1 The gravitational field strength at the surface of a planet, X, is 19 N kg^{-1}.

(a) (i) Calculate the gravitational potential difference between the surface of X and a point 10 m above the surface, if the gravitational field can be considered to be uniform over such a small distance.

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(ii) Calculate the minimum amount of energy required to lift a 9.0 kg rock a vertical distance of 10 m from the surface of X.

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(iii) State whether the minimum amount of energy you have found in part (ii) would be different if the 9.0 kg mass were lifted a vertical distance of 10 m from a point near the top of the highest mountain of planet X. Explain your answer.

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(3)

(b) Calculate the gravitational field strength at the surface of another planet, Y, that has the same mass as planet X, but twice the diameter of X.

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(2)

(Total 5 marks)

2 (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)

3 (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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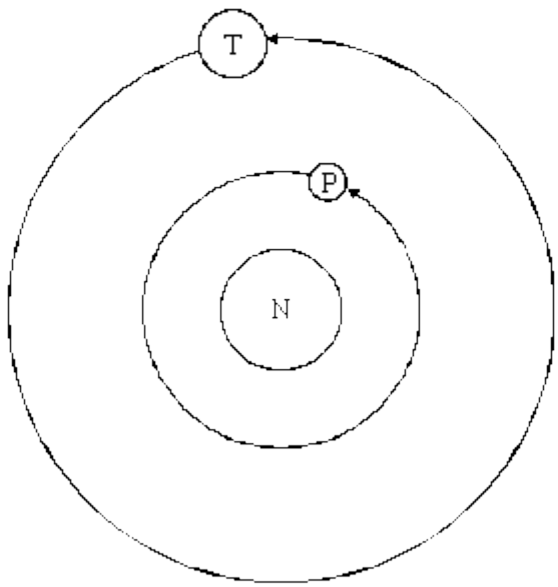
(2)

(Total 7 marks)

4 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.

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(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)

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

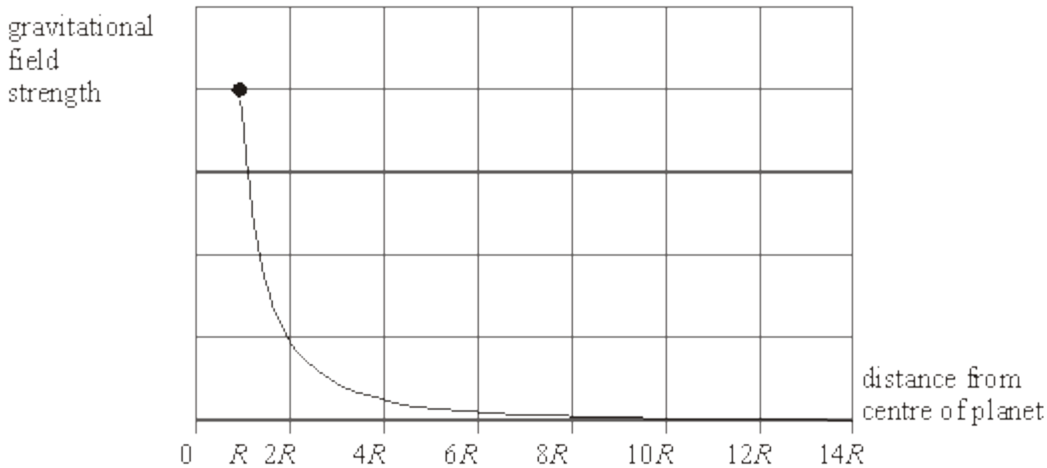
(ii) State the SI unit of gravitational field strength.

(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)

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

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

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(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,

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(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.

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(6)

(Total 8 marks)

7 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)

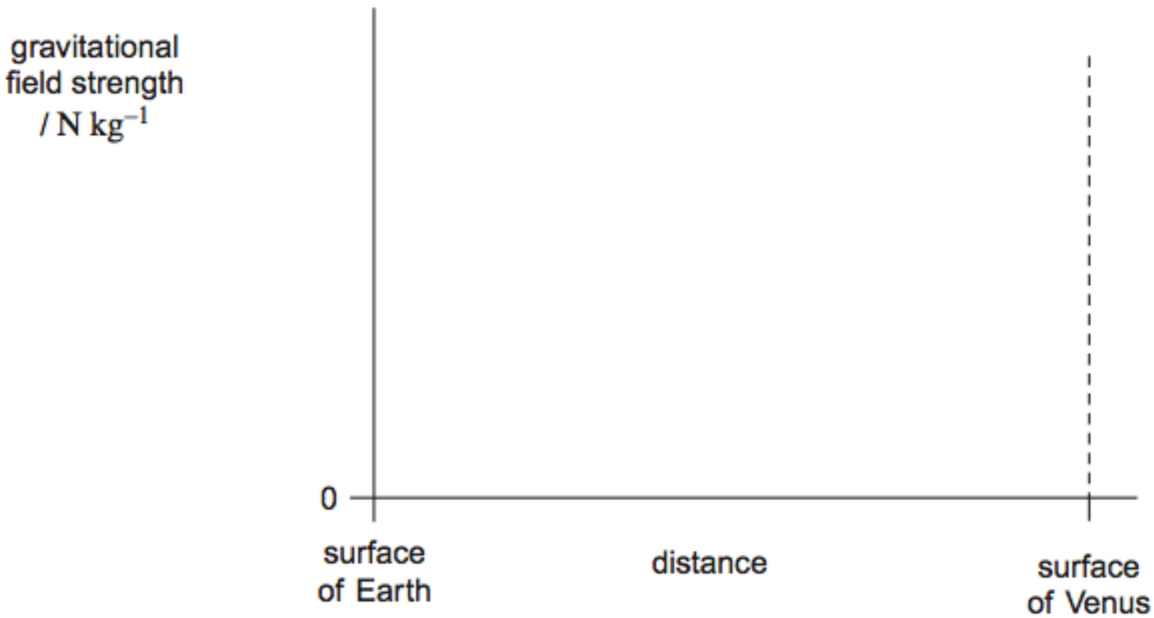
(ii) Calculate the radius of Venus.

Give your answer to an appropriate number of significant figures.

radius = ____________________ m

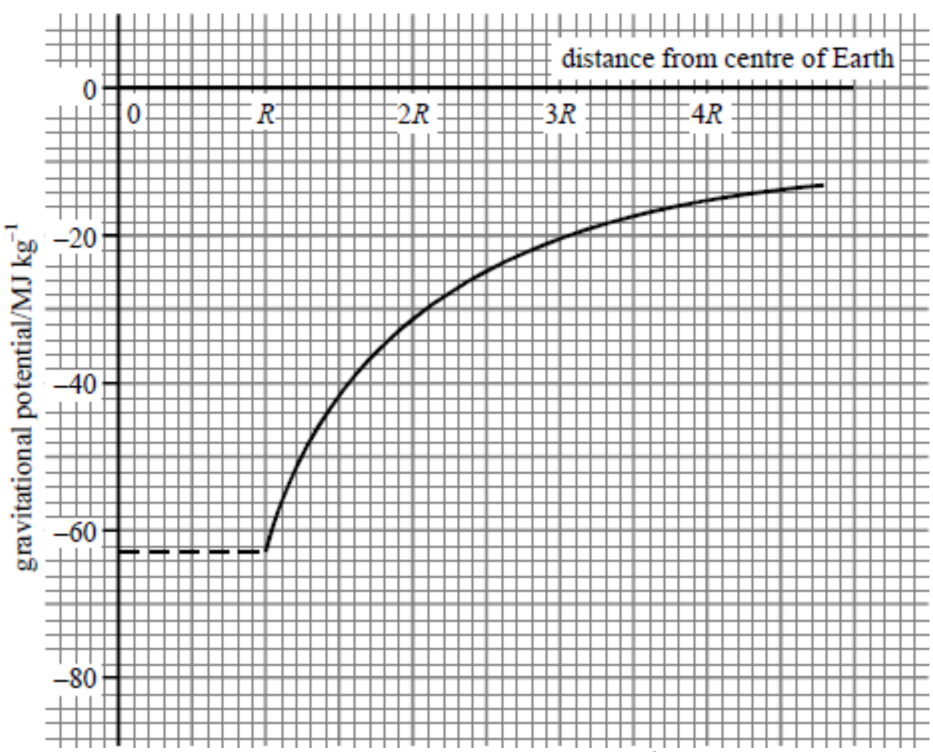
(3)

(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)

8 (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,

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(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 $3R$.

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(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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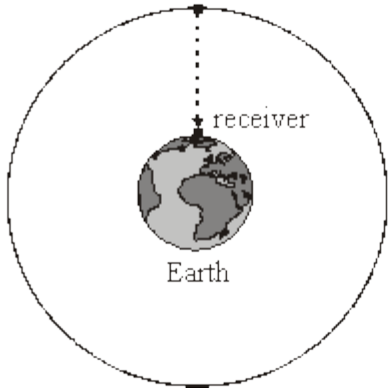
(5)

(Total 9 marks)

9 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)

10 (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.

(1)

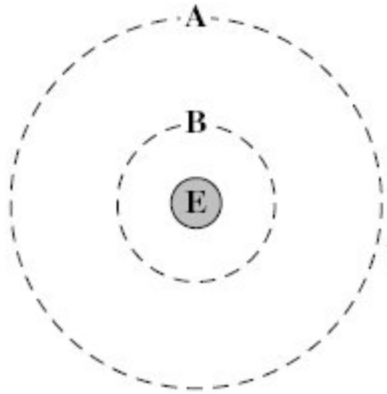
(ii) What is the effect, if any, on the values of E_p and V if the mass m is doubled?

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)

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

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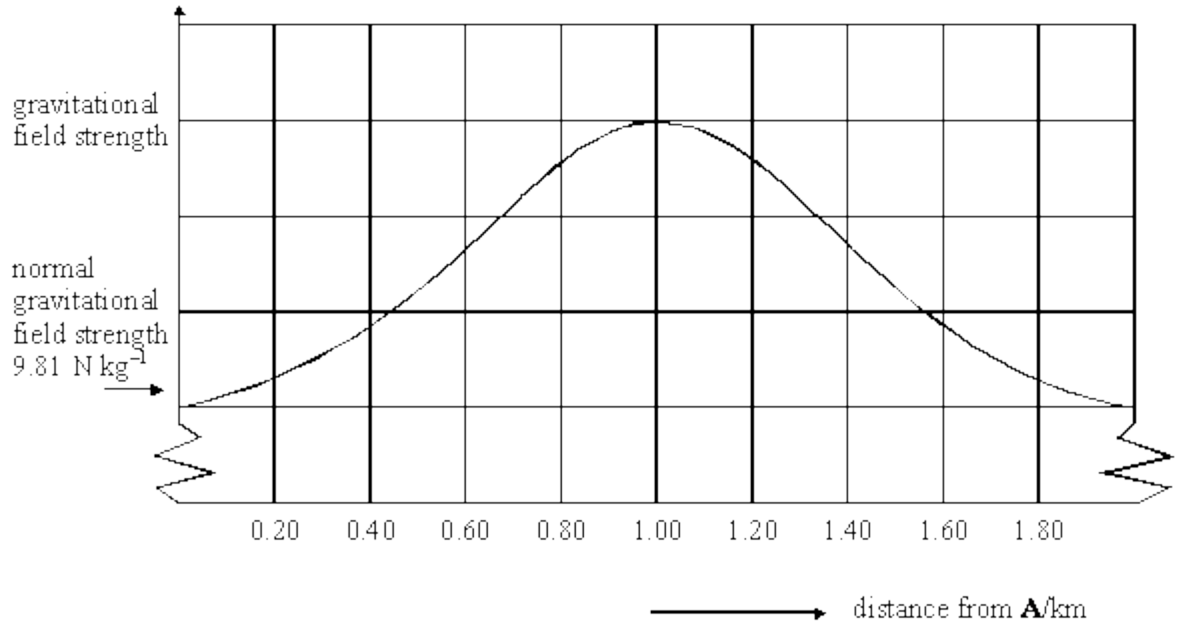
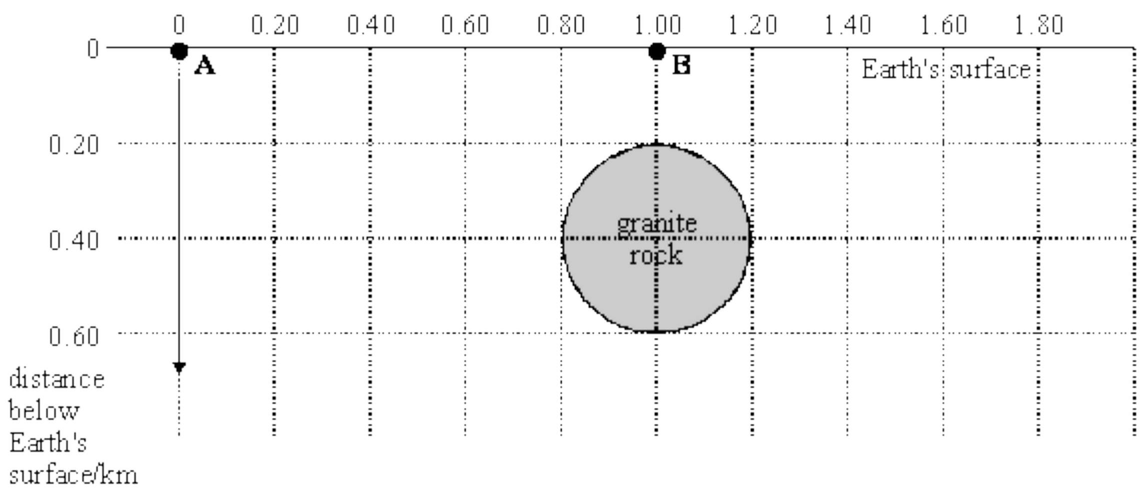
(2)

(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)

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

(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.

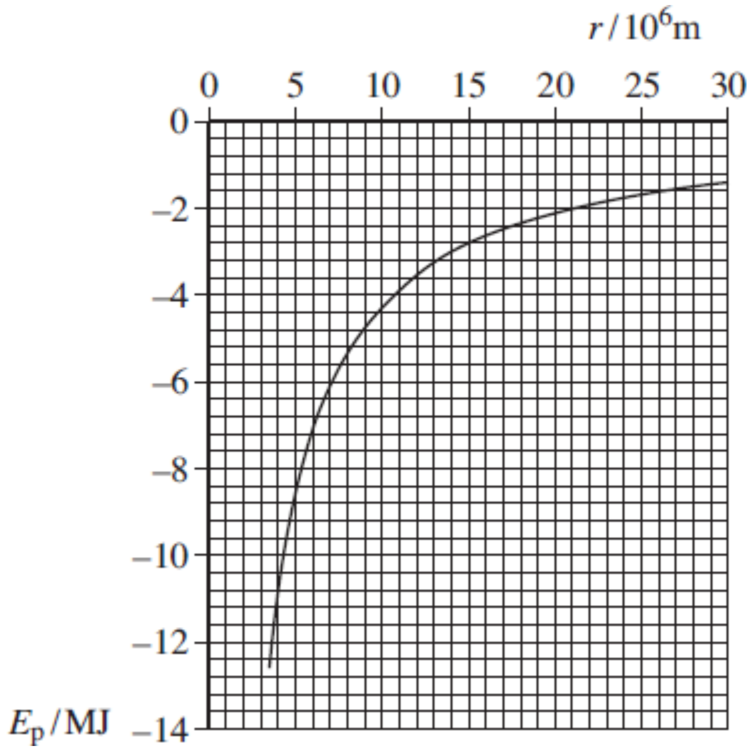
(ii) Neptune orbits the Sun once every 165 Earth years.

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

(4)

(Total 10 marks)

13 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.

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(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)

14 (a) Derive an expression to show that for satellites in a circular orbit

$$T^2 \propto r^3$$

where T is the period of orbit and r is the radius of the orbit.

(2)

(b) Pluto is a dwarf planet. The mean orbital radius of Pluto around the Sun is 5.91×10^9 km compared to a mean orbital radius of 1.50×10^8 km for the Earth.

Calculate in years the orbital period of Pluto.

orbital period of Pluto = ____________________ yr

(2)

(c) A small mass released from rest just above the surface of Pluto has an acceleration of 0.617 m s^{-2}.

Assume Pluto has no atmosphere that could provide any resistance to motion.

Calculate the mass of Pluto.

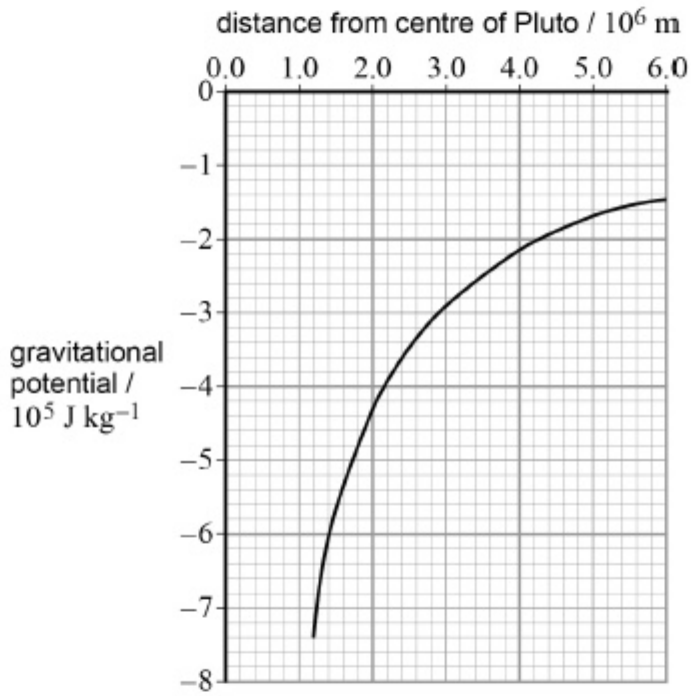
Give your answer to an appropriate number of significant figures.

radius of Pluto = 1.19×10^6 m

mass of Pluto = ____________________ kg

(3)

(d) The graph shows the variation in gravitational potential with distance from the centre of Pluto for points at and above its surface.



A meteorite hits Pluto and ejects a lump of ice from the surface that travels vertically at an initial speed of 1400 m s^{-1}.

Determine whether this lump of ice can escape from Pluto.

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(3)

(Total 10 marks)

15 (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.

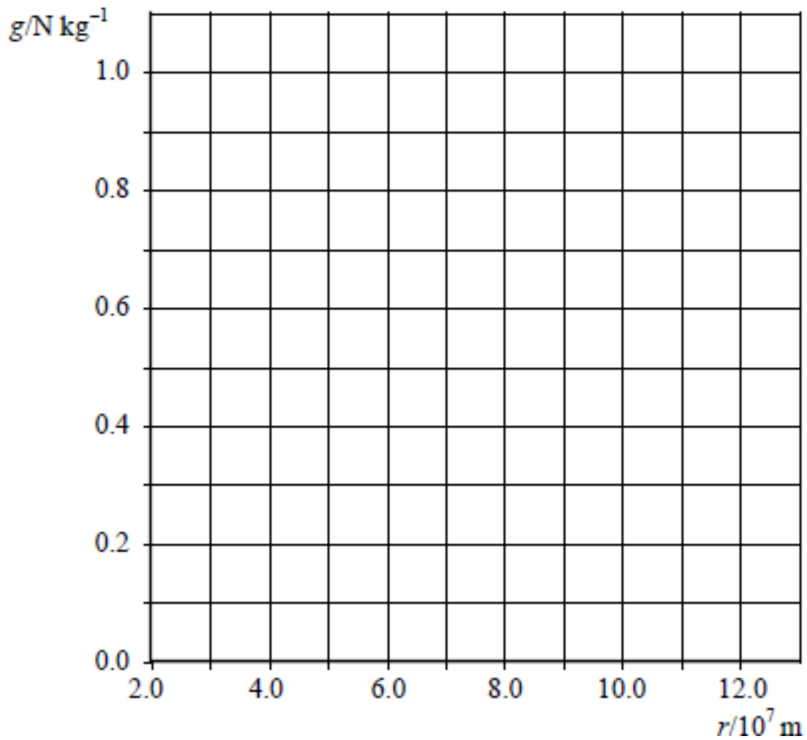
(6)

(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)

16 (a) Define the gravitational potential at a point.

(2)

(b) Explain why gravitational potential is always negative.

(2)

(c) Show that the magnitude of the gravitational potential at the Earth's surface due to the mass of the Earth is about 6.3×10^7 J kg^{-1}.

(2)

(d) A satellite is launched into a geostationary orbit.

Describe and explain **two** features of a geostationary orbit.

1.

2.

(2)

(e) The satellite has a mass of 1200 kg and the radius of its orbit is 4.23×10^7 m.

Calculate the gain in gravitational potential energy of the satellite when it is placed into orbit from the Earth's surface.

gain in potential energy = ____________________________J

(3)

(f) Impulse engines are used to place the satellite into an orbit with a longer period.

Discuss any changes this makes to the orbital motion of the satellite.

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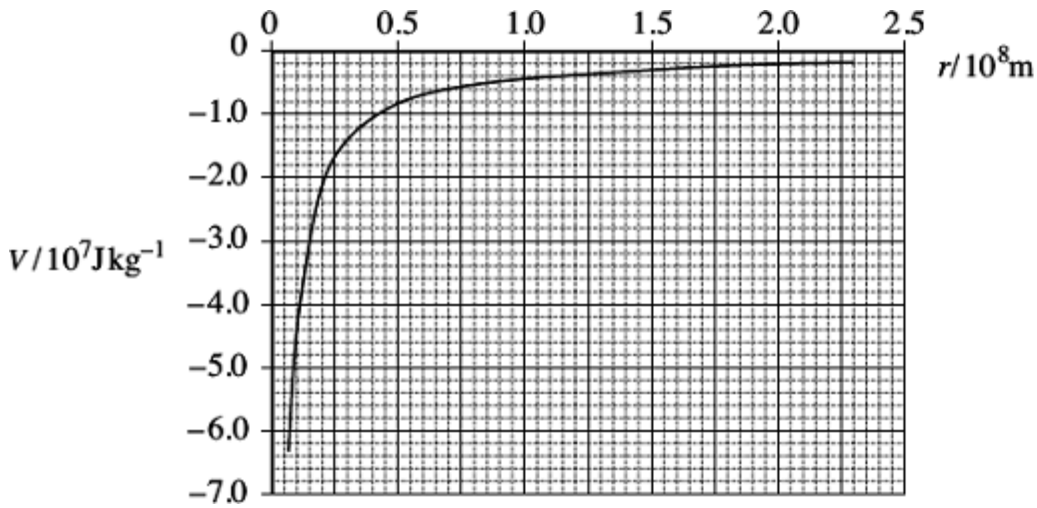
(4)

(Total 15 marks)

17 The figure below shows the variation of gravitational potential, V, with distance from the centre of the Earth, r. The radius of the Earth is 6.4×10^6 m.



(a) Explain why the V values are negative.

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(3)

(b) Use data from the graph to show that the mass of the Earth is approximately 6×10^{24} kg.

(3)

(c) (i) Calculate the work done in raising a satellite of mass 2100 kg from the surface of the Earth to a height of 850 km above the surface of the Earth.

work done ______________________ J

(3)

(ii) Calculate the change in the kinetic energy of the satellite when it moves from its 850 km orbit to one at a height of 700 km above the Earth's surface. Make it clear whether the change in kinetic energy is an increase or decrease.

kinetic energy change ______________________ J

(4)

(iii) Without performing any further calculations explain how the change in kinetic energy relates to the change of the potential energy when the satellite's orbit alters as in part (c)(ii).

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(2)

(Total 15 marks)

18 (a) State the law that governs the magnitude of the force between two point masses.

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(2)

(b) The table shows how the gravitational potential varies for three points above the centre of the Sun.

distance from centre of Sun/10^8 m	**gravitational potential/10^{10} J kg^{-1}**
7.0 (surface of Sun)	–19
16	–8.3
35	–3.8

(i) Show that the data suggest that the potential is inversely proportional to the distance from the centre of the Sun.

(2)

(ii) Use the data to determine the gravitational field strength near the surface of the Sun.

(3)

(iii) Calculate the change in gravitational potential energy needed for the Earth to escape from the gravitational attraction of the Sun.

mass of the Earth	=	6.0×10^{24} kg
distance of Earth from centre of Sun	=	1.5×10^{11} m

(3)

(iv) Calculate the kinetic energy of the Earth due to its orbital speed around the Sun and hence find the minimum energy that would be needed for the Earth to escape from its orbit. Assume that the Earth moves in a circular orbit.

(3)

(Total 13 marks)

19 (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)

20 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)

Not on current spec

(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}

Not on current spec

(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)

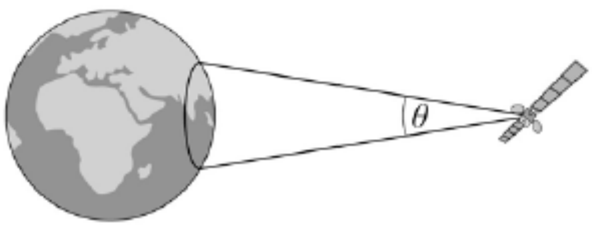
(Total 20 marks)

21 **Read the following passage and answer the questions that follow**

Satellites used for telecommunications are usually in geostationary orbits. Using suitable dishes to transmit the signals, communication over most of the Earth's surface is possible at all times using only 3 satellites.

Satellites used for meteorological observations and observations of the Earth's surface are usually in low Earth orbits. Polar orbits, in which the satellite passes over the North and South Poles of the Earth, are often used.

One such satellite orbits at a height of about 12 000 km above the Earth's surface circling the Earth at an angular speed of 2.5×10^{-4} rad s^{-1}. The microwave signals from the satellite are transmitted using a dish and can only be received within a limited area, as shown in the image below.



not to scale

The signal of wavelength λ is transmitted in a cone of angular width θ, in radian, given by

$$\theta = \frac{\lambda}{d}$$

where d is the diameter of the dish.

The satellite transmits a signal at a frequency of 1100 MHz using a 1.7 m diameter dish. As this satellite orbits the Earth, the area over which a signal can be received moves. There is a maximum time for which a signal can be picked up by a receiving station on Earth.

(a) Describe **two** essential features of the orbit needed for the satellite to appear geostationary.

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(2)

(b) Calculate the time taken, in s, for the satellite mentioned in line 7 in the passage to complete one orbit around the Earth.

time taken = ______________ s

(1)

(c) Show that at a distance of 12 000 km from the satellite the beam has a width of 1900 km.

(3)

(d) The satellite is in a polar orbit and passes directly over a stationary receiver at the South Pole.

Show that the receiver can remain in contact with the satellite for no more than about 20 minutes each orbit.

radius of the Earth = 6400 km

maximum time = ____________________________ minute

(3)

(e) The same satellite is moved into a higher orbit.

Discuss, with reasons, how this affects the signal strength and contact time for the receiver at the South Pole.

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(4)

(Total 13 marks)

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

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(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)

23 (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).

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(2)

(Total 14 marks)

24 (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)