PapaCambridge

Cambridge International AS & A Level

# PHYSICS

## Paper 4

Topical Past Paper Questions
+ Answer Scheme

**2016 - 2021**

PapaCambridge

Chapter 2

# Gravitational fields

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.

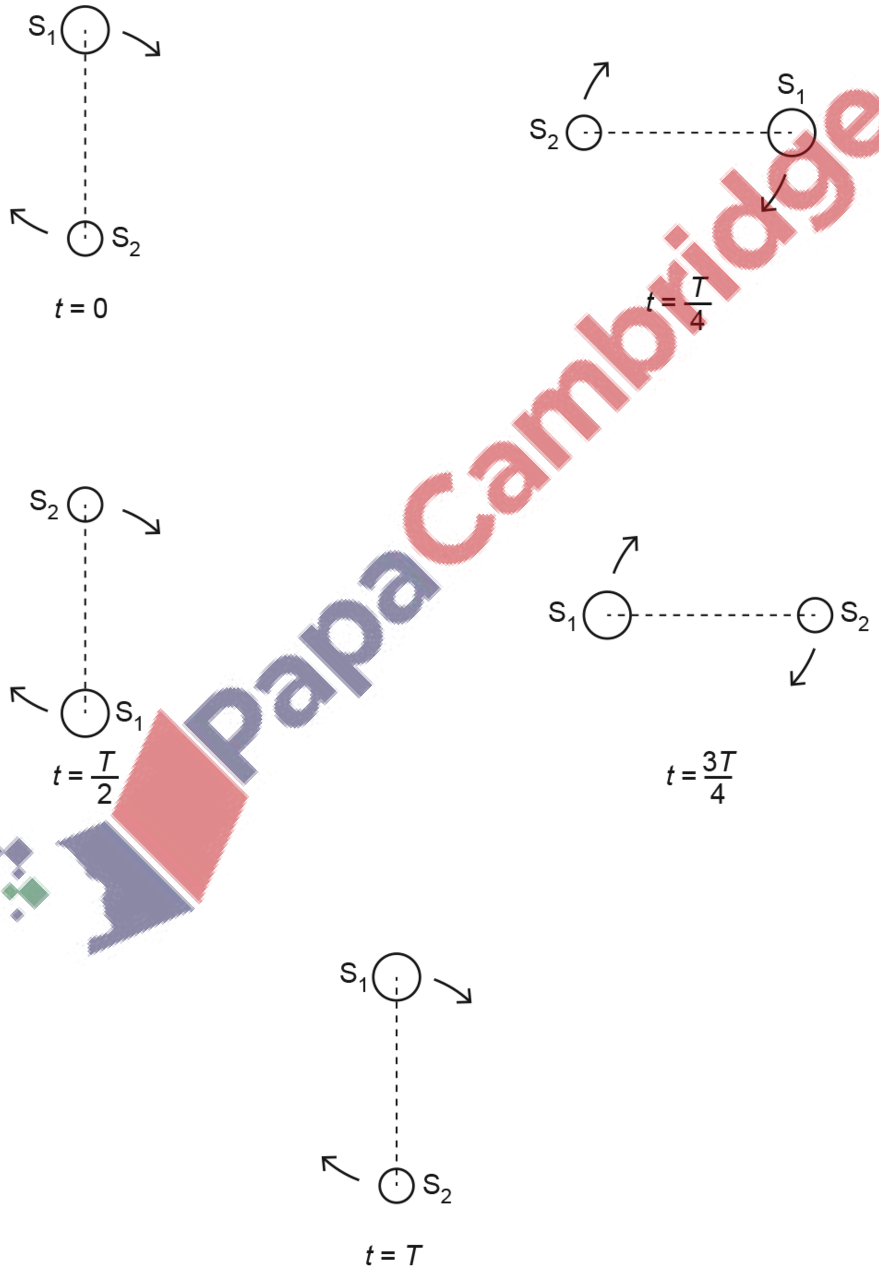


**Fig. 1.1** (not to scale)

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

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

[1]

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

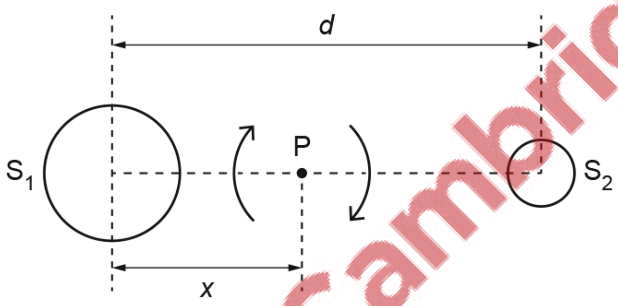


**Fig. 1.2** (not to scale)

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 $\omega$.

$\omega$ = ............................................ 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.

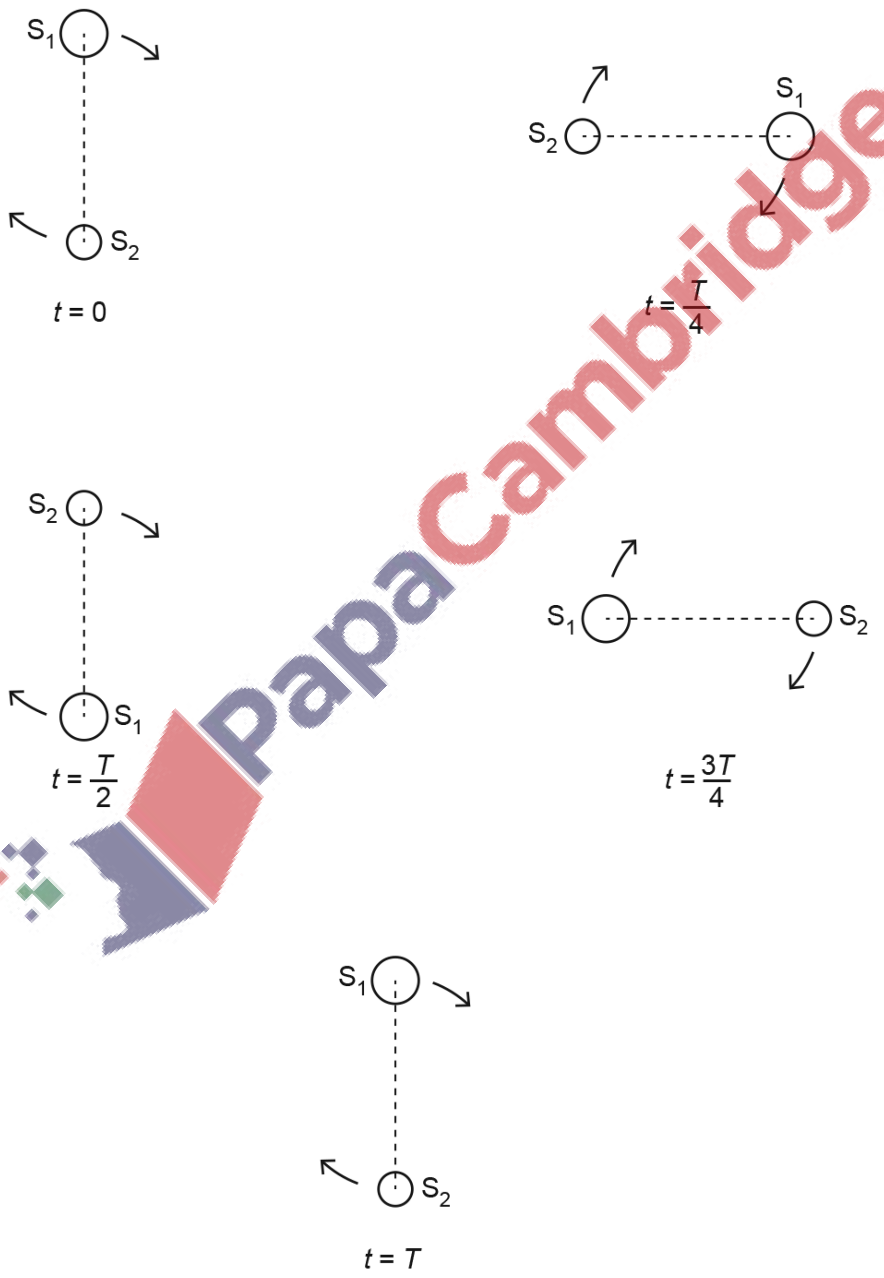


**Fig. 1.1** (not to scale)

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

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

[1]

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

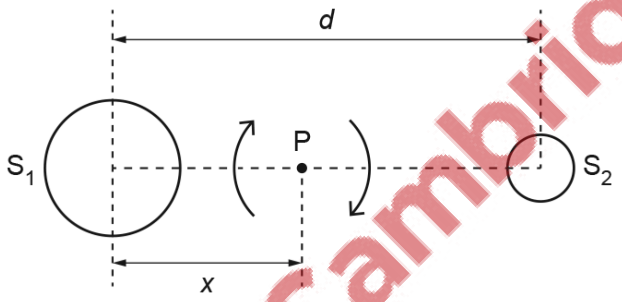


**Fig. 1.2** (not to scale)

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 $\omega$.

$\omega$ = ............................................. 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 $4.23 \times 10^4$ 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 $4.38 \times 10^6$ 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 $4.23 \times 10^4$ 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 | $9.6 \times 10^{10}$ | $2.5 \times 10^{11}$ |
| e | $4.0 \times 10^{11}$ | $1.8 \times 10^{13}$ |
| g | $2.1 \times 10^{12}$ | $2.6 \times 10^{15}$ |

**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 | $9.6 \times 10^{10}$ | $2.5 \times 10^{11}$ |
| e | $4.0 \times 10^{11}$ | $1.8 \times 10^{13}$ |
| g | $2.1 \times 10^{12}$ | $2.6 \times 10^{15}$ |

**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 $\rho$. The Moon, mass $m$, is in a circular orbit about the Earth with radius $nR$, as illustrated in Fig. 1.1.

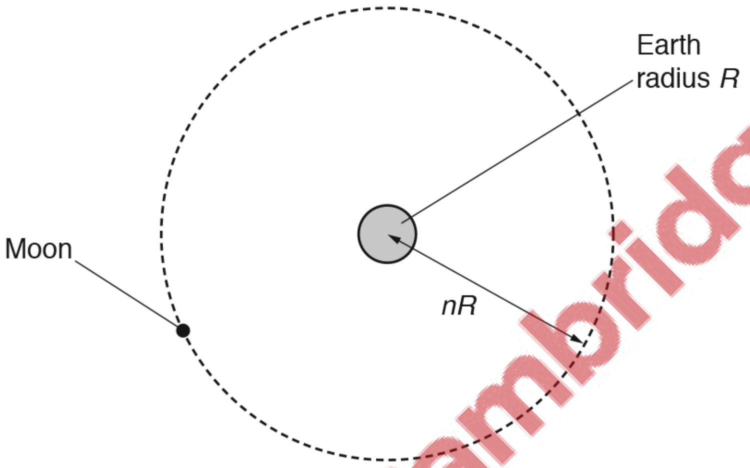


**Fig. 1.1**

The Moon makes one complete orbit of the Earth in time $T$.
Show that the mean density $\rho$ 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 $6.38 \times 10^3$ km and the distance between the centre of the Earth and the centre of the Moon is $3.84 \times 10^5$ km.
The period $T$ of the orbit of the Moon about the Earth is 27.3 days.
Use the expression in **(b)** to calculate $\rho$.

$\rho$ = ................................................ 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 $\rho$.
Io has mass $m$ and is in a circular orbit about Jupiter with radius $nR$, as illustrated in Fig. 1.1.

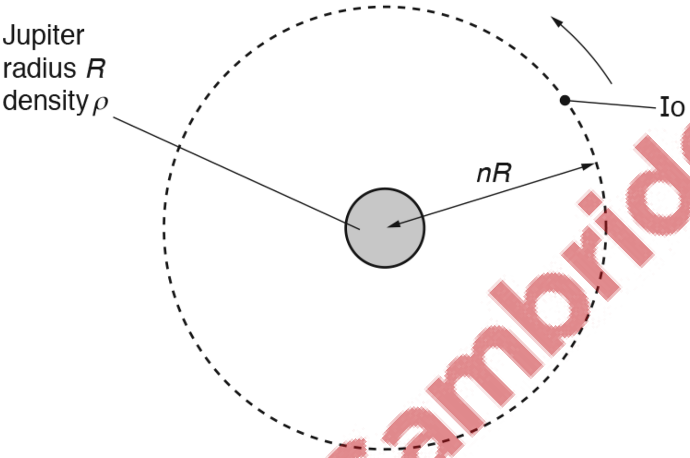


**Fig. 1.1**

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

Show that the time $T$ is related to the mean density $\rho$ 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 $7.15 \times 10^4$ km and the distance between the centres of Jupiter and Io is $4.32 \times 10^5$ km.
The period $T$ of the orbit of Io is 42.5 hours.

Calculate the mean density $\rho$ of Jupiter.

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

**(ii)** The Earth has a mean density of $5.5 \times 10^3$ 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.

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...............................................................................................................................[1]

[Total: 10]

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.

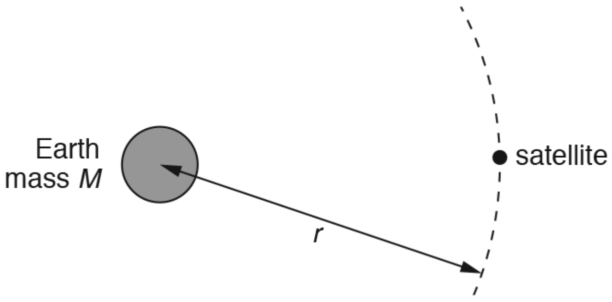


**Fig. 1.1**

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 $6.0 \times 10^{24}$ 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 $2.0 \times 10^4$ km above the Earth's surface.
The radius of the Earth is $6.4 \times 10^3$ 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.

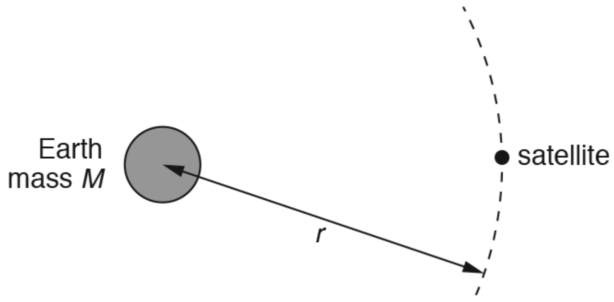


**Fig. 1.1**

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 $6.0 \times 10^{24}$ 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 $2.0 \times 10^4$ km above the Earth's surface.
The radius of the Earth is $6.4 \times 10^3$ 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 $3.39 \times 10^6$ m. Its mass of $6.42 \times 10^{23}$ 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.

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........................................................................................................................ [1]

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

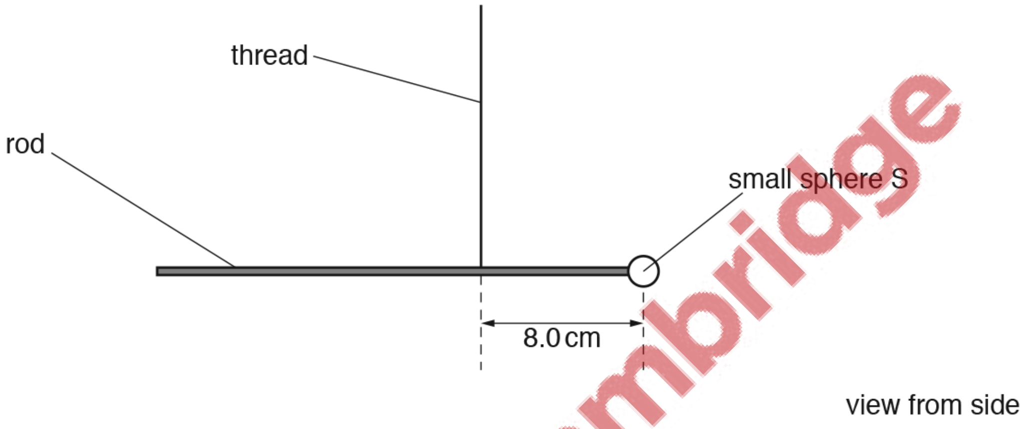


**Fig. 1.1** (not to scale)

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.

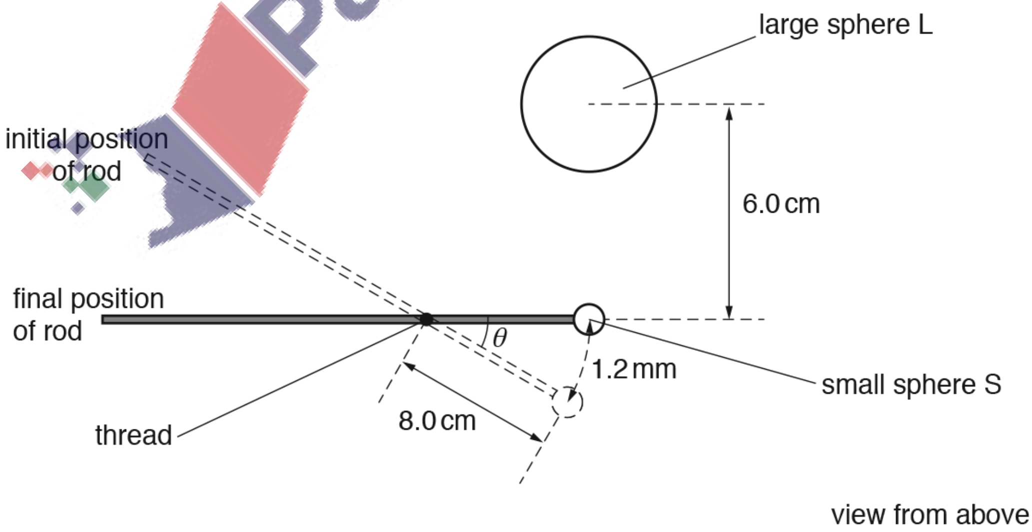


**Fig. 1.2** (not to scale)

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 $\theta$ through which the rod rotates is $1.5 \times 10^{-2}$ 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 $\beta$ (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.

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..........................................................................................................................................[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.

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..........................................................................................................................................

.....................................................................................................................................[3]

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

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..........................................................................................................................

.....................................................................................................................[3]

**(b)** The Moon may be considered to be a uniform sphere of diameter $3.4 \times 10^3$ km and mass $7.4 \times 10^{22}$ 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.

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.......................................................................................................................................

.......................................................................................................................................[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 $x = 4R$.

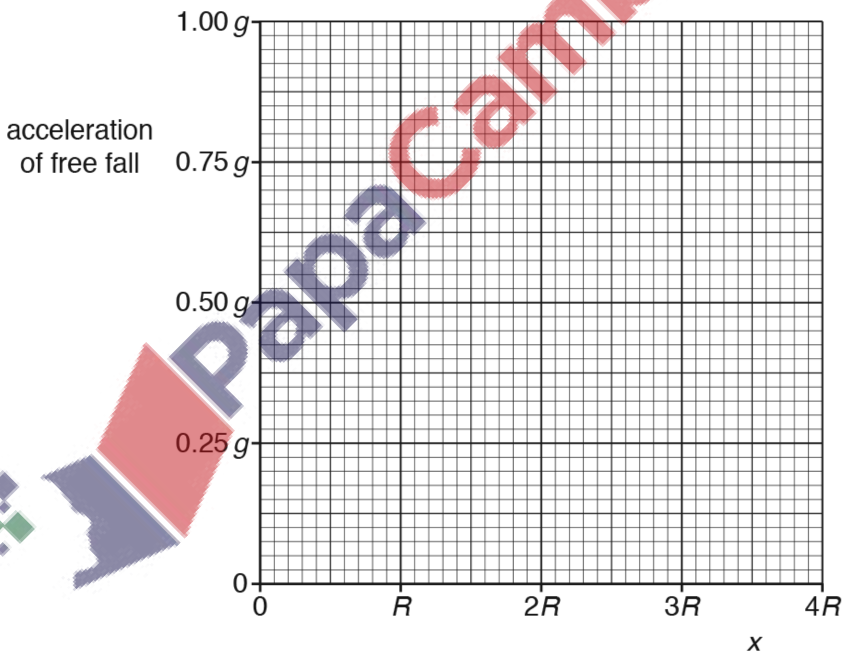


**Fig. 1.1**

[3]

**(c)** The planet in **(b)** has radius $R$ equal to $3.4 \times 10^3$ km and mean density $4.0 \times 10^3$ 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 $\rho$. The Moon, mass $m$, is in a circular orbit about the Earth with radius $nR$, as illustrated in Fig. 1.1.

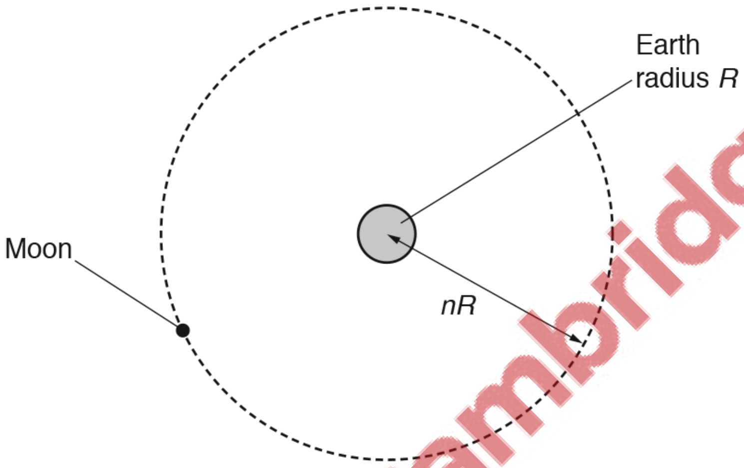


**Fig. 1.1**

The Moon makes one complete orbit of the Earth in time $T$.
Show that the mean density $\rho$ 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 $6.38 \times 10^3$ km and the distance between the centre of the Earth and the centre of the Moon is $3.84 \times 10^5$ km.
The period $T$ of the orbit of the Moon about the Earth is 27.3 days.
Use the expression in **(b)** to calculate $\rho$.

$\rho$ = ............................................... 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 $1.0 \times 10^{13}$ kg.

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

field strength = ................................................ $\text{N kg}^{-1}$ [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.

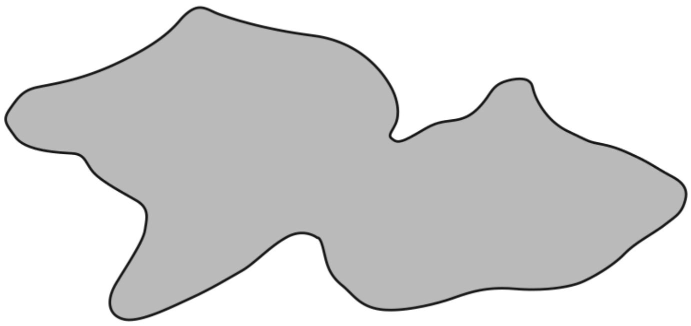

**Fig. 1.1**

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 $1.5 \times 10^8$ 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.

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.............................................................................................................................. [2]

**(c)** The orbit of the Earth about the Sun is approximately circular with a radius of $1.5 \times 10^8$ 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.

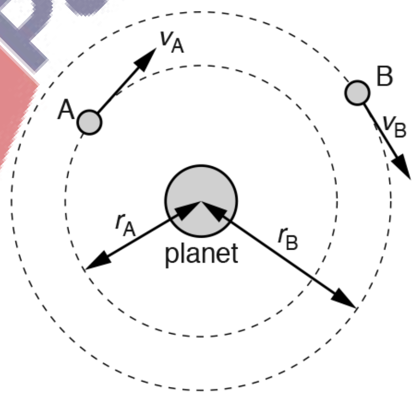


**Fig. 1.1** (not to scale)

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

**(i)** Determine the ratio

**1.** $\dfrac{v_A}{v_B}$,

ratio = ..........................................................[2]

**2.** $\dfrac{T_A}{T_B}$.

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 $2.5 \times 10^{29}$ kg and is a distance of $4.0 \times 10^{13}$ km from the Sun.
The Sun has a mass of $2.0 \times 10^{30}$ 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 $4.0 \times 10^{13}$ 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.

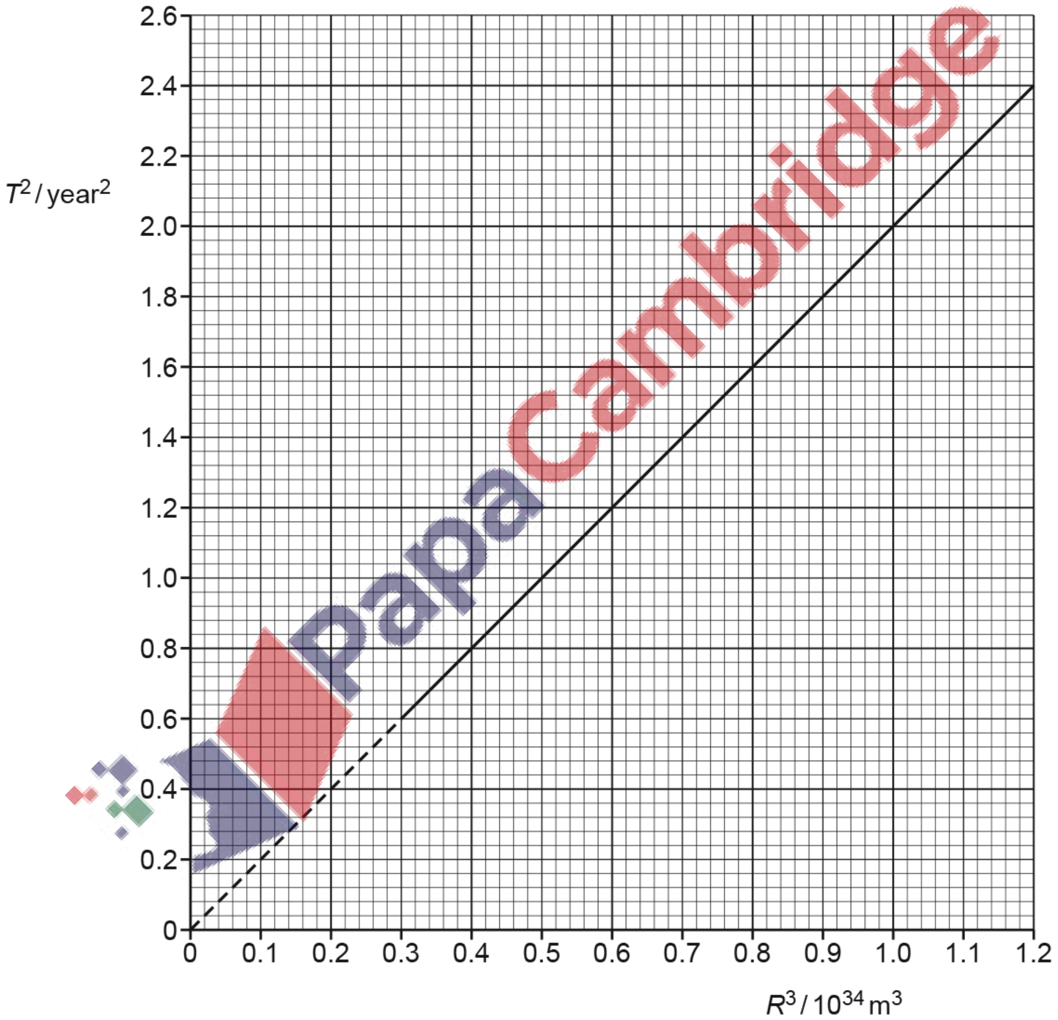


**Fig. 1.1**

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 $6.0 \times 10^{24}$ 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 $9.4 \times 10^{6}$ 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 $6.0 \times 10^{24}$ 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 $9.4 \times 10^{6}$ 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 $5.98 \times 10^{24}$ kg and the mass of the Moon is $7.35 \times 10^{22}$ kg. The Earth and the Moon are separated by a distance of $3.84 \times 10^{8}$ m, as shown in Fig. 2.1.

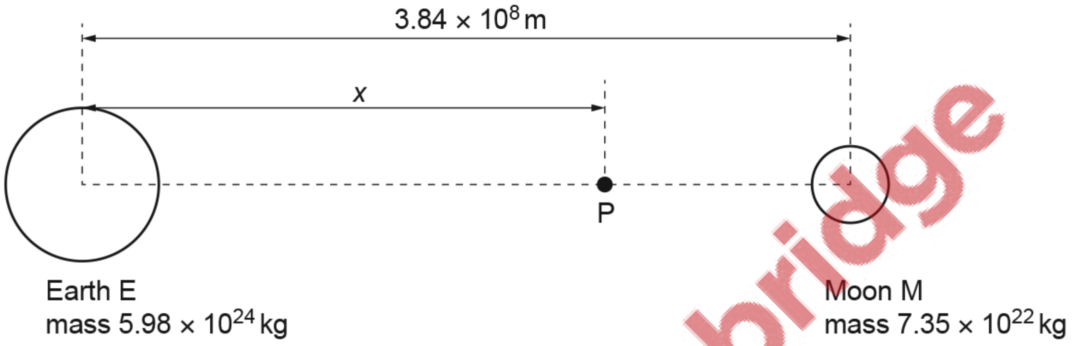


**Fig. 2.1** (not to scale)

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 $3.5 \times 10^{8}$ m.

[2]

**(iii)** Calculate the gravitational potential $\phi$ at point P.

$\phi$ = ............................................... $J\,kg^{-1}$ [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.

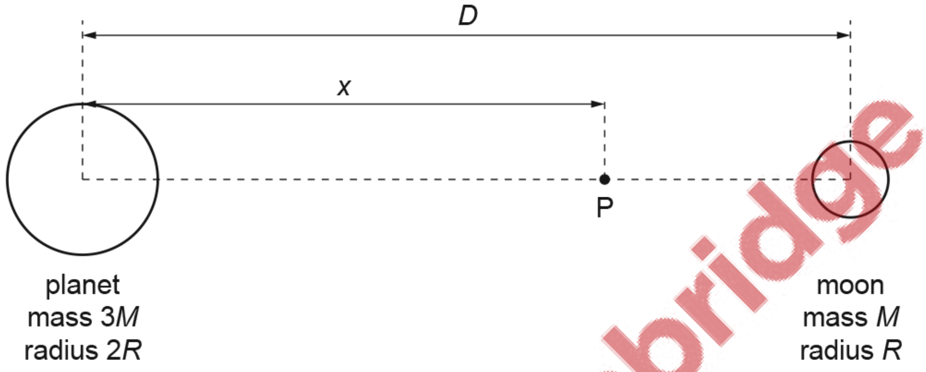


**Fig. 2.1**

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 $\phi$ at point P, for points between the planet and the moon, is shown in Fig. 2.2.

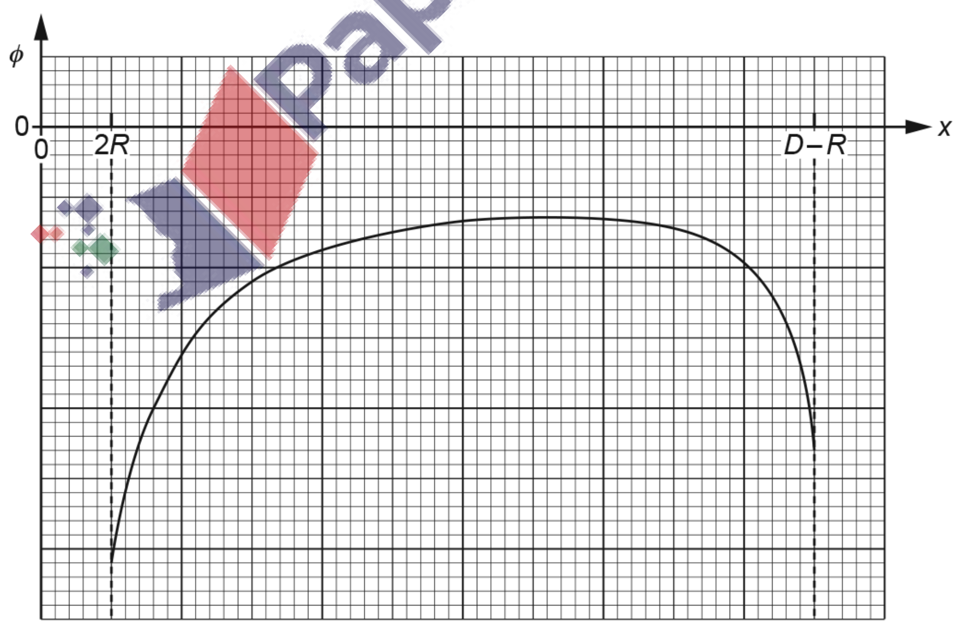


**Fig. 2.2**

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

..............................................................................................................................

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.............................................................................................................................. [3]

**(ii)** One of the features of Fig. 2.2 is that $\phi$ 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 $x = D - R$.

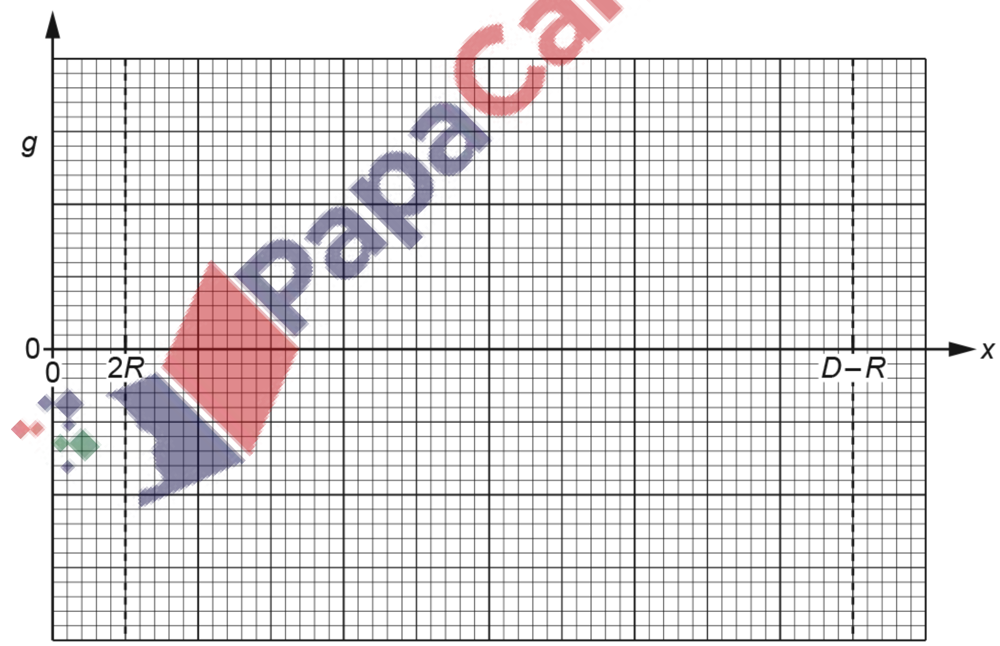


**Fig. 2.3**

[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 $5.98 \times 10^{24}$ kg and the mass of the Moon is $7.35 \times 10^{22}$ kg. The Earth and the Moon are separated by a distance of $3.84 \times 10^{8}$ m, as shown in Fig. 2.1.

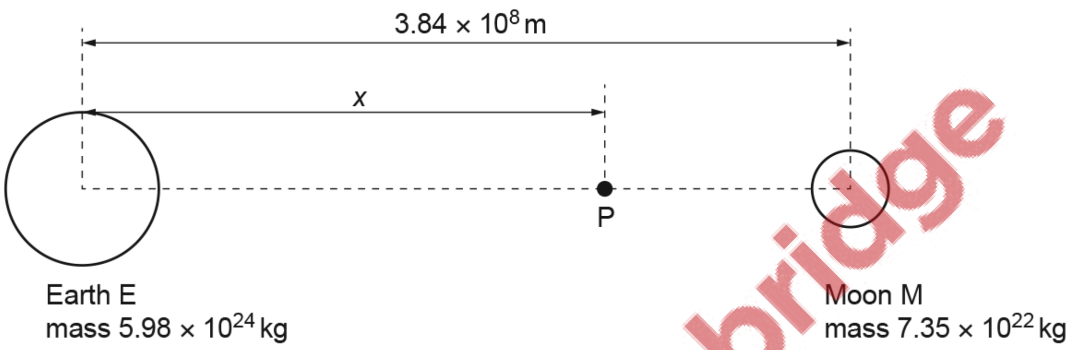


**Fig. 2.1** (not to scale)

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 $3.5 \times 10^{8}$ m.

[2]

**(iii)** Calculate the gravitational potential $\phi$ at point P.

$\phi$ = .............................................. $J\,kg^{-1}$ [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.

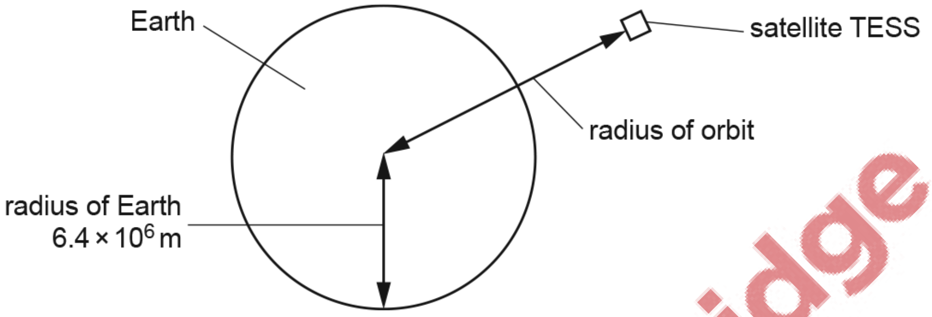


**Fig. 1.1** (not to scale)

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

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

Show that the radius of orbit of TESS is $2.4 \times 10^8$ 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 $\phi$.

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 $d = 4r$.

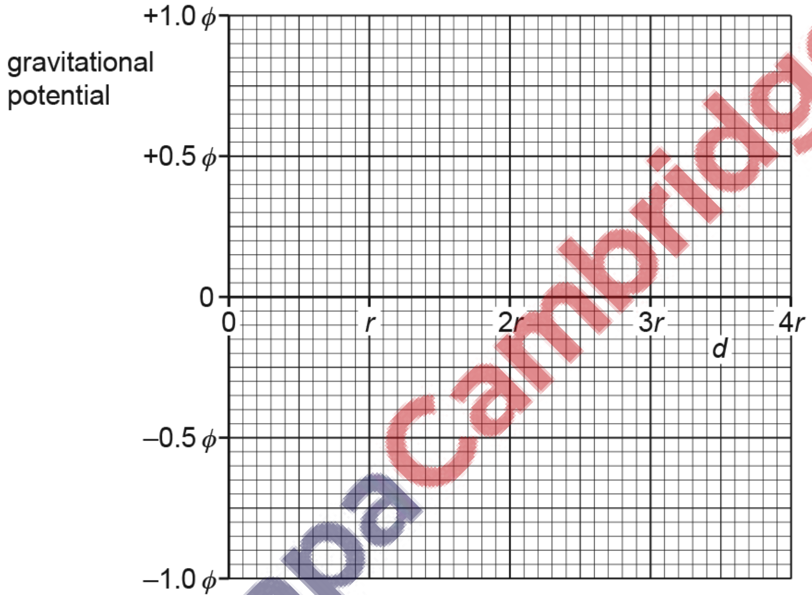


**Fig. 1.1**

[3]

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

A rock of mass $3.4 \times 10^{3}$ 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.

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..........................................................................................................................

.................................................................................................................... [2]

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

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..........................................................................................................................

..........................................................................................................................

.................................................................................................................... [3]

**(b)** A spherical planet has mass $6.00 \times 10^{24}$ kg and radius $6.40 \times 10^{6}$ 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 $9.00 \times 10^{5}$ m above its surface.

For the satellite:

**(i)** show that its orbital speed is $7.4 \times 10^{3}$ 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.

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..........................................................................................................................................

..........................................................................................................................................

.................................................................................................................................... [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 $7.5 \times 10^{23}$ kg. The radius of the planet is $3.4 \times 10^{6}$ m.

**(i)** The spacecraft is to orbit the planet at a height of $2.4 \times 10^{5}$ 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 $3.7 \times 10^{3}\,\mathrm{m\,s^{-1}}$.

[2]

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

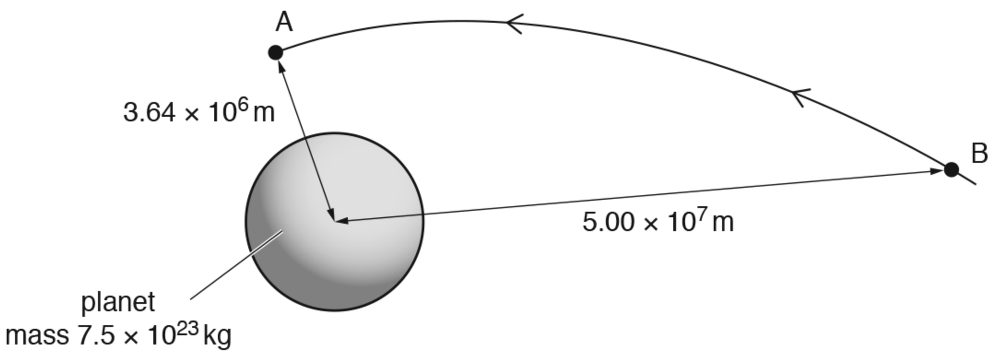


**Fig. 1.1** (not to scale)

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

At point B, a distance of $5.00 \times 10^7\,\text{m}$ from the centre of the planet, the spacecraft has a speed of $4.1 \times 10^3\,\text{m}\,\text{s}^{-1}$. 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 $8.3 \times 10^9\,\text{J}$.

[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.

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..............................................................................................................................

.............................................................................................................................. [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 $7.5 \times 10^{23}$ kg. The radius of the planet is $3.4 \times 10^{6}$ m.

**(i)** The spacecraft is to orbit the planet at a height of $2.4 \times 10^{5}$ 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 $3.7 \times 10^{3}$ m s$^{-1}$.

[2]

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

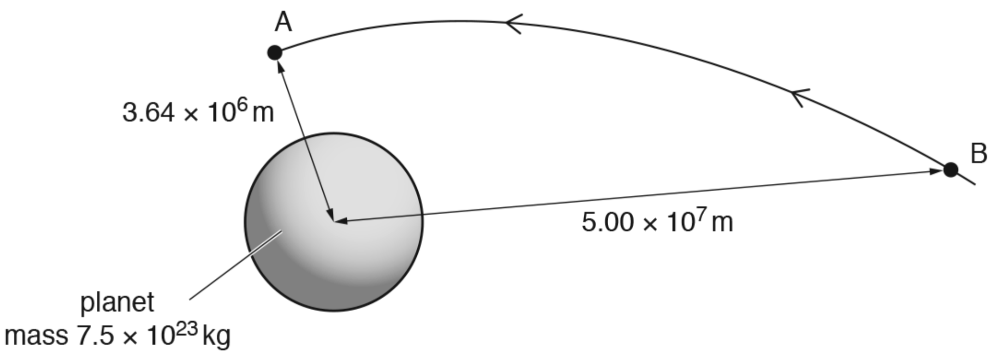


**Fig. 1.1** (not to scale)

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

At point B, a distance of $5.00 \times 10^7\,m$ 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 $8.3 \times 10^9\,J$.

[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 $3.5 \times 10^3$ km and a mass of $7.4 \times 10^{22}$ 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 $3.5 \times 10^3$ km and a mass of $7.4 \times 10^{22}$ 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.

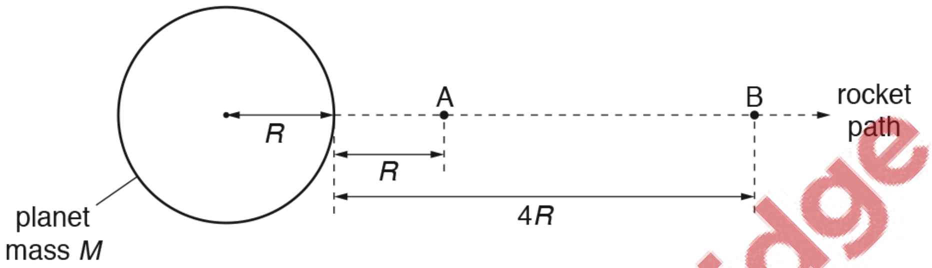


**Fig. 1.1**

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 $4.7 \times 10^4$ kg and its kinetic energy changes from 1.70 TJ to 0.88 TJ.

For the planet, the product *GM* is $4.0 \times 10^{14}$ N m$^2$ 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]