

## 2002

The Mars Odyssey spacecraft was launched from Earth on 7 April 2001 and arrived at Mars on 23 October 2001. Figure 1 is a graph of the gravitational force acting on the 700 kg Mars Odyssey spacecraft plotted against height above Earth's surface.

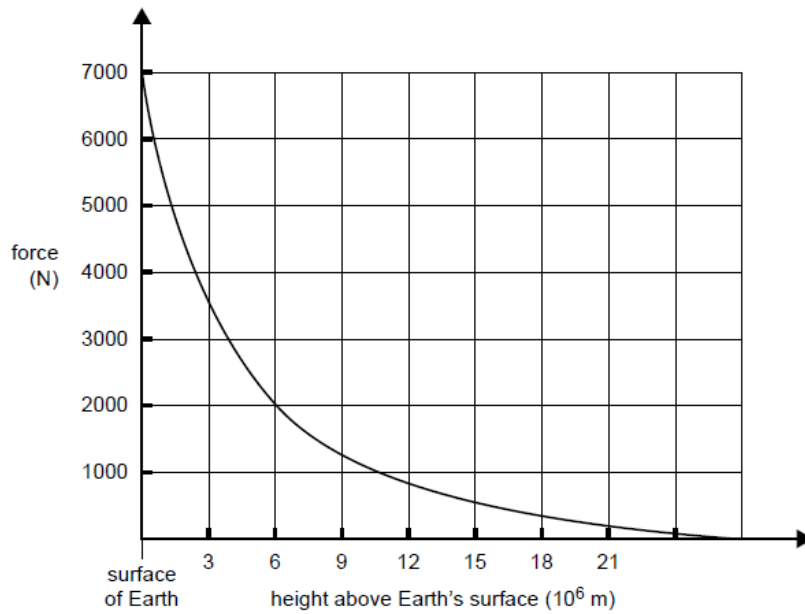


Figure 1

### Question 1 (38%)

Estimate the minimum launch energy needed for Mars Odyssey to escape Earth's gravitational attraction.

3 marks

2003

Figure 1 is a graph of the force of gravitational attraction between the 400 kg spacecraft Odyssey and the planet Mars versus distance above the surface of Mars.

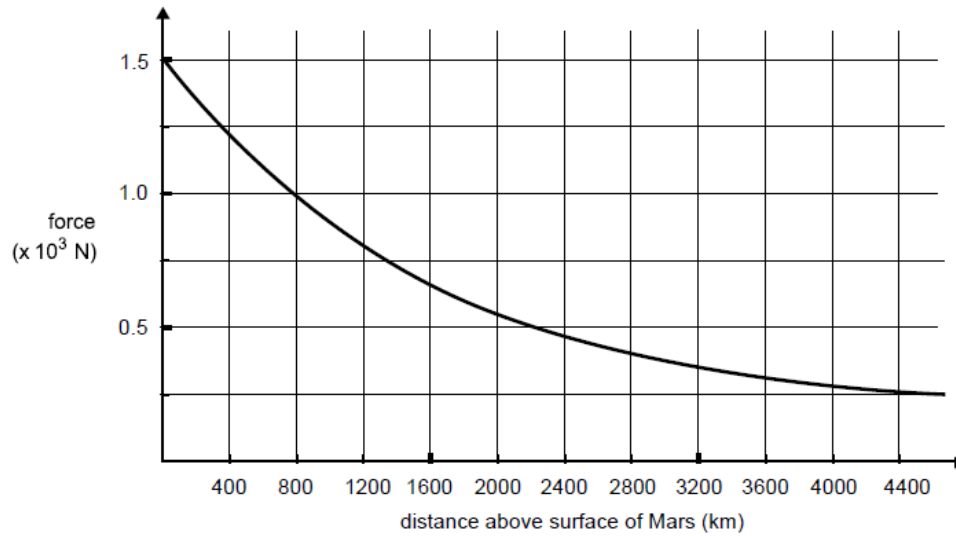


Figure 1

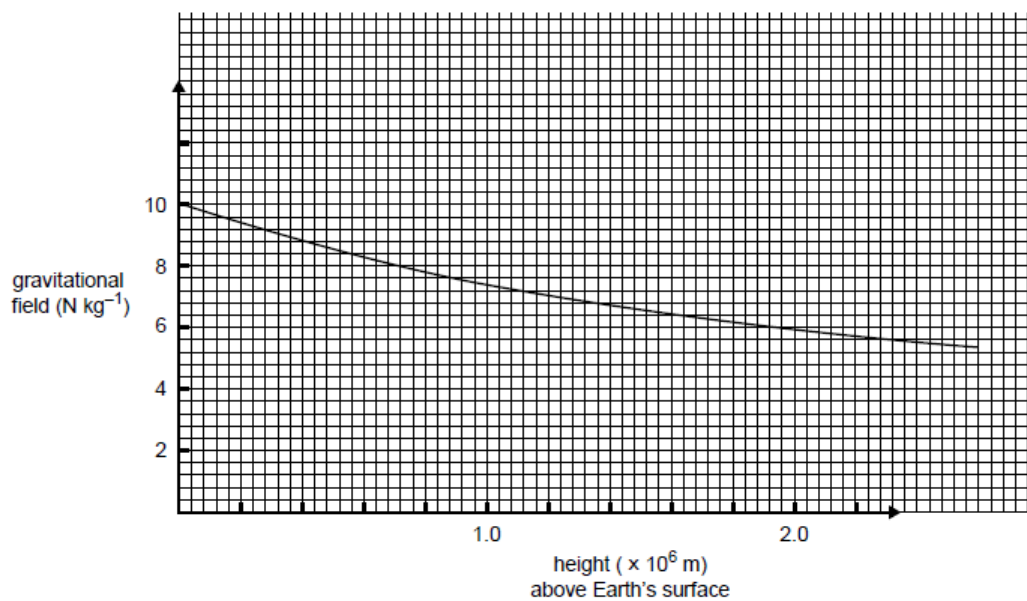
Before its orbit around Mars, Odyssey was originally launched from Earth and took 200 days to reach Mars. At a distance of 3200 km away from the surface of Mars it was travelling at approximately 24 000 m/s. At this point it was speeding up due to the gravitational attraction of Mars.

**Question 2 (13%)**

Describe, **but do not calculate**, the method you would use to determine the speed of Odyssey at a distance of 1200 km above the surface of Mars. 4 marks

**2004**

Figure 1 shows the variation of gravitational field with height above Earth's surface.



**Figure 1**

**Question 3 (1%)**

Calculate the energy needed to take the 400 kg spacecraft from rest at the surface of Earth and place it in a stable circular orbit of height  $1.70 \times 10^6$  m. You must show your working.

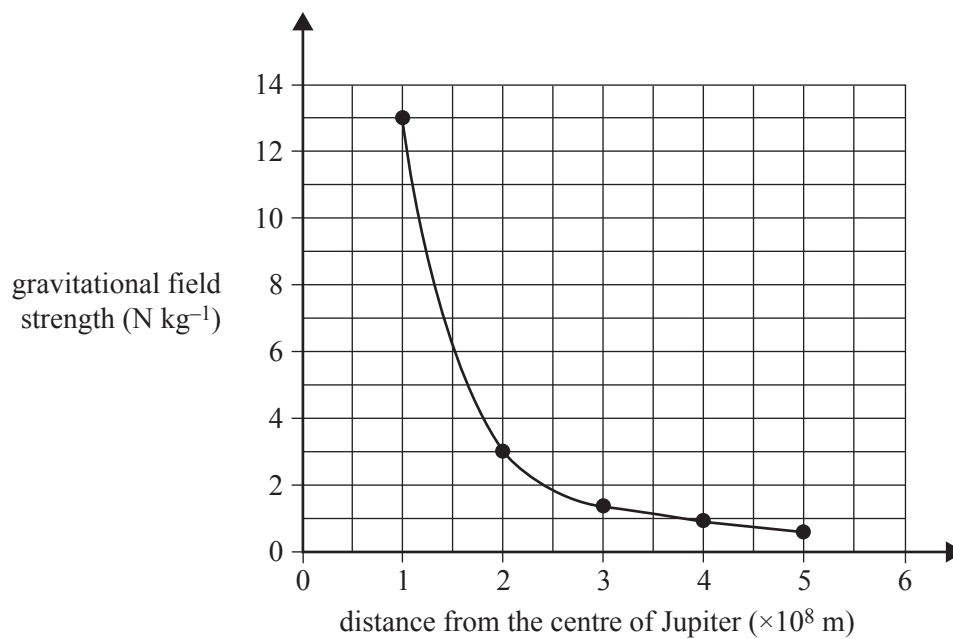
5 marks

✓ **Question 9** (8 marks)

The spacecraft *Juno* has been put into orbit around Jupiter. The table below contains information about the planet Jupiter and the spacecraft *Juno*. Figure 11 shows gravitational field strength ( $\text{N kg}^{-1}$ ) as a function of distance from the centre of Jupiter.

**Data**

mass of Jupiter	$1.90 \times 10^{27} \text{ kg}$
radius of Jupiter	$7.00 \times 10^7 \text{ m}$
mass of spacecraft <i>Juno</i>	1500 kg



**Figure 11**

- a. Calculate the gravitational force acting on *Juno* by Jupiter when *Juno* is at a distance of  $2.0 \times 10^8 \text{ m}$  from the centre of Jupiter. Show your working. 2 marks

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- b. Use the graph in Figure 11 to estimate the magnitude of the change in gravitational potential energy of the spacecraft *Juno* as it moves from a distance of  $2.0 \times 10^8$  m to a distance of  $1.0 \times 10^8$  m from the centre of Jupiter. Show your working.

3 marks

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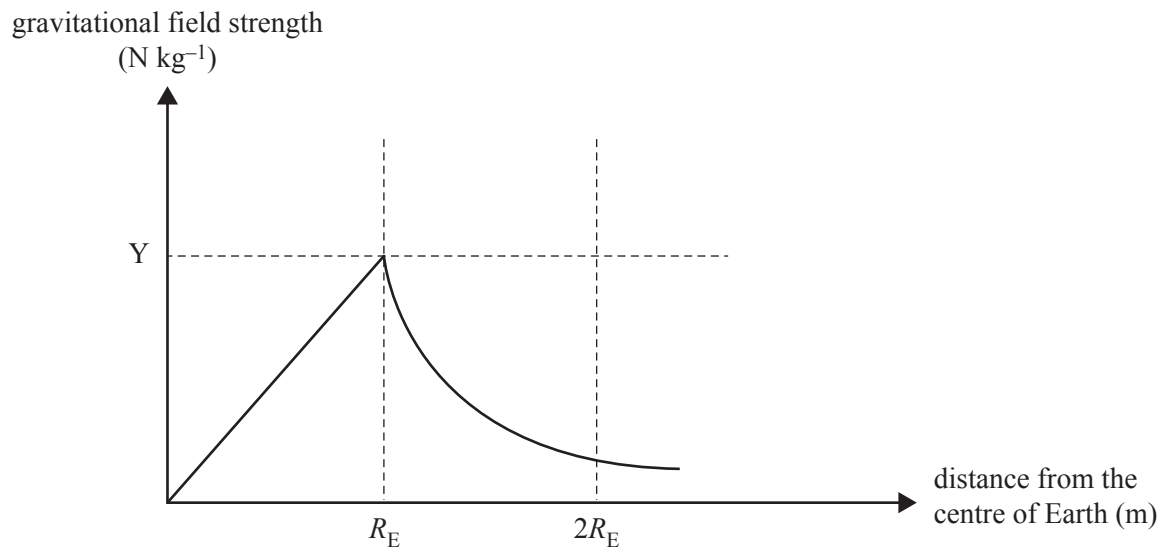
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**✓ Question 4** (5 marks)

Assume that a journey from approximately 2 Earth radii ( $2R_E$ ) down to the centre of Earth is possible. The radius of Earth ( $R_E$ ) is  $6.37 \times 10^6$  m. Assume that Earth is a sphere of constant density.

A graph of gravitational field strength versus distance from the centre of Earth is shown in Figure 4.



**Figure 4**

- c. Calculate the increase in potential energy for a 75 kg person hypothetically moving from the centre of Earth to the surface of Earth. Show your working.

2 marks

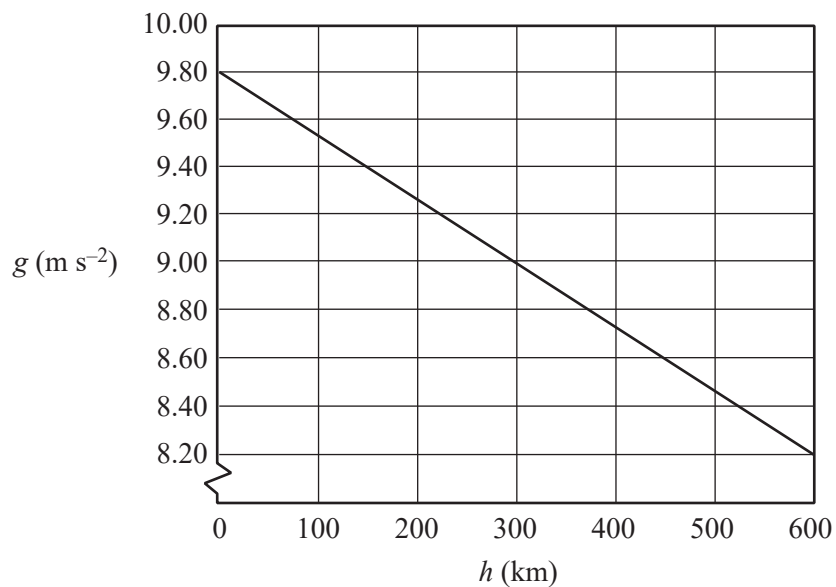
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4. d. Figure 3 shows the strength of Earth's gravitational field,  $g$ , as a function of orbital altitude,  $h$ , above the surface of Earth.



**Figure 3**

Determine the change in gravitational potential energy of the ICON satellite as it travels from Earth's surface to its orbital altitude of 600 km above Earth's surface. The mass of the ICON satellite is 288 kg.

3 marks

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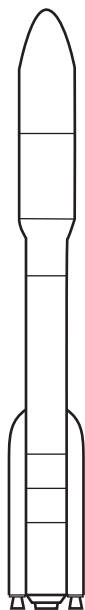
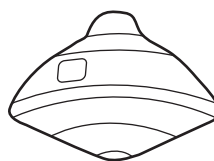
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**Question 8** (11 marks)

On 30 July 2020, the National Aeronautics and Space Administration (NASA) launched an Atlas rocket (Figure 7a) containing the Perseverance rover space capsule (Figure 7b) on a scientific mission to explore the geology and climate of Mars, and search for signs of ancient microbial life.

**Figure 7a****Figure 7b**

- a. At lift-off from launch, the acceleration of the rocket was  $7.20 \text{ m s}^{-2}$ . The total mass of the rocket and capsule at launch was 531 tonnes.

Calculate the magnitude and the direction of the thrust force on the rocket at launch. Take the gravitational field strength at the launch site to be  $g = 9.80 \text{ N kg}^{-1}$ . Give your answer in meganewtons. Show your working.

3 marks

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On 18 February 2021, the Perseverance rover space capsule, travelling at  $20\,000\text{ km h}^{-1}$ , entered Mars's atmosphere at an altitude of  $300\text{ km}$  above the surface of Mars. The mass of the capsule was  $1000\text{ kg}$ .

**b.** Calculate the kinetic energy of the capsule at this point. Show your working.

2 marks

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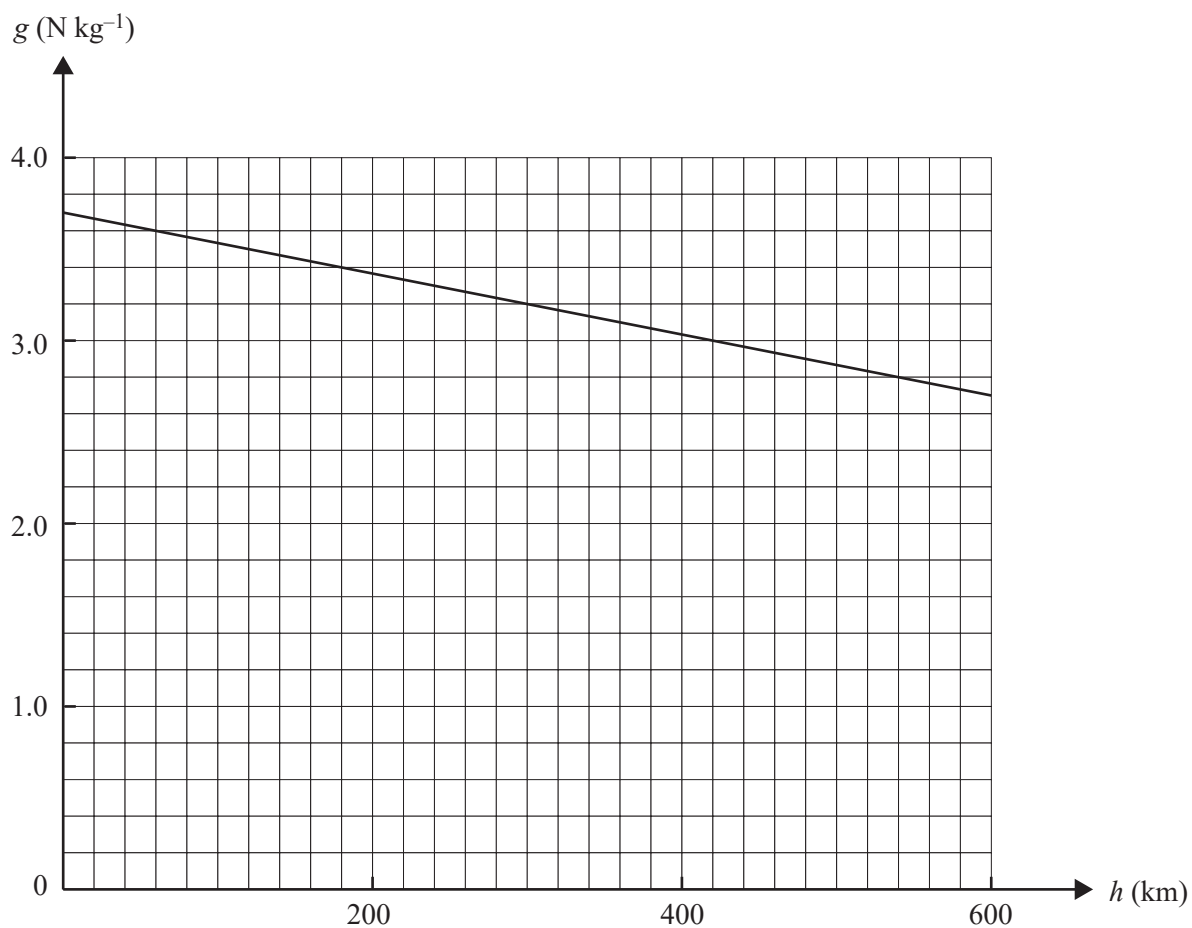
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Figure 8 shows the gravitational field strength of Mars ( $g$ ) versus altitude ( $h$ ).



**Figure 8**

- c. Calculate the gravitational potential energy of the capsule relative to the surface of Mars at an altitude of 300 km. Show your working.

3 marks

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- d. The capsule used aerodynamic braking as it descended through Mars's atmosphere to reduce its speed from  $20\,000\text{ km h}^{-1}$  to  $1600\text{ km h}^{-1}$ . The capsule was then at an altitude of 10 km above the surface of Mars and had  $\sim 1\%$  of its original combined gravitational potential energy and kinetic energy remaining.

Describe how  $\sim 99\%$  of the gravitational potential energy and kinetic energy of the capsule was transformed and dissipated as the capsule descended from an altitude of 300 km above the surface of Mars to an altitude of 10 km above the surface of Mars. No calculations are required.

3 marks

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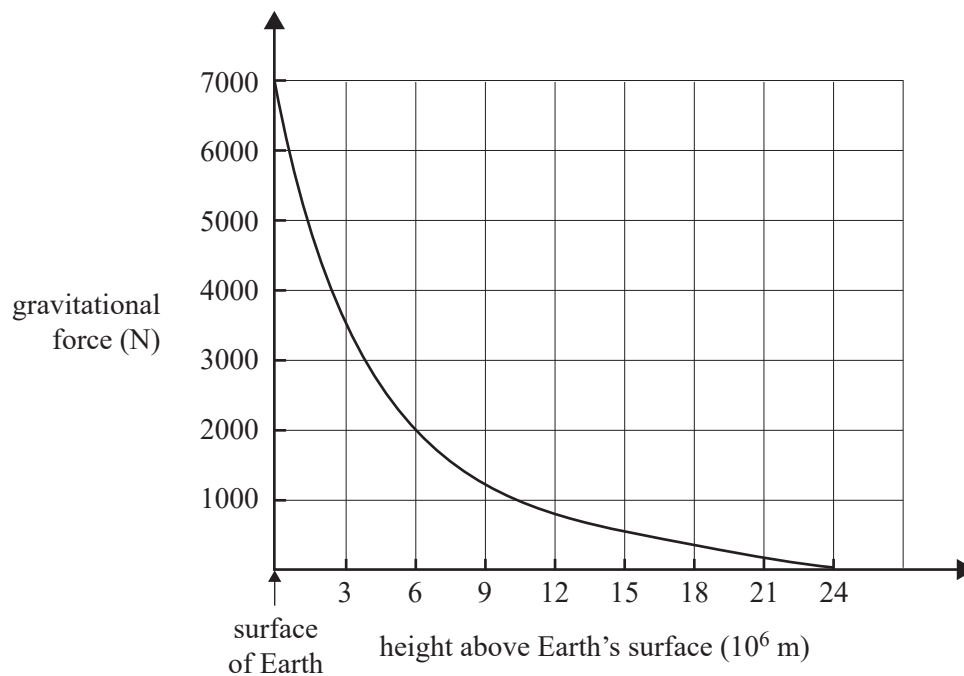
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**Question 4**

The Mars *Odyssey* spacecraft was launched from Earth to explore Mars. The graph below shows the gravitational force acting on the 700 kg Mars *Odyssey* spacecraft plotted against its height above Earth's surface.



Which one of the following is closest to the minimum launch energy needed for the Mars *Odyssey* spacecraft to 'escape' Earth's gravitational attraction?

- A.  $4.0 \times 10^4$  J
- B.  $1.5 \times 10^5$  J
- C.  $4.0 \times 10^{10}$  J
- D.  $1.5 \times 10^{11}$  J

**Question 6** (5 marks)

Measuring very small changes in Earth's surface mass, the 600 kg satellite GRACE-FO1 is in a circular orbit around Earth at an altitude of 500 km. The radius of Earth is  $6.37 \times 10^6$  m.

- a. Calculate the magnitude and direction of the satellite's centripetal acceleration. Give your answer correct to three significant figures. 3 marks

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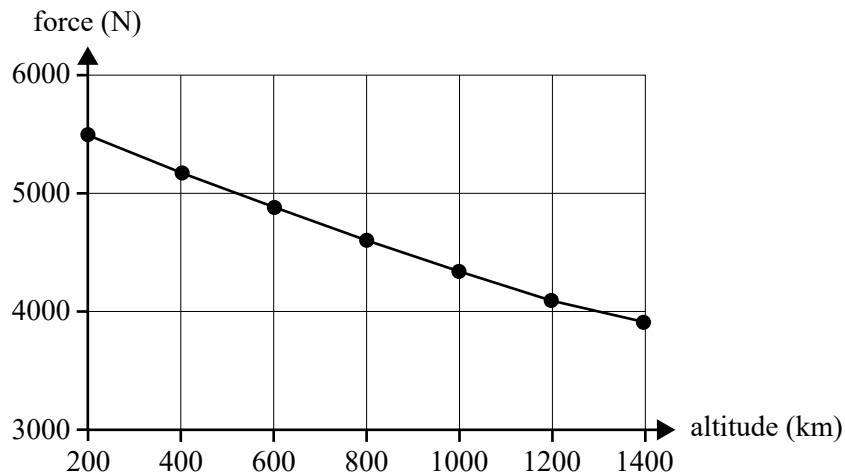
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$\text{m s}^{-2}$	
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- b. Figure 6 shows a graph of the gravitational force that would act on GRACE-FO1 for a range of altitudes.



**Figure 6**

Estimate the energy required to lift the satellite from its present orbit at an altitude of 500 km to a new orbit at an altitude of 1400 km. 2 marks

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