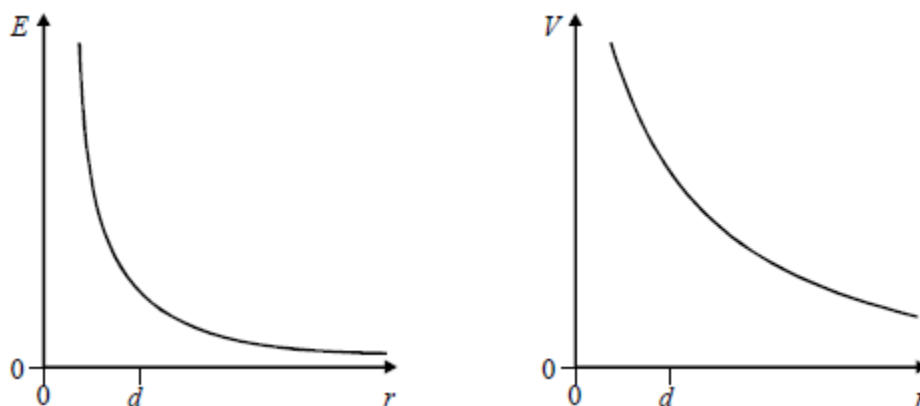


- 1** **Graph 1** shows the variation of electric field strength  $E$  with separation  $r$  for two point charges. **Graph 2** shows the corresponding variation of electric potential  $V$  with separation.



Which line in the table correctly relates data for the two graphs?

|          | Magnitude of electric field strength at separation $d$    | Magnitude of electric potential at separation $d$         |
|----------|-----------------------------------------------------------|-----------------------------------------------------------|
| <b>A</b> | Gradient of <b>graph 2</b> at separation $d$              | Area under <b>graph 1</b> from separation $d$ to $\infty$ |
| <b>B</b> | Area under <b>graph 2</b> from separation $d$ to $\infty$ | Area under <b>graph 1</b> from separation $d$ to $\infty$ |
| <b>C</b> | Gradient of <b>graph 2</b> at separation $d$              | Gradient of <b>graph 1</b> at separation $d$              |
| <b>D</b> | Area under <b>graph 2</b> from separation $d$ to $\infty$ | Gradient of <b>graph 1</b> at separation $d$              |

(Total 1 mark)

- 2** The gravitational potential difference between the surface of a planet and a point P, 10 m above the surface, is  $8.0 \text{ J kg}^{-1}$ . Assuming a uniform field, what is the value of the gravitational field strength in the region between the planet's surface and P?

- A**  $0.80 \text{ N kg}^{-1}$
- B**  $1.25 \text{ N kg}^{-1}$
- C**  $8.0 \text{ N kg}^{-1}$
- D**  $80 \text{ N kg}^{-1}$

(Total 1 mark)

**3**

Which one of the following has different units to the other three?

- A** gravitational potential
- B** gravitational field strength
- C** force per unit mass
- D** gravitational potential gradient

(Total 1 mark)

**4**

A mass of 5 kg is moved in a gravitational field from a point **X** at which the gravitational potential is  $-20 \text{ J kg}^{-1}$  to a point **Y** where it is  $-10 \text{ J kg}^{-1}$ . The change in potential energy of the mass, in J, between **X** and **Y** is

- A**  $-50$
- B**  $-10$
- C**  $+10$
- D**  $+50$

(Total 1 mark)

**5**

$g$  is the strength of the gravitational field at the surface of the Earth;  $R$  is the radius of the Earth. The potential energy lost by a satellite of mass  $m$  falling to the Earth's surface from a height  $R$  above the surface is

- A**  $4mgR$
- B**  $2mgR$
- C**  $\frac{mgR}{2}$
- D**  $\frac{mgR}{4}$

(Total 1 mark)

6

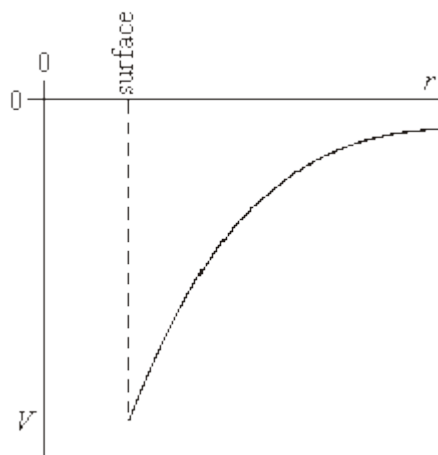
At a distance  $R$  from a fixed charge, the electric field strength is  $E$  and the electric potential is  $V$ . Which line, **A** to **D**, gives the electric field strength and electric potential at a distance  $2R$  from the charge?

|          | electric field strength | electric potential |
|----------|-------------------------|--------------------|
| <b>A</b> | $\frac{E}{2}$           | $\frac{V}{4}$      |
| <b>B</b> | $\frac{E}{2}$           | $\frac{V}{2}$      |
| <b>C</b> | $\frac{E}{4}$           | $\frac{V}{2}$      |
| <b>D</b> | $\frac{E}{4}$           | $\frac{V}{4}$      |

(Total 1 mark)

7

The graph shows how the gravitational potential,  $V$ , varies with the distance,  $r$ , from the centre of the Earth.



What does the gradient of the graph at any point represent?

- A** the magnitude of the gravitational field strength at that point
- B** the magnitude of the gravitational constant
- C** the mass of the Earth
- D** the potential energy at the point where the gradient is measured

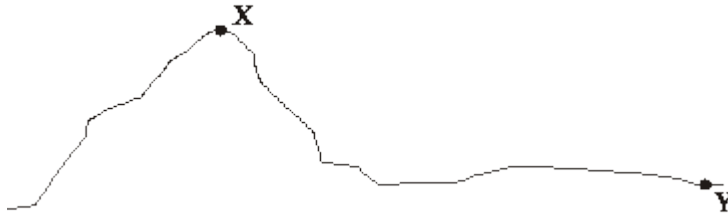
(Total 1 mark)

**8** Two protons are  $1.0 \times 10^{-14}$  m apart. Approximately how many times is the electrostatic force between them greater than the gravitational force between them?

- A**  $10^{23}$
- B**  $10^{30}$
- C**  $10^{36}$
- D**  $10^{42}$

(Total 1 mark)

**9** The diagram shows two positions, **X** and **Y**, at different heights on the surface of the Earth.



Which line, **A** to **D**, in the table gives correct comparisons at **X** and **Y** for gravitational potential and angular velocity?

|          | gravitational potential at X compared with Y | angular velocity at X compared with Y |
|----------|----------------------------------------------|---------------------------------------|
| <b>A</b> | greater                                      | greater                               |
| <b>B</b> | greater                                      | same                                  |
| <b>C</b> | greater                                      | smaller                               |
| <b>D</b> | same                                         | same                                  |

(Total 1 mark)

**10**

When at the surface of the Earth, a satellite has weight  $W$  and gravitational potential energy  $-U$ . It is projected into a circular orbit whose radius is equal to twice the radius of the Earth. Which line, **A** to **D**, in the table shows correctly what happens to the weight of the satellite and to its gravitational potential energy?

|          | weight                | gravitational potential energy |
|----------|-----------------------|--------------------------------|
| <b>A</b> | becomes $\frac{W}{2}$ | increases by $\frac{U}{2}$     |
| <b>B</b> | becomes $\frac{W}{4}$ | increases by $\frac{U}{2}$     |
| <b>C</b> | remains $W$           | increases by $U$               |
| <b>D</b> | becomes $\frac{W}{4}$ | increases by $U$               |

**(Total 1 mark)****11**

Which one of the following could be a unit of gravitational potential?

- A** N
- B** J
- C** N kg<sup>-1</sup>
- D** J kg<sup>-1</sup>

**(Total 1 mark)**

12

At the surface of the Earth the gravitational field strength is  $g$ , and the gravitational potential is  $V$ . The radius of the Earth is  $R$ . An object, whose weight on the surface of the Earth is  $W$ , is moved to a height  $3R$  above the surface. Which line, **A** to **D**, in the table gives the weight of the object and the gravitational potential at this height?

|          | weight         | gravitational potential |
|----------|----------------|-------------------------|
| <b>A</b> | $\frac{W}{16}$ | $\frac{V}{4}$           |
| <b>B</b> | $\frac{W}{4}$  | $\frac{V}{3}$           |
| <b>C</b> | $\frac{W}{4}$  | $\frac{V}{4}$           |
| <b>D</b> | $\frac{W}{16}$ | $\frac{V}{3}$           |

(Total 1 mark)

13

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.

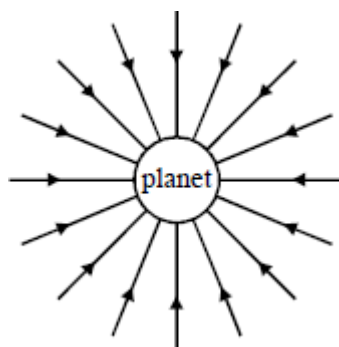


Figure 1

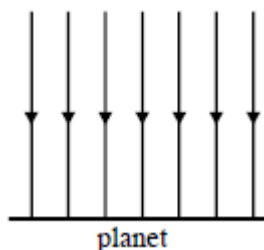


Figure 2

(Total 4 marks)

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 =  $81 \times$  mass of Moon

radius of Earth =  $3.7 \times$  radius of Moon

gravitational potential at surface of the Earth =  $-63 \text{ MJ kg}^{-1}$

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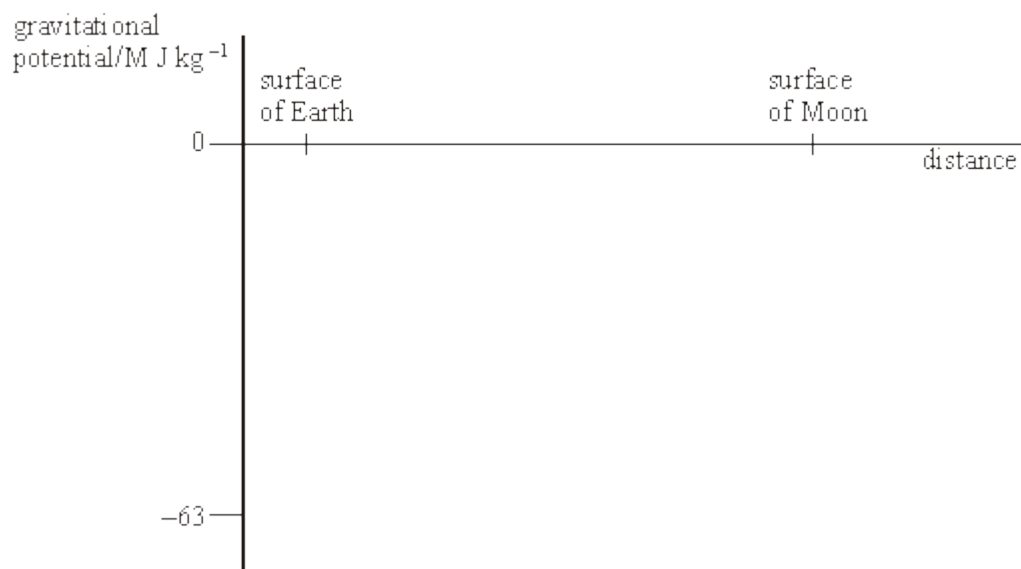
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(3)

- (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.

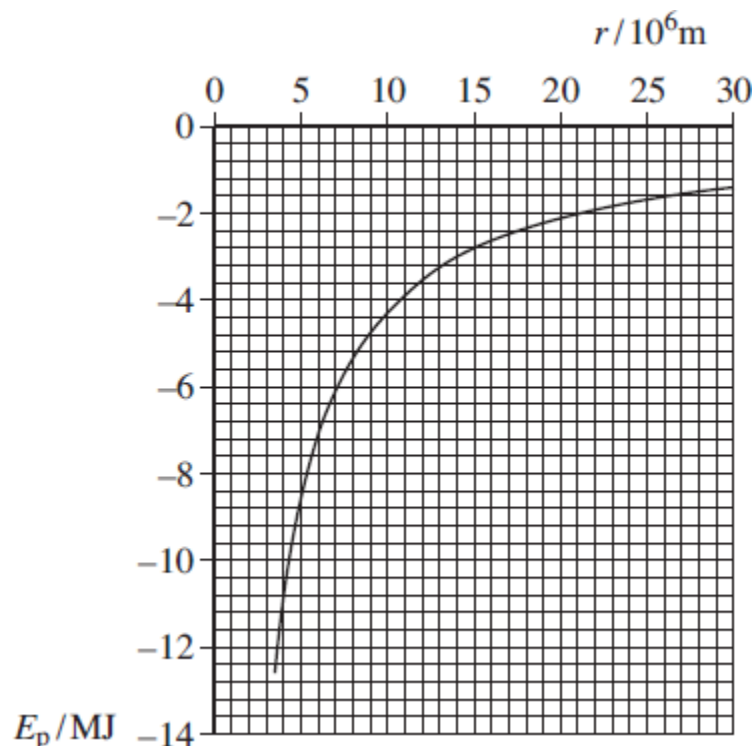


(3)

(Total 8 marks)

15

The 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<sup>-1</sup>

(3)

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

(3)

(Total 11 marks)

16

- (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  $5.91 \times 10^9$  km compared to a mean orbital radius of  $1.50 \times 10^8$  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  $0.617 \text{ m s}^{-2}$ .

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

Calculate the mass of Pluto.

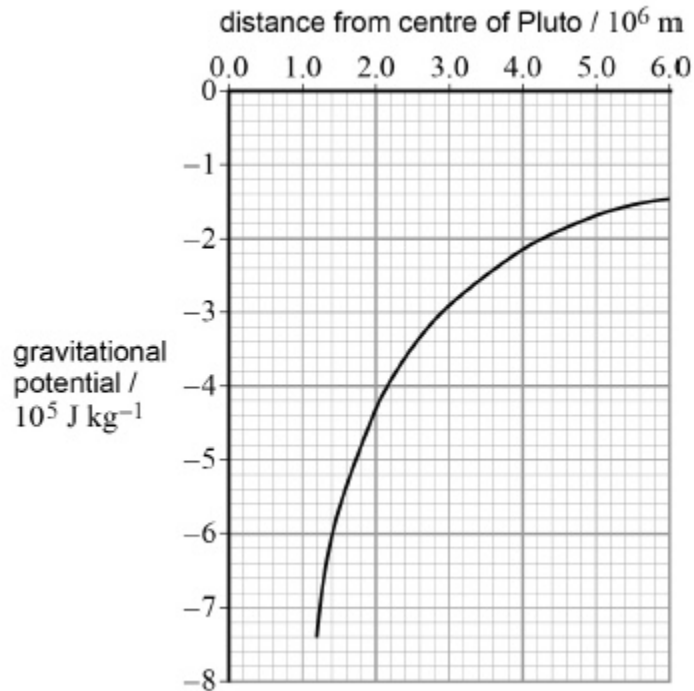
Give your answer to an appropriate number of significant figures.

radius of Pluto =  $1.19 \times 10^6$  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  $1400 \text{ m s}^{-1}$ .

Determine whether this lump of ice can escape from Pluto.

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(3)

(Total 10 marks)

17

- (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.

$$\text{mass of the Earth} = 6.0 \times 10^{24} \text{ kg}$$

$$\text{distance of Earth from centre of Sun} = 1.5 \times 10^{11} \text{ m}$$

**(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)**

18

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

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(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<br>$r / \text{km}$ | gravitational potential<br>$V / 10^7 \text{ J kg}^{-1}$ |
|--------------------------------------------------|---------------------------------------------------------|
| 7500                                             | -5.36                                                   |
| 12500                                            | -3.22                                                   |
| 22500                                            | -1.79                                                   |

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

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(2)

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

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(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.

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(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 =  $6.0 \times 10^{24}$  kg

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kinetic energy \_\_\_\_\_ GJ

(4)

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

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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.

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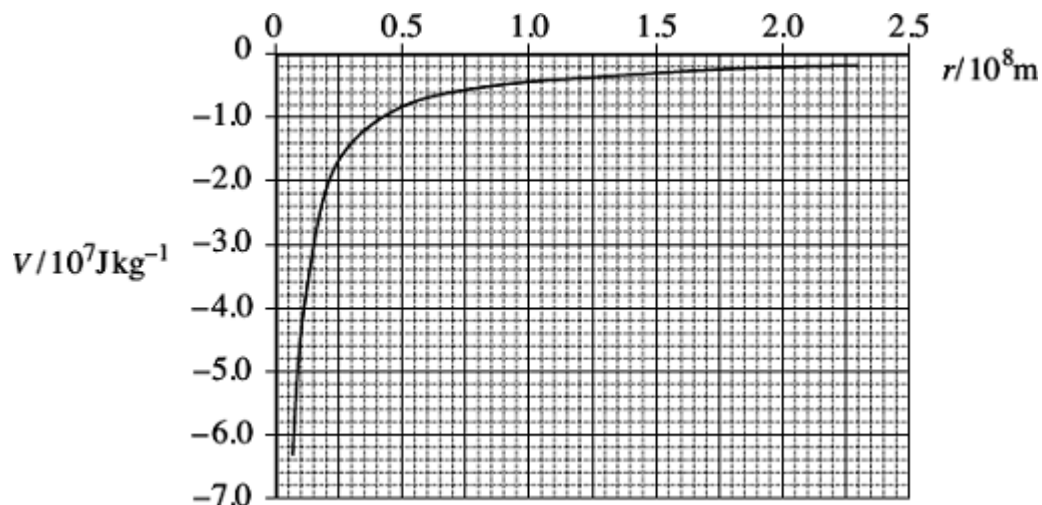
total energy \_\_\_\_\_ GJ

(1)

(Total 16 marks)

19

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  $6.4 \times 10^6$  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  $6 \times 10^{24}$  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)**

**20**

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

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**(2)**

- (b) Explain why gravitational potential is always negative.

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**(2)**

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

**(2)**

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

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

1. \_\_\_\_\_

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2. \_\_\_\_\_

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**(2)**

- (e) The satellite has a mass of 1200 kg and the radius of its orbit is  $4.23 \times 10^7$  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)**