Gravitational Fields

Question paper 2

Level	International A Level
Subject	Physics
Exam Board	CIE
Topic	Gravitational Fields
Sub Topic	
Paper Type	Theory
Booklet	Question paper 2

Time Allowed: **78 minutes**

Score: **/65**

Percentage: **/100**

A*	A	B	C	D	E	U
>85%	'77.5%	70%	62.5%	57.5%	45%	<45%

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

....

....

.... [2]

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

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

Fig. 1.1

(i) State Newton's law of gravitation.

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....

....

.... [3]

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

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

ratio = ... [3]

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

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

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

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

[3]

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

mass = ... kg [2]

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

....

....

....

.... [3]

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

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

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

[4]

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

radius = ... m [3]

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

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....

.... [2]

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

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

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

[2]

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

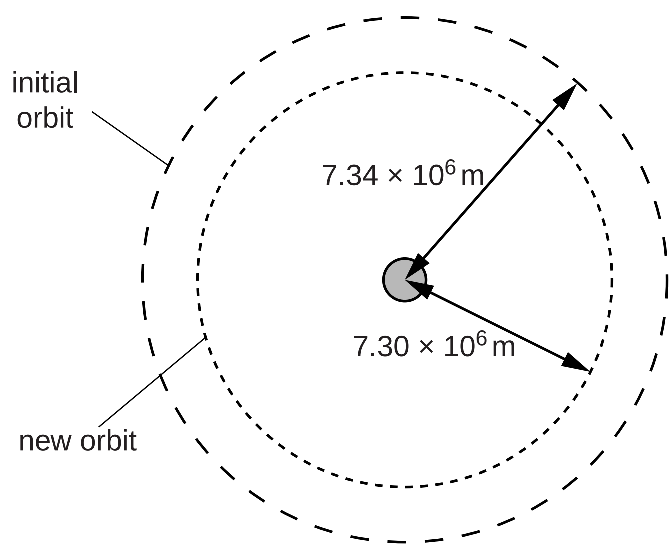

Fig. 1.1 (not to scale)

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

Determine, for the satellite, the change in

1. kinetic energy,

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

2. gravitational potential energy.

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

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

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....

.... [2]

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

....

.... [1]

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

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

where G is the gravitational constant.

Explain the significance of the negative sign in this expression.

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....

.... [2]

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

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

$$\Delta E_P = mgh$$

where g is the acceleration of free fall.

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.... [4]

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

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

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

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

....

....

....[2]

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

Show that

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

[1]

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

[2]

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

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

force = ... N [2]

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

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

energy change = ... J [3]

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

For this rock,

(a) **(i)** determine its weight,

weight = ... N [3]

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

[2]

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

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

(c) The mean translational kinetic energy $\langle E_K \rangle$ of a molecule of an ideal gas is given by the expression

$$\langle E_K \rangle = \tfrac{3}{2}kT$$

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

(i) Determine the temperature at which the root-mean-square (r.m.s.) speed of hydrogen molecules is equal to the speed calculated in **(b)**.
Hydrogen may be assumed to be an ideal gas.
A molecule of hydrogen has a mass of 2 u.

temperature = ... K [2]

(ii) State and explain one reason why hydrogen molecules may escape from Mars at temperatures below that calculated in **(i)**.

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....

.... [2]