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

....

....

.... [2]

(b) A binary star consists of star A, of mass 4.0×10^{30} kg, and star B, of mass 2.0×10^{30} kg, separated by a distance of 3.3×10^{12} m. The stars are both in circular orbit around their common centre of gravity X, as shown in Fig. 1.1.

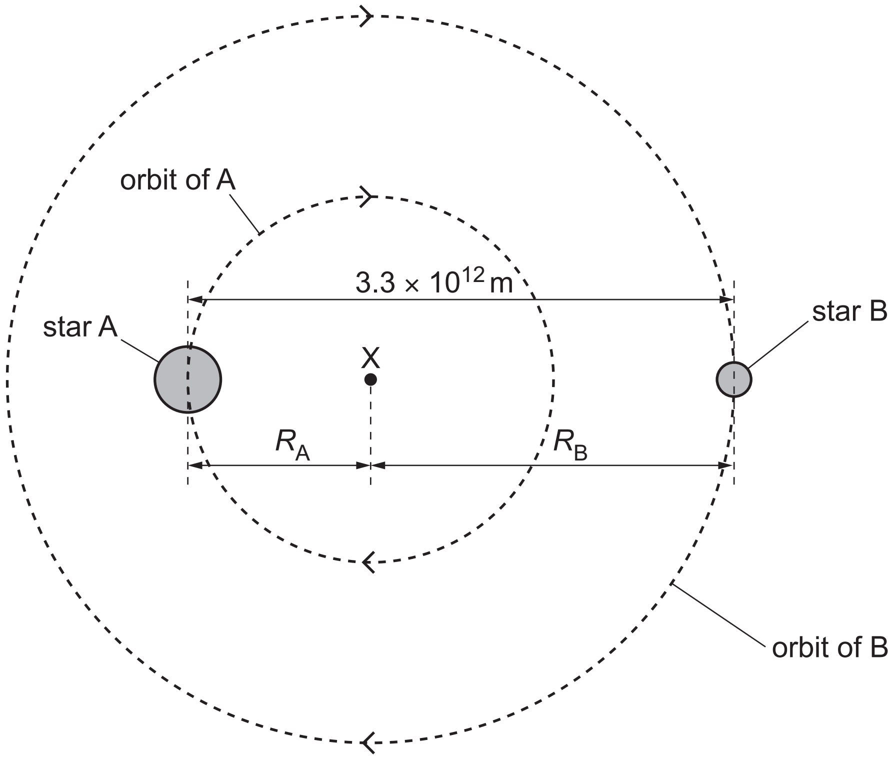

Fig. 1.1

The radius R_B of the orbit of star B is double the radius R_A of the orbit of star A.

(i) Use Newton's law of gravitation to calculate the magnitude of the gravitational force exerted by each star on the other.

force = ... N [2]

(ii) Calculate the centripetal acceleration of star A.

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

(iii) Use your answer in **(b)(ii)** to determine the period of the orbit of star A.

period = ... s [3]

(iv) By placing a tick (✓) in each row, complete Table 1.1 to show how the quantities indicated for star B compare with the same quantities for star A.

Table 1.1

	B less than A	B equal to A	B greater than A
centripetal acceleration			
linear speed			
period			

[3]

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

....

....

.... [2]

(b) One of the basic assumptions of the kinetic theory of gases is that there are no forces exerted between the molecules of the gas except during collisions.

State **two** other basic assumptions of the kinetic theory of gases.

1 ....

....

2 ....

....

[2]

(c) Hydrogen gas consists of molecules that each have a mass of 3.34×10^{-27} kg. Hydrogen may be considered to be an ideal gas.

A spherical balloon contains 0.0160 mol of hydrogen gas at a temperature of 282 K. At this temperature, the volume of gas in the balloon is $1.87 \times 10^{-4}\,m^3$.

(i) Determine the pressure of the gas.

pressure = ... Pa [2]

(ii) Estimate the average separation of the hydrogen molecules in the gas.

average separation = ... m [2]

(d) **(i)** Use your answer in **(c)(ii)** to calculate the average gravitational force between adjacent molecules in hydrogen gas.

average force = ... N [2]

(ii) By considering the weight of a molecule, suggest with a reason whether your answer in **(d)(i)** is consistent with the assumption of the kinetic theory of gases that there are no forces exerted between molecules.

....

....

.... [1]

3 **(a)** Define gravitational field at a point.

....

.... [1]

(b) Fig. 3.1 shows an isolated point mass of mass M.

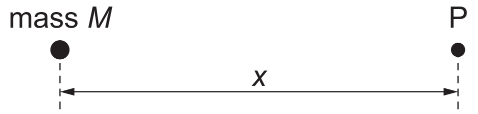

Fig. 3.1

Point P is at distance x from the point mass.

(i) By considering the force exerted by the point mass on a test mass of mass m placed at P, derive an equation for the gravitational field strength g at P, in terms of M and x. Identify any other symbols you use.

[2]

(ii) On Fig. 3.1, draw an arrow to indicate the direction of the gravitational field at P. [1]

(iii) Point Q is at distance $\frac{x}{2}$ from the point mass, on the opposite side of the mass from P, as shown in Fig. 3.2.

Fig. 3.2

Compare the gravitational field at Q with that at P.

....

....

.... [2]

(c) Two identical isolated uniform spheres X and Y each have radius R. The centres of the spheres are separated by distance L, as shown in Fig. 3.3.

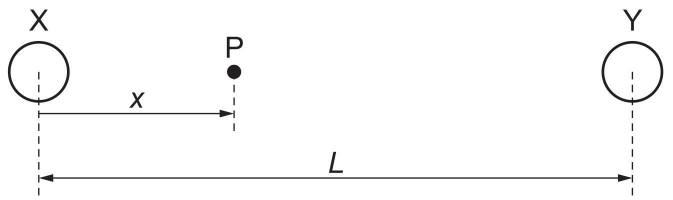

Fig. 3.3

Point P lies on the line joining the centres of X and Y, and is at a variable displacement x from the centre of sphere X.
The gravitational field strength at the surface of each sphere is g_0.

On Fig. 3.4, sketch the variation with x of the gravitational field g at point P between $x = R$ and $x = L - R$.

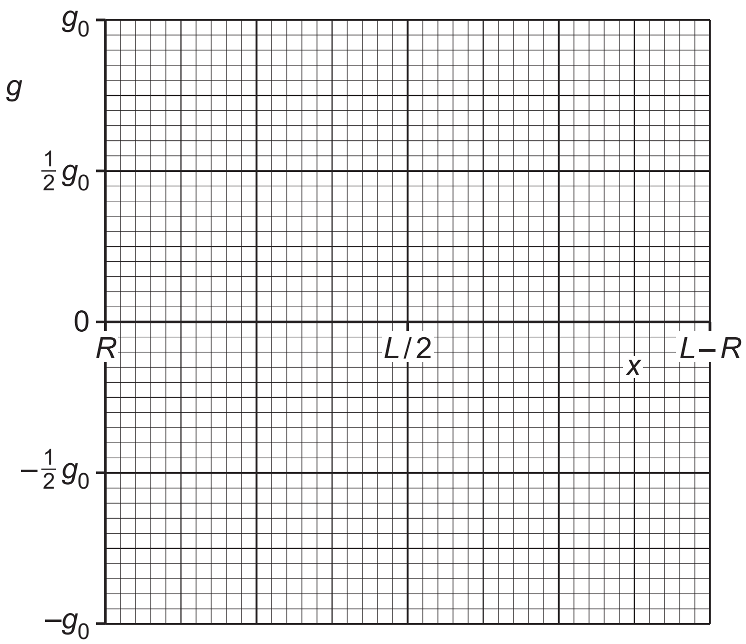

Fig. 3.4

[3]

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

....

.... [1]

(b) The gravitational field strength g at a distance x from the centre of a uniform spherical planet of mass M is given by the expression

$$g = \frac{GM}{x^2}$$

where G is the gravitational constant and distance x is greater than the radius of the planet.

(i) Describe the pattern of the field lines outside the planet that represent the gravitational field due to the planet.

....

....

.... [2]

(ii) Explain why, for small changes in vertical height near the surface of the planet, g may be assumed to be constant.

....

....

.... [2]

(c) Assume that the Earth is a uniform sphere. For the Earth, the product GM is equal to $3.99 \times 10^{14}\,\mathrm{m^3\,s^{-2}}$.

(i) Determine a value, to three significant figures, for the radius R of the Earth.

R = ... m [2]

(ii) Calculate the gravitational potential at the Earth's surface. Give a unit with your answer.

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

(d) Explain why the gravitational potential energy of two point masses is always negative.

....

....

.... [2]

2 **(a)** **(i)** State what is represented by a gravitational field line.

....

....

.... [2]

(ii) The Earth may be considered as a uniform sphere, as shown in Fig. 2.1.

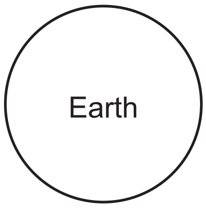

Fig. 2.1

On Fig. 2.1, draw field lines to represent the Earth's gravitational field outside the Earth. [2]

(b) The Earth's magnetic field may be considered as being due to the Earth acting as a long solenoid, as shown in Fig. 2.2.

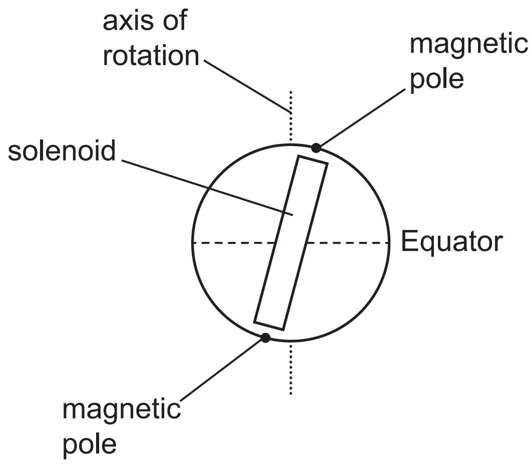

Fig. 2.2

The magnetic poles do not align with the geographic poles, which are on the axis of rotation.

Fig. 2.3 is a copy of Fig. 2.2 without the labels but with two magnetic field lines shown.

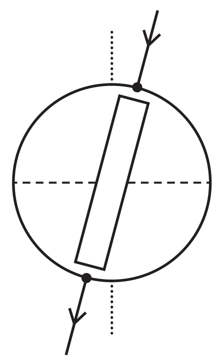

Fig. 2.3

(i) On Fig. 2.3, label the magnetic poles with the letters N and S to indicate which one is the magnetic N pole and which one is the magnetic S pole. [1]

(ii) On Fig. 2.3, draw field lines to represent the Earth's magnetic field outside the Earth. [2]

(c) An observer moves around the surface of the Earth.

(i) Use your answer in **(a)(ii)** to explain why the observed gravitational field of the Earth does not vary around the surface.

....

....

.... [2]

(ii) With reference to your answer in **(b)(ii)**, describe how the observed magnetic field of the Earth varies around the surface.

....

....

....

....

.... [3]

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

....

....

.... [2]

(b) Mars is a planet that may be considered to be an isolated uniform sphere of radius 3.4×10^6 m.

A satellite of mass 122 kg is in orbit around Mars at a constant height of 1.7×10^6 m above the surface of the planet.

The height of the orbit is increased to 6.8×10^6 m above the surface. This increases the gravitational potential energy of the satellite by 5.1×10^8 J.

(i) Show that the mass of Mars is 6.4×10^{23} kg.

[3]

(ii) Calculate the gravitational potential ϕ at the surface of Mars. Give a unit with your answer.

ϕ = ... unit .... [2]

(c) The satellite in **(b)** is moved to an orbit in which the satellite remains at the same point above the surface of Mars.

(i) The orbit has a period of 25 hours.

State what can be deduced from this about the rotation of Mars on its axis.

....

.... [1]

(ii) State **one** other feature of this orbit.

....

.... [1]

2 **(a)** The magnitude of the gravitational potential on the surface of a planet of radius R is ϕ. The planet can be considered to be an isolated sphere.

On Fig. 2.1, sketch the variation of the gravitational potential with distance x from the centre of the planet for values of x between R and $4R$.

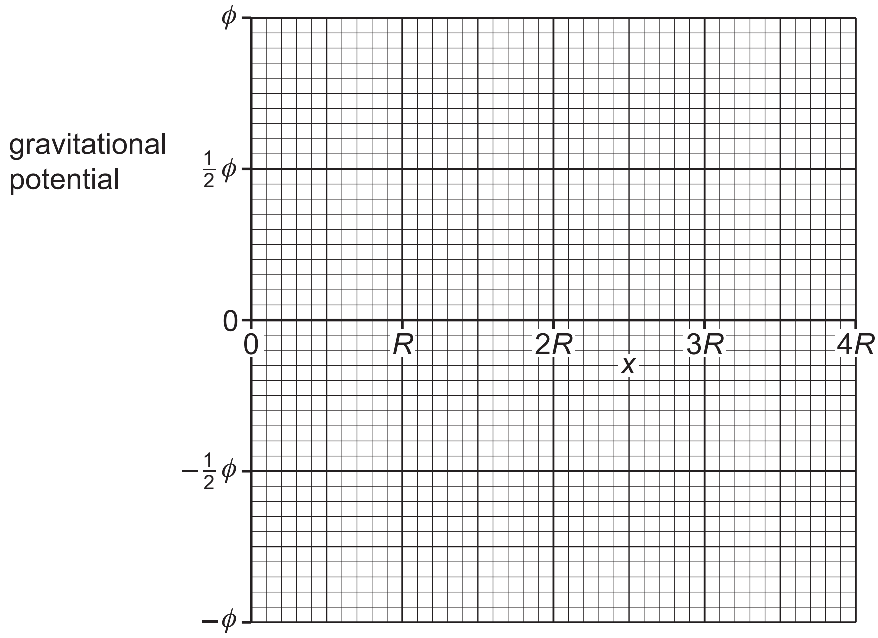

Fig. 2.1

[3]

(b) A satellite is in a geostationary orbit above the Earth. At time $t = 0$, the magnitude of the gravitational potential due to the Earth at the location of the satellite is ϕ.

On Fig. 2.2, sketch the variation of the gravitational potential due to the Earth at the location of the satellite for values of t between $t = 0$ and $t = 24$ hours.

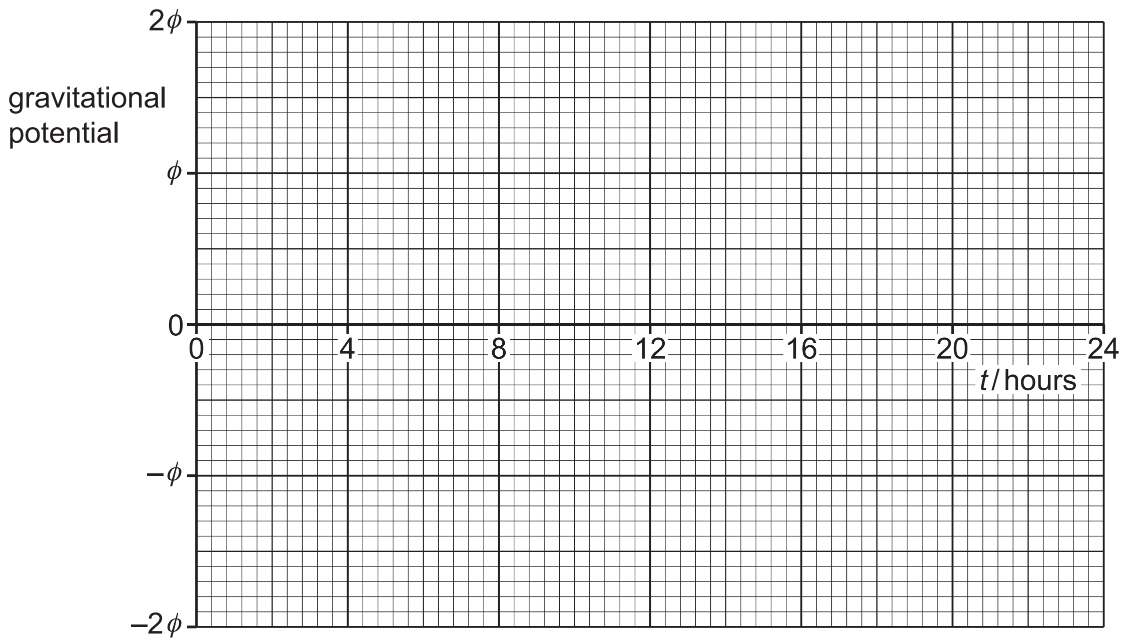

Fig. 2.2

[2]

(c) The electric potential difference (p.d.) between two parallel plates is V, as shown in Fig. 2.3.

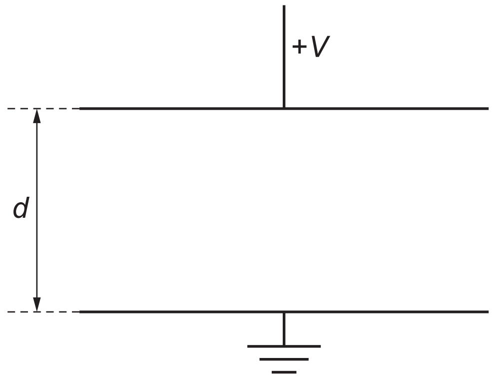

Fig. 2.3

The distance between the plates is d. The region between the plates is a vacuum.

On Fig. 2.4, sketch the variation of the electric potential with distance from the positive plate.

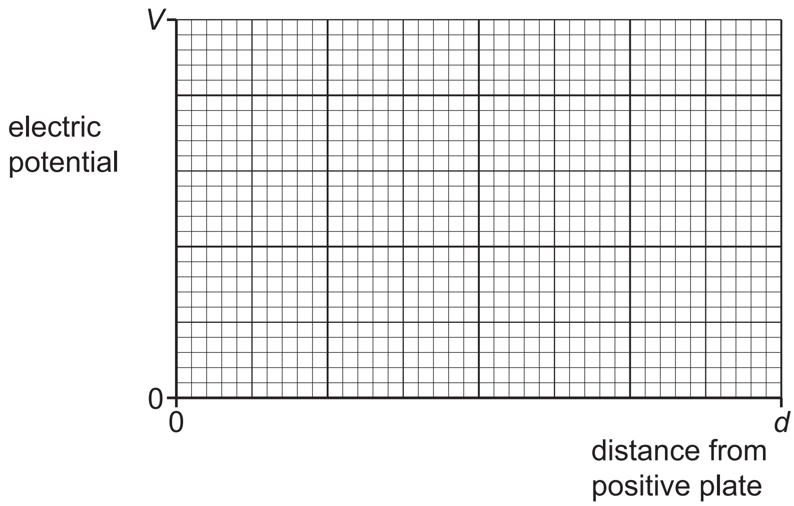

Fig. 2.4

[2]

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

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

(a) Define gravitational field.

....

.... [1]

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

(i) calculate g

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

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

E_P = ... J [2]

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

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

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

[3]

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

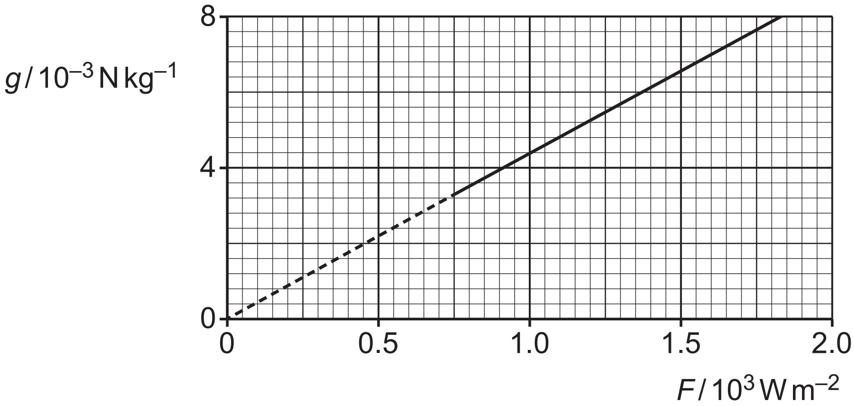

Fig. 2.1

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

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

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

r = ... m [2]

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

....

....

.... [2]

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

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

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

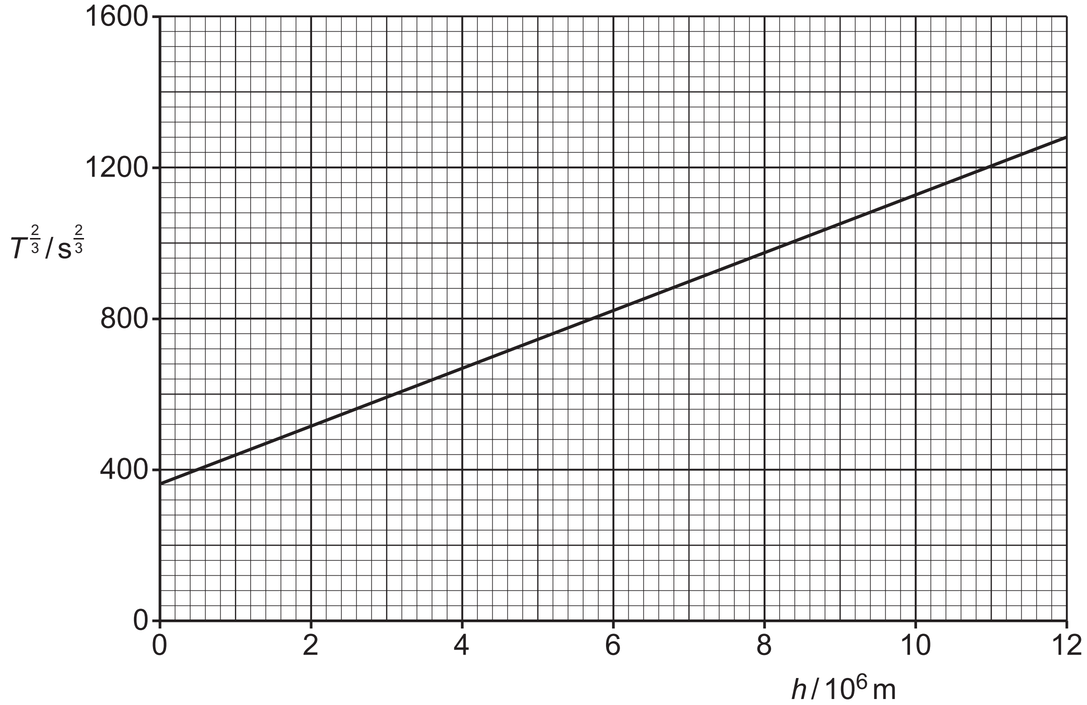

Fig. 1.1

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

....

....

.... [2]

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

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

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

[3]

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

A = ... unit ....

B = ... unit ....
[5]

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

....

....

.... [2]

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

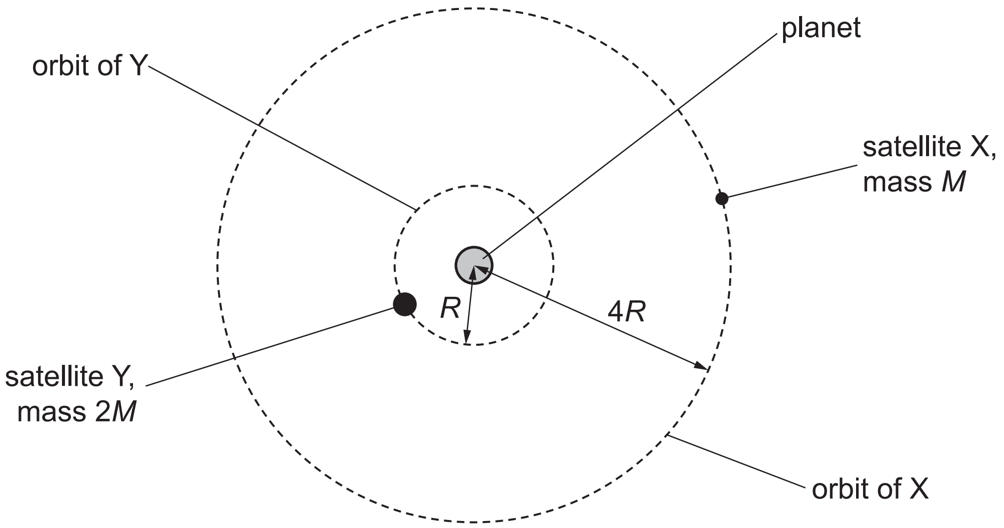

Fig. 1.1 (not to scale)

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

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

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

....

....

.... [2]

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

gravitational potential = ... [2]

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

Table 1.1

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

[4]

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

....

....

....

.... [2]

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

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

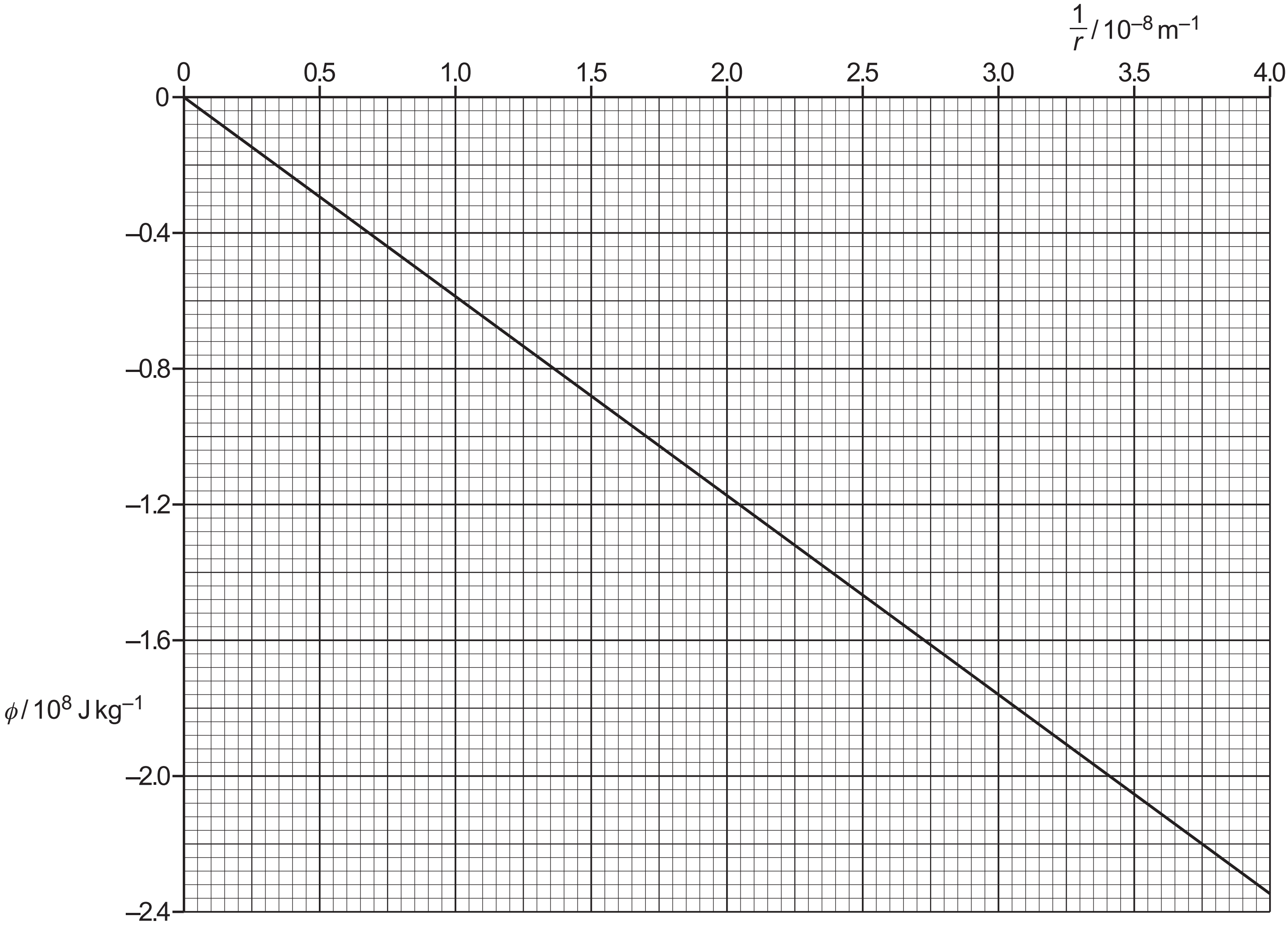

Fig. 1.1

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

[2]

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

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

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

R = ... m [3]

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

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

energy required = ... J [3]

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

....

....

.... [2]

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

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

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

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

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

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

E_P = ... [1]

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

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

[2]

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

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

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

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

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

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

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

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

....

.... [1]

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.

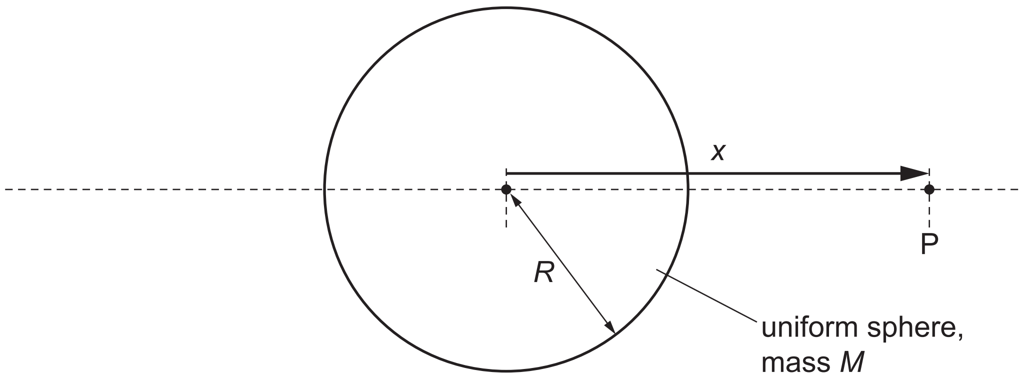

Fig. 1.1

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.

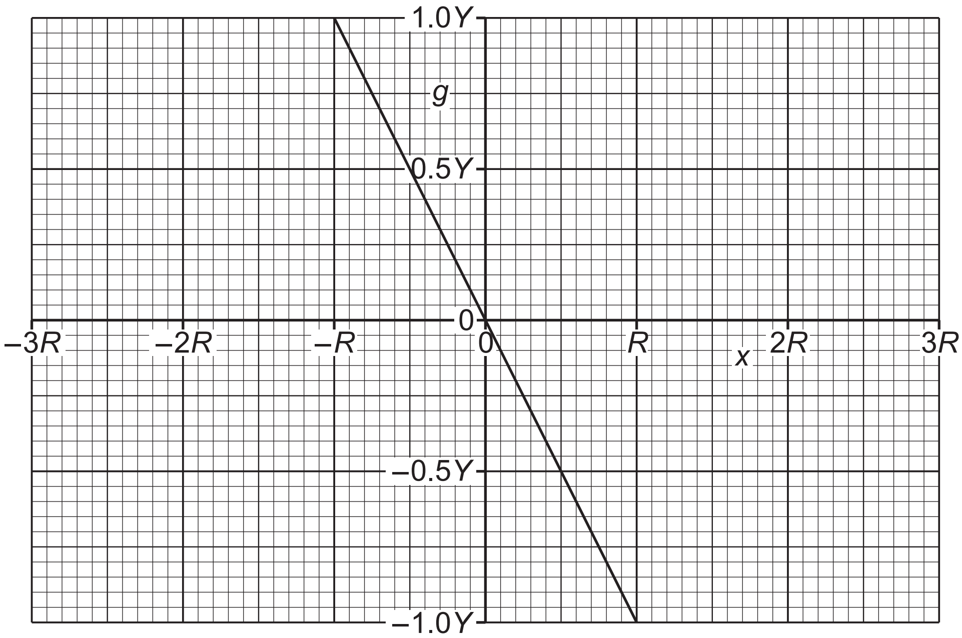

Fig. 1.2

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]

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

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

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

[2]

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

A geostationary satellite is in orbit around the Earth.

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

height = ... m [3]

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

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

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

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

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

1 ....

....

2 ....

....
[2]

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.

[3]

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

[1]

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

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

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

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

.... [1]

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.

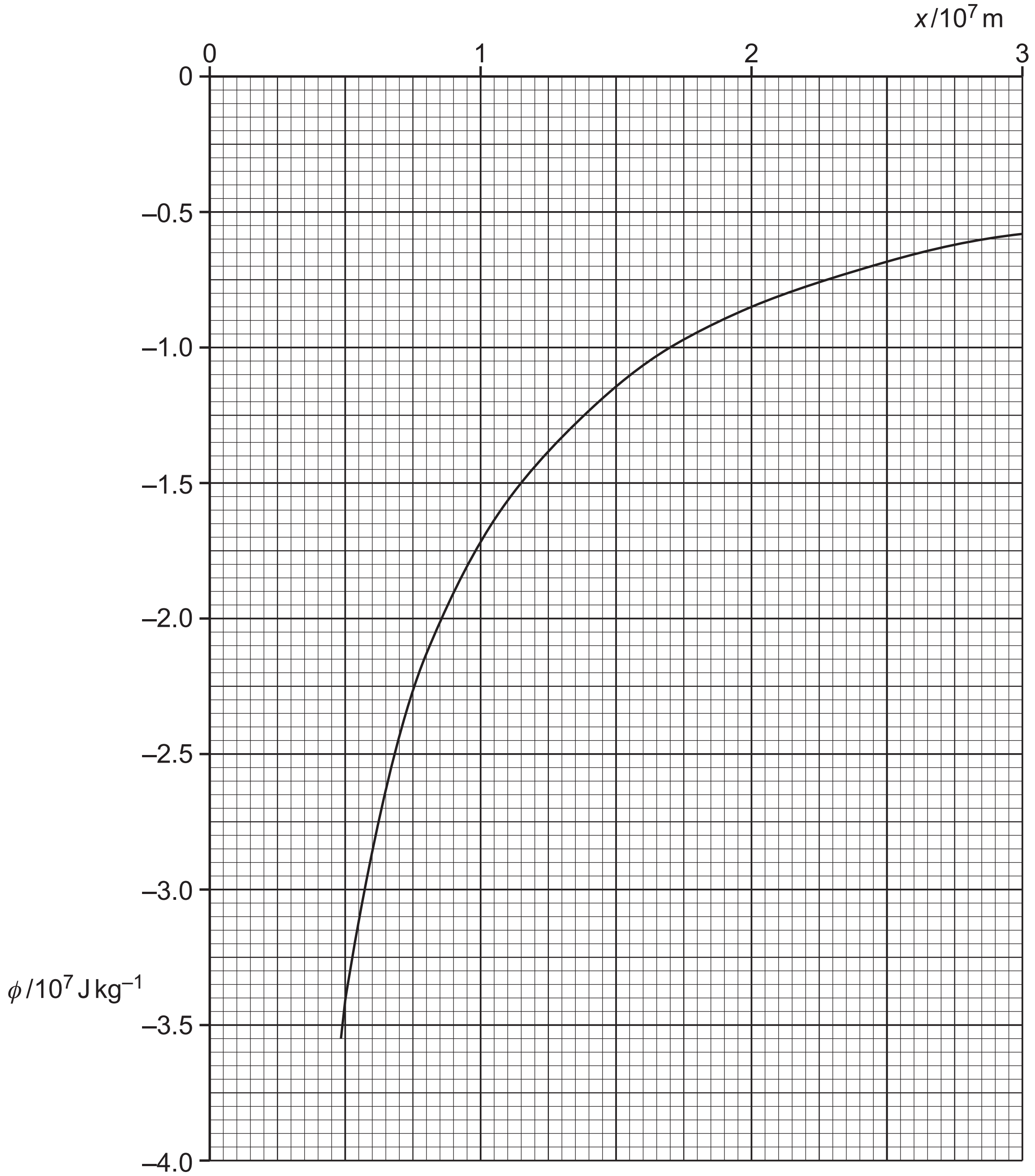

Fig. 1.1

(i) The radius of Artemis is 4800 km.

Determine the value of ϕ on the surface of Artemis.

ϕ = ... $J\,kg^{-1}$ [1]

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

[1]

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

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

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

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

period = ... hours [4]

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

similarity ....

....

difference ....

....
[2]

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

....

.... [1]

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

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

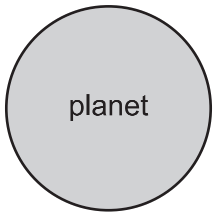

Fig. 1.1

[2]

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

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

....

....

.... [2]

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

(i) Determine the centripetal acceleration of the object.

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

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

....

....

.... [2]

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

[2]

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

Show that the period T of the orbit is given by

$$T^2 = kR^3$$

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

[3]

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

(i) Calculate the radius of the orbit.

radius = ... m [2]

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

1 ....

....

2 ....

....
[2]