For Examiner's Use

May June 2003

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]

May June 2006

2 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]

May June 2007

3 **(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.

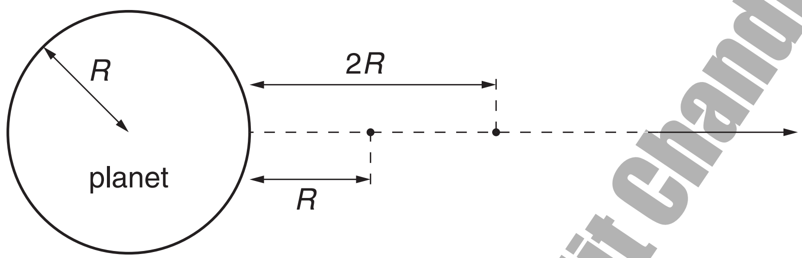

Fig. 1.1

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 $3.40 \times 10^6\,m$.

(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]

October November 2005

5 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]

For Examiner's Use

October November 2006

6 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]

May June 2004

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

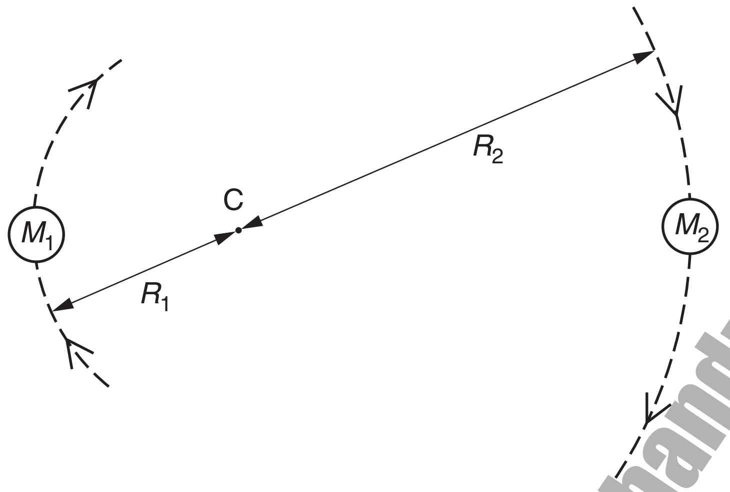

Fig. 3.1

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]

8 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]

(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]

October November 2006

9 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]

10 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.

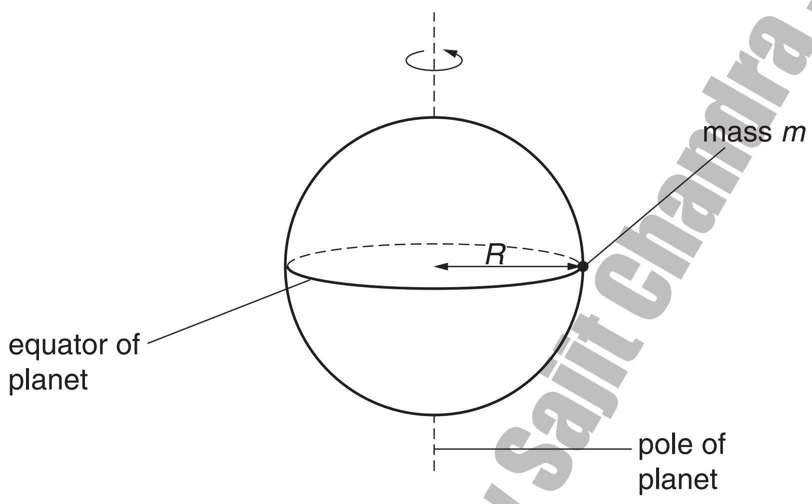

Fig. 1.1

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

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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]

For Examiner's Use

11 **(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 $8.6\,\mathrm{N\,kg^{-1}}$.
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 $-5.3 \times 10^7\,\mathrm{J\,kg^{-1}}$.
For point Y above the surface of the planet, the gravitational potential is $-6.8 \times 10^7\,\mathrm{J\,kg^{-1}}$.

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

12 **(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]

For Examiner's Use

13 **(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]

14 **(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.

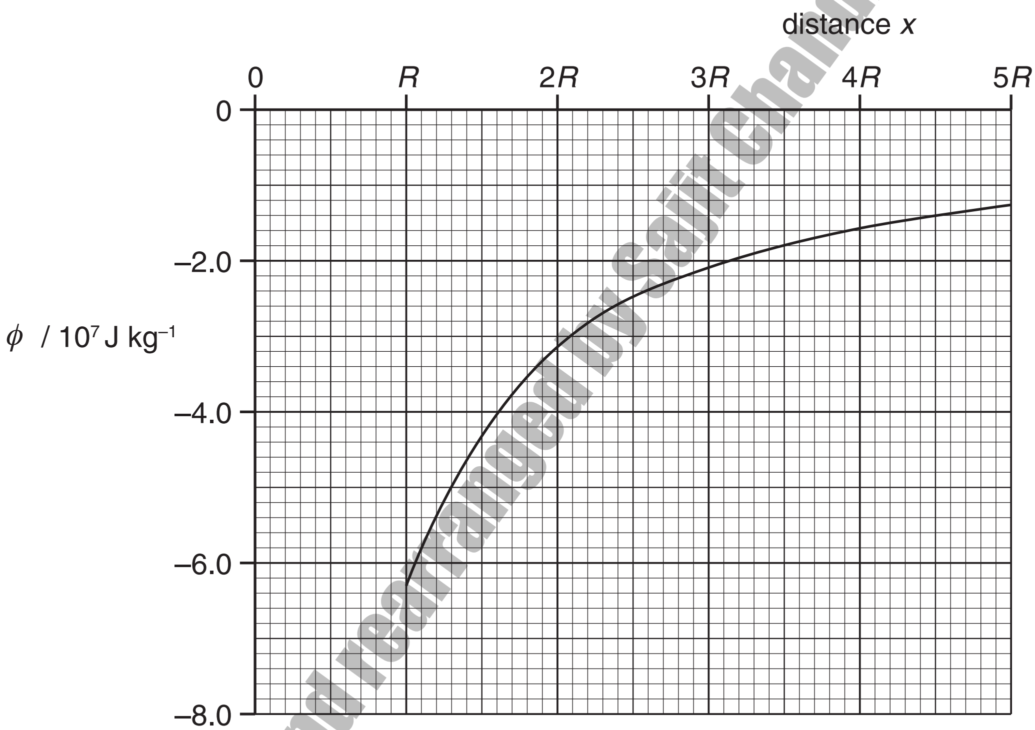

Fig. 1.1

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.

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Calculate the speed of the meteorite when it is at a distance of 2*R* 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]

Section A

Answer **all** the questions in the spaces provided.

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 $4R$.

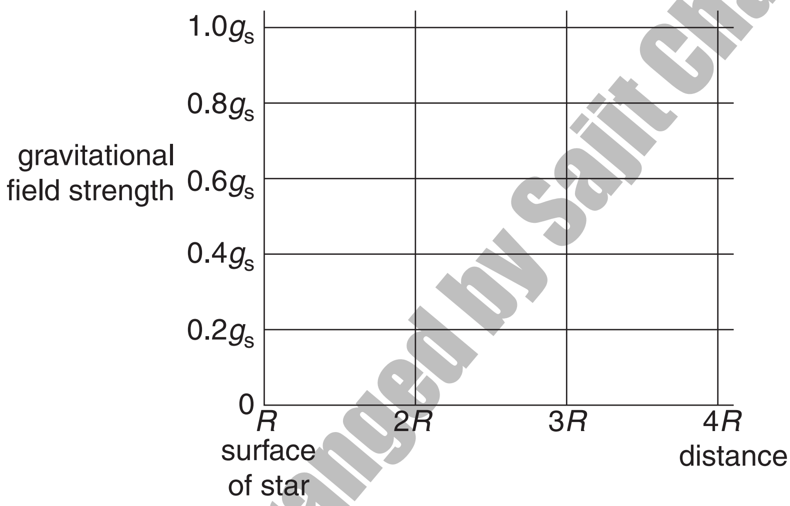

Fig. 1.1

[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.

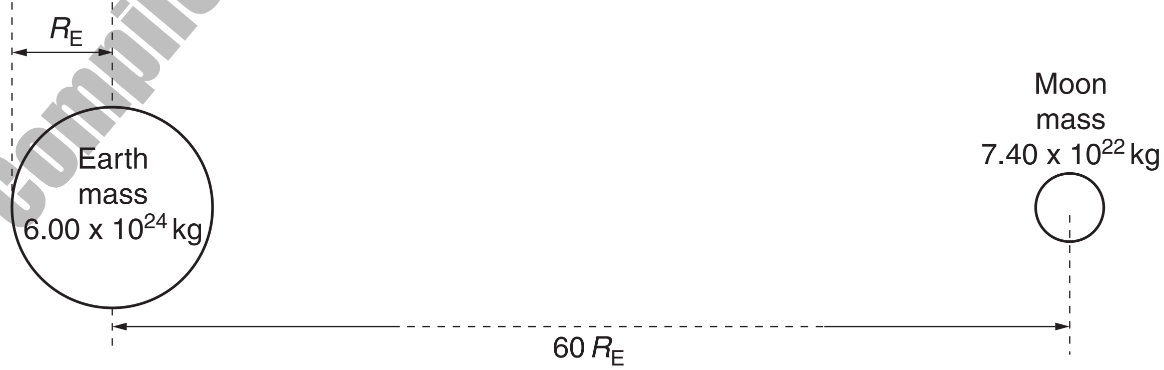

Fig. 1.2 (not to scale)

For Examiner's Use

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

....

....

.... [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.

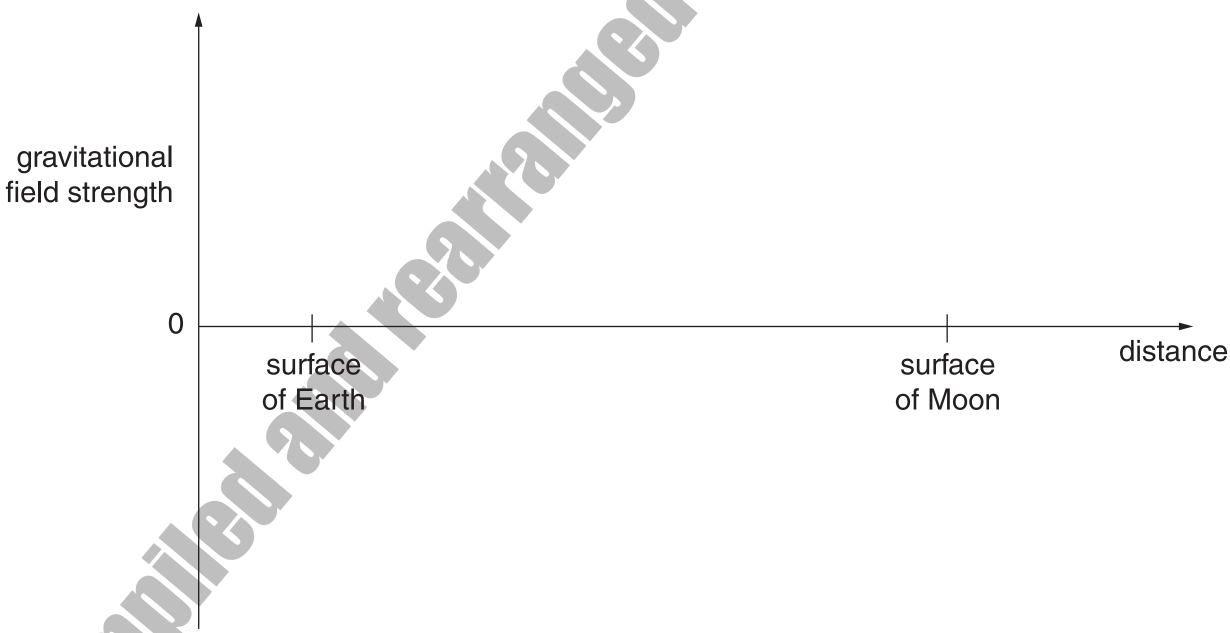

Fig. 1.3

[3]

Section A

Answer **all** the questions in the spaces provided.

For Examiner's Use

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.

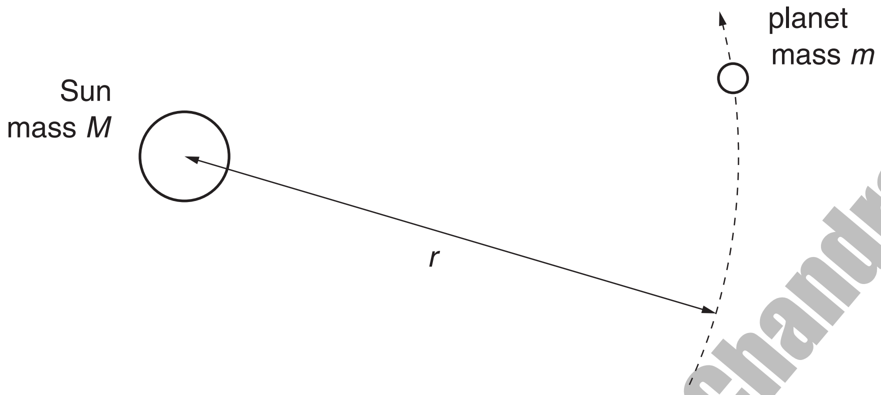

Fig. 1.1

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.

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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]

Section A

Answer **all** the questions in the spaces provided.

For Examiner's Use

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]

Section A

For Examiner's Use

Answer **all** the questions in the spaces provided.

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]