Mark schemes

Q1.

(a) Max 2 ✓✓

- $\omega = \frac{2\pi}{T} = \frac{2\pi}{27.3\times24\times60\times60} = 2.664\times10^{-6}\ (\text{rad s}^{-1})$

  or $v = \frac{2\pi r}{T} = \frac{2\pi\times4.489\times10^{8}}{27.3\times24\times60\times60} = 1196\ (\text{m s}^{-1})$

  Substitution or value
- Idea (resultant) gravitational field strength is equal to centripetal acceleration e.g.

  $g_R = a$ or $g_R = rw^2$ or $g_R = \frac{v^2}{r}$ $(= 3.19\times10^{-3}\ \text{m s}^{-2})$
- Idea that $g_M = g_R - g_E$

MP1 may be part of MP2

Ignore PoT, rounding errors and minor copy errors for MP1 and MP2

A substitution into $T^2 = \frac{4\pi^2 r^3}{GM}$ or equivalent is not accepted for the first bullet.

In the second bullet point do not allow g_m

MP3 must follow from correct working

1.21×10^{-3} ≥ 3 SF from correct working ✓ (N kg^{-1})

3

(b)

$$r = \sqrt{\frac{GM}{g_M}} = \sqrt{\frac{6.67\times10^{-11}\times7.35\times10^{22}}{1.21\times10^{-3}}}\ ✓$$

Allow ecf from ***part (a)***

6.37×10^{7} (m) ✓

Allow 6.38×10^{7} or 6.39×10^{7} or 6.4×10^{7} (m)

2

(c) Idea that the force from the Moon is in the opposite direction to the force from the Earth ✓1

An expression of why S_2 can't orbit Earth at this *ω* and *r* without the moon.

Idea that the Earth's gravitational force is too great or that it causes an angular velocity that is too great (without the presence of the Moon)

OR

Application of the idea that orbital period decreases with radius ✓2

An expression of how the moon enables S_2 to orbit Earth with this *ω* and *r*.
Idea that the Moon and the Earth reduce the resultant or centripetal force (causes the angular speed of S_2 and the Moon to be the same)
OR
Effect of the moon's gravitational force or field is to reduce the (angular) speed or increase period ✓$_3$

✓$_1$ Allow gravitational field strength from the Moon is in the opposite direction to the gravitational field strength from the Earth.

Condone balanced forces for ✓$_1$ but not ✓$_3$.

✓$_2$ Alternatives

(Without the Moon's gravitational influence)

- *the force or gravitational field (strength) from the Earth is too large*
- *the force or gravitational field is larger as it is closer to the Earth (than **S_1** or the moon)*
- *the required centripetal force is smaller as it closer to the Earth (than **S_1** or the moon, at the same angular velocity)*
- *satellite's angular velocity is greater than the Moon*
- *satellite's period is less than the moons*
- *satellite's angular velocity would be too large.*

✓$_3$ The resultant/total centripetal force/centripetal acceleration/gravitational field strength is less (because of the Moon's presence and so orbits at the same angular velocity as the Moon).

Reject the idea that the centripetal force on the moon and S_2 are the same.

Do not credit arguments based around being closer to moon

3

[8]

Q2.

(a) Any **one** from: ✓$_1$

- region in which a mass experiences force due to another mass
- (the field is conservative so) any change in potential energy only depends on the initial and final positions and not on path taken OWTTE
- the force is always attractive **OR** field lines point to the (centre of) mass **OR** the equipotential surfaces are spherical about the (centre of) mass
- gravitational force is a non-contact force

The field strength/force has an inverse-square variation (with distance). ✓$_2$

✓$_1$ is a general point about gravitational fields

✓$_2$ is specific to a radial gravitational field

The 'force is attractive' is insufficient

When required the term "force" must be used rather than words like "effect&", "gravity" etc.

When required the word 'mass' must be used rather than object or similar.terms

Condone reference to "circular" for "spherical" in describing an equipotential surface

2

(b) The shaded area corresponds to:
the (minimum) energy needed/work done to launch the space probe to a height of 8×10^6 m

OR

the <u>change</u> in GPE of the probe when moved from Earth's surface to a height of 8×10^6 m ✓

1

(c) Evaluates the gravitational field strength due to the Sun = 5.90×10^{-3} (N kg^{-1})
OR shows substitution into a valid equation ✓$_1$

Evaluates $\frac{g_S}{g_E}\left(=\frac{5.90\times10^{-3}}{9.81}=\right)$ 6.0×10^{-4} or 0.060% ✓$_2$

✓$_1$ $g_S = \frac{GM_S}{r^2} = \frac{6.67\times10^{-11}\times1.99\times10^{30}}{(1.50\times10^{11})^2}$

✓$_1$ ALTERNATIVE

The Universal gravitational equation for both bodies may be used:

$$\frac{g_{Sun}}{g_{Earth}} = \frac{M_{Sun}}{M_{Earth}} \times \left(\frac{r_{Earth}}{r_{Sun}}\right)^2$$

✓$_2$ Answer needed to at least 2 sf. If 3+ sf are seen, the answer must round to (6.01 or 6.02)×10^{-4}.

2

(d) The force from Earth because of its smaller mass, is less than the force from the Sun at a similar distance.

OR

The total work done in moving a long way from the Sun is much greater than that in moving a long way from the Earth because $m_E \ll m_S$.

Condone reference to "edge of Solar System" as "a similar distance".

1

(e) change in kinetic energy or kinetic energy per unit mass formulated ✓1 allow 2 sf

change in gravitational potential energy / potential formulated ✓2

evidence of intention to equate their ΔE_k and ΔE_p (even if not carried through; allow ecf) ✓3

mass of **X** = 6.3 × 10^{20} kg ✓4

✓1 $\frac{1}{2}m\left(v_B^2 - v_A^2\right)$ ***OR*** *1.18 × 10^{10} (J)* ***OR***

$\frac{\Delta E_k}{m} = \frac{1}{2}\left(v_B^2 - v_A^2\right)$ ***OR*** *m × 2.40 × 10^5 J*

✓2 $\Delta E_p = GMm\left(\frac{1}{1.7\times10^5} - \frac{1}{6.0\times10^6}\right)$

= GMm × 5.72 × 10^{-6}

OR $\frac{\Delta E_p}{m} = GM\left(\frac{1}{1.7\times10^5} - \frac{1}{6.0\times10^6}\right)$

Loss and gain may be replaced with change or Δ's for this mark.

✓3 $\frac{1}{2}\left(v_B^2 - v_A^2\right) = \frac{-GM}{r_A} - \frac{-GM}{r_B}$ *and*

substitution of data into working equation.

This can be seen anywhere in the solution.

4

[10]

Q3.

(a) G has greater mass with evidence from diagram ✓1

Explanation based on gravitational field strength or gravitational potential ✓2

E.g.

ALTERNATIVE A

G has greater mass because null point is closer to H ✓1

G field equals that of H at a greater distance from null than H ✓2

ALTERNATIVE B

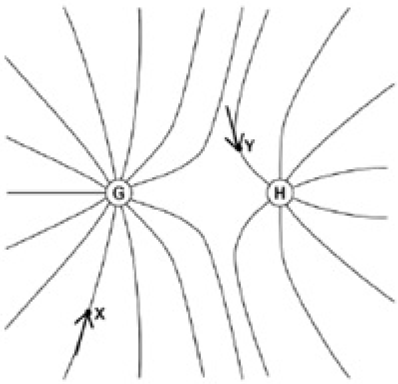
G has greater mass because the density of field lines is greater ✓1

Density of field lines depends on mass ✓2

Allow arguments based on potential maximum at null point.

2

(b) The lines given tangential arrows at X and Y that flow towards **G** and **H** respectively. ✓



Condone arrow heads only but if arrows are drawn in full they must not follow a curved line.

*Arrows are acceptable if drawn alongside X and Y but must not be further away than the **X** or **Y** label.*

1

(c)

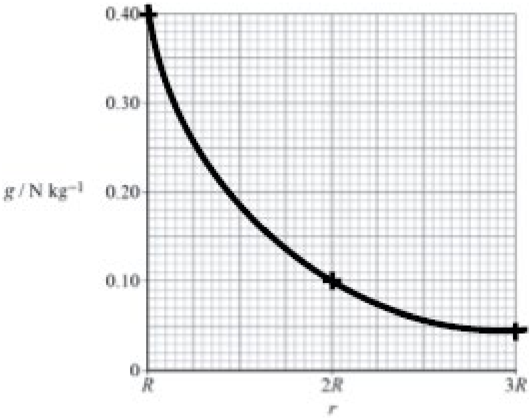
$$R = \left(\left\{ \frac{GM}{g} \right\}^{1/2} = \left\{ \frac{6.67 \times 10^{-11} \times 2.0 \times 10^{20}}{0.40} \right\}^{1/2} \right) = 1.8 \times 10^{5} \text{ (m)} \checkmark$$

1

(d) Sketch must pass through coordinates (R, 0.40), ($2R$, 0.10) and ($3R$, 0.044) ✓

Must be within one 1/2 small division of coordinates requested.

If plotted points differ a little from the line drawn then plotted points take priority.



1

(e) ALTERNATIVE A

(The area underneath) represents the energy transferred/work done (for an object) of 1 kg / unit mass ✓1a

Accept reverse direction $2R$ to R with appropriate direction of energy transfer/gravitational potential.

OR

(area is) energy transferred to/work done on the object per unit mass when it is moving from R to $2R$ ✓1a✓2a

In each alternative, the first answer is only awarded MP1. The second, fuller answer scores MP1 and MP2.

ALTERNATIVE B

change in gravitational potential ✓1b

OR

increase in gravitational potential when moving from R to $2R$ ✓1b✓2b

R may be given as 1.8×10^5

2

(f) Use of $F = \frac{GMm}{r^2}$ to find the force between **P** and **H** ✓1
($F_{(PH)}$ = 1.8 × 10^{13} N)

✓1 $F_{(PH)} = \frac{6.67\times10^{-11}\times3.0\times10^{25}\times2.0\times10^{20}}{(1.5\times10^{11})^2}$

✓2 Mark is for the use of the equation allowing for ecf from candidate's force calculation.

✓3 Correct answer only, no ecf this interim calculation may be subsumed in the next mark.

(Calculation of the resultant force

Use of $F_{\text{total}} = (F_{(PH)}^2 + F_{(PG)}^2)^{1/2}$) ✓2

$$\left(F_{\text{total}} = \left[(1.8\times10^{13})^2 + (6.4\times10^{12})^2\right]^{1/2}\right)$$

$F_{\text{total}} = 1.9\times10^{13}$ ✓3

Use of $a = \frac{F}{m} = \frac{1.9\times10^{13}}{2.0\times10^{20}}$ = 9.4 to 9.5 × 10^{-8} (m s^{-2}) ✓4

✓4 Allow ecf from F_{total}

Condone the vector addition of the acceleration to obtain the answer

acc^n due to G = 3.91 × 10^{-8} m s^{-2}

acc^n due to H = 8.9 × 10^{-8} m s^{-2}

4

(g) The resultant force is not (centripetal and continually) directed towards the centre of **H**.
OR
A circular orbit does not follow a gravitational equipotential (owtte) ✓

Condone lack of "resultant"

The answer can focus on the conditions necessary for circular motion eg the need for a centripetal force.

Or

At different locations on a circular path the total gravitational potential energy is different which requires energy which is not provided.

NB stating that the force is not perpendicular to the motion does not count as a full explanation as the motion has not been established.

1

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