Do not write outside the box

**0 2** The Global Positioning System (GPS) uses satellites to support navigation on Earth.

**0 2 . 1** One GPS satellite is in a circular orbit at a height $h$ above the surface of the Earth.
The Earth has mass $M$ and radius $R$.

Show that the angular speed $\omega$ of the satellite is given by

$$\omega = \sqrt{\frac{GM}{(R+h)^3}}$$

**[2 marks]**

$$F = \frac{GMm}{r^2} = m\omega^2 r$$

$$r = R + h$$

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

$$\Rightarrow \omega = \sqrt{\frac{GM}{(R+h)^3}}$$

**0 2 . 2** Calculate the orbital period of the satellite when $h$ equals $2.02 \times 10^7$ m.

**[2 marks]**

$$\omega = \frac{2\pi}{T} = \sqrt{\frac{GM}{(R+h)^3}} \Rightarrow 2\pi\sqrt{\frac{(R+h)^3}{GM}} = T$$

$$R + h = 2.657 \times 10^7 \text{ m}$$

$$T = 4.3 \times 10^4 \text{ s}$$

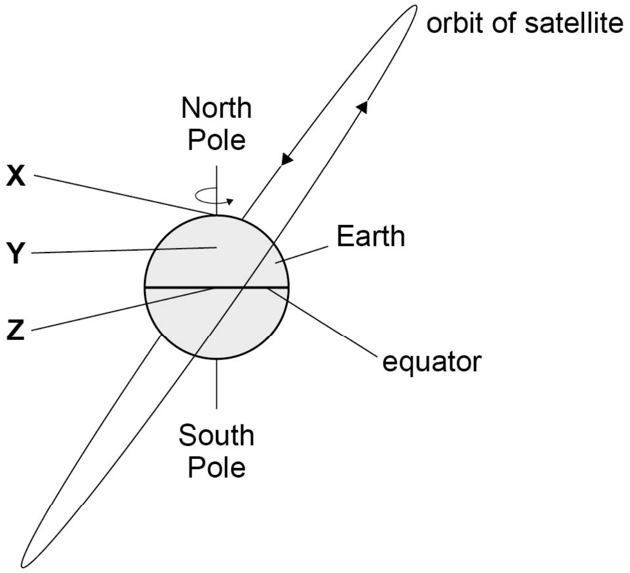
orbital period = ____________________ s

Do not write outside the box

**0 2 . 3** **Figure 3** shows the orbital plane of the satellite inclined at an angle to the equator. **X**, **Y** and **Z** are locations on the Earth.

**X** is at the North Pole, **Y** is on a high mountain and **Z** is on the equator.

**Figure 3**




The satellite is to be launched from one of the locations.

State and explain which launch site **X**, **Y** or **Z** minimises the amount of fuel required to send the satellite into its orbit.

**[2 marks]**

Nearer to the equator the satellite has more itial Ek from the rotation of the earth. So Z is best

(y might be better but the mountain would have to high enough that the difference in potential is greater than the reduced Ek - but then hard to launch from a mountain)

**Question 2 continues on the next page**

Do not write outside the box

**0 2 . 4** The satellite has a mass of 1630 kg.

Calculate the gravitational potential energy of the satellite when in the orbit in Question **02.2**.

**[2 marks]**

$R+h = 2.657\times10^{7}$ m :

$GPE = -\frac{GMm}{r}$

gravitational potential energy = $2.44\times10^{10}$ J J

**0 2 . 5** A different satellite is in a higher circular orbit.

Explain how the linear speed of this satellite compares with the linear speed of the satellite in Question **02.1**.

**[2 marks]**

$$v = \omega r \rightarrow \omega = \frac{v}{r}$$

$$F = \frac{GMm}{r^2} = m\omega^2 r$$

$$\frac{GM}{r^3} = \frac{v^2}{r^2} \rightarrow \frac{GM}{r} = v^2$$

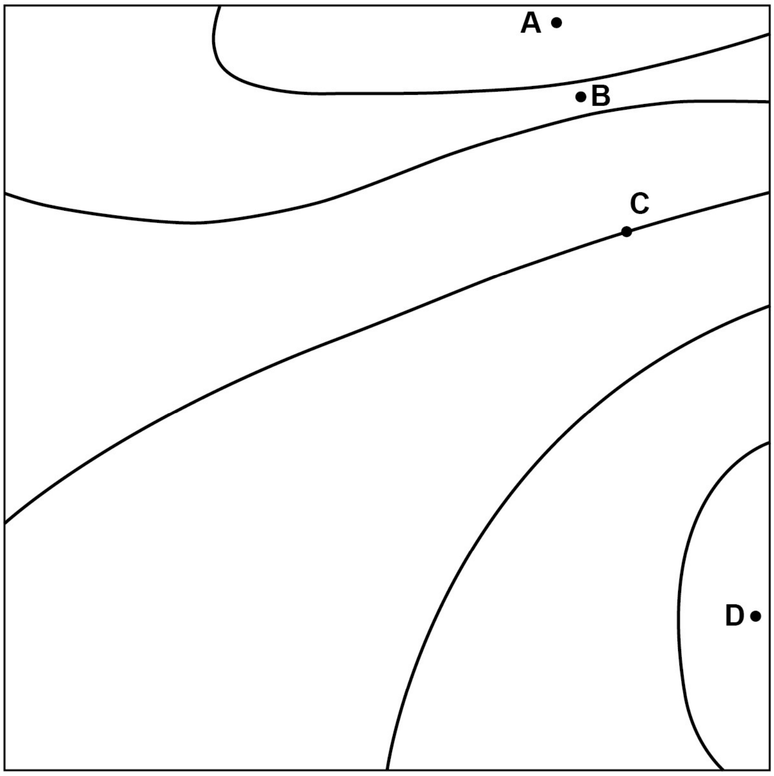
$$\sqrt{\frac{GM}{r}} = v$$

if r is greater then v will be smaller. v and root r are inversely proportional

10

Do not write outside the box

**1 1** The diagram shows gravitational equipotentials. Adjacent equipotentials are separated by an equal gravitational potential difference $V$.




Which point has the greatest gravitational field strength?

**[1 mark]**

**A** ⬭

**B** ⬭

**C** ⬭

**D** ⬭

gradient of potential is field strenghth

Do not write outside the box

**1 2** A planet has radius $R$ and density $\rho$. The gravitational field strength at the surface is $g$.

What is the gravitational field strength at the surface of a planet of radius $2R$ and density $2\rho$?

**[1 mark]**

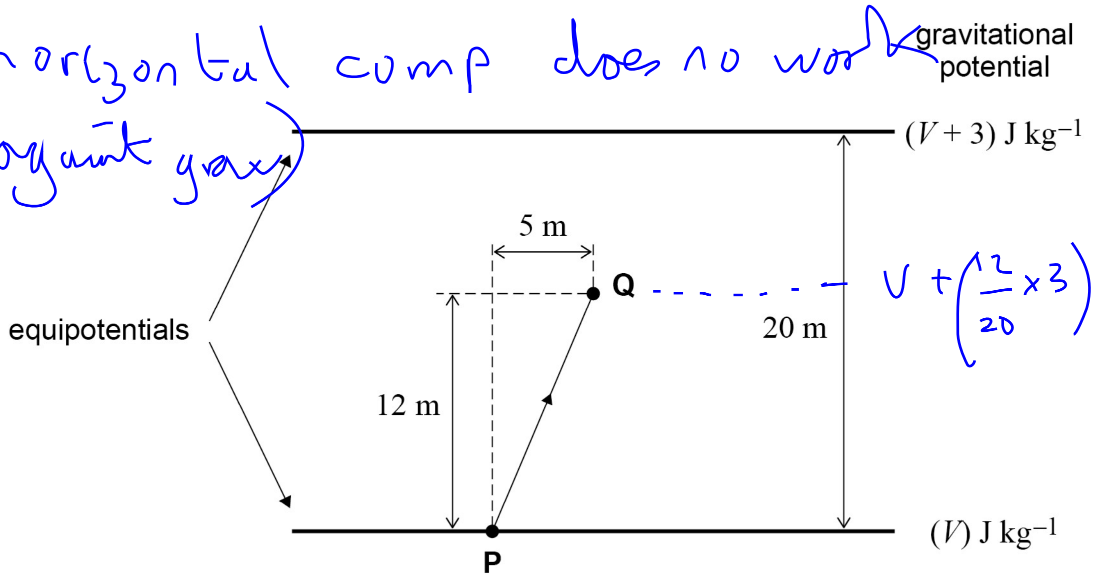
**A** $2g$ ☐

**B** $4g$ ☐

**C** $8g$ ☐

**D** $16g$ ☐

**1 3** The diagram shows equipotential lines for a uniform gravitational field. The lines are separated by 20 m.




An object of mass 4 kg is moved from **P** to **Q**.

What is the work done against gravity to move the object?

**[1 mark]**

**A** 7.2 J ☐

**B** 7.8 J ☐

**C** 10.2 J ☐

**D** 36 J ☐