Gravitational Fields

Long Answer Questions

Name:

Class:

Date:

Time: **286 minutes**

Marks: **249 marks**

Comments:

1 Both gravitational and electric field strengths can be described by similar equations written in the form

$$a = \frac{bc}{d^2}.$$

(a) Complete the following table by writing down the names of the corresponding quantities, together with their SI units, for the two types of field.

symbol	*gravitational field* quantity	SI unit	*electrical field* quantity	SI unit
a	gravitational field strength			
b			$\frac{1}{4\pi\varepsilon_0}$	m F^{-1}
c				
d				

(4)

(b) Two isolated charged objects, A and B, are arranged so that the gravitational force between them is equal and opposite to the electric force between them.

(i) The separation of A and B is doubled without changing their charges or masses. State and explain the effect, if any, that this will have on the resultant force between them.

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(ii) At the original separation, the mass of A is doubled, whilst the charge on A and the mass of B remain as they were initially. What would have to happen to the charge on B to keep the resultant force zero?

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(3)

(Total 7 marks)

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

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(2)

(b) In 1798 Cavendish investigated Newton's law by measuring the gravitational force between two unequal uniform lead spheres. The radius of the larger sphere was 100 mm and that of the smaller sphere was 25 mm.

(i) The mass of the smaller sphere was 0.74 kg. Show that the mass of the larger sphere was about 47 kg.

density of lead = 11.3×10^3 kg m^{-3}

(2)

(ii) Calculate the gravitational force between the spheres when their surfaces were in contact.

answer = ______________________ N

(2)

(c) Modifications, such as increasing the size of each sphere to produce a greater force between them, were considered in order to improve the accuracy of Cavendish's experiment. Describe and explain the effect on the calculations in part (b) of doubling the radius of both spheres.

(4)

(Total 10 marks)

3 (a) Explain why astronauts in an orbiting space vehicle experience the sensation of weightlessness.

(2)

(b) A space vehicle has a mass of 16 800 kg and is in orbit 900 km above the surface of the Earth.

mass of the Earth = 5.97×10^{24} kg
radius of the Earth = 6.38×10^{6} m

(i) Show that the orbital speed of the vehicle is approximately 7400 m s^{-1}.

(4)

(ii) The space vehicle moves from the orbit 900 km above the Earth's surface to an orbit 400 km above the Earth's surface where the orbital speed is 7700 m s $^{-1}$.

Calculate the total change that occurs in the energy of the space vehicle.
Assume that the vehicle remains outside the atmosphere after the change of orbit.
Use the value of 7400 m s^{-1} for the speed in the initial orbit.

change in energy ____________________ J

(4)

(Total 10 marks)

4 (a) State, in words, Newton's law of gravitation.

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(3)

(b) By considering the centripetal force which acts on a planet in a circular orbit, show that $T^2 \propto R^3$, where T is the time taken for one orbit around the Sun and R is the radius of the orbit.

(3)

(c) The Earth's orbit is of mean radius 1.50×10^{11} m and the Earth's year is 365 days long.

(i) The mean radius of the orbit of Mercury is 5.79×10^{10} m. Calculate the length of Mercury's year.

(ii) Neptune orbits the Sun once every 165 Earth years.

Calculate the ratio $\frac{\text{distance from Sun to Neptune}}{\text{distance from Sun to Earth}}$.

(4)

(Total 10 marks)

5 The planet Venus may be considered to be a sphere of uniform density 5.24×10^3 kg m^{-3}.
The gravitational field strength at the surface of Venus is 8.87 N kg^{-1}.

(a) (i) Show that the gravitational field strength g_s at the surface of a planet is related to the the density ρ and the radius R of the planet by the expression

$$g_s = \frac{4}{3}\pi G R \rho$$

where G is the gravitational constant.

(2)

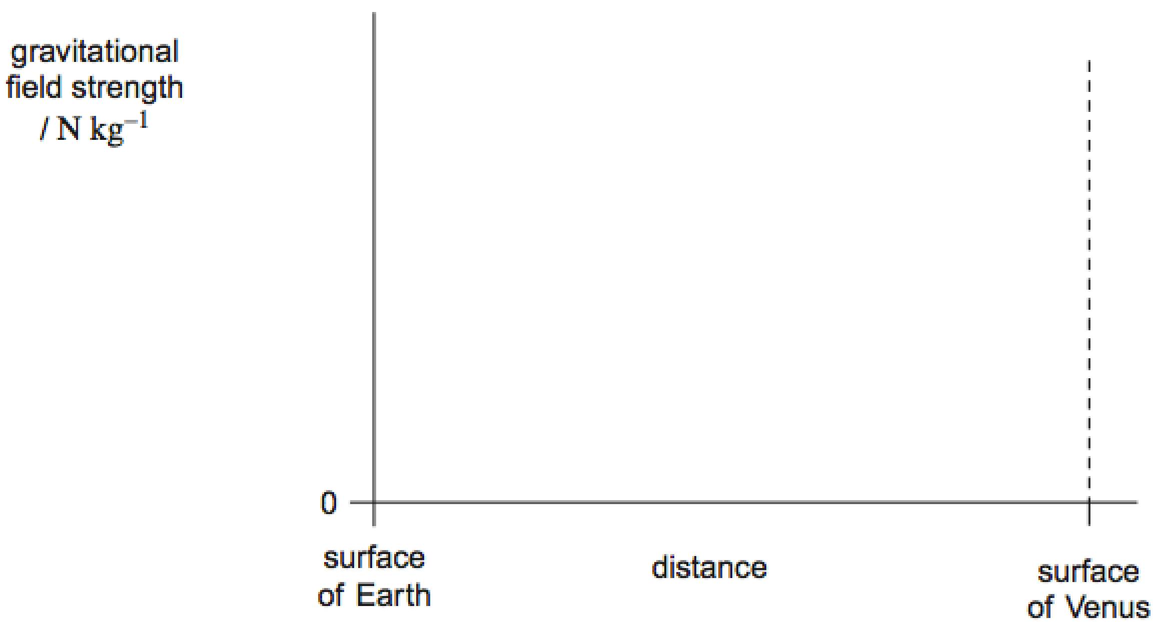
(ii) Calculate the radius of Venus.

Give your answer to an appropriate number of significant figures.

radius = ____________________ m

(3)

(b) At a certain time, the positions of Earth and Venus are aligned so that the distance between them is a minimum.
Sketch a graph on the axes below to show how the magnitude of the gravitational field strength *g* varies with distance along the shortest straight line between their surfaces.
Consider only the contributions to the field produced by Earth and Venus.
Mark values on the vertical axis of your graph.



(3)

(Total 8 marks)

6 (a) The weight w of an object on the Earth can be represented either as $w = mg$ or $w = \frac{GMm}{r^2}$.

(i) Explain the meaning of g and G in these equations.

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(3)

(ii) Use the equations above to show that $M = \frac{gr^2}{G}$.

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(1)

(iii) Calculate the mass of the Earth to a precision consistent with the data below.

mean radius of the Earth, = 6.4×10^6 m

$G = 6.7 \times 10^{-11}$ N m^2 kg^{-2}

$g = 9.8$ N kg^{-1}

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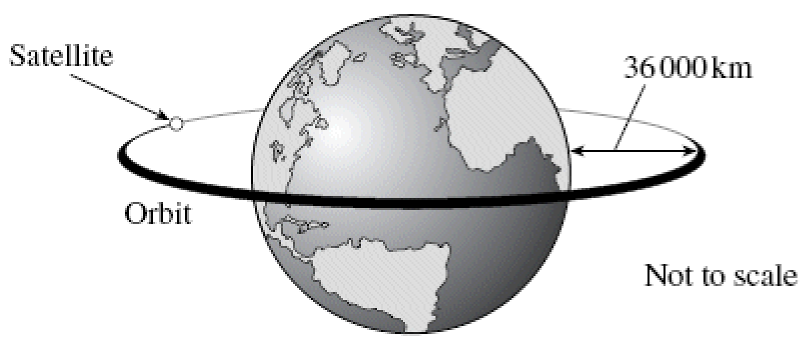
mass of the Earth ____________________ kg

(3)

(b) The figure below shows a satellite in a geostationary orbit around the Earth.



(i) State the time period for a geostationary satellite.

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(1)

(ii) The height of a geostationary satellite in orbit is approximately 36 000 km above the surface of the Earth.
Calculate the radius of a geostationary orbit.

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radius ______________________ m

(1)

(iii) Calculate the speed, in km s^{-1}, of a satellite in a geostationary orbit.

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speed ______________________ km s^{-1}

(3)

(iv) State a common use for a geostationary satellite.

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(1)

(v) Explain why a geostationary orbit is necessary for this use.

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(1)

(Total 14 marks)

7 The Rosetta space mission placed a robotic probe on Comet 67P in 2014.

(a) The total mass of the Rosetta spacecraft was 3050 kg. This included the robotic probe of mass 108 kg and 1720 kg of propellant. The propellant was used for changing velocity while travelling in deep space where the gravitational field strength is negligible.

Calculate the change in gravitational potential energy of the Rosetta spacecraft from launch until it was in deep space.
Give your answer to an appropriate number of significant figures.

Mass of the Earth = 6.0×10^{24} kg
Radius of the Earth = 6400 km

change in gravitational potential energy ____________________ J

(4)

(b) As it approached the comet, the speed of the Rosetta spacecraft was reduced to match that of the comet. This was done in stages using four 'thrusters'. These were fired simultaneously in the same direction.

Explain how the propellant produces the thrust.

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(3)

(c) Each thruster provided a constant thrust of 11 N.

Calculate the deceleration of the Rosetta spacecraft produced by the four thrusters when its mass was 1400 kg.

decleration ____________________ m s^{-2}

(1)

(d) Calculate the maximum change in speed that could be produced using the 1720 kg of propellants.

Assume that the speed of the exhaust gases produced by the propellant was 1200 m s^{-1}

maximum change in speed ____________________ m s^{-1}

(3)

(e) When the robotic probe landed, it had to be anchored to the comet due to the low gravitational force. Comet 67P has a mass of about 1.1×10^{13} kg. A possible landing site was about 2.0 km from the centre of mass.

(i) Calculate the gravitational force acting on the robotic probe when at a distance of 2.0 km from the centre of mass of the comet.

gravitational force ____________________ N

(3)

(ii) Calculate the escape velocity for an object 2.0 km from the centre of mass of the comet.

escape velocity ____________________ $m\ s^{-1}$

(3)

(iii) A scientist suggests using a drill to make a vertical hole in a rock on the surface of the comet. The anchoring would be removed from the robotic probe before the drill was used. The drill would exert a force of 25 N for 4.8 s.

Explain, with the aid of a calculation, whether this process would cause the robotic probe to escape from the comet.

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(3)

(Total 20 marks)

8 (a) (i) State what is meant by the term **escape velocity**.

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(1)

(ii) Show that the escape velocity, v, at the Earth's surface is given by $v = \sqrt{\frac{2GM}{R}}$

where M is the mass of the Earth
and R is the radius of the Earth.

(2)

(iii) The escape velocity at the Moon's surface is 2.37×10^{3} m s^{-1} and the radius of the Moon is 1.74×10^{6} m.

Determine the mean density of the Moon.

mean density ____________________ kg m^{-3}

(2)

(b) State **two** reasons why rockets launched from the Earth's surface do **not** need to achieve escape velocity to reach their orbit.

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(2)

(Total 7 marks)

9 (a) (i) Define gravitational field strength and state whether it is a scalar or vector quantity.

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(2)

(ii) A mass m is at a height h above the surface of a planet of mass M and radius R. The gravitational field strength at height h is g. By considering the gravitational force acting on mass m, derive an equation from Newton's law of gravitation to express g in terms of M, R, h and the gravitational constant G.

(2)

(b) (i) A satellite of mass 2520 kg is at a height of 1.39×10^7 m above the surface of the Earth. Calculate the gravitational force of the Earth attracting the satellite.
Give your answer to an appropriate number of significant figures.

force attracting satellite ____________________ N

(3)

(ii) The satellite in part (i) is in a circular polar orbit. Show that the satellite would travel around the Earth three times every 24 hours.

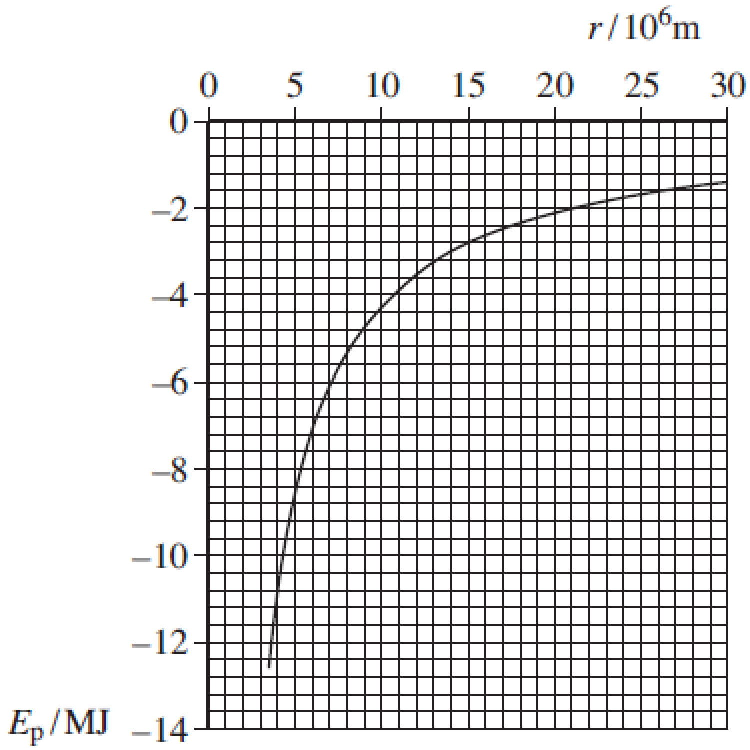
(5)

(c) State and explain **one** possible use for the satellite travelling in the orbit in part (ii).

(2)

(Total 14 marks)

10 The graph below shows how the gravitational potential energy, E_p, of a 1.0 kg mass varies with distance, r, from the centre of Mars. The graph is plotted for positions above the surface of Mars.



(a) Explain why the values of E_p are negative.

(2)

(b) Use data from the graph to determine the mass of Mars.

mass of Mars ____________________ kg

(3)

(c) Calculate the escape velocity for an object on the surface of Mars.

escape velocity ____________________ m s^{-1}

(3)

(d) Show that the graph data agree with $E_p \propto \frac{1}{r}$

(3)

(Total 11 marks)

11 (a) Explain why the mass of an object is constant but its weight may change.

(3)

(b) The table gives the gravitational potentials, V, at three different distances, r, from the centre of the Earth.

distance from centre of Earth r **/ km**	**gravitational potential** V **/** 10^7 **J kg**$^{-1}$
7500	–5.36
12500	–3.22
22500	–1.79

(i) Explain why the gravitational potential at a point in a gravitational field is negative.

(2)

(ii) Show that the data in the table are consistent with $V \propto r^{-1}$.

(3)

(iii) A satellite of mass 450 kg is moved from an orbit of radius 7500 km around the Earth to an orbit of radius 12 500 km.

Use data from the table to show that the potential energy of the satellite increases, by about 10 GJ.

(2)

(c) The kinetic energy of a 450 kg satellite orbiting the Earth with a radius of 7500 km is 12 GJ.

(i) Calculate the kinetic energy of the 450 kg satellite when it is in an orbit of radius 12 500 km.

mass of the Earth = 6.0×10^{24} kg

kinetic energy ______________________ GJ

(4)

(ii) Calculate the change in kinetic energy of the satellite when it moves into the higher orbit.

change in kinetic energy ______________________ GJ

(1)

(iii) Calculate the **total** energy that has to be supplied to move the 450 kg satellite from an orbit of radius 7500 km to an orbit of radius 12 500 km.

total energy ______________________ GJ

(1)

(Total 16 marks)

12 The Hubble space telescope was launched in 1990 into a circular orbit near to the Earth. It travels around the Earth once every 97 minutes.

(a) Calculate the angular speed of the Hubble telescope, stating an appropriate unit.

answer = ______________________

(3)

(b) (i) Calculate the radius of the orbit of the Hubble telescope.

answer = ______________________ m

(3)

(ii) The mass of the Hubble telescope is 1.1×10^4 kg. Calculate the magnitude of the centripetal force that acts on it.

answer = ______________________ N

(2)

(Total 8 marks)

13 (a) (i) State the relationship between the *gravitational potential energy*, E_p, and the *gravitational potential*, V, for a body of mass m placed in a gravitational field.

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(1)

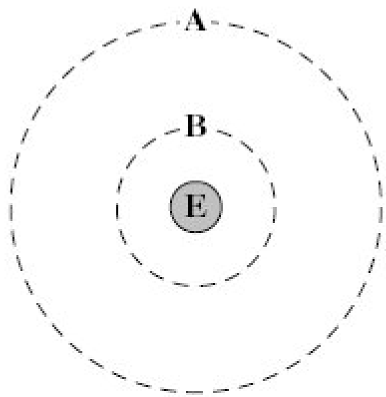
(ii) What is the effect, if any, on the values of E_p and V if the mass m is doubled?

value of E_p ____

value of V ____

(2)

(b)



The diagram above shows two of the orbits, **A** and **B**, that could be occupied by a satellite in circular orbit around the Earth, **E**.
The gravitational potential due to the Earth of each of these orbits is:

orbit **A** – 12.0 MJ kg^{-1}
orbit **B** – 36.0 MJ kg^{-1}.

(i) Calculate the radius, from the centre of the Earth, of orbit **A**.

answer = ______________________ m

(2)

(ii) Show that the radius of orbit **B** is approximately 1.1×10^4 km.

(1)

(iii) Calculate the centripetal acceleration of a satellite in orbit **B**.

answer = ____________________ m s^{-2}

(2)

(iv) Show that the gravitational potential energy of a 330 kg satellite decreases by about 8 GJ when it moves from orbit **A** to orbit **B**.

(1)

(c) Explain why it is not possible to use the equation $\Delta E_p = mg\Delta h$ when determining the change in the gravitational potential energy of a satellite as it moves between these orbits.

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(1)

(Total 10 marks)

14 (a) Explain what is meant by the *gravitational potential* at a point in a gravitational field.

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(2)

(b) Use the following data to calculate the gravitational potential at the surface of the Moon.

mass of Earth = 81 × mass of Moon
radius of Earth = 3.7 × radius of Moon
gravitational potential at surface of the Earth = –63 MJ kg^{-1}

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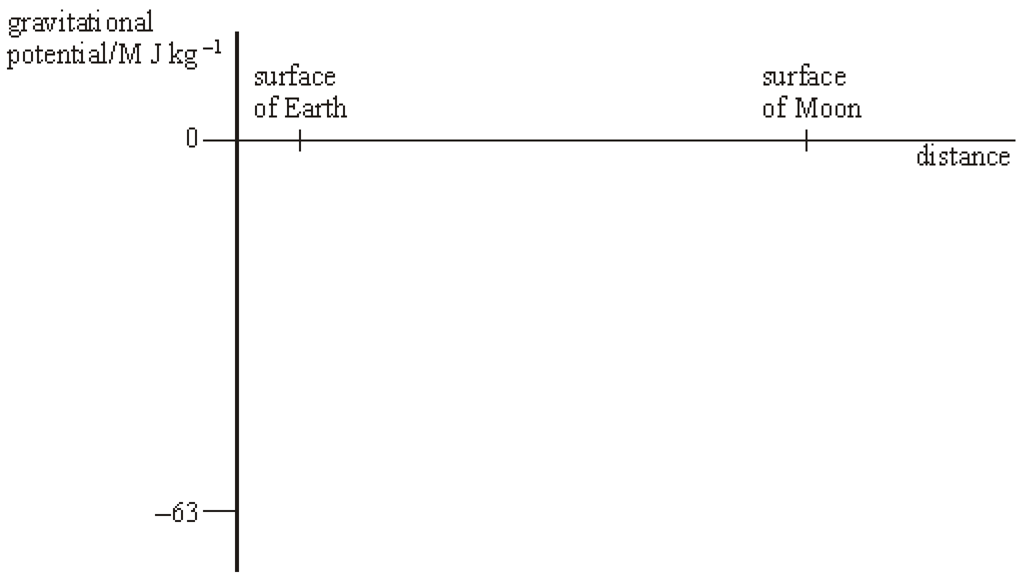
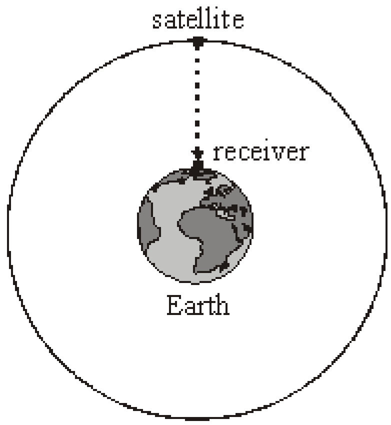
(3)

(c) Sketch a graph on the axes below to indicate how the gravitational potential varies with distance along a line outwards from the surface of the Earth to the surface of the Moon.



(3)
(Total 8 marks)

15 The Global Positioning System (GPS) is a system of satellites that transmit radio signals which can be used to locate the position of a receiver anywhere on Earth.



(a) A receiver at sea level detects a signal from a satellite in a circular orbit when it is passing directly overhead as shown in the diagram above.

(i) The microwave signal is received 68 ms after it was transmitted from the satellite. Calculate the height of the satellite.

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(ii) Show that the gravitational field strength of the Earth at the position of the satellite is 0.56 N kg^{-1}.

mass of the Earth = 6.0×10^{24} kg
mean radius of the Earth = 6400 km

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(4)

(b) For the satellite in this orbit, calculate

(i) its speed,

(ii) its time period.

(5)
(Total 9 marks)

16 Communications satellites are usually placed in a *geo-synchronous orbit*.

(a) State **two** features of a geo-synchronous orbit.

(2)

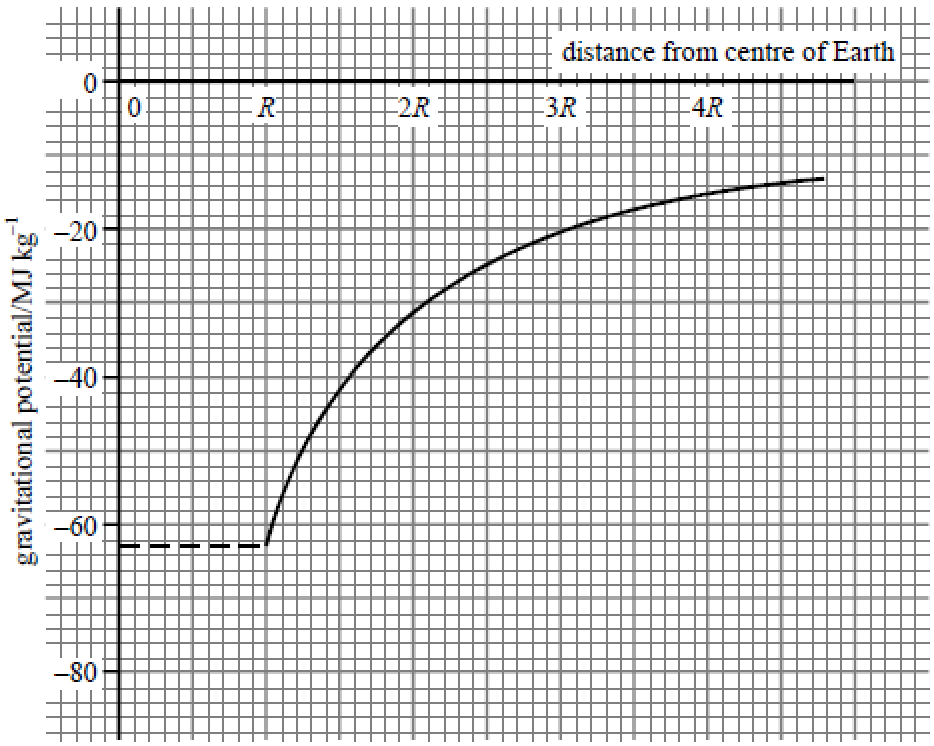
(b) Given that the mass of the Earth is 6.00×10^{24} kg and its mean radius is 6.40×10^{6} m,

(i) show that the radius of a geo-synchronous orbit must be 4.23×10^{7} m,

(ii) calculate the increase in potential energy of a satellite of mass 750 kg when it is raised from the Earth's surface into a geo-synchronous orbit.

(6)
(Total 8 marks)

17 (a) The graph shows how the gravitational potential varies with distance in the region above the surface of the Earth. R is the radius of the Earth, which is 6400 km. At the surface of the Earth, the gravitational potential is −62.5 MJ kg^{-1}.



Use the graph to calculate

(i) the gravitational potential at a distance $2R$ from the centre of the Earth,

(ii) the increase in the potential energy of a 1200 kg satellite when it is raised from the surface of the Earth into a circular orbit of radius $3R$.

(4)

(b) (i) Write down an equation which relates gravitational field strength and gravitational potential.

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(ii) **By use of the graph** in part (a), calculate the gravitational field strength at a distance $2R$ from the centre of the Earth.

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(iii) Show that your result for part (b)(ii) is consistent with the fact that the surface gravitational field strength is about 10 N kg^{-1}.

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(5)
(Total 9 marks)

18 (a) State, in words, Newton's law of gravitation.

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(2)

(b) Some of the earliest attempts to determine the gravitational constant, G, were regarded as experiments to "weigh" the Earth. By considering the gravitational force acting on a mass at the surface of the Earth, regarded as a sphere of radius R, show that the mass of the Earth is given by

$$M = \frac{gR^2}{G},$$

where g is the value of the gravitational field strength at the Earth's surface.

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(2)

(c) In the following calculation use these data.

radius of the Moon	$= 1.74 \times 10^6$ m
gravitational field strength at Moon's surface	$= 1.62$ N kg $^{-1}$
mass of the Earth M	$= 6.00 \times 10^{24}$ kg
gravitational constant G	$= 6.67 \times 10^{-11}$ N m^2 kg^{-2}

Calculate the mass of the Moon and express its mass as a percentage of the mass of the Earth.

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(3)
(Total 7 marks)

19 The gravitational field associated with a planet is radial, as shown in **Figure 1**, but near the surface it is effectively uniform, as shown in **Figure 2**.

Alongside each figure, sketch a graph to show how the gravitational potential V associated with the planet varies with distance r (measured outwards from the surface of the planet) in each of these cases.

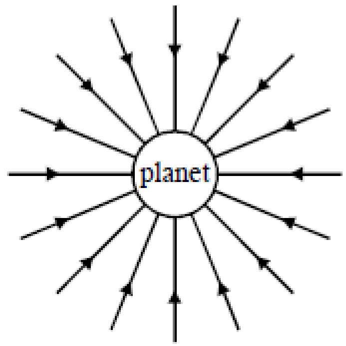

Figure 1

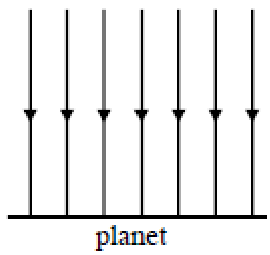

Figure 2

(Total 4 marks)

20 (a) (i) Explain what is meant by the *gravitational field strength* at a point in a gravitational field.

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(ii) State the SI unit of gravitational field strength.

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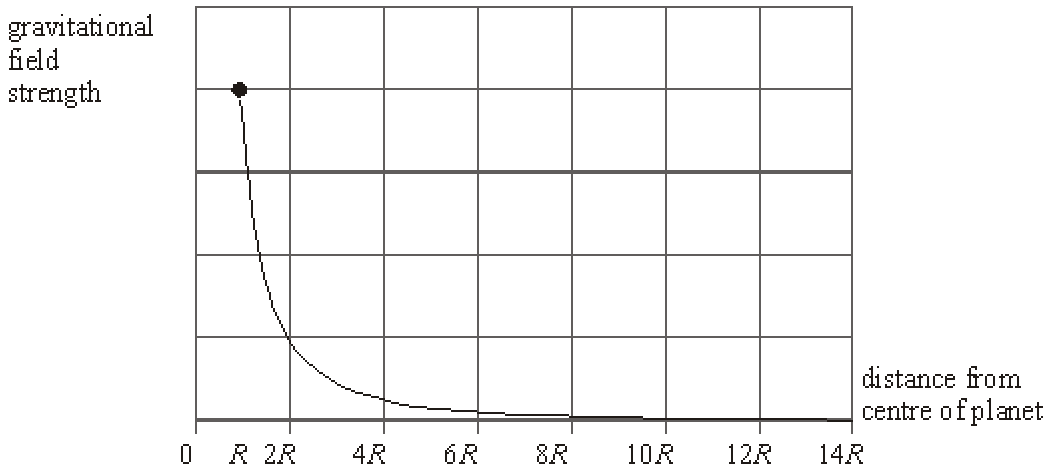
(2)

(b) Planet **P** has mass *M* and radius *R*. Planet **Q** has a radius 3*R*. The values of the gravitational field strengths at the surfaces of **P** and **Q** are the same.

(i) Determine the mass of **Q** in terms of *M.*

(ii) The figure below shows how the gravitational field strength above the surface of planet **P** varies with distance from its centre. Draw on the diagram the variation of the gravitational field strength above the surface of **Q** over the range shown.



(6)

(Total 8 marks)

21 (a) Define *gravitational field strength* at a point in a gravitational field.

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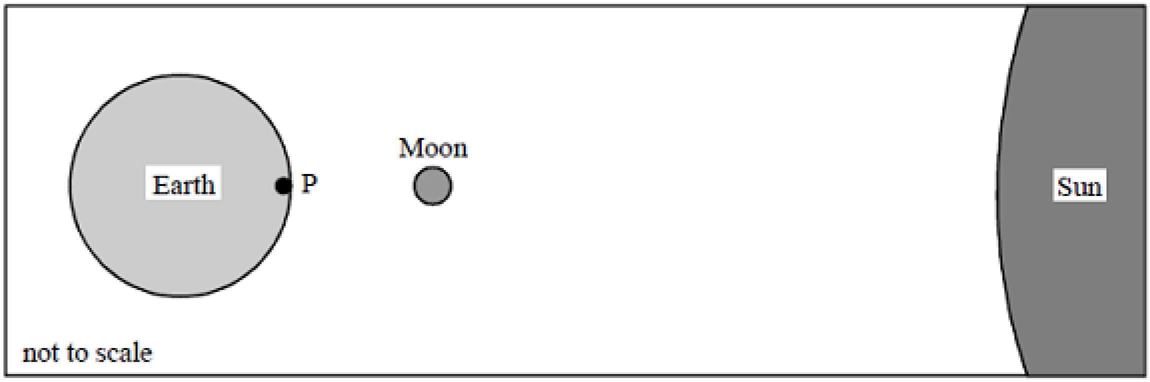
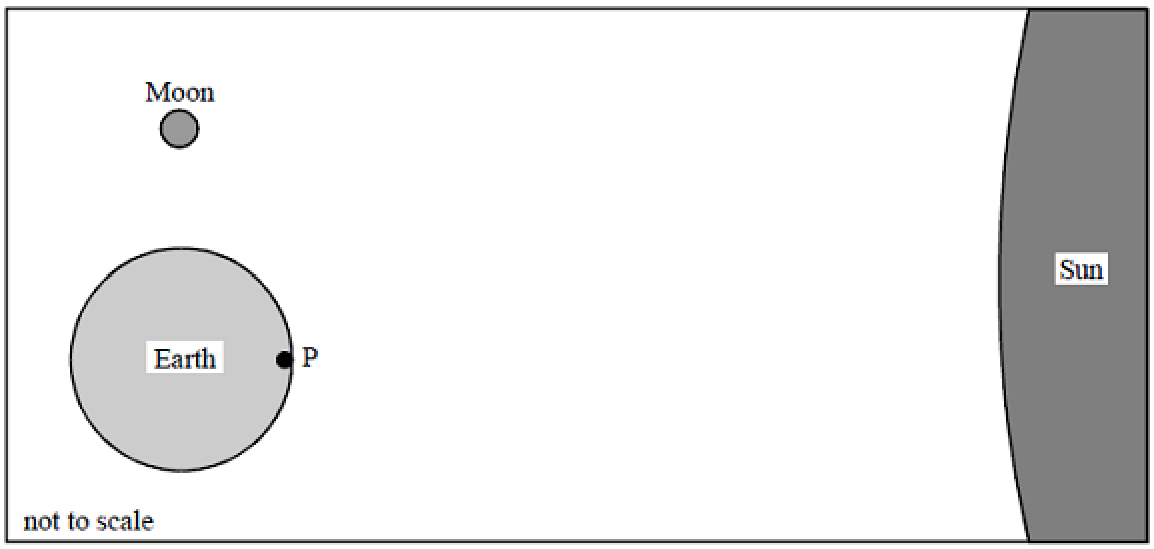
(1)

(b) Tides vary in height with the relative positions of the Earth, the Sun and the moon which change as the Earth and the Moon move in their orbits. Two possible configurations are shown in **Figure 1**.



Configuration A



Configuration B

Figure 1

Consider a 1 kg mass of sea water at position **P**. This mass experiences forces F_E, F_M and F_S due to its position in the gravitational fields of the Earth, the Moon and the Sun respectively.

(i) Draw labelled arrows on **both** diagrams in **Figure 1** to indicate the three forces experienced by the mass of sea water at **P**.

(3)

(ii) State and explain which configuration, **A** or **B**, of the Sun, the Moon and the Earth will produce the higher tide at position **P**.

(2)

(c) Calculate the magnitude of the gravitational force experienced by 1 kg of sea water on the Earth's surface at **P**, due to the **Sun**'s gravitational field.

radius of the Earth's orbit = 1.5×10^{11} m

mass of the Sun = 2.0×10^{30} kg

universal gravitational constant, G = 6.7×10^{-11} Nm^2 kg^{-2}

(3)

(Total 9 marks)

22 (a) (i) Explain what is meant by *gravitational field strength*.

(1)

(ii) Describe how you would measure the gravitational field strength close to the surface of the Earth. Draw a diagram of the apparatus that you would use.

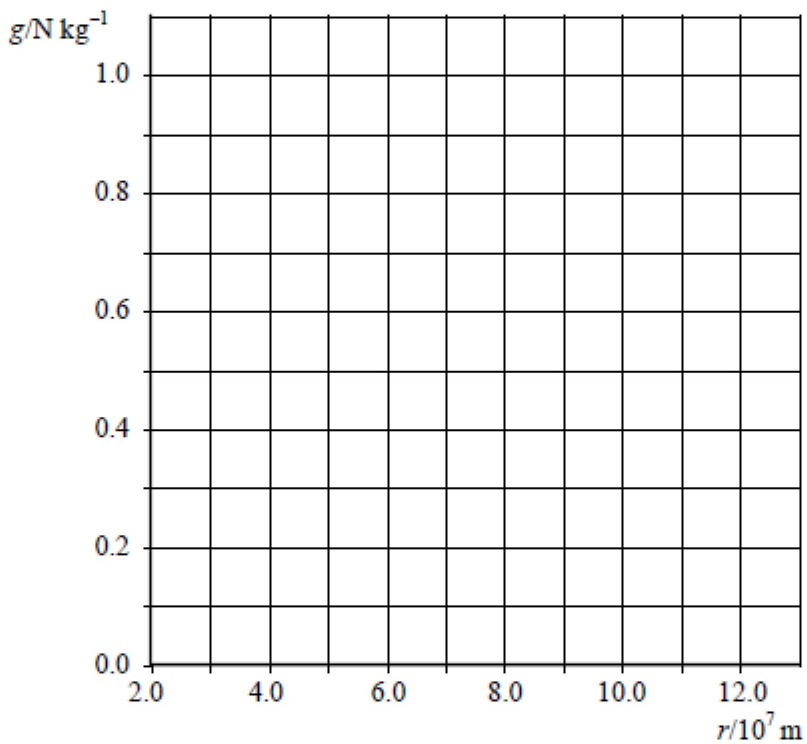
(6)

(b) (i) The Earth's gravitational field strength (g) at a distance (r) of 2.0×10^7 m from its centre is 1.0 N kg^{-1}. Complete the table with the 3 further values of g.

g/N kg^{-1}	1.0			
r/10^7 m	2.0	4.0	6.0	8.0

(2)

(ii) Below is a grid marked with g and r values on its axes. Draw a graph showing the variation of g with r for values of r between 2.0×10^7 m and 10.0×10^7 m.



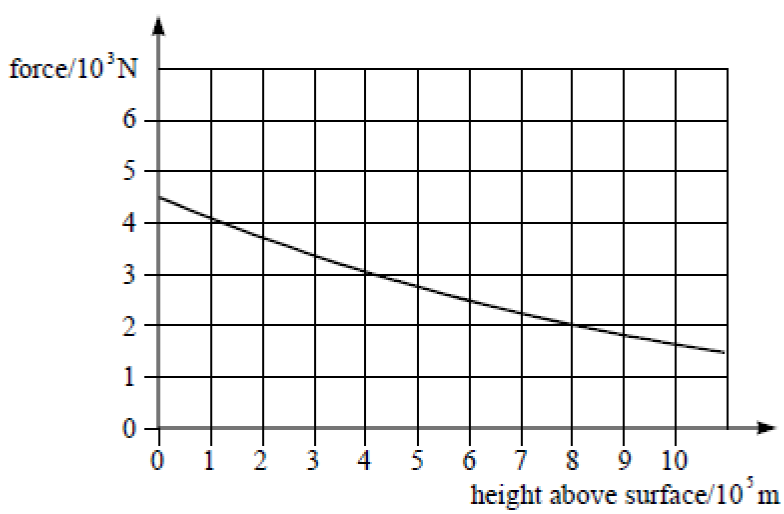
(2)

(iii) Estimate the energy required to raise a satellite of mass 800 kg from an orbit of radius 4.0×10^7 m to one of radius 10.0×10^7 m.

(3)

(Total 14 marks)

23 A lunar landing module and its parent craft are orbiting the Moon at a height above the surface of 6.0×10^5 m. The mass of the lunar module is 2.7×10^3 kg. The graph below shows the variation of the gravitational force on the module with height above the surface of the Moon.



(a) (i) Using data from the graph, find the gravitational force on the lunar module and hence find its speed when its orbital height is 6.0×10^5 m.

(3)

(ii) Using data from the graph, find the change in gravitational potential energy of the lunar module as it descends from its orbit to the surface of the Moon.

(3)

(b) The descent of the lunar module is controlled by a set of rockets. Describe how you would use the data which you have already calculated to determine the minimum fuel load which would enable the lunar module to land on the surface of the Moon and subsequently to rejoin its parent craft in orbit. State what additional information you would need to know.

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(3)

(Total 9 marks)

24 (a) State the factors that affect the gravitational field strength at the surface of a planet.

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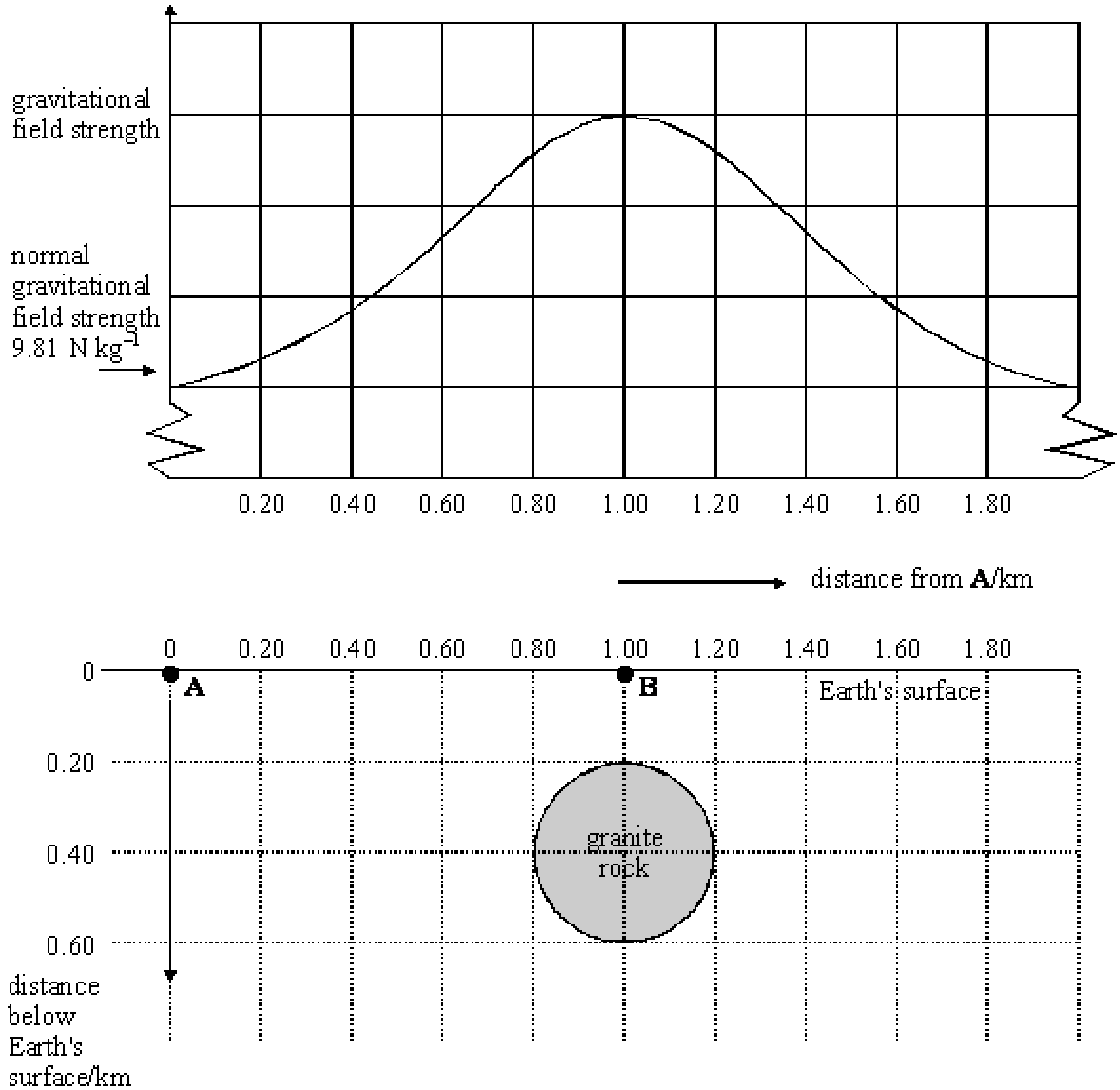
(2)

(b) The diagram below shows the variation, called an anomaly, of gravitational field strength at the Earth's surface in a region where there is a large spherical granite rock buried in the Earth's crust.



The density of the granite rock is 3700 kg m^{-3} and the mean density of the surrounding material is 2200 kg m^{-3}.

(i) Show that the difference between the mass of the granite rock and the mass of an equivalent volume of the surrounding material is 5.0×10^{10} kg.

(4)

(ii) The universal gravitational constant $G = 6.7 \times 10^{-11}$ N m^2 kg^{-2}. Calculate the difference between the gravitational field strength at **B** and that at point **A** on the Earth's surface that is a long way from the granite rock.

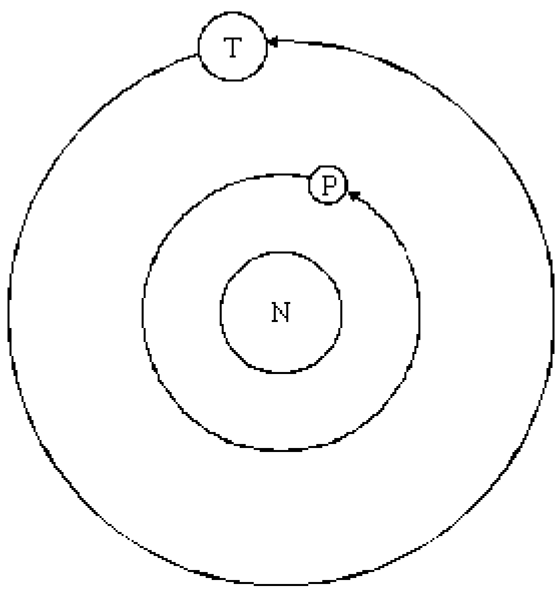
(4)

(iii) Add to the diagram above a graph to show how the variation in gravitational field strength would change if the granite rock were buried deeper in the Earth's crust.

(1)

(Total 11 marks)

25 The diagram below (not to scale) shows the planet Neptune (N) with its two largest moons, Triton (**T**) and Proteus (**P**). Triton has an orbital radius of 3.55×10^8 m and that of Proteus is 1.18×10^8 m. The orbits are assumed to be circular.



(a) Explain why the velocity of each moon varies whilst its orbital speed remains constant.

___

___

(1)

(b) Write down an equation that shows how Neptune's gravitational attraction provides the centripetal force required to hold Triton in its orbit. Hence show that it is unnecessary to know the mass of Triton in order to find its angular speed.

(3)

(c) Show that $\frac{\text{the orbital period of Triton}}{\text{the orbital period of Proteus}}$ is approximately 5.2.

(4)
(Total 8 marks)

Mark schemes

1 (a)

________	N kg^{-1}	electric field strength	N C^{-1} or V m^{-1}	**(1)**
gravitational constant	N m^2 kg^{-2}	________	________	**(1)**
mass	kg	charge	C	**(1)**
distance (from mass to point)	m	distance (from charge to point)	m	**(1)**

(4)

(b) (i) none **(1)**

both F_E and $F_G \propto \frac{1}{r^2}$ (hence both reduced to $\frac{1}{4}$ [affected equally] **(1)**

(ii) charge on B must be doubled **(1)**

(3)

[7]

2 (a) force of attraction between two point masses (or particles) **(1)**

proportional to product of masses **(1)**

inversely proportional to square of distance between them **(1)**

[**alternatively**

quoting an equation, $F = \frac{GM_1M_2}{r^2}$ with all terms defined **(1)**

reference to point masses (or particles) **or** *r* is distance between centres **(1)**

F identified as an attractive force **(1)**]

max 2

(b) (i) mass of larger sphere M_L (= $\frac{4}{3}\pi r^3 \rho$) = $\frac{4}{3}$ π × $(0.100)^3$ × 11.3 × 10^3 **(1)**

= 47(.3) (kg) **(1)**

[**alternatively**

use of M µ r^3 gives $\frac{M_L}{0.74} = \left(\frac{100}{25}\right)^3$ **(1)** (= 64)

and M_L = 64 × 0.74 = 47(.4) (kg) **(1)**]

2

(ii) gravitational force F $\left(= \frac{GM_L M_S}{x^2}\right) = \frac{6.67 \times 10^{-11} \times 47.3 \times 0.74}{0.125^2}$ **(1)**

= 1.5 × 10^{-7} (N) **(1)**

2

(c) for the spheres, mass µ volume (or µ r^3, or $M = \frac{4}{3}\pi r^3 \rho$) **(1)**

mass of either sphere would be 8 × greater (378 kg, 5.91 kg) **(1)**

this would make the force 64 × greater **(1)**

but separation would be doubled causing force to be 4 × smaller **(1)**

net effect would be to make the force (64/4) = 16 × greater **(1)**
(ie 2.38 × 10^{-6} N)

max 4

[10]

3 (a) Idea that both astronaut and vehicle are travelling at same (orbital) speed or have the same (centripetal) acceleration / are in freefall

Not falling at the same speed

B1

No (normal) reaction (between astronaut and vehicle)

B1

2

(b) (i) Equates centripetal force with gravitational force using appropriate formulae

E.g. $\frac{GMm}{r^2} = \frac{mv^2}{r}$ or $mr\omega^2$

B1

Correct substitution seen e.g. $v^2 = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{\text{any value of radius}}$

B1

(Radius of) 7.28×10^6 seen or $6.38 \times 10^6 + 0.9 \times 10^6$

B1

7396 (m s^{-1}) to at least 4 sf
Or $v^2 = 5.47 \times 10^7$ seen

B1

4

(ii) $\Delta PE = 6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1.68 \times 10^{4} (1 / (7.28 \times 10^{6}) - 1 / (6.78 \times 10^{6}))$

C1

-6.8×10^{10} J

C1

$\Delta KE = 0.5 \times 1.68 \times 10^{4} \times (7700^2 - 7400^2) = 3.81 \times 10^{10}$ J

C1

$\Delta KE - \Delta PE = (-)\ 2.99 \times 10^{10}$ (J)

A1

OR

Total energy in original orbit shown to be (−)$GMm / 2r$
or $mv^2 / 2 - GMm / r$

C1

Initial energy
$= -6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1.68 \times 10^{4} / (2 \times 7.28 \times 10^{6})$
$= 4.59 \times 10^{11}$

C1

Final energy
$= -6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1.68 \times 10^{4} / (2 \times 6.78 \times 10^{6})$
$= 4.93 \times 10^{11}$

3.4×10^{10}(J)

Condone power of 10 error for C marks

A1

4

[10]

4 (a) attractive **force** between point masses **(1)**
proportional to (product of) the masses **(1)**
inversely proportional to square of separation/distance apart **(1)**

3

(b) $m\omega^2 R = (-)\frac{GMm}{R^2}\left(\text{or} = \frac{mv^2}{R}\right)$ **(1)**

(use of $T = \frac{2\pi}{\omega}$ gives) $\frac{4\pi^2}{T^2} = \frac{GM}{R^3}$ **(1)**

G and M are constants, hence $T^2 \propto R^3$ **(1)**

3

(c) (i) (use of $T^2 \propto R^3$ gives) $\frac{365^2}{(1.50 \times 10^{11})^3} = \frac{T_m^2}{(5.79 \times 10^{10})^3}$ **(1)**

T_m = 87(.5) days **(1)**

(ii) $\frac{1^2}{(1.50 \times 10^{11})^3} = \frac{165^2}{R_N^3}$ **(1)** (gives $R_N = 4.52 \times 10^{12}$ m)

ratio = $\frac{4.51 \times 10^{12}}{1.50 \times 10^{11}}$ = 30(.1) **(1)**

4

[10]

5 (a) (i) $M = \frac{4}{3}\pi R^3 \rho$ ✓

combined with $g_s = \frac{GM}{R^2}$ (gives $g_s = \frac{4}{3}\pi G R \rho$) ✓

Do not allow r instead of R in final answer but condone in early stages of working.

Evidence of combination, eg cancelling R^2 required for second mark.

2

(ii) $R = \left(\frac{3g_s}{4\pi G\rho}\right) = \frac{3 \times 8.87}{4\pi 6.67 \times 10^{-11} \times 5.24 \times 10^3}$ ✓

gives $R = 6.06 \times 10^6$ (m) ✓

answer to **3SF** ✓

SF mark is independent but may only be awarded after some working is presented.

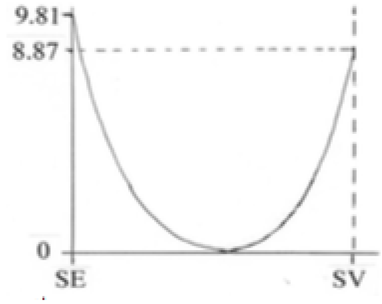
3

(b) line starts at 9.81 and ends at 8.87 ✓

correct shape curve which falls and rises ✓

falls to zeo value near centre of and to right of centre of distance scale ✓

[*Minimum of graph in 3rd point to be >0.5 and <0.75 SE-SV distance]*



For 3rd mark accept flatter curve than the above in central region.

3

[8]

6 (a) (i) *g* gravitational field strength, *G* gravitational constant

C1

g force on 1 kg (on or close to) Earth's surface

A1

G universal constant relating attraction of any two masses to their separation/constant in Newton's law of gravitation

A1

3

(ii) equates *w* and cancels *m*

B1

1

(iii) substitutes values into equation

B1

correct calculation 5.99×10^{24}

C1

answer to two significant figures 6.0×10^{24} (kg)

A1

3

(b) (i) 1 day/24 hours/86400 (s)

B1

1

(ii) 4.24×10^7 (m)

B1

1

(iii) $v = 2\pi r/T$ or equivalent

C1

conversion of period to seconds (allow in (b)(i))

C1

3.08 (cao)

A1

3

(iv) communication/specific example of communication (eg satellite TV/weather)

B1

1

(v) avoids dish having to track/stationary **footprint**

B1

1

[14]

7 (a) Total mass of spacecraft = 3050 kg

Change in PE = $\frac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times 3050}{6400 \times 10^{3}}$

1.9×10^{11}(J)

2 sf

condone errors in powers of 10 and incorrect mass for payload

Allow if some sensible working

4

(b) Chemical combustion of propellant / fuel or gases produced at high pressure

Gas is expelled / expands through nozzle

Change in momentum of gases escaping

equal and opposite change in momentum of the spacecraft

Thrust = rate of change of change in momentum

Max 3

N3 in terms of forces worth 1

3

(c) 0.031(4) (m s^{-2})

1

(d) Use of rocket equation

$v = 1200 \ln \frac{3050}{1330}$

996 (m s^{-1})

Condone 1000 (m s^{-1})

3

(e) (i) Use of correct mass 108 kg

$$F = \frac{6.67 \times 10^{-11} \times 1.1 \times 10^{13} \times 108}{(2 \times 10^3)^2}$$

0.0198 N

Allow incorrect powers of 10 and mass

3

(ii) Use of $v = \sqrt{\frac{2GM}{r}}$

Correct substitution $v = \frac{2 \times 6.67 \times 10^{-11} \times 1.1 \times 10^{18}}{2 \times 10^8}$

0.86 (m s^{-1})

Recognisable mass – condone incorrect power of 10

3

(iii) Impulse = 25 N × 4.8 = 120 N s

(120 = 108 v so) Velocity = 1.1 m s^{-1}

Clear conclusion

ie explanation/comparison of calculated velocity with escape velocity from **(e)(ii)**

May use F = ma approach

3

[20]

8 (a) (i) (Minimum) Speed (given at the Earth's surface) that will allow an object to leave / escape the (Earth's) gravitational field (with no further energy input)

Not gravity

Condone gravitational pull / attraction

B1

1

(ii) $\frac{1}{2} mv^2 = \frac{GMm}{r}$

B1

Evidence of correct manipulation

At least one other step before answer

B1

2

(iii) Substitutes data and obtains $M = 7.33 \times 10^{22}$(kg)

or

Volume = $(1.33 \times 3.14 \times (1.74 \times 10^6)^3$ or 2.2×10^{19}

or $\rho = \frac{3v^2}{8\pi G r^2}$

C1

3300 (kg m^{-3})

A1

2

(b) (Not given all their KE at Earth's surface) energy continually added in flight / continuous thrust provided / can use fuel (continuously)

B1

Less energy needed to achieve orbit than to escape from Earth's gravitational field / it is not leaving the gravitational field

B1

2

[7]

9 (a) (i) force per unit mass ✓

a vector quantity ✓

Accept force on 1 kg (or a unit mass).

2

(ii) force on body of mass *m* is given by $F = \frac{GMm}{(R+h)^2}$ ✓

gravitational field strength $g\left(= \frac{F}{m}\right) = \frac{GM}{(R+h)^2}$ ✓

For both marks to be awarded, correct symbols must be used for M and m.

2

(b) (i) $F\left(= \frac{GMm}{(R+h)^2}\right) = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times 2520}{\left((6.37 \times 10^{6}) + (1.39 \times 10^{7})\right)^2}$ ✓

= 2.45×10^3 (N) ✓ to **3SF** ✓

1st mark: all substituted numbers must be to at least 3SF.
If 1.39×10^7 is used as the complete denominator, treat as AE with ECF available.
3rd mark: ***SF mark is independent.***

3

(ii) $F = m\omega^2 (R + h)$ gives $\omega^2 = \frac{2450}{2520 \times 2.03 \times 10^7}$ ✓

from which $\omega = 2.19 \times 10^{-4}$ (rad s^{-1}) ✓

time period $T\left(= \frac{2\pi}{\omega}\right) = \frac{2\pi}{2.19 \times 10^{-4}}$ **or** = 2.87 ✓ 10^4 s ✓

[**or** $F = \frac{mv^2}{R+h}$ gives $v^2 = \frac{2.45 \times 10^3 \times ((6.37 \times 10^6) + (13.9 \times 10^6))}{2520}$ ✓

from which v = 4.40 ✓ 10^3 (m s–1) ✓

time period $T\left(= \frac{2\pi(R+h)}{v}\right) = \frac{2\pi \times 2.03 \times 10^7}{4.40 \times 10^3}$ **or** = 2.87 × 10^4 s ✓]

[**or** $T^2 = \frac{4\pi^2 (R+h)^3}{GM}$ ✓

$= \frac{4\pi^2 ((6.37 \times 10^6) + (13.9 \times 10^6))^3}{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}$ ✓

gives time period T = 2.87 × 10^4s ✓]

$= \frac{2.87 \times 10^4}{3600}$ = 7.97 (hours) ✓

number of transits in 1 day = $\frac{24}{7.97}$ = 3.01 (≈ 3) ✓

Allow ECF from wrong F value in (i) but mark to max 4 (because final answer won't agree with value to be shown).

First 3 marks are for determining time period (or frequency). Last 2 marks are for relating this to the number of transits.

Determination of f = 3.46 × 10^{-5} (s^{-1}) is equivalent to finding T by any of the methods.

5

(c) acceptable use ✓

satisfactory explanation ✓

e.g. monitoring weather **or** surveillance:

whole Earth may be scanned **or** Earth rotates under orbit

or information can be updated regularly

or communications: limited by intermittent contact

or gps: several satellites needed to fix position on Earth

Any reference to equatorial satellite should be awarded 0 marks.

2

[14]

10 (a) zero potential at infinity (a long way away)

B1

energy input needed to move to infinity (from the point)
work done by the field moving object from infinity
potential energy falls as object moves from infinity

B1

2

(b) Any pair of coordinates read correctly

C1

±1/2 square

Use of E_p or $V = (-)\dfrac{GM}{r}$

C1

Rearrange for M

6.4 (±0.5) × 10^{23} kg

A1

3

(c) Reads correct potential at surface of Mars = −12.6 (MJ)

C1

or reads radius of mars correctly (3.5 × 10^{6})

equates to ½ v^2 (condone power of 10 in MJ)

C1

use of v = √(2GM/r) with wrong radius

5000 ± *20* m s^{-1} (condone 1sf e.g. 5 km s^{-1})

A1

e.c.f. value of M from (b) may be outside range for other method 6.2 × 10^{-9}x √their M

3

(d) Attempts 1 calculation of *Vr*

B1

Many values give 4.2.... so allow mark is for reading and using correct coordinates but allow minor differences in readings
Ignore powers of 10 but consistent

Two correct calculation of *Vr*

B1

Three correct calculations with conclusion

B1

3

[11]

11 (a) mass depends only on the amount of matter present owtte

B1

weight is force between body and Earth/depends on *g/mg/* gravitational field strength or answers in terms of Newton's gravitational law

B1

g (etc) varies at different points on and above the Earth or is different on different planets etc

B1

3

(b) (i) reference is ‘infinity’ where potential is 0

B1

energy has to be put in/work has to be done to move mass to infinity or a bodies energy/PE decreases as a body moves from infinity towards the Earth

B1

2

(ii) need to show *Vr* to be constant, clear from algebra or final statement

B1

two sets of data used correctly

B1

all three sets of data used correctly (4.02, 4.025, 4.028)

B1

3

(iii) energy change per kg = $(5.36 - 3.22) \times 10^7$ (J)

B1

total change = 963 (960) $\times 10^7$ J

B1

2

(c) (i) $GMm/r^2 = mv^2/r$ or $v = \sqrt{(GM/r)}$

C1

$v^2 = 3.2 \times 10^7 m^2 s^{-2}$ or $v = 5670$ ms^{-1}

C1

use of KE = ½ mv^2 using their v

C1

7.2 GJ

A1

4

(ii) KE changes by 4.8 GJ (allow ecf, 12 – their ci)

B1

1

(iii) total energy (supplied) = (4.8) GJ (cnao)

(allow 5.2 GJ using 10 GJ for change in E_p)
(allow variations due to rounding off if physics is correct in previous parts)

B1

1

[16]

12 (a) $\omega \left(= \frac{2\pi}{T}\right) = \frac{2\pi}{97 \times 60}$ [or $\omega\left(= \frac{360}{T}\right) = \frac{360}{97 \times 60}$]

$= 1.1 \times 10^{-3}$ (1.08×10^{-3}) **(1)** [$= 6.2$ (6.19) $\times 10^{-2}$]

rad s^{-1} [accept s^{-1}] **(1)** [degree s^{-1}]

3

(b) (i) $\frac{GMm}{r^2} = m\omega^2 r$ **or** $r^3 = \frac{GM}{\omega^2}$ **(1)**

gives $r^3 = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(1.08 \times 10^{-3})^2}$ **(1)**

$\therefore r = 6.99 \times 10^6$ (m) **(1)**

3

(ii) $F\ (= m\omega^2 r) = 1.1 \times 10^4 \times (1.08 \times 10^{-3})^2 \times 6.99 \times 10^6$ **(1)**

$= 9.0 \times 10^4\ (8.97 \times 10^4)$ (N) **(1)**

[**or** $F\left(= \frac{GMm}{r^2}\right) = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times 1.1 \times 10^4}{(6.99 \times 10^6)^2}$ **(1)**

$= 9.0 \times 10^4\ (8.98 \times 10^4)$ (N) **(1)**]

2

[8]

13 (a) (i) relationship between them is $E_p = mV$ (allow $\Delta E_p = m\Delta V$) [or V is energy per unit mass (or per kg)] **(1)**

1

(ii) value of E_p is doubled **(1)**

value of V is unchanged **(1)**

2

(b) (i) use of $V = -\frac{GM}{r}$ gives $r_A = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{12.0 \times 10^6}$ **(1)**

$= 3.3(2) \times 10^7$ (m) **(1)**

2

(ii) since $V \propto (-)\frac{1}{r}\left(\text{or } \frac{r_A}{r_B} = \frac{v_B}{v_A} = \frac{36.0}{12.0} = 3\right) r_B = \frac{3.32 \times 10^7 \text{ m}}{3}$ **(1)**

(which is ≈ 1.1×10^4 km)

1

(iii) centripetal acceleration $g_B = \frac{GM}{{r_B}^2} = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(1.11 \times 10^7)^2}$ **(1)**

[allow use of 1.1×10^7 m from (b)(ii)]

$= 3.2$ (m s^{-2}) **(1)**

[**alternatively**, since $g_B = (-)\frac{v_B}{v_a}, g_B = \frac{36.0 \times 10^6}{1.11 \times 10^7}$ **(1)**

$= 3.2$ (m s^{-2}) **(1)**]

2

(iv) use of $\Delta E_p = m\Delta V$ gives $\Delta E_p = 330 \times (-12.0 - (-36.0)) \times 10^6$ **(1)**

(which is 7.9×10^9 J or ≈ 8 GJ)

1

(c) g is not constant over the distance involved

(**or** g decreases as height increases
or work done per metre decreases as height increases
or field is radial and/or not uniform) **(1)**

1

[10]

14 (a) work done/energy change (against the field) per unit mass **(1)**
when moved from infinity to the point **(1)**

2

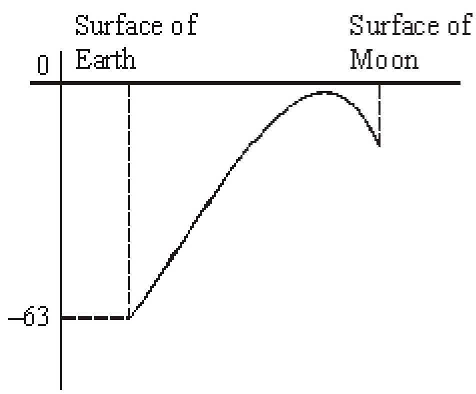
(b) $V_E = -\frac{GM_E}{R_E}$ and $V_M = -\frac{GM_M}{R_M}$ **(1)**

$V_M = -G \times \frac{M_E}{81} \times \frac{3.7}{R_E} = \frac{3.7}{81} V_E$ **(1)**

$= 4.57 \times 10^{-2} \times (-63) = -2.9$ MJ kg^{-1} **(1)** (2.88 MJ kg^{-1})

3

(c)



limiting values ($-63, -V_M$) on correctly curving line **(1)**
rises to value close to but below zero **(1)**
falls to Moon **(1)**
from point much closer to M than E **(1)**

max 3

[8]

15 (a) (i) h (= ct) (= $3.0 \times 10^8 \times 68 \times 10^{-3}$) = $2.0(4) \times 10^7$ m **(1)**

(ii) $g = (-)\frac{GM}{r^2}$ **(1)**

r (= $6.4 \times 10^6 + 2.04 \times 10^7$) = 2.68×10^7 (m) **(1)**
(allow C.E. for value of h from (i) for first two marks, but not 3rd)

$g = \frac{6.67 \times 10^{-11} \times 6.0 \times 10^{24}}{(2.68 \times 10^7)^2}$ **(1)** (= 0.56 N kg^{-1})

4

(b) (i) $g = \frac{v^2}{r}$ **(1)**

$v = [0.56 \times (2.68 \times 10^7)]^{½}$ **(1)**

$= 3.9 \times 10^3$ m s^{-1} **(1)** (3.87×10^3 m s^{-1})

(allow C.E. for value of *r* from a**(ii)**

[or $v^2 = \frac{GM}{r}$ = **(1)**

$v = \left(\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{2.68 \times 10^7}\right)^{1/2}$ **(1)**

$= 3.9 \times 10^3$ m s^{-1} **(1)**]

(ii) $T\left(= \frac{2\pi r}{v}\right) = \frac{2\pi \times 2.68 \times 10^7}{3.87 \times 10^3}$ **(1)**

$= 4.3(5) \times 10^4$s **(1)** (12.**(1)** hours)
(use of $v = 3.9 \times 10^3$ gives $T = 4.3$**(1)** $\times 10^4$ s = 12.0 hours)
(allow C.E. for value of *v* from (I)

[alternative for (b):

(i) $v\left(\frac{2\pi r}{T}\right) = \frac{2\pi \times 2.68 \times 10^7}{4.36 \times 10^4}$ **(1)**

$= 3.8(6) \times 10^3$ m s^{-1} **(1)**]

(allow C.E. for value of *r* from (a)(ii) and value of *T*)

(ii) $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$ **(1)**

$\left(= \frac{4\pi^2}{6.67 \times 10^{-11} \times 6.0 \times 10^{24}} \times (2.68 \times 10^7)^3\right) = (1.90 \times 10^9$ **(**s^2**) (1)**

$T = 4.3(6) \times 10^4$ s **(1)**

5

[9]

16 (a) period = 24 hours or equals period of Earth's rotation **(1)**
remains in fixed position relative to surface of Earth **(1)**
equatorial orbit **(1)**
same angular speed as Earth or equatorial surface **(1)**

max 2

(b) (i) $\frac{GMm}{r^2} = m\omega^2 r$ **(1)**

$T = \frac{2\pi}{\omega}$ **(1)**

$r\left(= \frac{GMT^2}{4\pi^2}\right)^{1/3} = \left(\frac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times (24 \times 3600)^2}{4\pi^2}\right)^{1/3}$ **(1)**

(gives $r = 42.3 \times 10^3$ km)

(ii) $\Delta V = GM\left(\frac{1}{R} - \frac{1}{r}\right)$ **(1)**

$= 6.67 \times 10^{-11} \times 6 \times 10^{24} \times \left(\frac{1}{6.4 \times 10^6} - \frac{1}{4.23 \times 10^7}\right)$

$= 5.31 \times 10^7$ (J kg^{-1}) **(1)**

$\Delta E_p = m\Delta V$ (= 750 × 5.31 × 10^7) = 3.98 × 10^{10} J **(1)**

(allow C.E. for value of ΔV)

[alternatives:

calculation of $\frac{GM}{R}$ (6.25 × 10^7) or $\frac{GM}{r}$ (9.46 × 10^6) **(1)**

or calculation of $\frac{GMm}{R}$ (4.69 × 10^{10}) or $\frac{GMm}{r}$ (7.10× 10^9) **(1)**

calculation of both potential energy values **(1)**
subtraction of values or use of $m\Delta V$ with correct answer **(1)**]

6

[8]

17 (a) (i) –31 MJ kg^{-1} **(1)**

(ii) increase in potential energy = $m\Delta V$ **(1)**
= 1200 × (62 – 21) × 10^6 **(1)**
= 4.9 × 10^{10} J **(1)**

(4)

(b) (i) $g = -\frac{\Delta V}{\Delta x}$ **(1)**

(ii) g is the gradient of the graph = $\frac{62.5 \times 10^6}{4 \times 6.4 \times 10^6}$ **(1)**

$= 2.44 \text{ N kg}^{-1}$ **(1)**

(iii) $g \propto \frac{1}{R^2}$ and R is doubled **(1)**

expect g to be $\frac{9.81}{4}$ $= 2.45 \text{ N kg}^{-1}$ **(1)**

[*alternative (iii)*

$g \propto \frac{1}{R^2}$ and R is halved **(1)**

expect g to be $2.44 \times 4 = 9.76 \text{ N kg}^{-1}$ **(1)**]

(5)

[9]

18 (a) attractive force between two particles (or point masses) **(1)**
proportional to product of masses and inversely proportional to square of separation [or distance] **(1)**

2

(b) (for mass, m, at Earth's surface) $mg = \frac{GMm}{R^2}$ **(1)**

rearrangement gives result **(1)**

2

(c) $M_{\text{moon}} \left(= \frac{gR^2}{G} \right) = \frac{1.62 \times (1.74 \times 10^6)^2}{6.62 \times 10^{24}}$ **(1)**

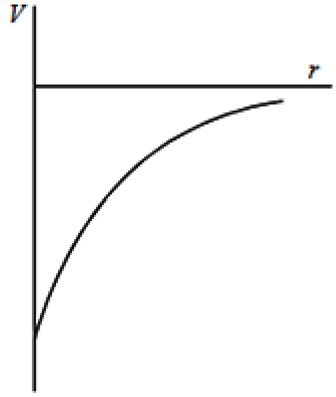
$= 7.35 \times 10^{22}$ kg **(1)**

$\frac{M_{\text{moon}}}{M_{\text{earth}}} = \frac{7.35 \times 10^{22}}{6.00 \times 10^{24}}$ (= 0.0123) ∴ 1.23%

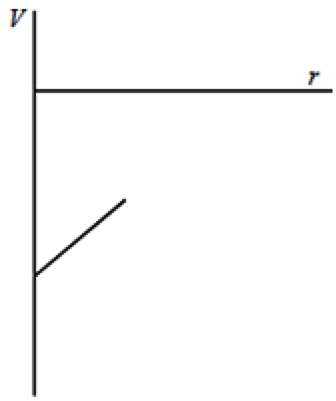
3

[7]

19



gradient decreases as r increases **(1)**
V increases as r increases **(1)**
only negative values of V shown **(1)**



constant gradient **(1)**
V increases as r increases **(1)**

[max 4]

20

(a) (i) force per unit mass/force per kg

B1

(ii) N kg^{-1} **not** ms^{-2} alone

B1

2

(b) (i) GM/R^2 seen

C1

$GM_Q/(3R)^2$ seen

C1

mass of Q = 9*M*

A1

(ii) passes through (3*R*, *g*) and falls off in curve

M1

two further points checked e.g., (6*R*,*g*/4) (12*R*, *g*/16)

M1

overall line quality – single smooth line (both Ms for this)

A1

6

[8]

21

(a) force acting per unit mass **or** $g = F / m$ **or** $g = \frac{GM}{R^2}$ with terms defined

(1)

(b) (i) direction of F_E correct in each diagram

B1

direction of F_M correct in each diagram

B1

direction of F_S correct in each diagram

B1

F_S must be distinguished from F_M

penalty of 1 mark for any missing labelling

(3)

(ii) sun and moon pulling in same direction / resultant of F_M and F_S is greatest / clear response including summation of F_M and F_S

M1

configuration A

A1

(2)

(c) $F = GMm / R^2$

C1

correct substitution $\frac{6.7 \times 10^{-11} \times 2.0 \times 10^{30}}{(1.5 \times 10^{11})^2}$

C1

(5.95 **or** 5.96 **or** 5.9 **or** 6.0) × 10^{-3} N kg^{-1}

A1

(3)

[9]

22 (a) (i) force per unit mass (allow equation with defined terms)

B1

(1)

(ii) diagram of method that will work
(pendulum / light gates / solenoid and mechanical gate / strobe photography / video)

B1

pair of measurements (eg length of pendulum and (periodic) time / distance and time of fall – could be shown on diagram)

M1

instruments to measure named quantities (may be on diagram)

A1

correct procedure (eg calculate period for range of lengths, measure the time of fall for range of heights)

B1

good practice – series of values and averages / use of gradient of graph

B1

appropriate formula and how g calculated

B1

(6)

(b) (i) evidence of gr^2 being used

C1

values of 0.25, 0.11, 0.06(25)
no s.f. penalty here unless values given as fractions

A1

(2)

(ii) points correctly plotted on grid (e.c.f.)

B1

smooth curve of high quality at least to 10 × 10^7 m, no intercept on r axis

B1

(2)

(iii) attempt to use area under curve

B1

evidence of × 800 kg

B1

(4.3 – 5.3) × 10^9 J

B1

or

use of equation for potential $\Delta E_G = m(g_1 r_1 - g_2 r_2)$

B1

evidence of × 800 kg

B1

(4.7 – 4.9) × 10^9 J

B1

max 2 if assumed values of G and M used

allow calculation of GM from graph followed by substitution into $\Delta E_G = M_G(m / r_1 - m / r_2)$ for 3 marks

(3)

[14]

23 (a) (i) F = 2500 or 2600 N

B1

$F = mv^2 / r$

B1

1500 m s^{-1} / 1480 m s^{-1}

or any further progress towards a solution such as

attempting to use: $F = GMm / r^2$

or $\frac{1}{2} mv^2 = mgh$

or equations of motion

or r = 6 ××10^5

or $F = mv^2 / (r + h)$

or evidence of time wasted, for example, repeated attempts at a solution

no unit penalty or s.f. penalty

B1

(3)

(ii) using the area under the graph between 0 and 6.0×10^5 m

or use of $V_G = GM / r$ or $PE = GMm / r$

C1

between 20 and 22 squares

or 1 square = 10^8 J

or uses the trapezium rule or rectangle and triangle
(allow if they fail with powers of ten)

or attempts to find the difference between the 2 values of PE

C1

2.0×10^9 J to 2.2×10^9 J

or attempt to complete the calculation
(may be confounded by lack of *r*)

A1
(3)

(b) (work done by motors) relates to change in PE or (PE + KE)

B1

2 × (PE + KE) condone 2 × (PE)

B1

need to know energy value of fuel / fuel density / energy density of fuel / fuel economy / efficiency of engines

B1
(3)
[9]

24 (a) the radius/diameter of the planet **not** 'size'

B1

the mass (or density) of the planet

B1
2

(b) (i) volume of the granite = $4/3\pi r^3$
or
radius of the granite = 0.2 km (may be seen in an incorrect equation)

B1

200^3 or $4/3\pi\ 0.2^3$ or 3.35×10^7 m^3

B1

Mass = density × volume used with any density and their volume
(Volume may be in formula form)
If they use correct volume then either 1.24×10^{11}
or 7.37×10^{10} gets the mark)

B1

(3700-2200) × 3.35×10^7 **or** 1500 × 3.35×10^7 kg
or ($1.24 \times 10^{11} - 7.37 \times 10^{10}$) **or** 5.025×10^{10}
or 5.03×10^{10} seen
Condone rounding off early leading to 4.6×10^{10} kg

B1

4

NB
1) the fourth mark is not for 5.0×10^{10} – all working must be shown
2) those who do not show conversion of radius from km to m in the calculation but otherwise correct will get 3

(ii) Gravitation field strength $g = GM/r^2$
or
uses distance of 0.4 km for r

C1

Substitution for extra field strength
$= 6.7 \times 10^{-11} \times 5.0 \times 10^{10}/(0.4\times10^3)^2$
Condone $r = 0.4$ for this mark

C1

Correct substitution for the extra field strength
with **correct**
powers of 10

C1

2.1×10^{-5} N kg^{-1} (condone m s^{-2})
or
1.9×10^{-5} if 4.6×10^{10} carried forward from (i)

A1

4

(iii) Correct general shape always below original curve

B1

1

Alternative scheme for different approach to (ii)

(ii) Gravitation field strength = GM/r^2
or
uses distance of 0.4 km for r

C1

Correct substitution for field strength for granite (or soil)
$6.7 \times 10^{-11} \times 1.24 \times 10^{11}/(0.4\times10^3)^2$ or $6.7 \times 10^{-11} \times 7.37 \times 10^{10}/(0.4\times10^3)^2$
Condone r = 0.4 for this mark

C1

Correct substitution for field strength for soil (or granite)

C1

2.1×10^{-5} N kg^{-1} (condone m s^{-2})

A1

4

[11]

25 (a) direction changing, velocity vector

B1

1

(b) Newton's law equation

M1

centripetal force equation

M1

cancel mass of Triton

A1

3

(c) $\omega = 2\pi f$ or $\omega = 2\pi/T$

M1

$\omega^2 r^3$ = constant or $\omega^2 = \frac{GM}{r^3}$

M1

$\frac{T_T^2}{T_P^2} = \frac{r_T^3}{r_P^3}$ **or** statement of Kepler III for B3

$\frac{T_T}{T_P} = \sqrt{\frac{(3.55 \times 10^8)^3}{(1.18 \times 10^8)^3}}$ = 5.2(2)

M1

4

[8]