Past-paper walk-through

Gravitational potential ▪ 13.4

eXercise

Questions in this set

- 9702/41 J25 Q1 ▪ 9 marks
- 9702/43 J25 Q1 ▪ 9 marks
- 9702/42 M25 Q2 ▪ 7 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 1

9702/41 J25 ▪ Q1 ▪ 9 marks

(a) Define gravitational potential at a point. **[2]**

(b)(i) Show that the mass of Mars is 6.4×10^{23} kg. **[3]**

(b)(ii) Calculate the gravitational potential ϕ at the surface of Mars. Give a unit with your answer. **[2]**

(c)(i) The orbit has a period of 25 hours.

State what can be deduced from this about the rotation of Mars on its axis. **[1]**

(c)(ii) State **one** other feature of this orbit. **[1]**

Solution 1

(a)

Mark scheme

- work done per unit mass **B1**
- work (done in) moving mass from infinity (to the point) **B1**

Solution 1

(b)(i) Worked steps

The orbital radius is measured from the **centre** of Mars, so add the planet's radius to the orbit's height before anything else.

- $r = 3.4 \times 10^6 + 1.7 \times 10^6 = 5.1 \times 10^6$ m
- For a circular orbit, gravity provides the centripetal force: $\dfrac{GMm}{r^2} = mr\omega^2$, so $GM = r^3\omega^2$ with $\omega = \dfrac{2\pi}{T}$.
- Rearranged: $M = \dfrac{4\pi^2 r^3}{GT^2}$.
- Substituting the values gives $M = 6.4 \times 10^{23}$ kg, as required.

Solution 1

Forgetting to add the radius is the single commonest error here, and it changes the answer by a factor of about two.

Mark scheme

- evidence of addition of 3.4×106 to 1.7×106 or 6.8×106 **C1**
- $GM \times 122 / (5.1 \times 106)$ or $GM \times 122 / (10.2 \times 106)$ **C1**
- $6.67 \times 10–11 \times M \times 122 \times [(5.1 \times 106)–1 – (10.2 \times 106)–1] = 5.1 \times 108$ leading to $M = 6.4 \times 1023$ kg **A1**

Solution 1

(b)(ii) Worked steps

- $\phi = -\dfrac{GM}{r}$, taken at the **surface**, so $r = 3.4 \times 10^6$ m.
- $\phi = -\dfrac{6.67 \times 10^{-11} \times 6.4 \times 10^{23}}{3.4 \times 10^6}$
- $\phi = -1.3 \times 10^7$ J kg^{-1}

Solution 1

The unit is asked for, and the **minus sign** is part of the answer: potential is zero at infinity and negative everywhere else.

Mark scheme

- $\phi =$ (–) (6.67 × 10–11 × 6.4 × 1023) / (3.4 × 106) C1
- $=$ –1.3 × 107 J kg–1 A1

Solution 1

(c)(i)

Mark scheme

- Mars takes (just under) 25 hours to rotate once on its axis **B1**

(c)(ii)

Mark scheme

- orbit is equatorial or orbit is in same direction as direction of rotation of Mars **B1**

Question 1

9702/43 J25 ▪ Q1 ▪ 9 marks

1 **(a)** Define gravitational potential at a point.

Question 1

(b) Mars is a planet that may be considered to be an isolated uniform sphere of radius 3.4×10^6 m.

A satellite of mass 122 kg is in orbit around Mars at a constant height of 1.7×10^6 m above the surface of the planet.

The height of the orbit is increased to 6.8×10^6 m above the surface. This increases the gravitational potential energy of the satellite by 5.1×10^8 J.

(i) Show that the mass of Mars is 6.4×10^{23} kg.

Question 1

[3]

(ii) Calculate the gravitational potential ϕ at the surface of Mars. Give a unit with your answer.

Question 1

(c) The satellite in **(b)** is moved to an orbit in which the satellite remains at the same point above the surface of Mars.

(i) The orbit has a period of 25 hours.

State what can be deduced from this about the rotation of Mars on its axis.

Question 1

(ii) State **one** other feature of this orbit.

Question 1

[Total: 9]

Solution 1

(a)

Mark scheme

- work done per unit mass
- work (done in) moving mass from infinity (to the point)

Solution 1

(b)(i) Worked steps

The orbital radius is measured from the **centre**, so add the planet's radius first.

- $r = 3.4 \times 10^6 + 1.7 \times 10^6 = 5.1 \times 10^6$ m
- Gravity supplies the centripetal force: $\dfrac{GMm}{r^2} = mr\omega^2$, so $GM = r^3\omega^2$ with $\omega = \dfrac{2\pi}{T}$.
- $M = \dfrac{4\pi^2 r^3}{GT^2} = 6.4 \times 10^{23}$ kg, as required.

Solution 1

Mark scheme

- evidence of addition of 3.4×106 to 1.7×106 or 6.8×106
- $GM \times 122 / (5.1 \times 106)$ or $GM \times 122 / (10.2 \times 106)$
- $6.67 \times 10–11 \times M \times 122 \times [(5.1 \times 106)–1 – (10.2 \times 106)–1] = 5.1 \times 108$
- leading to $M = 6.4 \times 1023$ kg

Solution 1

(b)(ii) Worked steps

- $\phi = -\dfrac{GM}{r}$ at the **surface**, so $r = 3.4 \times 10^6$ m.
- $\phi = -\dfrac{6.67 \times 10^{-11} \times 6.4 \times 10^{23}}{3.4 \times 10^6}$
- $\phi = -1.3 \times 10^7$ J kg^{-1}

Solution 1

The unit is asked for, and the sign is part of the answer: potential is zero at infinity, so everywhere else it is negative.

Mark scheme

- $\phi = (–)\ (6.67 \times 10–11 \times 6.4 \times 1023)\ /\ (3.4 \times 106)$
- $= –1.3 \times 107$ J kg–1

Solution 1

(c)(i)

Mark scheme

- Mars takes (just under) 25 hours to rotate once on its axis

Solution 1

(c)(ii) Worked steps

A satellite that stays above one point on the surface has to match the planet's own rotation in **two** ways, and the question asks for the condition beyond the period.

- Its orbit must be **equatorial** — an orbit inclined to the equator carries the satellite north and south of its starting latitude, so it traces a figure of eight rather than staying put.
- It must travel **in the same direction as the planet's rotation**, west to east for Mars as for the Earth.

Solution 1

Either statement earns the mark. Both follow from the same requirement: the satellite's angular velocity must equal the planet's as a **vector**, not just in magnitude — same direction and same axis, and the period alone fixes only the magnitude.

Mark scheme

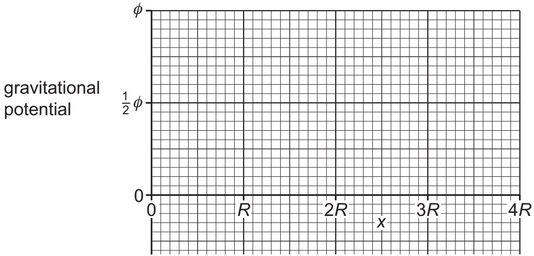
- orbit is equatorial
- or
- orbit is in same direction as direction of rotation of Mars
- 9702/43
- May/June 2025

Question 2

9702/42 M25 ▪ Q2 ▪ 7 marks

2 **(a)** The magnitude of the gravitational potential on the surface of a planet of radius R is ϕ. The planet can be considered to be an isolated sphere.

On Fig. 2.1, sketch the variation of the gravitational potential with distance x from the centre of the planet for values of x between R and $4R$.



Question 2

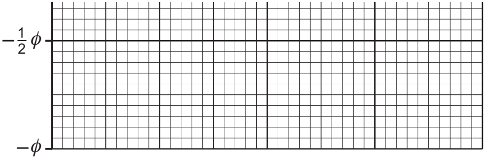
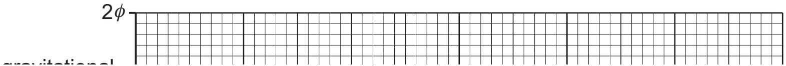


Fig. 2.1

[3]

(b) A satellite is in a geostationary orbit above the Earth. At time t = 0, the magnitude of the gravitational potential due to the Earth at the location of the satellite is ϕ.

On Fig. 2.2, sketch the variation of the gravitational potential due to the Earth at the location of the satellite for values of t between t = 0 and t = 24 hours.



Question 2

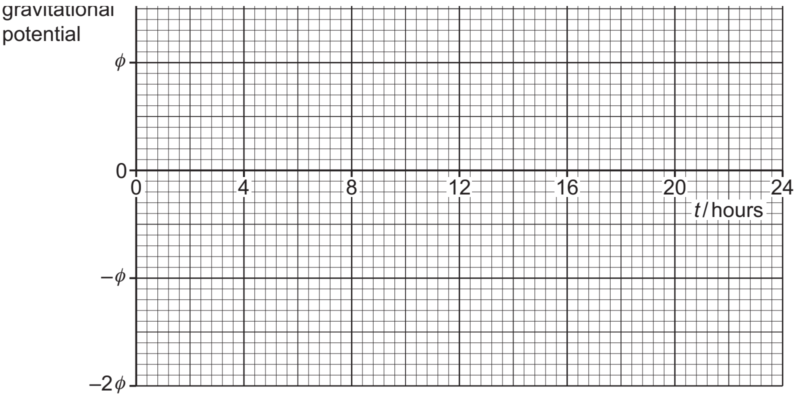


Fig. 2.2

[2]

Question 2

(c) The electric potential difference (p.d.) between two parallel plates is V, as shown in Fig. 2.3.

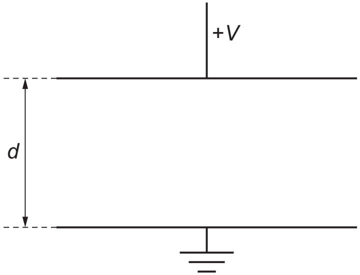


Fig. 2.3

The distance between the plates is d. The region between the plates is a vacuum.

On Fig. 2.4, sketch the variation of the electric potential with distance from the positive plate

Question 2

On Fig. 2.4, sketch the variation of the electric potential with distance from the positive plate.

Question 2

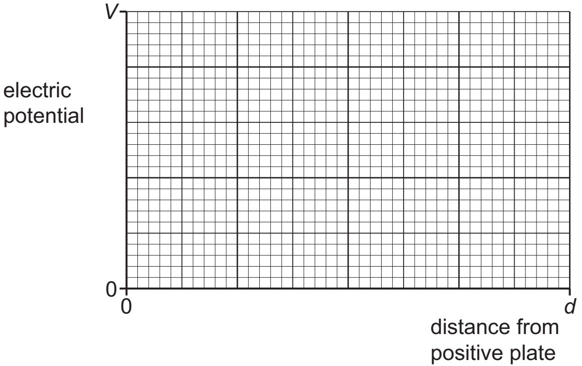


Fig. 2.4

[2]

Question 2

Question 2

[Total: 7]

Solution 2

(a) Worked steps

Let the algebra draw the graph. Gravitational potential is $\varphi = -\dfrac{GM}{r}$, so between $r = R$ and $r = 4R$ the sketch must show three things, and each carries a mark:

1. The line lies **entirely below the axis** — potential is defined as zero at infinity and is negative everywhere else, because gravity is attractive.
2. It is a **curve starting at** (R, φ) whose magnitude decreases continuously and whose gradient also decreases in magnitude — the curve rises towards the axis and flattens as it goes.
3. It passes through $(2R, \frac{1}{2}\varphi)$ and $(4R, \frac{1}{4}\varphi)$ — because $\varphi \propto \dfrac{1}{r}$, doubling the distance halves the magnitude.

Solution 2

Those two plotted points are what distinguish a $1/r$ curve from a $1/r^2$ one. Field strength falls as the inverse square; **potential falls as the inverse first power**, and sketching the wrong one is the standard way to lose two of the three marks.
The curve rises towards zero but never reaches it inside the range.

Mark scheme

- sketch:
- line from x $=$ R to x $=$ 4R entirely in the negative ϕ region
- curve with continuously decreasing magnitude and with gradient of continuously decreasing magnitude, starting at (R, $\pm\phi$)
- line passing through (2R, $\pm$½ϕ) and (4R, $\pm$¼ϕ)

Solution 2

(b) Worked steps

For a **circular** orbit the distance from the centre never changes, so neither does the potential.

- $\varphi = -\dfrac{GM}{r}$ with r constant, so φ is constant.
- The graph is therefore a **horizontal straight line** from $t = 0$ to $t = 24$ hours, starting at the negative value the orbital radius gives.

Solution 2

The line stays **below** the time axis for its whole length. The temptation is to draw something that varies over the orbit; nothing does, because potential depends only on the distance, and in a circle that is fixed.

Mark scheme

- horizontal straight line from $t = 0$ to $t = 24$ hours
- line starting at $(0, -\phi)$
- 9702/42
- February/March 2025

Solution 2

(c)

Mark scheme

- straight line with non-zero gradient from 0 to d
- line with negative gradient from (0, V) to (d, 0)