For Examiner's Use

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]

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

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

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

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

[2]

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

(i) its kinetic energy,

kinetic energy = ... [1]

(ii) its gravitational potential energy,

potential energy = ... [1]

(iii) its total energy.

total energy = ... [2]

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

State and explain the effect of this decrease on

(i) the radius *r* of the orbit,

....

....

.... [2]

(ii) the linear speed *v* of the satellite.

....

....

.... [2]

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

....

.... [1]

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

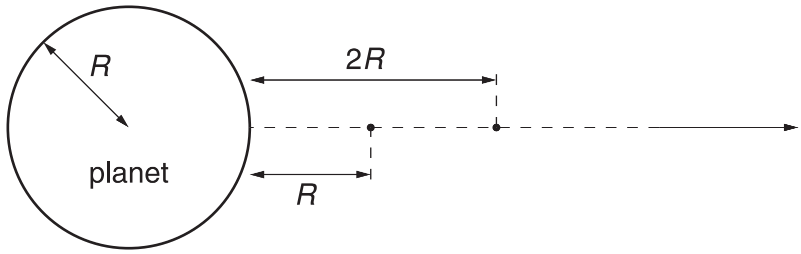

Fig. 1.1

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

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

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

[2]

(ii) During the ascent from a height R to a height $2R$, the speed of the rocket changes from $7600\,\mathrm{m\,s^{-1}}$ to $7320\,\mathrm{m\,s^{-1}}$. 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 $3.40 \times 10^6\,\mathrm{m}$.

(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]

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

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

[3]

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

energy = ……………………………….. J [4]

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

....

....[1]

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

(a) State one similarity between these two definitions.

....

.... [1]

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

....

....

....

....

.... [4]

2 A mercury-in-glass thermometer is to be used to measure the temperature of some oil.

The oil has mass 32.0 g and specific heat capacity 1.40 J g^{-1} K^{-1}. The actual temperature of the oil is 54.0 °C.

The bulb of the thermometer has mass 12.0 g and an average specific heat capacity of 0.180 J g^{-1} K^{-1}. Before immersing the bulb in the oil, the thermometer reads 19.0 °C.

The thermometer bulb is placed in the oil and the steady reading on the thermometer is taken.

(a) Determine

(i) the steady temperature recorded on the thermometer,

temperature = ... °C [3]

(ii) the ratio

$$\frac{\text{change in temperature of oil}}{\text{initial temperature of oil}}.$$

ratio = ... [1]

(b) Suggest, with an explanation, a type of thermometer that would be likely to give a smaller value for the ratio calculated in **(a)(ii)**.

....

....

.... [2]

(c) The mercury-in-glass thermometer is used to measure the boiling point of a liquid. Suggest why the measured value of the boiling point will **not** be affected by the thermal energy absorbed by the thermometer bulb.

....

....

....

.... [2]

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

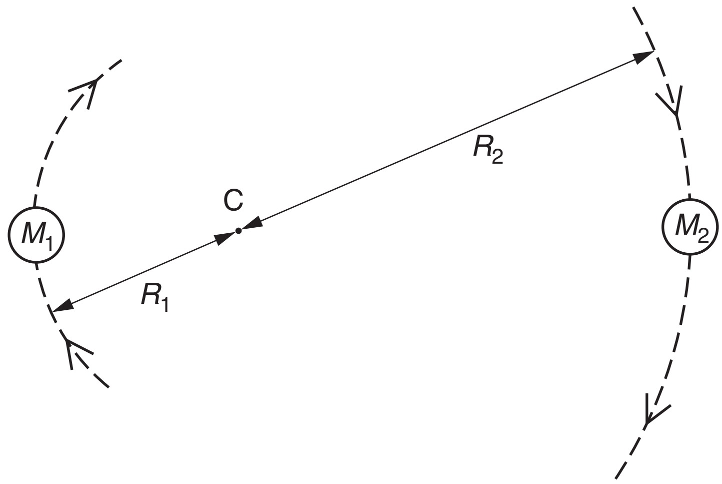

Fig. 3.1

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

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

(i) the gravitational force between the two stars,

....

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

....
[2]

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

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

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

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

[2]

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

Calculate the radii R_1 and R_2.

R_1 = ... m

R_2 = ... m
[2]

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

mass of star = ... kg

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

....
[4]

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

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

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

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

(ii) Hence show that

$$v^2 = 2Rg,$$

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

[3]

(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]

5 Some capacitors are marked '48 μF, safe working voltage 25 V'.

Show how a number of these capacitors may be connected to provide a capacitor of capacitance

(a) 48 μF, safe working voltage 50 V,

[2]

(b) 72 μF, safe working voltage 25 V.

[2]

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

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

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

Fig. 4.1

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

(a) Write down an expression in terms of

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

.... [1]

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

.... [1]

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

M = ... kg [3]