Past-paper walk-through

Circular Motion ▪ 2.9

eXercise

Questions in this set

- 2024 Q1
- 2023 Q3
- 2018 Q1

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

2024 ▪ Q1

[Figure showing a track: Point A is at the top of a curved ramp at height $6R$ above the horizontal, with a block of mass M shown as a small square on the ramp near A. The ramp curves down to the horizontal level. On the horizontal section there is a small circular loop (Point B at its highest point, radius R) and further along, at the far right, a larger circular loop (Point C at its highest point, radius R) that sits on a raised platform of height $2R$ above the horizontal ground level.]
A block of mass M is released from rest at Point A, a height $6R$ above the horizontal. After being released, the block slides down a track, as shown. When released from Point A, the block does not lose contact with the track at any point. Points B and C are located at the highest points of their respective circular loops, both of radius R. All frictional forces are negligible.

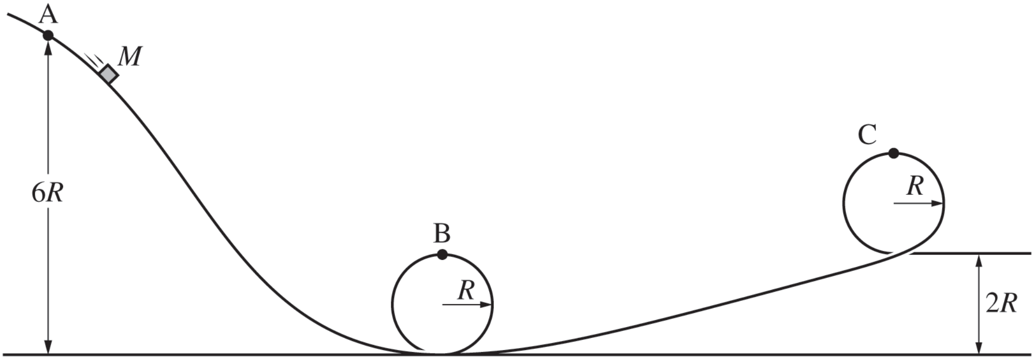
Question 1

(a) [Two energy bar chart diagrams, each with a vertical "Energy" axis (no numerical scale, gridlines shown as horizontal dashed lines) and two columns labeled U_g and K on the horizontal axis.]
Diagram A shows an energy bar chart that represents the gravitational potential energy U_g of the block-Earth system and the kinetic energy K of the block at Point A, when the block is released from rest at height $6R$. In Diagram A, the U_g column is shaded up to a height representing the full scale (six gridline units above zero), and the K column has zero height (block released from rest).
Diagram B has the same axes ("Energy" vertical axis with the same gridline scale, columns labeled U_g and K) but is unshaded, to be completed by the student.
(a) **Draw** shaded regions in Diagram B that represent the gravitational potential energy U_g and kinetic energy K of the block-Earth system when the block is located at Point B, a height $2R$ above the horizontal.

Question 1

- Shaded regions should start at the dashed line that represents zero energy.
- Represent any energy that is equal to zero with a distinct line on the zero-energy line.
- The relative height of each shaded region should reflect the magnitude of the respective energy consistent with the scale shown in Diagram A.

Question 1



Question 1

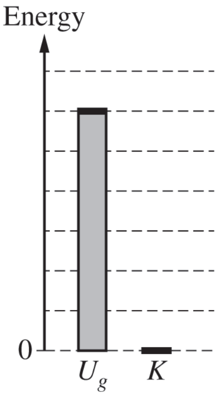


Diagram A

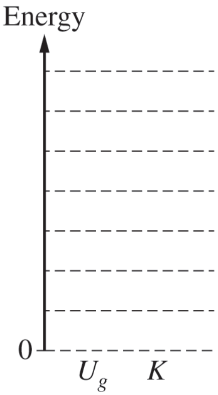


Diagram B

Question 1

2024 ▪ Q1

[Figure showing a track: Point A is at the top of a curved ramp at height $6R$ above the horizontal, with a block of mass M shown as a small square on the ramp near A. The ramp curves down to the horizontal level. On the horizontal section there is a small circular loop (Point B at its highest point, radius R) and further along, at the far right, a larger circular loop (Point C at its highest point, radius R) that sits on a raised platform of height $2R$ above the horizontal ground level.]

A block of mass M is released from rest at Point A, a height $6R$ above the horizontal. After being released, the block slides down a track, as shown. When released from Point A, the block does not lose contact with the track at any point. Points B and C are located at the highest points of their respective circular loops, both of radius R. All frictional forces are negligible.

(b) Starting with conservation of energy, **derive** an expression for the speed of the block at Point B. Express your answer in terms of R and physical constants, as

Question 1

appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference book.

Question 1

2024 ▪ Q1

[Figure showing a track: Point A is at the top of a curved ramp at height $6R$ above the horizontal, with a block of mass M shown as a small square on the ramp near A. The ramp curves down to the horizontal level. On the horizontal section there is a small circular loop (Point B at its highest point, radius R) and further along, at the far right, a larger circular loop (Point C at its highest point, radius R) that sits on a raised platform of height $2R$ above the horizontal ground level.]

A block of mass M is released from rest at Point A, a height $6R$ above the horizontal. After being released, the block slides down a track, as shown. When released from Point A, the block does not lose contact with the track at any point. Points B and C are located at the highest points of their respective circular loops, both of radius R. All frictional forces are negligible.

(c)(i) [A single dot representing the block, drawn on the page, with blank space around it for the student to draw force vectors.]

Question 1

On the following dot that represents the block, **draw** and **label** the forces (not components) that are exerted on the block at the instant the block slides through Point C. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

(c)(ii) A student claims that $4R$ is the minimum height of Point A, such that the block can slide through Point C without losing contact with the track after the block is released from rest. Briefly **explain** why this claim is incorrect.

Solution 1

(a)

Mark scheme

- Diagram A (given, at Point A, height $6R$): the U_g bar fills the whole scale (6 units) and $K = 0$ since the block starts at rest. By conservation of mechanical energy the total energy stays 6 units everywhere on the track. At Point B (height $2R$), U_g is proportional to height, so $U_g = 2$ units, and the rest converts to kinetic energy: $K = 6 - 2 = 4$ units. Full credit (2 points): draw the two bars in Diagram B so their total heights sum to 6 units (1 point — may be earned even if only one bar is drawn), AND draw the U_g bar with height exactly 2 units (1 point).

Solution 1

(b)

Mark scheme

- Derive v_B from conservation of energy: $E_i = E_f \Rightarrow U_{gA} = U_{gB} + K_B \Rightarrow mgy_A = mgy_B + \frac{1}{2}mv^2$. Substituting $y_A = 6R$, $y_B = 2R$: $Mg(6R) = Mg(2R) + \frac{1}{2}Mv^2 \Rightarrow g(6R) = g(2R) + \frac{1}{2}v^2 \Rightarrow \frac{1}{2}v^2 = 4gR \Rightarrow v = \sqrt{8gR}$. Points: a multi-step derivation that begins with conservation of energy (1 point); AND one of — the correct final answer $v = \sqrt{8gR}$, or the correct substitution of the initial/final heights ($6R$, $2R$, consistent with part (a)) (1 point).

Solution 1

(c)(i)

Mark scheme

- At Point C (top of the vertical loop) draw two arrows starting on the dot, both pointing straight down (toward the center of the loop): one labeled as the gravitational force (F_g, F_G, W, mg, Mg, "grav force", etc. — not G or g alone) and one labeled as the normal force (F_N, F_n, N, "normal force", or "track force"). Arrows of any nonzero magnitude earn credit. Points: downward arrow labeled gravitational force (1 point); downward arrow labeled normal force (1 point).

Solution 1

(c)(ii) Mark scheme

- The claim that $4R$ is the minimum height is incorrect: if the block were released from height $4R$, then by energy conservation the block would have speed equal to zero at Point C — and if the speed at the top of the loop is zero, the block cannot maintain contact with the track there (it needs nonzero speed so gravity plus the normal force can supply the centripetal force). So $4R$ is too low, not the true minimum. Full credit (1 point) for indicating any of: the block must be moving at the top of the loop to remain in contact; zero speed at Point C means the block loses contact; the block doesn't have enough kinetic energy/momentum and will lose contact.

Question 3

2023 ▪ Q3

[Figure: A small block attached to one end of a spring, the spring's other end attached to a short post; the post is mounted via a rod of length L to a vertical rod ("Rod") fixed on a horizontal rotating table.]

A small block of mass m_0 is attached to the end of a spring of spring constant k_0 that is attached to a rod on a horizontal table. The rod is attached to a motor so that the rod can rotate at various speeds about its axis. When the rod is not rotating, the block is at rest and the spring is at its unstretched length L, as shown. All frictional forces are negligible.

[Figure 1 (labeled "$t = t_1$"): Top view of the rotating table; the post/rod is at the center, a dashed circular path is shown, the block sits on the spring at distance L from the center plus a stretch d_1 (spring stretched a distance d_1 from its unstretched length).]

Question 3

[Figure 2 (labeled "$t = t_2$"): Same top-view setup, dashed circular path shown, block at distance L from the center plus a stretch d_2 from unstretched length, with d_2 drawn longer than d_1.]
(a)(i) At time $t = t_1$, the rod is spinning such that the block moves in a circular path with a constant tangential speed v_1 and the spring is stretched a distance d_1 from the spring's unstretched length, as shown in Figure 1. At time $t = t_2$, the rod is spinning such that the block moves in a circular path with a constant tangential speed v_2 and the spring is stretched a distance d_2 from the spring's unstretched length, where $d_2 > d_1$, as shown in Figure 2.
i. On the following dots, which represent the block at the locations shown in Figure 1 and Figure 2, draw the force that is exerted on the block by the spring at times $t = t_1$ and $t = t_2$. The spring force must be represented by a distinct arrow starting on, and

Question 3

pointing away from, the dot. Note: Draw the relative lengths of the vectors to reflect the relative magnitudes of the forces exerted by the spring at both times.
[Two blank boxes each containing a single dot in the center, labeled below "$t = t_1$" and "$t = t_2$" respectively, on which the student draws force-vector arrows.]
(a)(ii) ii. Referencing d_1 and d_2, describe your reasoning for drawing the arrows the length that you did in part (a)(i).
(a)(iii) iii. Is the tangential speed v_1 of the block at time $t = t_1$ greater than, less than, or equal to the tangential speed v_2 of the block at time $t = t_2$?
_______ $v_1 > v_2$ _______ $v_1 < v_2$ _______ $v_1 = v_2$
Justify your answer without using equations.

Question 3

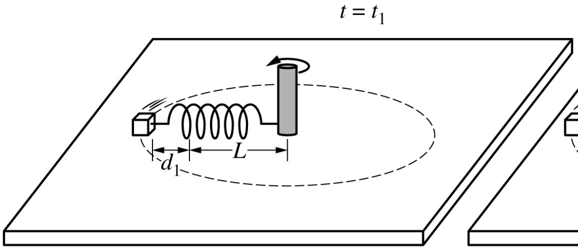


Figure 1

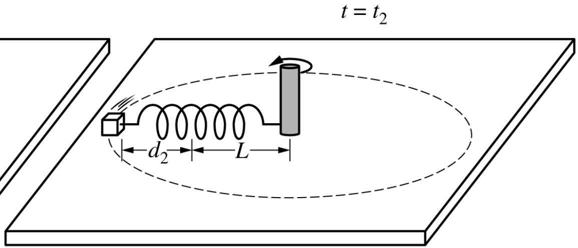
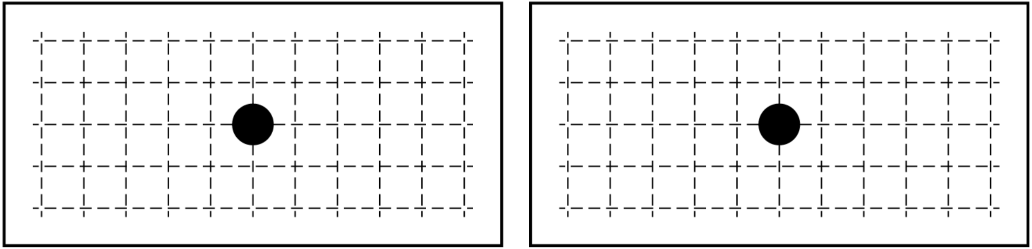


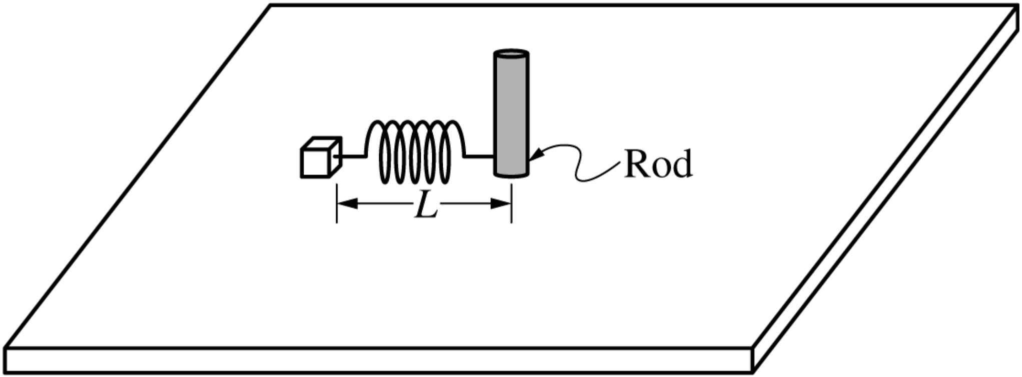
Figure 2

Question 3



$t = t_1$ $t = t_2$

Question 3



Question 3

2023 ▪ Q3

[Figure: A small block attached to one end of a spring, the spring's other end attached to a short post; the post is mounted via a rod of length L to a vertical rod ("Rod") fixed on a horizontal rotating table.]

A small block of mass m_0 is attached to the end of a spring of spring constant k_0 that is attached to a rod on a horizontal table. The rod is attached to a motor so that the rod can rotate at various speeds about its axis. When the rod is not rotating, the block is at rest and the spring is at its unstretched length L, as shown. All frictional forces are negligible.

[Figure 1 (labeled "$t = t_1$"): Top view of the rotating table; the post/rod is at the center, a dashed circular path is shown, the block sits on the spring at distance L from the center plus a stretch d_1 (spring stretched a distance d_1 from its unstretched length).]

[Figure 2 (labeled "$t = t_2$"): Same top-view setup, dashed circular path shown, block at distance L from the center plus a stretch d_2 from unstretched length, with d_2 drawn longer than d_1.]

Question 3

(b)(i) Consider a scenario where the block travels in a circular path where the spring is stretched a distance d from its unstretched length L.
i. Determine an expression for the magnitude of the net force F_{net} exerted on the block. Express your answer in terms of m_0, k_0, L, d, and fundamental constants, as appropriate.
(b)(ii) ii. Derive an equation for the tangential speed v of the block. Express your answer in terms of m_0, k_0, L, d, and fundamental constants, as appropriate.

Question 3

2023 ▪ Q3

[Figure: A small block attached to one end of a spring, the spring's other end attached to a short post; the post is mounted via a rod of length L to a vertical rod ("Rod") fixed on a horizontal rotating table.]
A small block of mass m_0 is attached to the end of a spring of spring constant k_0 that is attached to a rod on a horizontal table. The rod is attached to a motor so that the rod can rotate at various speeds about its axis. When the rod is not rotating, the block is at rest and the spring is at its unstretched length L, as shown. All frictional forces are negligible.
[Figure 1 (labeled "$t = t_1$"): Top view of the rotating table; the post/rod is at the center, a dashed circular path is shown, the block sits on the spring at distance L from the center plus a stretch d_1 (spring stretched a distance d_1 from its unstretched length).]
[Figure 2 (labeled "$t = t_2$"): Same top-view setup, dashed circular path shown, block at distance L from the center plus a stretch d_2 from unstretched length, with d_2 drawn longer than d_1.]

Question 3

(c) Does your equation for the tangential speed v of the block from part (b)(ii) agree with your reasoning from part (a)?

_______ Yes _______ No

Explain your reasoning.

Solution 3

(a)(i) Mark scheme

- On each dot (representing the block viewed from above at $t = t_1$ and $t = t_2$), draw a single vector arrow pointing consistently toward the center of the circular path (i.e., in the same direction in both diagrams, e.g. rightward), representing the net (spring) force on the block. 1 point for drawing consistently directed (e.g. rightward) arrows in both diagrams. 1 point for making the arrow at $t = t_2$ longer than the arrow at $t = t_1$, since the spring is stretched farther at t_2 ($d_2 > d_1$) so the force is greater there. Note: a maximum of 1 of the 2 points can be earned if extraneous unlabeled arrows are drawn, or if incorrect/extra labeled forces are drawn (only the net/spring force should be shown).

Solution 3

(a)(ii)

Mark scheme

- The spring (net) force is proportional to the stretch distance, $F = k_0 d$. Since $d_2 > d_1$, the spring is stretched farther at $t = t_2$, so the spring force — and therefore the net force on the block — is greater at t_2 than at t_1. This is why the force arrow drawn at $t = t_2$ in part (a)(i) is longer than the one at $t = t_1$.

Solution 3

(a)(iii) Mark scheme

- Select $v_1 < v_2$. Justification (no equations required): the net force on the block (the spring force) is greater at t_2 than at t_1 because $d_2 > d_1$; this net force provides the centripetal force that keeps the block on its circular path, and a larger net/centripetal force is associated with a greater tangential speed. So $v_2 > v_1$. Points: 1 for a correct selection with an attempted relevant justification (or one consistent with the response to part (a)(ii)); 1 for indicating that the spring force is the net force (stating $F = kx$ alone earns this); 1 for indicating that the net force is related to the block's speed or acceleration (the relationship need not be stated precisely).

Solution 3

(b)(i)

Mark scheme

- $F_{\text{net}} = k_0 d$ — the net force on the block equals the spring force, since the spring provides the only force along the direction of interest on the frictionless rotating rod: $F_{\text{net}} = \Sigma F = F_s = k_0 d$. (A bare answer of kx, without substituting the problem's own variables k_0 and d, does not earn this point, though it can be earned via a correct part (b)(ii).)

Solution 3

(b)(ii) Mark scheme

- Starting from Newton's second law for uniform circular motion, $\Sigma F = ma_c = \dfrac{m_0 v^2}{r}$, with radius $r = L + d$ and $F_{\text{net}} = k_0 d$: $k_0 d = \dfrac{m_0 v^2}{L+d}$. Solving for v: $v = \sqrt{\dfrac{k_0 d(L+d)}{m_0}}$. Points: 1 for a multistep derivation that begins with Newton's second law $\Sigma F = ma$; 1 for correctly substituting one of $\{k_0 d$ for force, v^2/r for centripetal acceleration, $(L+d)$ for the radius$\}$; 1 for the fully consistent final expression $v = \sqrt{k_0 d(L+d)/m_0}$ in terms of m_0, k_0, L, d.

Solution 3

(c) Mark scheme

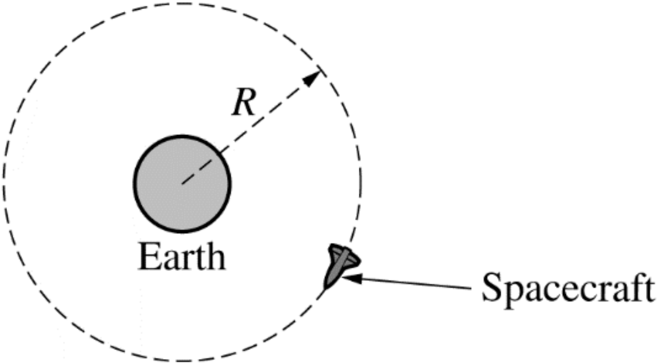
- Select 'Yes' — the equation from (b)(ii) agrees with the reasoning from part (a). Explanation: in $v = \sqrt{k_0 d(L+d)/m_0}$, v increases as d increases (both factors d and $L+d$ grow with d), consistent with the qualitative reasoning in part (a) that a larger stretch distance d (and hence larger spring/net force) produces a larger tangential speed — i.e., $v_2 > v_1$ since $d_2 > d_1$. Points: 1 for attempting to use functional dependence to relate tangential speed to the stretched distance (need not be applied correctly); 1 for a correct explanation of why the derived equation does (or does not) support the part (a) reasoning.

Question 1

2018 ▪ Q1

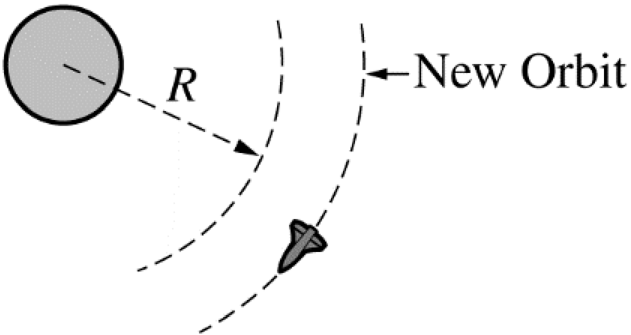
A spacecraft of mass m is in a clockwise circular orbit of radius R around Earth, as shown in the figure above. The mass of Earth is M_E.
[Figure: Earth (a solid grey circle, labeled "Earth") at the center, with a dashed circular orbit of radius R around it; a spacecraft icon sits on the orbit path, labeled "Spacecraft", indicating clockwise motion. Note: Figure not drawn to scale.]
(a) In the figure below, draw and label the forces (not components) that act on the spacecraft. Each force must be represented by a distinct arrow starting on, and pointing away from, the spacecraft.
[Figure: Earth shown at upper left with the spacecraft positioned on a dashed arc representing part of its orbit, provided blank for the student to draw and label force arrows. Note: Figure not drawn to scale.]

Question 1



Note: Figure not drawn to scale.

Question 1



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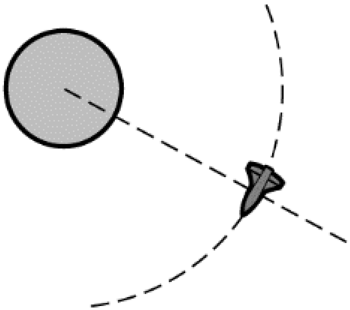
Question 1



Note: Figure not drawn to scale.

Question 1

2018 ▪ Q1

A spacecraft of mass m is in a clockwise circular orbit of radius R around Earth, as shown in the figure above. The mass of Earth is M_E.

[Figure: Earth (a solid grey circle, labeled "Earth") at the center, with a dashed circular orbit of radius R around it; a spacecraft icon sits on the orbit path, labeled "Spacecraft", indicating clockwise motion. Note: Figure not drawn to scale.]

(b)(i) Derive an equation for the orbital period T of the spacecraft in terms of m, M_E, R, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

(b)(ii) A second spacecraft of mass $2m$ is placed in a circular orbit with the same radius R. Is the orbital period of the second spacecraft greater than, less than, or equal to the orbital period of the first spacecraft?

Question 1

_____ Greater than _____ Less than _____ Equal to
Briefly explain your reasoning.

Question 1

2018 ▪ Q1

A spacecraft of mass m is in a clockwise circular orbit of radius R around Earth, as shown in the figure above. The mass of Earth is M_E.

[Figure: Earth (a solid grey circle, labeled "Earth") at the center, with a dashed circular orbit of radius R around it; a spacecraft icon sits on the orbit path, labeled "Spacecraft", indicating clockwise motion. Note: Figure not drawn to scale.]

(c) The first spacecraft is moved into a new circular orbit that has a radius greater than R, as shown in the figure below.

[Figure: Earth with the original dashed orbit of radius R shown alongside a larger, concentric dashed orbit labeled "New Orbit"; the spacecraft is shown on this larger new orbit. Note: Figure not drawn to scale.]

Is the speed of the spacecraft in the new orbit greater than, less than, or equal to the original speed?

Question 1

_____ Greater than _____ Less than _____ Equal to
Briefly explain your reasoning.

Solution 1

(a)

Mark scheme

- Only one force acts on the orbiting spacecraft: the gravitational force from Earth. Draw a single arrow starting on the spacecraft and pointing directly toward Earth's center, labeled F_g (gravity). No other forces (e.g. a forward 'motion' force) should be drawn. Scoring (2 points, 1 each): (1) an arrow directed toward Earth's center; (2) a correct label on that arrow identifying it as the gravitational force, with the arrow pointing toward Earth's center. Note: a maximum of 1 point can be earned if extraneous (incorrect) forces are also present.

Solution 1

(b)(i) Mark scheme

- Apply Newton's second law, setting the gravitational force equal to the centripetal force: $F_g = ma = \frac{mv^2}{R}$, so $\frac{GmM_E}{R^2} = \frac{mv^2}{R}$. Relate speed to period via the orbit's circumference: $v = \frac{2\pi R}{T}$. Combine and solve for T: $T = \sqrt{\frac{4\pi^2 R^3}{GM_E}}$ (equivalently $T^2 = \frac{4\pi^2 R^3}{GM_E}$, an acceptable final form). Scoring (3 points, 1 each): (1) using (or implying) Newton's second law and equating the centripetal force to the gravitational force, $\frac{GmM_E}{R^2} = \frac{mv^2}{R}$; (2) explicitly or implicitly determining

Solution 1

$v = \dfrac{2\pi R}{T}$; (3) a correct final answer algebraically equivalent to $T = \sqrt{4\pi^2 R^3/(GM_E)}$.

Solution 1

(b)(ii) Mark scheme

- Correct answer: 'Equal to.' The orbital period does not depend on the spacecraft's mass – from part (b)(i), $T = \sqrt{4\pi^2 R^3/(GM_E)}$ contains no dependence on m (mass cancels out of Newton's second law), so doubling the mass to $2m$ leaves the period unchanged for the same orbital radius R. Scoring (1 point): for a correct explanation that the period does not depend on the spacecraft's mass (or depends only on Earth's mass and the orbital radius), OR an explanation consistent with the (possibly incorrect) equation derived in part (b)(i). The explanation must be consistent with whichever box is checked.

Solution 1

(c)

Mark scheme

- Correct answer: 'Less than.' From the derivation in part (b)(i), $v = \sqrt{GM_E/R}$, so orbital speed decreases as the orbital radius R increases; a spacecraft in a larger orbit therefore moves slower than in the original orbit. Scoring (1 point): for a correct explanation of why speed decreases with increasing orbital radius (e.g., citing the part (b)(i) derivation step showing $v \propto 1/\sqrt{R}$). Note: if the wrong option is selected, the explanation is not graded.