Q21.

1 **(a)** The Earth may be considered to be a uniform sphere of radius 6.38×10^3 km, with its mass concentrated at its centre.

(i) Define *gravitational field strength*.

.....

..... [1]

(ii) By considering the gravitational field strength at the surface of the Earth, show that the mass of the Earth is 5.99×10^{24} kg.

[2]

(b) The Global Positioning System (GPS) is a navigation system that can be used anywhere on Earth. It uses a number of satellites that orbit the Earth in circular orbits at a distance of 2.22×10^4 km above its surface.

(i) Use data from **(a)** to calculate the angular speed of a GPS satellite in its orbit.

angular speed = ... rad s^{-1} [3]

(ii) Use your answer in **(i)** to show that the satellites are not in geostationary orbits.

For Examiner Use

[3]

(c) The planes of the orbits of the GPS satellites in **(b)** are inclined at an angle of 55° to the Equator.

Suggest why the satellites are not in equatorial orbits.

.....

..... [1]

Q22.

1 **(a)** Define *gravitational field strength*.

.....

.....[1]

(b) An isolated star has radius R. The mass of the star may be considered to be a point mass at the centre of the star.
The gravitational field strength at the surface of the star is g_s.

On Fig. 1.1, sketch a graph to show the variation of the gravitational field strength of the star with distance from its centre. You should consider distances in the range R to $4R$.

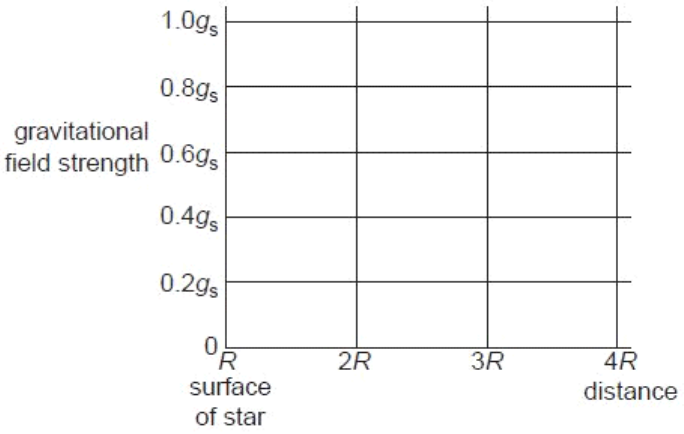


Fig. 1.1

[2]

(c) The Earth and the Moon may be considered to be spheres that are isolated in space with their masses concentrated at their centres.
The masses of the Earth and the Moon are 6.00×10^{24} kg and 7.40×10^{22} kg respectively.
The radius of the Earth is R_E and the separation of the centres of the Earth and the Moon is $60\,R_E$, as illustrated in Fig. 1.2.

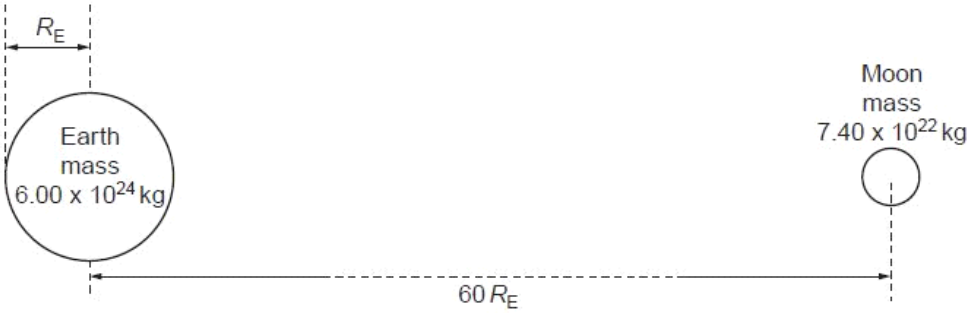


Fig. 1.2 (not to scale)

(i) Explain why there is a point between the Earth and the Moon at which the gravitational field strength is zero.

For Examiner Use

.....

.....

.....[2]

(ii) Determine the distance, in terms of R_E, from the centre of the Earth at which the gravitational field strength is zero.

distance = ...R_E [3]

(iii) On the axes of Fig. 1.3, sketch a graph to show the variation of the gravitational field strength with position between the surface of the Earth and the surface of the Moon.

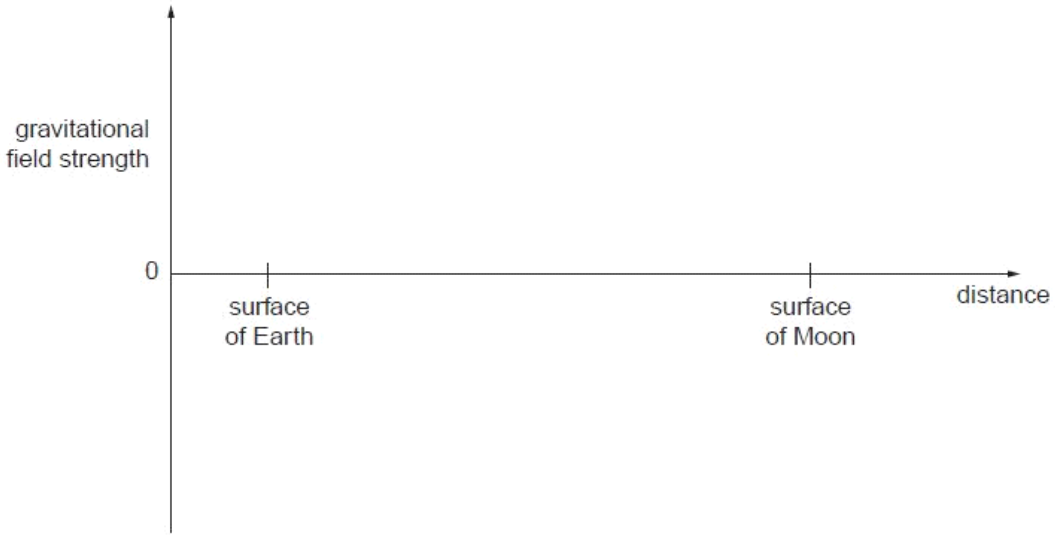


Fig. 1.3

[3]

Q23.

1 A planet of mass m is in a circular orbit of radius r about the Sun of mass M, as illustrated in Fig. 1.1.

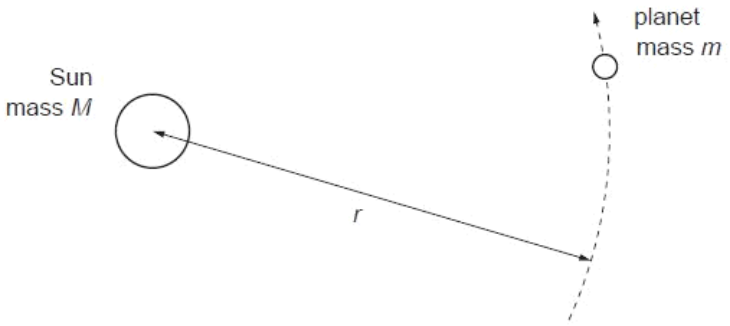


Fig. 1.1

The magnitude of the angular velocity and the period of revolution of the planet about the Sun are ω and T respectively.

(a) State

(i) what is meant by *angular velocity*,

.....

.....

.....[2]

(ii) the relation between ω and T.

.....[1]

(b) Show that, for a planet in a circular orbit of radius r, the period T of the orbit is given by the expression

$$T^2 = cr^3$$

where c is a constant. Explain your working.

[4]

(c) Data for the planets Venus and Neptune are given in Fig. 1.2.

planet	r / 10^8 km	T / years
Venus	1.08	0.615
Neptune	45.0	

Fig. 1.2

Assume that the orbits of both planets are circular.

(i) Use the expression in **(b)** to calculate the value of T for Neptune.

T = ... years [2]

(ii) Determine the linear speed of Venus in its orbit.

speed = ... km s^{-1} [2]

Q24.

1 **(a)** A moon is in a circular orbit of radius r about a planet. The angular speed of the moon in its orbit is ω. The planet and its moon may be considered to be point masses that are isolated in space.

Show that r and ω are related by the expression

$$r^3\omega^2 = \text{constant}.$$

Explain your working.

[3]

(b) Phobos and Deimos are moons that are in circular orbits about the planet Mars. Data for Phobos and Deimos are shown in Fig. 1.1.

moon	radius of orbit /m	period of rotation about Mars /hours
Phobos	9.39×10^6	7.65
Deimos	1.99×10^7	

Fig. 1.1

(i) Use data from Fig. 1.1 to determine

For Examiner's Use

1. the mass of Mars,

mass = ... kg [3]

2. the period of Deimos in its orbit about Mars.

period = ... hours [3]

(ii) The period of rotation of Mars about its axis is 24.6 hours.
Deimos is in an equatorial orbit, orbiting in the same direction as the spin of Mars about its axis.

Use your answer in **(i)** to comment on the orbit of Deimos.

.....

.....[1]

Q25.

1 The planet Mars may be considered to be an isolated sphere of diameter 6.79×10^6 m with its mass of 6.42×10^{23} kg concentrated at its centre.
A rock of mass 1.40 kg rests on the surface of Mars.

For this rock,

(a) (i) determine its weight,

weight = ... N [3]

(ii) show that its gravitational potential energy is -1.77×10^7 J.

[2]

(b) Use the information in **(a)(ii)** to determine the speed at which the rock must leave the surface of Mars so that it will escape the gravitational attraction of the planet.

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

Q26.

1 **(a)** State Newton's law of gravitation.

.....

.....

.....[2]

(b) A satellite of mass m is in a circular orbit of radius r about a planet of mass M.
For this planet, the product GM is $4.00 \times 10^{14}\,\text{N m}^2\text{kg}^{-1}$, where G is the gravitational constant.
The planet may be assumed to be isolated in space.

(i) By considering the gravitational force on the satellite and the centripetal force, show that the kinetic energy E_K of the satellite is given by the expression

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

[2]

(ii) The satellite has mass 620 kg and is initially in a circular orbit of radius 7.34×10^6 m, as illustrated in Fig. 1.1.

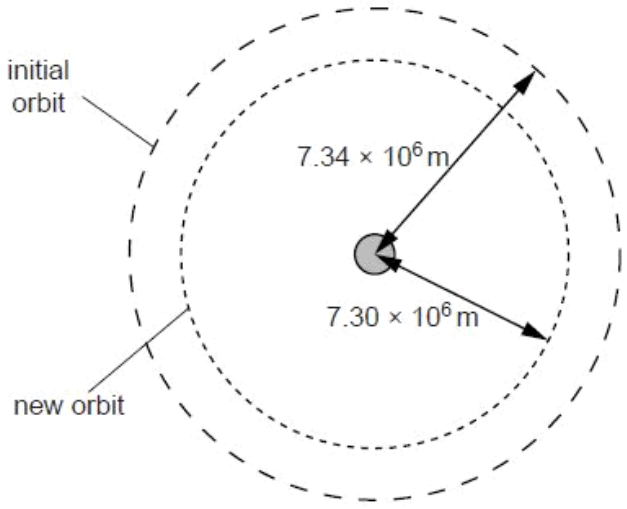


Fig. 1.1 (not to scale)

Resistive forces cause the satellite to move into a new orbit of radius 7.30×10^6 m.

For Examiner's Use

Determine, for the satellite, the change in

1. kinetic energy,

change in kinetic energy = ... J [2]

2. gravitational potential energy.

change in potential energy = ... J [2]

(iii) Use your answers in **(ii)** to explain whether the linear speed of the satellite increases, decreases or remains unchanged when the radius of the orbit decreases.

.....

.....

.....[2]

Q27.

1 **(a)** Define *gravitational potential* at a point.

.....

.....

.....[2]

(b) The Moon may be considered to be an isolated sphere of radius 1.74×10^3 km with its mass of 7.35×10^{22} kg concentrated at its centre.

(i) A rock of mass 4.50 kg is situated on the surface of the Moon. Show that the change in gravitational potential energy of the rock in moving it from the Moon's surface to infinity is 1.27×10^7 J.

[1]

(ii) The escape speed of the rock is the minimum speed that the rock must be given when it is on the Moon's surface so that it can escape to infinity.
Use the answer in **(i)** to determine the escape speed. Explain your working.

speed = ... $m\,s^{-1}$ [2]

(c) The Moon in **(b)** is assumed to be isolated in space. The Moon does, in fact, orbit the Earth.
State and explain whether the minimum speed for the rock to reach the Earth from the surface of the Moon is different from the escape speed calculated in **(b)**.

.....

.....

.....[2]

Q28.

1 **(a)** State Newton's law of gravitation.

.....

.....

.....[2]

(b) A star and a planet are isolated in space. The planet orbits the star in a circular orbit of radius R, as illustrated in Fig. 1.1.

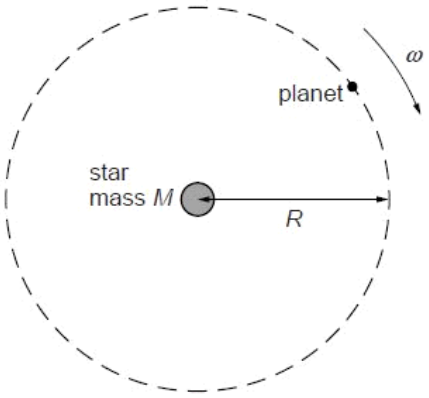


Fig. 1.1

The angular speed of the planet about the star is ω.
By considering the circular motion of the planet about the star of mass M, show that ω and R are related by the expression

$$R^3\omega^2 = GM$$

where G is the gravitational constant. Explain your working.

[3]

(c) The Earth orbits the Sun in a circular orbit of radius 1.5×10^8 km. The mass of the Sun is 2.0×10^{30} kg.
A distant star is found to have a planet that has a circular orbit about the star. The radius of the orbit is 6.0×10^8 km and the period of the orbit is 2.0 years.

For Examiner's Use

Use the expression in **(b)** to calculate the mass of the star.

mass = ... kg [3]

Q29.

1 **(a)** Define *gravitational potential* at a point.

.....

.....

..... [2]

(b) A stone of mass m has gravitational potential energy E_P at a point X in a gravitational field. The magnitude of the gravitational potential at X is ϕ.

State the relation between m, E_P and ϕ.

..... [1]

(c) An isolated spherical planet of radius R may be assumed to have all its mass concentrated at its centre. The gravitational potential at the surface of the planet is -6.30×10^7 J kg^{-1}.

A stone of mass 1.30 kg is travelling towards the planet such that its distance from the centre of the planet changes from $6R$ to $5R$.

Calculate the change in gravitational potential energy of the stone.

change in energy = ... J [4]

Q30.

1 The mass M of a spherical planet may be assumed to be a point mass at the centre of the planet.

(a) A stone, travelling at speed v, is in a circular orbit of radius r about the planet, as illustrated in Fig. 1.1.

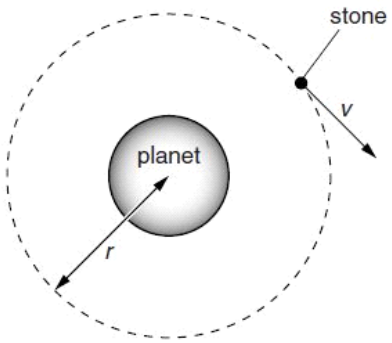


Fig. 1.1

Show that the speed v is given by the expression

$$v = \sqrt{\left(\frac{GM}{r}\right)}$$

where G is the gravitational constant.
Explain your working.

[2]

(b) A second stone, initially at rest at infinity, travels towards the planet, as illustrated in Fig. 1.2.

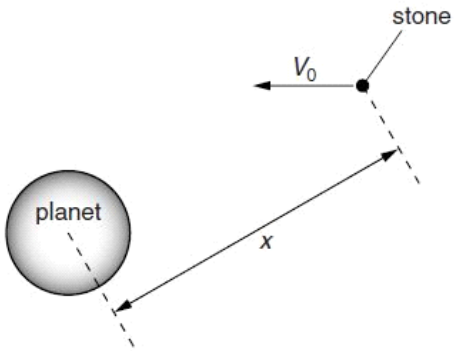


Fig. 1.2 (not to scale)

The stone does not hit the surface of the planet.

(i) Determine, in terms of the gravitational constant G and the mass M of the planet, the speed V_0 of the stone at a distance x from the centre of the planet. Explain your working. You may assume that the gravitational attraction on the stone is due only to the planet.

[3]

(ii) Use your answer in **(i)** and the expression in **(a)** to explain whether this stone could enter a circular orbit about the planet.

.....

.....

.....

..... [2]

Q31.

1 An isolated spherical planet has a diameter of 6.8×10^6 m. Its mass of 6.4×10^{23} kg may be assumed to be a point mass at the centre of the planet.

(a) Show that the gravitational field strength at the surface of the planet is $3.7\,\text{N kg}^{-1}$.

[2]

(b) A stone of mass 2.4 kg is raised from the surface of the planet through a vertical height of 1800 m.
Use the value of field strength given in **(a)** to determine the change in gravitational potential energy of the stone.
Explain your working.

change in energy = ... J [3]

(c) A rock, initially at rest at infinity, moves towards the planet. At point P, its height above the surface of the planet is $3.5D$, where D is the diameter of the planet, as shown in Fig. 1.1.

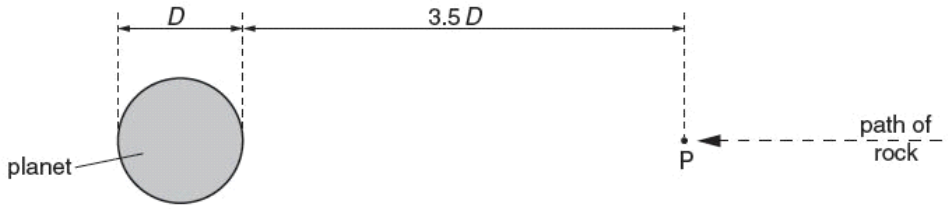


Fig. 1.1

Calculate the speed of the rock at point P, assuming that the change in gravitational potential energy is all transferred to kinetic energy.

speed = ... $m\,s^{-1}$ [4]

Q32.

2 (a) On the axes of Fig. 2.1, sketch the variation with distance from a point mass of the gravitational field strength due to the mass.

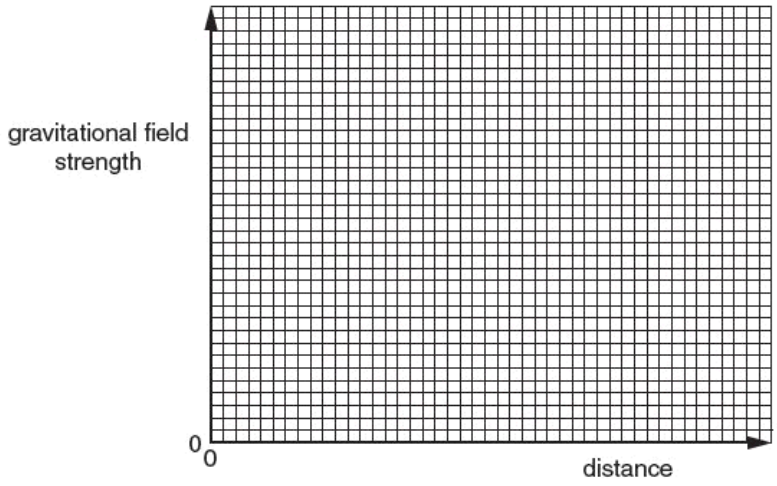


Fig. 2.1

[2]

(b) On the axes of Fig. 2.2, sketch the variation with speed of the magnitude of the force on a charged particle moving at right-angles to a uniform magnetic field.

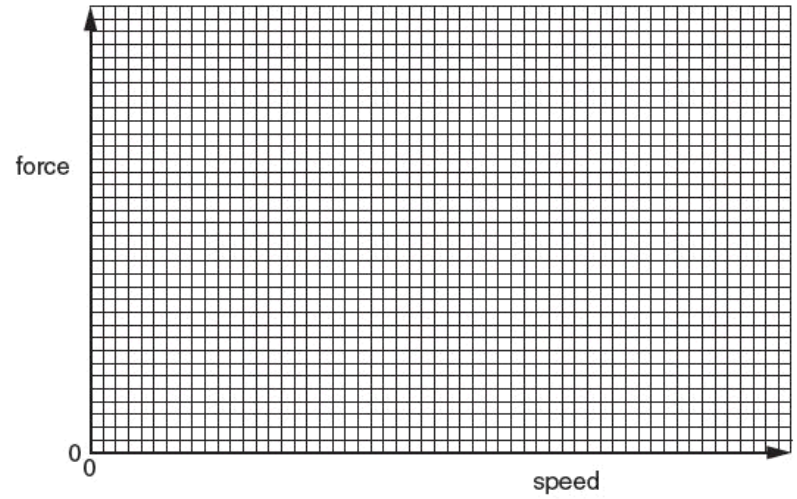


Fig. 2.2

[2]

(c) On the axes of Fig. 2.3, sketch the variation with time of the power dissipated in a resistor by a sinusoidal alternating current during two cycles of the current.

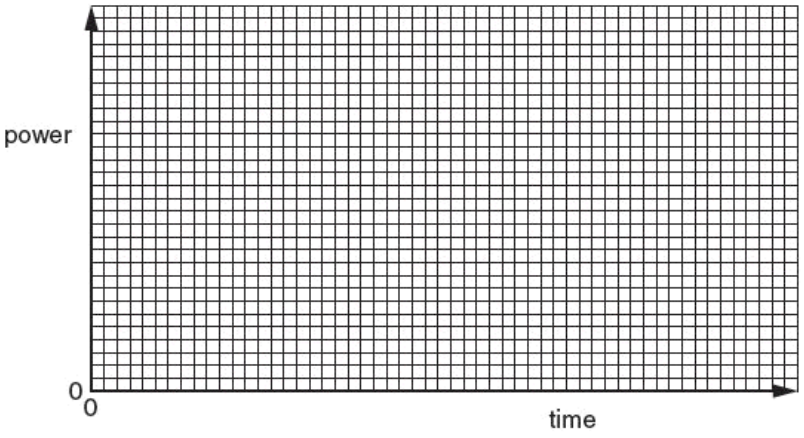


Fig. 2.3

[3]

Gravitational Field - 2020 A2

1. Nov/2020/Paper_41/No.1

(a) (i) State what is meant by a *field of force*.

.....

.....

..... [2]

(ii) Define *gravitational field strength*.

.....

..... [1]

(b) An isolated planet may be assumed to be a uniform sphere of radius 3.39×10^6 m with its mass of 6.42×10^{23} kg concentrated at its centre.

Calculate the gravitational field strength at the surface of the planet.

field strength = ... $N\,kg^{-1}$ [3]

(c) Calculate the height above the surface of the planet in **(b)** at which the gravitational field strength is 1.0% less than its value at the surface of the planet.

height = ... m [3]

[Total: 9]

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2. Nov/2020/Paper_42/No.1

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

.....

.....

..... [2]

(b) The Earth may be considered to be a uniform sphere of radius 6.4×10^6 m with its mass of 6.0×10^{24} kg concentrated at its centre.

A satellite of mass 2.4×10^3 kg is launched from the Equator. It is placed in an equatorial orbit at a height of 5.6×10^6 m above the Earth's surface.

(i) Calculate the change ΔE_P in gravitational potential energy of the satellite for its movement from the surface of the Earth to its position in the equatorial orbit.

ΔE_P = ... J [3]

(ii) Determine the speed of the satellite when in orbit.

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

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(c) Before the satellite in **(b)** is launched, its speed at the Equator due to the Earth's rotation is $470\,m\,s^{-1}$.

Suggest why the energy required to launch the satellite depends on whether the satellite, in its orbit, is travelling from west to east or from east to west.

.....

..... [1]

[Total: 9]

3. June/2020/Paper_41/No.1

(a) State what is meant by a *gravitational force*.

.....

..... [1]

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(b) A binary star system consists of two stars S_1 and S_2, each in a circular orbit.

The orbit of each star in the system has a period of rotation T.

Observations of the binary star from Earth are represented in Fig. 1.1.

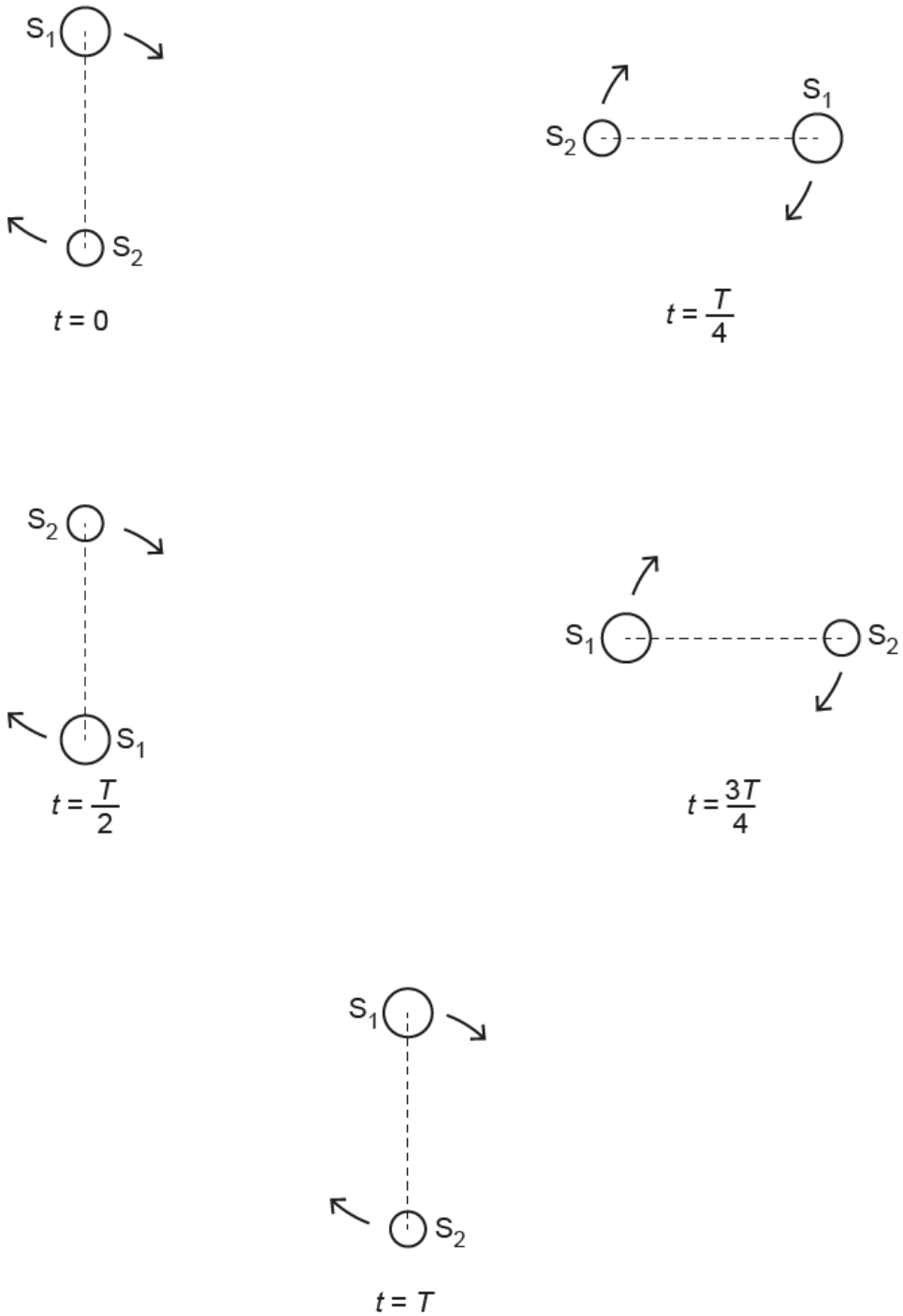


Fig. 1.1 (not to scale)

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Observed from Earth, the angular separation of the centres of S_1 and S_2 is 1.2×10^{-5} rad. The distance of the binary star system from Earth is 1.5×10^{17} m.

Show that the separation d of the centres of S_1 and S_2 is 1.8×10^{12} m.

[1]

(c) The stars S_1 and S_2 rotate with the same angular velocity ω about a point P, as illustrated in Fig. 1.2.

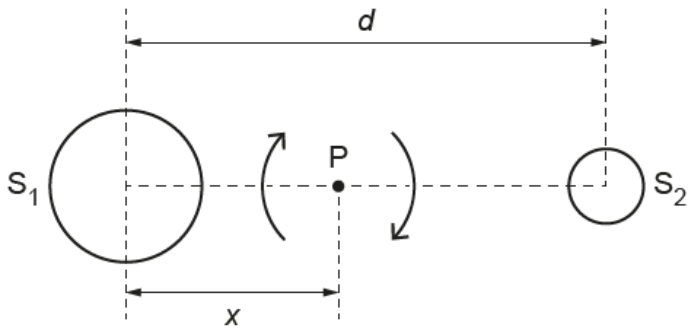


Fig. 1.2 (not to scale)

Point P is at a distance x from the centre of star S_1.
The period of rotation of the stars is 44.2 years.

(i) Calculate the angular velocity ω.

ω = ... rad s^{-1} [2]

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(ii) By considering the forces acting on the two stars, show that the ratio of the masses of the stars is given by

$$\frac{\text{mass of } S_1}{\text{mass of } S_2} = \frac{d - x}{x}.$$

[2]

(iii) The mass M_1 of star S_1 is given by the expression

$$GM_1 = d^2(d - x)\omega^2$$

where G is the gravitational constant.

The ratio in **(ii)** is found to be 1.5.

Use data from **(b)** and your answer in **(c)(i)** to determine the mass M_1.

M_1 = ... kg [3]

[Total: 9]

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4. June/2020/Paper_42/No.1

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

.....

.....

..... [2]

(b) An isolated solid sphere of radius r may be assumed to have its mass M concentrated at its centre. The magnitude of the gravitational potential at the surface of the sphere is ϕ.

On Fig. 1.1, show the variation of the gravitational potential with distance d from the centre of the sphere for values of d from $d = r$ to $d = 4r$.

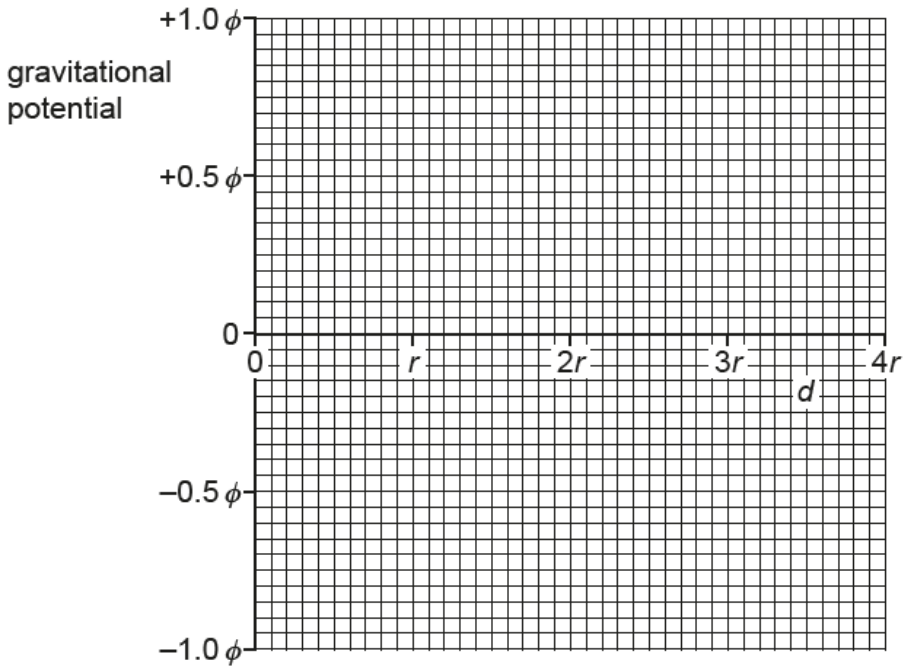


Fig. 1.1

[3]

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(c) The sphere in **(b)** is a planet with radius r of 6.4×10^6 m and mass M of 6.0×10^{24} kg. The planet has no atmosphere.

A rock of mass 3.4×10^3 kg moves directly towards the planet. Its distance from the centre of the planet changes from $4r$ to $3r$.

(i) Calculate the change in gravitational potential energy of the rock.

change = ... J [3]

(ii) Explain whether the rock's speed increases, decreases or stays the same.

.....

..... [2]

[Total: 10]

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5. March/2020/Paper_42/No.1

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

.....

.....

..... [2]

(b) TESS is a satellite of mass 360 kg in a circular orbit about the Earth as shown in Fig. 1.1.

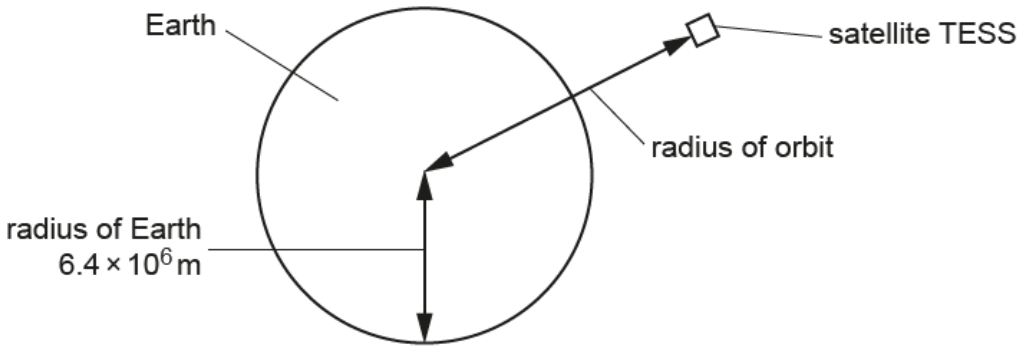


Fig. 1.1 (not to scale)

The radius of the Earth is 6.4×10^6 m and the mass of the Earth, considered to be a point mass at its centre, is 6.0×10^{24} kg.

(i) It takes TESS 13.7 days to orbit the Earth.

Show that the radius of orbit of TESS is 2.4×10^8 m.

[3]

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(ii) Calculate the change in gravitational potential energy between TESS in orbit and TESS on a launch pad on the surface of the Earth.

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

(iii) Use the information in **(b)(i)** to calculate the ratio:

$$\frac{\text{gravitational field strength on surface of Earth}}{\text{gravitational field strength at location of TESS in orbit}}.$$

ratio = ... [2]

[Total: 10]

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1. Nov/2021/Paper_41/No.2

(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.

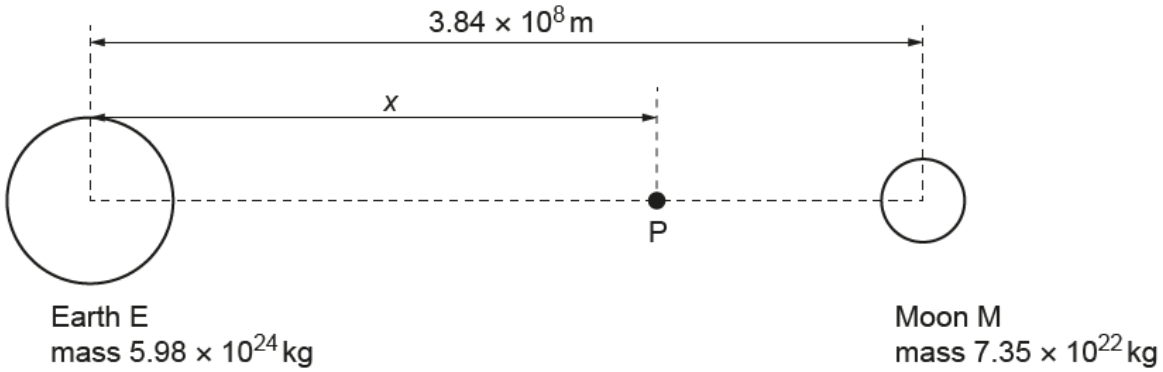


Fig. 2.1 (not to scale)

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.

(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]

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

ϕ = ... $J\,kg^{-1}$ [3]

[Total: 9]

2. Nov/2021/Paper_42/No.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.

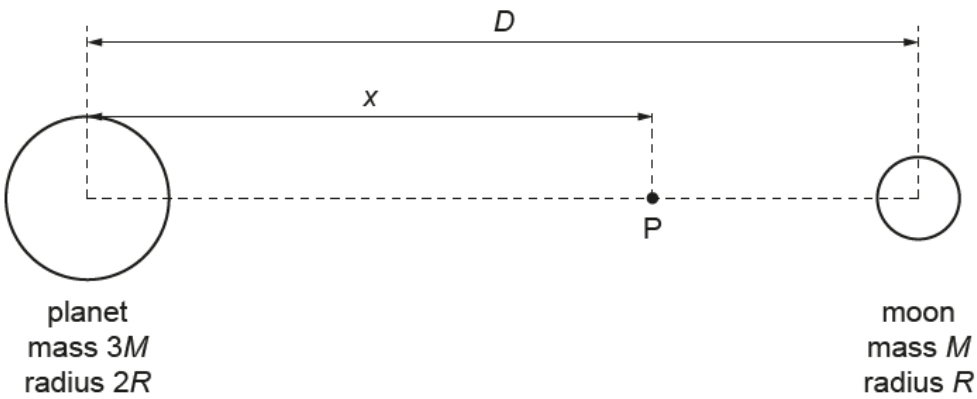


Fig. 2.1

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.

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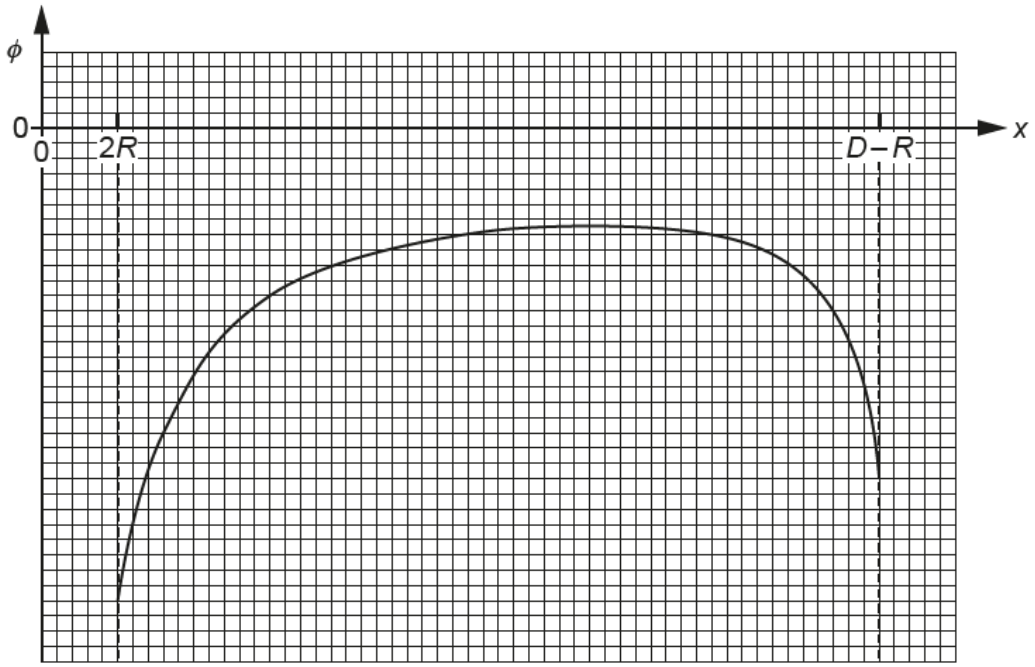


Fig. 2.2

(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]

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

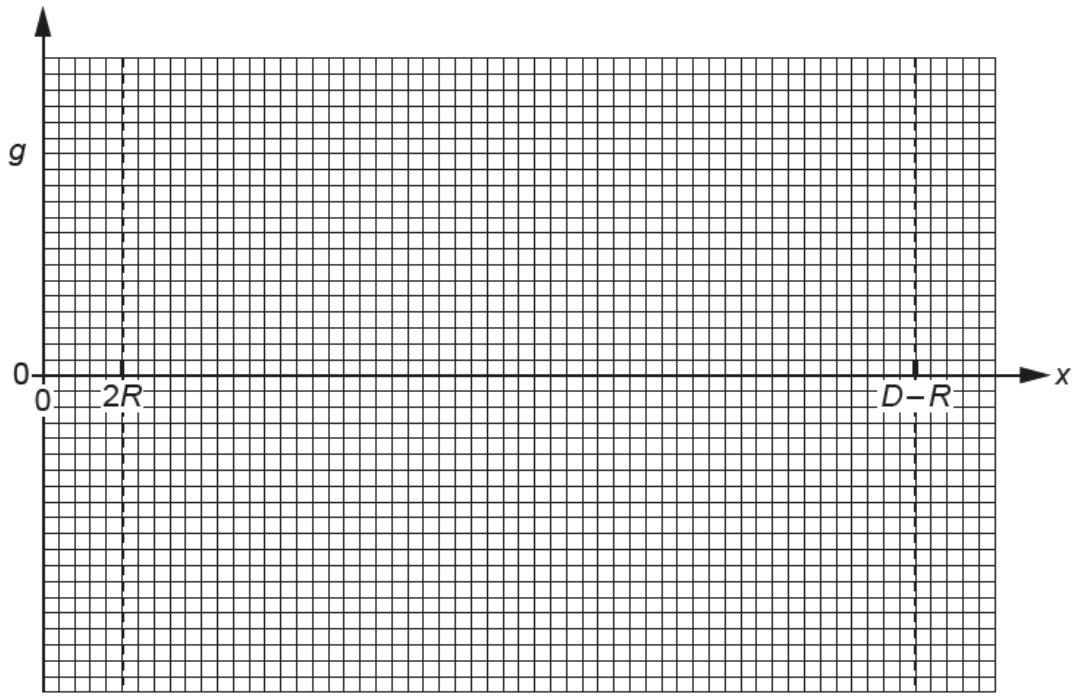


Fig. 2.3

[3]

[Total: 10]

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3. June/2021/Paper_41/No.1

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]

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

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

[Total: 10]

4. June/2021/Paper_42/No.1

(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]

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(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]

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5. March/2021/Paper_42/No.1

(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.

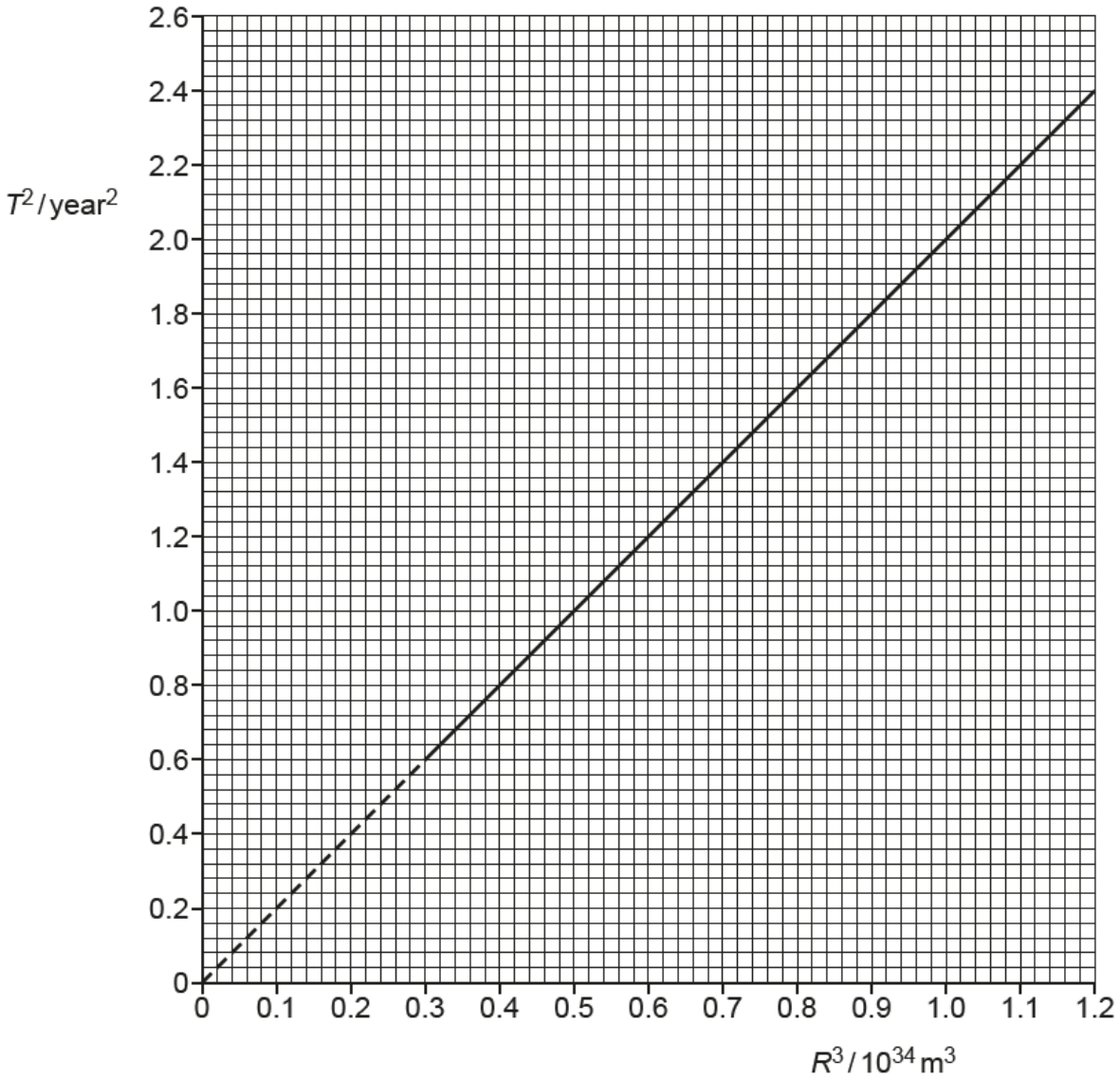


Fig. 1.1

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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]

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1. Nov/2023/Paper_9702/41/No.1

(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.

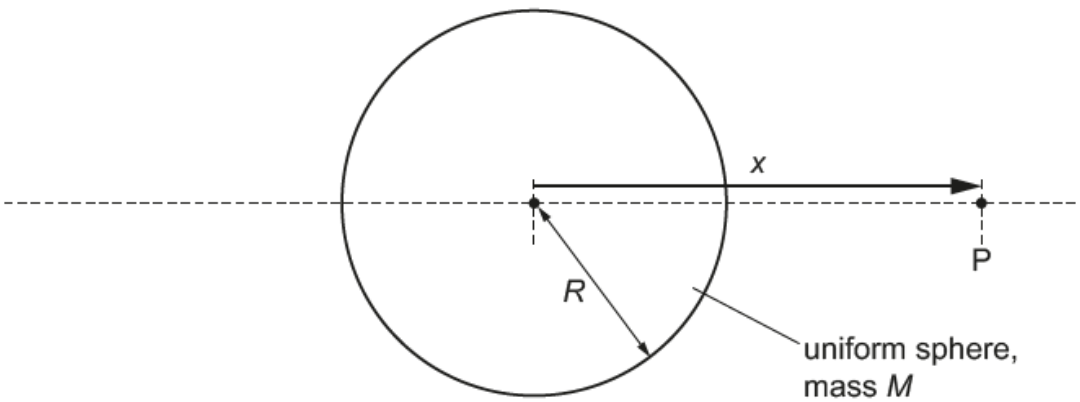


Fig. 1.1

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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.

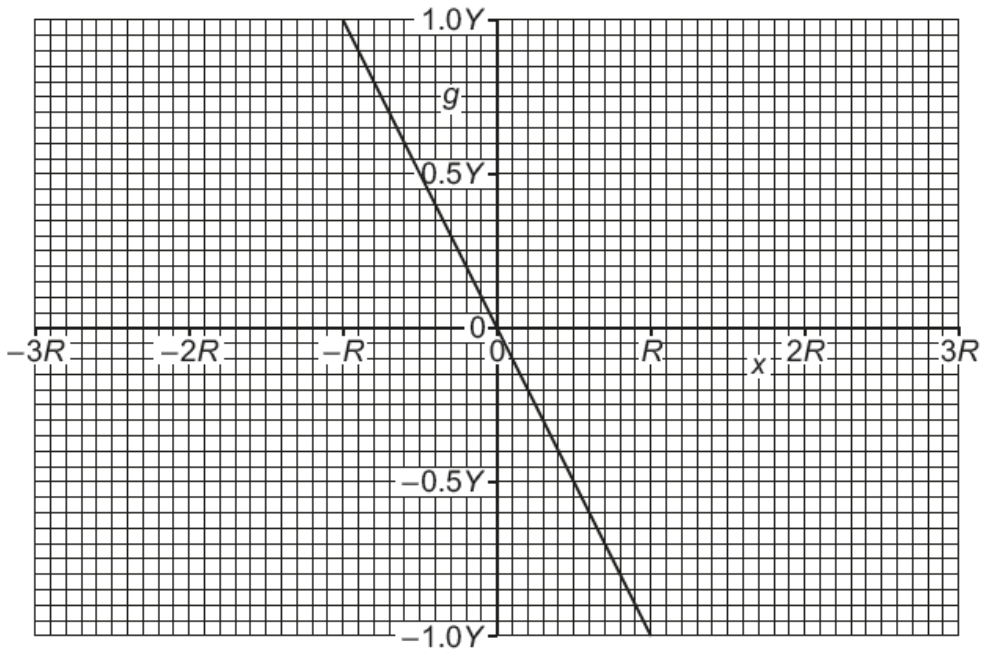


Fig. 1.2

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]

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2. Nov/2023/Paper_9702/42/No.2(a _ c)

(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]

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(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]

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(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]

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3. June/2023/Paper_9702/41/No.1

(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.

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

[1]

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(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]

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4. June/2023/Paper_9702/42/No.1

(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]

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(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]

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5. March/2023/Paper_9702/42/No.1

(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.

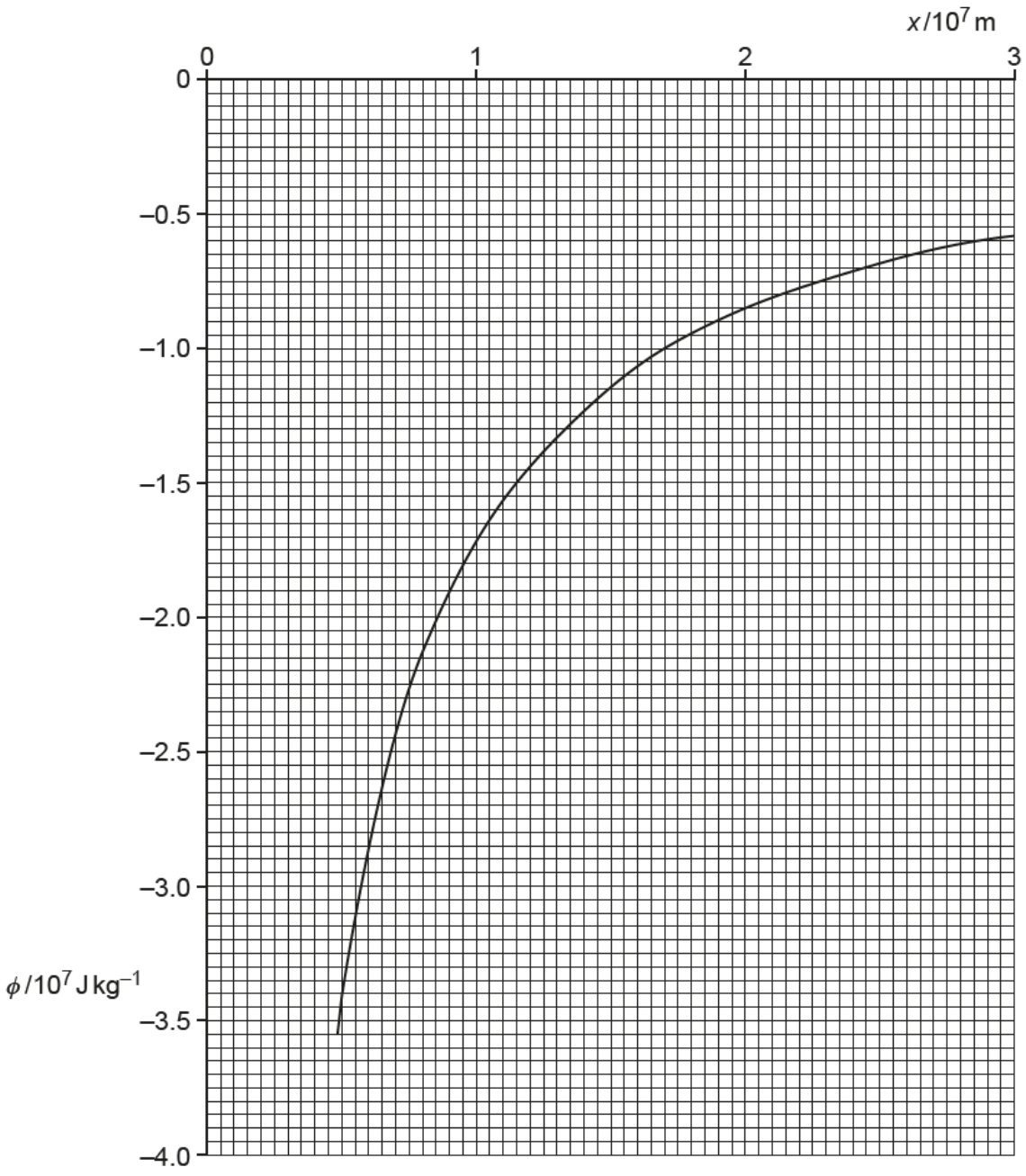


Fig. 1.1

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(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]

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(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]

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