Past-paper walk-through

Newton's Second Law ▪ 2.5

eXercise

Questions in this set

- 2025 Q4
- 2019 Q2
- 2018 Q1
- 2016 Q1
- 2015 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 4

2025 ▪ Q4

In Scenario 1, a swimmer holds a block of mass m at rest in a tank of freshwater with density ρ_1, as shown in Figure 1. The block is released from rest and accelerates upward with an initial acceleration a_1. All frictional forces are negligible.

Figure 1

[Figure 1: A tank of freshwater with density ρ_1 labeled in the bottom corner. A swimmer wearing scuba gear, mask, and flippers holds a block of mass m in both hands, arms extended forward, underwater.]

In Scenario 2, the swimmer holds the same block at rest in a tank of salt water with density ρ_2, where $\rho_2 > \rho_1$. The swimmer again releases the block from rest, and the block accelerates upward with initial acceleration a_2. All frictional forces are negligible.

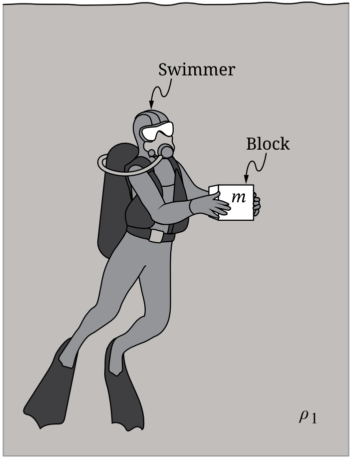
(a) Indicate whether a_1 is greater than, less than, or equal to a_2 by writing one of the following in your answer booklet.

Question 4

- $a_1 > a_2$
- $a_1 < a_2$
- $a_1 = a_2$

Justify your answer in terms of ALL forces exerted on the block in each scenario. Use qualitative reasoning beyond referencing equations.

Question 4



Question 4

2025 ▪ Q4

In Scenario 1, a swimmer holds a block of mass m at rest in a tank of freshwater with density ρ_1, as shown in Figure 1. The block is released from rest and accelerates upward with an initial acceleration a_1. All frictional forces are negligible.

Figure 1

[Figure 1: A tank of freshwater with density ρ_1 labeled in the bottom corner. A swimmer wearing scuba gear, mask, and flippers holds a block of mass m in both hands, arms extended forward, underwater.]

In Scenario 2, the swimmer holds the same block at rest in a tank of salt water with density ρ_2, where $\rho_2 > \rho_1$. The swimmer again releases the block from rest, and the block accelerates upward with initial acceleration a_2. All frictional forces are negligible.

(b) Consider the general case where a block of mass m and volume V is completely submerged in a fluid of density ρ.

Question 4

Starting with Newton's second law, **derive** an expression for the initial upward acceleration a of the block when the block is released from rest. Express your answer in terms of m, V, ρ, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

Question 4

2025 ▪ Q4

In Scenario 1, a swimmer holds a block of mass m at rest in a tank of freshwater with density ρ_1, as shown in Figure 1. The block is released from rest and accelerates upward with an initial acceleration a_1. All frictional forces are negligible.

Figure 1

[Figure 1: A tank of freshwater with density ρ_1 labeled in the bottom corner. A swimmer wearing scuba gear, mask, and flippers holds a block of mass m in both hands, arms extended forward, underwater.]

In Scenario 2, the swimmer holds the same block at rest in a tank of salt water with density ρ_2, where $\rho_2 > \rho_1$. The swimmer again releases the block from rest, and the block accelerates upward with initial acceleration a_2. All frictional forces are negligible.

Question 4

(c) Indicate whether the expression for the acceleration a you derived in part B is or is not consistent with the claim made in part A. Briefly **justify** your answer by referencing your derivation in part B.

Solution 4

(a) Mark scheme

- $a_1 < a_2$ (the freshwater block's acceleration is less than the saltwater block's). Justification: both blocks have the same weight mg (same mass), submerged in their respective fluids, so the downward gravitational force is identical in both cases. Since saltwater is denser than freshwater, and buoyant force is proportional to fluid density, the block in saltwater experiences a larger buoyant force than the block in freshwater. With equal weight but a larger buoyant force, the saltwater block has a larger net upward force and therefore a larger acceleration. Point A1 for indicating $a_1 < a_2$; Point A2 for a justification that the blocks have the same weight/mass; Point A3 for a justification that saltwater exerts a larger buoyant

Solution 4

force than freshwater (equivalently, that freshwater exerts a smaller buoyant force than saltwater).

Solution 4

(b) Mark scheme

- Starting from Newton's second law applied to the block: $\Sigma F = m_{\text{sys}} a_{\text{sys}}$, i.e. $F_B - mg = ma$. With the buoyant force $F_B = \rho V g$ (fluid density $\times$ submerged volume $\times g$): $\rho V g - mg = ma$, so $a = \dfrac{\rho V g}{m} - g$. Point B1 for a multistep derivation that includes Newton's second law; Point B2 for indicating $\rho V g$ is the buoyant force; Point B3 for a correct expression for the initial upward acceleration a consistent with the indicated buoyant-force expression. A correct, isolated final expression for a earns both B2 and B3.

Solution 4

(c) Mark scheme

- Yes — the expression derived in part B is consistent with the claim made in part A. In $a = \dfrac{\rho V g}{m} - g$, the acceleration a increases as the fluid density ρ increases, since ρ sits in the numerator of the $\frac{\rho V g}{m}$ term (i.e. a is directly/proportionally related to ρ). Because saltwater has a greater density than freshwater, this confirms the saltwater block has the larger acceleration, matching the $a_1 < a_2$ claim from part A. Point C1 for attempting to address the functional dependence between a and ρ in the part-B expression (using language such as proportional, inversely proportional, related, numerator, or denominator — it need not be used correctly to earn this point); Point C2 for correctly using that functional

Solution 4

dependence to evaluate the relationship between a and ρ, consistent with both the part-B expression and the part-A claim.

Question 2

2019 ▪ Q2

[Diagram: A horizontal tabletop with Block A resting on top of it near the right edge. A pulley is mounted at the right edge of the tabletop. A light string runs from Block A horizontally to the pulley, then vertically down over the pulley to Block B, which hangs below the tabletop's edge.]

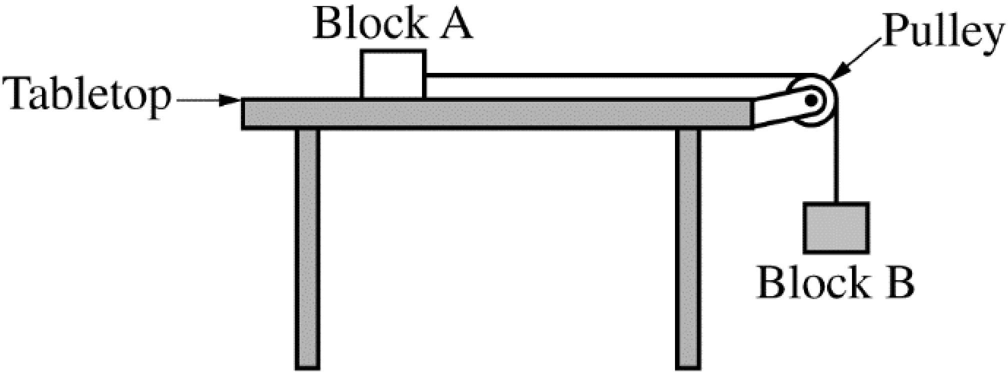
This problem explores how the relative masses of two blocks affect the acceleration of the blocks. Block A, of mass m_A, rests on a horizontal tabletop. There is negligible friction between block A and the tabletop. Block B, of mass m_B, hangs from a light string that runs over a pulley and attaches to block A, as shown above. The pulley has negligible mass and spins with negligible friction about its axle. The blocks are released from rest.

(a)(i) Suppose the mass of block A is much greater than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

Question 2

Briefly explain your reasoning without deriving or using equations.
(a)(ii) Now suppose the mass of block A is much less than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.
Briefly explain your reasoning without deriving or using equations.

Question 2



Question 2

Question 2

2019 ▪ Q2

[Diagram: A horizontal tabletop with Block A resting on top of it near the right edge. A pulley is mounted at the right edge of the tabletop. A light string runs from Block A horizontally to the pulley, then vertically down over the pulley to Block B, which hangs below the tabletop's edge.]

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(b) Now suppose neither block's mass is much greater than the other, but that they are not necessarily equal. The dots below represent block A and block B, as indicated by the labels. On each dot, draw and label the forces (not components) exerted on

Question 2

that block after release. Represent each force by a distinct arrow starting on, and pointing away from, the dot.
[Diagram: Two separate large dots side by side on the page, one labeled “Block A” below it and the other labeled “Block B” below it, for the student to draw force vectors on.]

Question 2

2019 ▪ Q2

[Diagram: A horizontal tabletop with Block A resting on top of it near the right edge. A pulley is mounted at the right edge of the tabletop. A light string runs from Block A horizontally to the pulley, then vertically down over the pulley to Block B, which hangs below the tabletop's edge.]

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(c) Derive an equation for the acceleration of the blocks after release in terms of m_A, m_B, and physical constants, as appropriate. If you need to draw anything other than

Question 2

what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

Question 2

2019 ▪ Q2

[Diagram: A horizontal tabletop with Block A resting on top of it near the right edge. A pulley is mounted at the right edge of the tabletop. A light string runs from Block A horizontally to the pulley, then vertically down over the pulley to Block B, which hangs below the tabletop's edge.]

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(d) Consider the scenario from part (a)(ii), where the mass of block A is much less than the mass of block B. Does your equation for the acceleration of the blocks from part (c) agree with your reasoning in part (a)(ii)?

Question 2

_____ Yes _____ No

Briefly explain your reasoning by addressing why, according to your equation, the acceleration becomes (or approaches) a certain value when m_A is much less than m_B.

Question 2

2019 ▪ Q2

[Diagram: A horizontal tabletop with Block A resting on top of it near the right edge. A pulley is mounted at the right edge of the tabletop. A light string runs from Block A horizontally to the pulley, then vertically down over the pulley to Block B, which hangs below the tabletop's edge.]

This problem explores how the relative masses of two blocks affect the acceleration of the blocks. Block A, of mass m_A, rests on a horizontal tabletop. There is negligible friction between block A and the tabletop. Block B, of mass m_B, hangs from a light string that runs over a pulley and attaches to block A, as shown above. The pulley has negligible mass and spins with negligible friction about its axle. The blocks are released from rest.

(e) While the blocks are accelerating, the tension in the vertical portion of the string is T_1. Next, the pulley of negligible mass is replaced with a second pulley whose mass is

Question 2

not negligible. When the blocks are accelerating in this scenario, the tension in the vertical portion of the string is T_2. How do the two tensions compare to each other?

_____ $T_2 > T_1$ _____ $T_2 = T_1$ _____ $T_2 < T_1$

Briefly explain your reasoning.

Solution 2

(a)(i) Mark scheme

- Correct claim: the acceleration is nearly zero / small / negligible / much less than g / '<<g'. Point 1: for a correct qualitative answer with an attempted, consistent justification. Point 2: for correct reasoning. Reasoning: block A has a much greater mass (much greater inertia) than block B, so block A strongly resists acceleration and the light block B cannot meaningfully accelerate it; the acceleration of the connected system is therefore nearly zero. (Example 2-point answers: 'Very small, because block A has a large inertia, it won't speed up much.' / 'Close to zero because block B is so light that it can hardly budge block A.')

Solution 2

(a)(ii)

Mark scheme

- Correct claim: the acceleration is nearly g (acceptable: 'g', '9.8 m/s^2', '10 m/s^2', or just '9.8'/'10'). The single point is earned for a correct answer WITH correct justification. Reasoning: block A has negligible mass compared to block B and negligible friction with the tabletop, so essentially no tension is needed to accelerate block A; block B is therefore nearly in free fall, and the string tension is nearly zero, giving the whole system an acceleration close to g.

Solution 2

(b) Mark scheme

- Free-body diagram, Block A (on the tabletop): three distinct force arrows – normal force N (or F_N) pointing straight UP from the table; gravity F_g (or mg, W, $m_A g$) pointing straight DOWN; tension F_T pointing horizontally toward the pulley (i.e. toward block B's side). Free-body diagram, Block B (hanging): two distinct force arrows – tension F_T pointing straight UP (toward the pulley); gravity F_g (or $m_B g$) pointing straight DOWN. Points: 1 for a correct, correctly labeled normal force on block A only (acceptable labels: N, F_N, 'normal force', F_{table}, 'table force', or any label indicating a normal/table force); 1 for correct, correctly labeled gravitational forces on BOTH diagrams (acceptable: F_g, F_{grav}, W, mg, $m_A g$ – NOT G or g alone – and no extraneous forces on either diagram); 1 for correct,

Solution 2

correctly labeled tension forces on BOTH diagrams (acceptable: 'tension', 'string force', F_T, $F_{tension}$, F_{string}, F_S, T – NOT $m_B g$, F_{m_B}, or 'force from block B'). Forces must be drawn as distinct arrows starting on and pointing away from the dot, not components.

Solution 2

(c) Mark scheme

- Apply Newton's second law separately to each block, then combine. Block B (down positive): $m_B g - T = m_B a$. Block A (horizontal): $T = m_A a$. Since the string is inextensible and the tension magnitude is the same on both blocks, combine to eliminate T: $m_B g - m_A a = m_B a \Rightarrow a = \frac{m_B}{m_A + m_B} g$. Alternate whole-system method: treat both blocks + string as one system of total mass $m_A + m_B$ with no net internal force; the only external force along the direction of motion is gravity on block B, so $F_{net} = m_B g = (m_A + m_B)a$, giving the same $a = \frac{m_B}{m_A + m_B} g$. Points: 1 for using separate Newton's-second-law equations for each block (or the equivalent whole-system equation containing no internal

Solution 2

forces); 1 for correctly combining the equations with correct notation, using m_A and m_B, correctly indicating that the same tension force acts on both blocks and that they share the same acceleration; 1 for the correct final equation with supporting work: $a = \frac{m_B}{m_A + m_B} g$.

Solution 2

(d) Mark scheme

- Correct answer: 'Yes' – the equation from part (c), $a = \dfrac{m_B}{m_A + m_B} g$, agrees with the reasoning in part (a)(ii). The single point is earned for valid reasoning connecting the two: when $m_A \ll m_B$, the m_A term in the denominator can be neglected, so $(m_A + m_B) \approx m_B$ and $a \approx \dfrac{m_B}{m_B} g = g$, matching the claim in part (a)(ii) that the acceleration approaches g. ('No' is acceptable ONLY if it is consistent with an equation from part (c) that does not actually reduce to g in this limit, or with an inconsistent answer given in (a)(ii).)

Solution 2

(e) Mark scheme

- Correct answer: $T_2 > T_1$ (a maximum of 1 point can be earned if the wrong option is selected). Point 1: for reasoning that the acceleration of both blocks is SMALLER in the second (heavier-pulley) scenario, because the pulley's now-nonzero rotational inertia requires torque/energy to spin it up, leaving less net force available to accelerate the blocks. Point 2: for connecting this, via Newton's second law applied to block B ($\vec{a} = \sum \vec{F}/m$, i.e. $T = m_B g - m_B a$ or $m_B g - T = m_B a$), to conclude that a SMALLER acceleration of block B implies a LARGER tension T_2 (closer in magnitude to the gravitational force on block B than T_1 was).

Question 1

2018 ▪ Q1

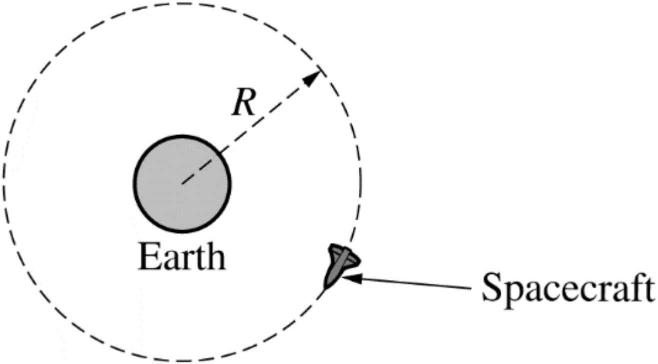
A spacecraft of mass m is in a clockwise circular orbit of radius R around Earth, as shown in the figure above. The mass of Earth is M_E.

[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.

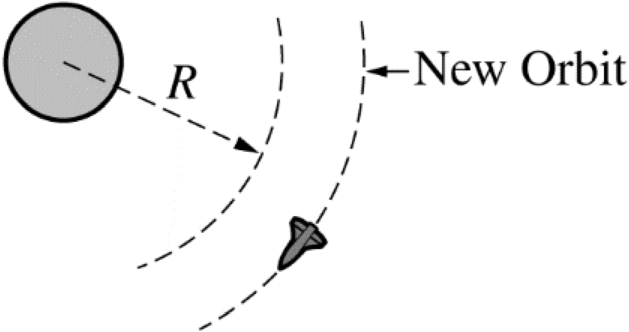
[Figure: Earth shown at upper left with the spacecraft positioned on a dashed arc representing part of its orbit, provided blank for the student to draw and label force arrows. Note: Figure not drawn to scale.]

Question 1



Note: Figure not drawn to scale.

Question 1



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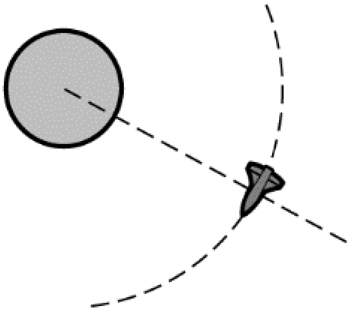
Question 1



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Question 1

2018 ▪ Q1

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[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.

Question 1

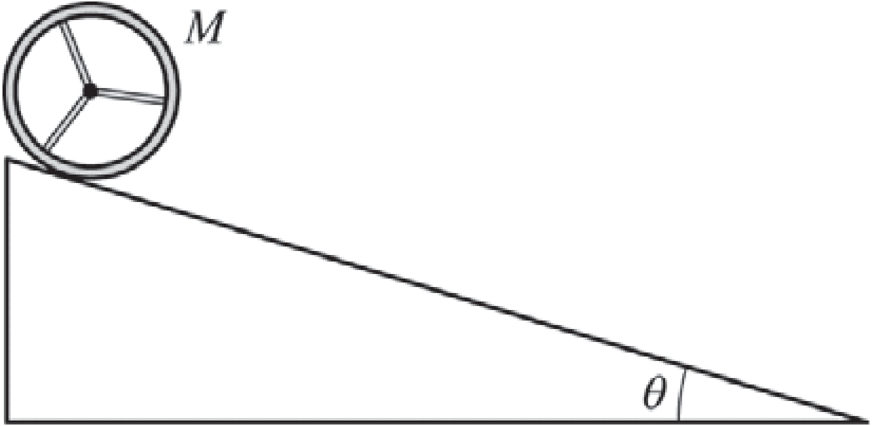
2016 ▪ Q1

A wooden wheel of mass M, consisting of a rim with spokes, rolls down a ramp that makes an angle θ with the horizontal, as shown above. The ramp exerts a force of static friction on the wheel so that the wheel rolls without slipping.
[Figure at top of page: A wheel of mass M sits at the top of an inclined ramp that makes angle θ with the horizontal (a right triangle shown in profile, with the wheel resting at the top of the incline).]
(a)(i) On the diagram below, draw and label the forces (not components) that act on the wheel as it rolls down the ramp, which is indicated by the dashed line. To clearly indicate at which point on the wheel each force is exerted, draw each force as a distinct arrow starting on, and pointing away from, the point at which the force is exerted. The lengths of the arrows need not indicate the relative magnitudes of the forces.

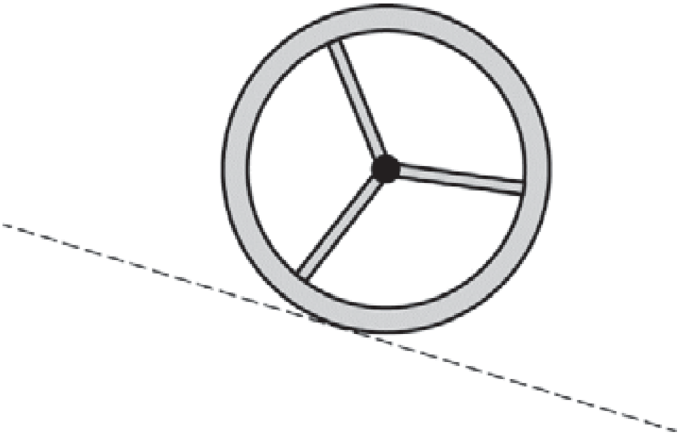
Question 1

[Diagram: a wheel with spokes resting on a dashed line representing the ramp surface, for the student to draw force vectors on.]
(a)(ii) As the wheel rolls down the ramp, which force causes a change in the angular velocity of the wheel with respect to its center of mass?
Briefly explain your reasoning.

Question 1



Question 1



Question 1

2016 ▪ Q1

A wooden wheel of mass M, consisting of a rim with spokes, rolls down a ramp that makes an angle θ with the horizontal, as shown above. The ramp exerts a force of static friction on the wheel so that the wheel rolls without slipping.

[Figure at top of page: A wheel of mass M sits at the top of an inclined ramp that makes angle θ with the horizontal (a right triangle shown in profile, with the wheel resting at the top of the incline).]

(b) For this ramp angle, the force of friction exerted on the wheel is less than the maximum possible static friction force. Instead, the magnitude of the force of static friction exerted on the wheel is 40 percent of the magnitude of the force or force component directed opposite to the force of friction. Derive an expression for the linear acceleration of the wheel's center of mass in terms of M, θ, and physical constants, as appropriate.

Question 1

2016 ▪ Q1

A wooden wheel of mass M, consisting of a rim with spokes, rolls down a ramp that makes an angle θ with the horizontal, as shown above. The ramp exerts a force of static friction on the wheel so that the wheel rolls without slipping.

[Figure at top of page: A wheel of mass M sits at the top of an inclined ramp that makes angle θ with the horizontal (a right triangle shown in profile, with the wheel resting at the top of the incline).]

(c) In a second experiment on the same ramp, a block of ice, also with mass M, is released from rest at the same instant the wheel is released from rest, and from the same height. The block slides down the ramp with negligible friction.

(c)(i) Which object, if either, reaches the bottom of the ramp with the greatest speed?

_____ Wheel _____ Block _____ Neither; both reach the bottom with the same speed.

Question 1

Briefly explain your answer, reasoning in terms of forces.

(c)(ii) Briefly explain your answer again, now reasoning in terms of energy.

Solution 1

(a)(i) Mark scheme

- Force diagram on the wheel: (1) a labeled arrow for the gravitational force mg, starting at the wheel's center and pointing straight down [1 pt]. (2) labeled arrows for the friction force F_f and normal force F_n (or a single arrow for their resultant), with no extraneous forces [1 pt] — F_f starts at the wheel-ramp contact point and points up the ramp (along the ramp surface); F_n starts at the wheel-ramp contact point and is perpendicular to the ramp, directed toward the wheel's center (does not need to pass exactly through the center, just reasonably close). Scoring: 1 pt for the correct mg arrow from the center downward; 1 pt for correct F_f/F_n (or resultant) arrows at the contact point with correct directions and no extra forces.

Solution 1

(a)(ii)

Mark scheme

- Correct answer: the friction force. No credit if the wrong force is named. Explanation: friction is the only one of the three forces (mg, F_n, F_f) that exerts a torque about the wheel's center of mass — both mg and F_n act through/toward the center, so they produce no torque about it — so friction is what changes the wheel's angular velocity. Full credit is also given for a causal-chain answer: gravity leads to a normal force (and acceleration down the ramp), which leads to a frictional force, which exerts a torque that changes the angular velocity.

Solution 1

(b) Mark scheme

- Along the ramp: $\sum F_{\|} = Mg \sin\theta - F_f$ [1 pt for recognizing there are two force components parallel to the ramp; the expression need not be correct or consistent with the force diagram in part (a)]. The friction force is 40

Solution 1

(c)

Mark scheme

- Context only, no response scored on this leaf: describes a second experiment on the same ramp in which a block of ice, also of mass M, is released from rest at the same instant and same height as the wheel, sliding down with negligible friction. This setup is used by parts (c)(i) and (c)(ii).

Solution 1

(c)(i)

Mark scheme

- Correct answer: Block. No credit for an answer without explanation. Explanation in terms of forces: the wheel experiences a counteracting frictional force (which reduces its linear acceleration along the ramp), so the block — with negligible friction — has a greater net force along the ramp and therefore greater acceleration, reaching the bottom with greater speed.

Solution 1

(c)(ii)

Mark scheme

- Explanation in terms of energy conservation: both the wheel-Earth system and the block-Earth system lose the same amount of gravitational potential energy (same mass, same height drop), so they gain the same total kinetic energy. With the ice block — but not the wheel — all of that kinetic energy is translational, and none is rotational, so the block's translational (linear) speed at the bottom is greater than the wheel's.

Question 1

2015 ▪ Q1

[Figure: Two blocks connected by a string over two pulleys mounted on a frame above a table. Block 1 (mass m_1) hangs on the left side, Block 2 (mass m_2) hangs on the right side. Note: Figure not drawn to scale.]

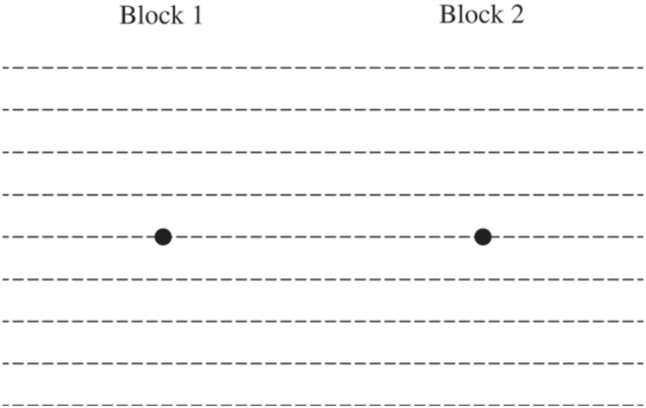
Two blocks are connected by a string of negligible mass that passes over massless pulleys that turn with negligible friction, as shown in the figure above. The mass m_2 of block 2 is greater than the mass m_1 of block 1. The blocks are released from rest.

(a) The dots below represent the two blocks. Draw free-body diagrams showing and labeling the forces (not components) exerted on each block. Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces.

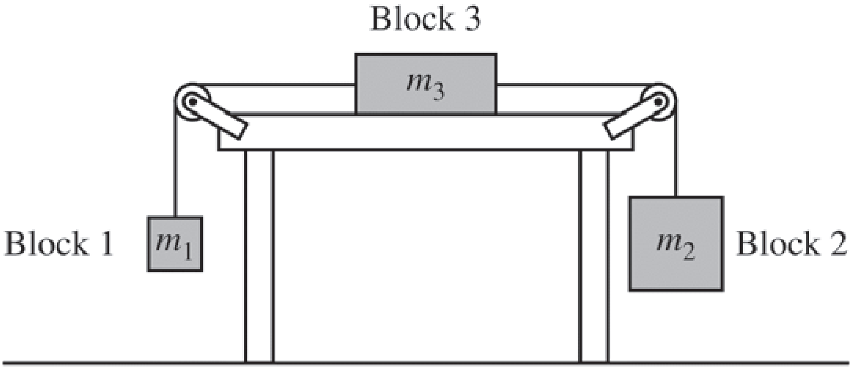
[Two blank labeled diagrams, each showing a single dot on a set of horizontal dashed reference lines, for the student to draw force vectors on: one labeled "Block 1", one labeled "Block 2".]

Question 1

(not components) exerted on each block. Draw the relative lengths of all vectors to
magnitudes of all the forces.

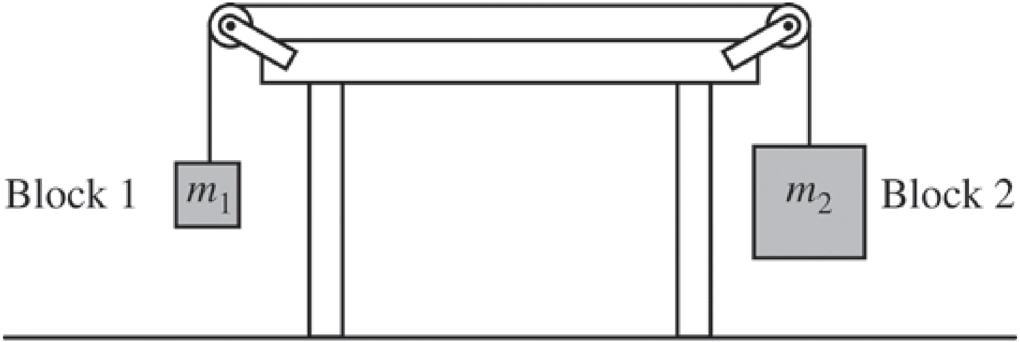


Question 1



Note: Figure not drawn to scale.

Question 1



Note: Figure not drawn to scale.

Question 1

2015 ▪ Q1

[Figure: Two blocks connected by a string over two pulleys mounted on a frame above a table. Block 1 (mass m_1) hangs on the left side, Block 2 (mass m_2) hangs on the right side. Note: Figure not drawn to scale.]

Two blocks are connected by a string of negligible mass that passes over massless pulleys that turn with negligible friction, as shown in the figure above. The mass m_2 of block 2 is greater than the mass m_1 of block 1. The blocks are released from rest.

(b) Derive the magnitude of the acceleration of block 2. Express your answer in terms of m_1, m_2, and g.

Question 1

2015 ▪ Q1

[Figure: Two blocks connected by a string over two pulleys mounted on a frame above a table. Block 1 (mass m_1) hangs on the left side, Block 2 (mass m_2) hangs on the right side. Note: Figure not drawn to scale.]

Two blocks are connected by a string of negligible mass that passes over massless pulleys that turn with negligible friction, as shown in the figure above. The mass m_2 of block 2 is greater than the mass m_1 of block 1. The blocks are released from rest.

(c) Block 3 of mass m_3 is added to the system, as shown below. There is no friction between block 3 and the table.

[Figure: Block 3 (mass m_3) now sits on top of the table, connected by strings over the same two pulleys to Block 1 (mass m_1) hanging on the left and Block 2 (mass m_2) hanging on the right. Note: Figure not drawn to scale.]

Question 1

Indicate whether the magnitude of the acceleration of block 2 is now larger, smaller, or the same as in the original two-block system. Explain how you arrived at your answer.

Solution 1

(a) Mark scheme

- Free-body diagrams for Block 1 and Block 2 (each hanging from a string over a pulley, connected to the other block). Each block has exactly two forces: tension T pointing up, and gravity ($m_1 g$ or $m_2 g$) pointing down. Scoring: 1 point for drawing two vectors starting on the dots that point upward, of equal length, both labeled as the tension force T. 1 point for drawing two vectors starting on the dots that point downward, where the vector for Block 1 (weight $m_1 g$) is shorter than the vector for Block 2 (weight $m_2 g$), both labeled as the gravitational force – consistent with $m_2 > m_1$ so the system accelerates with Block 2 moving down. Deduct 1 point for any extraneous vectors; deduct 1 point if the vector lengths would not allow the system to accelerate in the proper direction.

Solution 1

(b) Mark scheme

- Apply Newton's second law to each block (T = string tension, a = common acceleration magnitude): Block 1 (accelerates upward): $m_1 a = T - m_1 g$. Block 2 (accelerates downward): $m_2 a = m_2 g - T$. Eliminate T: from Block 1, $T = m_1 a + m_1 g$; substituting into Block 2's equation: $m_2 a = m_2 g - m_1 a - m_1 g \Rightarrow (m_2 + m_1)a = (m_2 - m_1)g$. Result: $a = \dfrac{(m_2 - m_1)g}{m_2 + m_1}$. Scoring (3 points): 1 for the correct Newton's-second-law equation for Block 1, 1 for Block 2, 1 for correctly eliminating T to reach an equation solvable for a. Alternate (system) solution earns the same 3 points via: $F_{net} = (m_2 - m_1)g$ (1 pt), $F_{net} = (m_2 + m_1)a$ (1 pt), combine to solve for a (1 pt) – same final answer.

Solution 1

(c) Mark scheme

- Block 3 (mass m_3, frictionless on the table) is inserted into the same string/pulley system between Block 1 and Block 2. The acceleration of Block 2 is now SMALLER than in the original two-block system. Reasoning: the total mass being accelerated increases from $(m_1 + m_2)$ to $(m_1 + m_2 + m_3)$ while the net driving force $(m_2 - m_1)g$ is unchanged, so $a = (m_2 - m_1)g/(m_1 + m_2 + m_3)$ is smaller; equivalently the tension on Block 2 increases (more mass for the string to pull along) which reduces its net accelerating force. Scoring (2 points): 1 point for indicating the mass of the system is larger, 1 point for a clear indication that the tension on Block 2 is greater. (Alternate solution, same 2 points: 1 for indicating the system mass is larger, 1 for indicating the net force exerted on the system

Solution 1

stays the same.) No points are earned for a correct prediction without a reasonable explanation attempt, and no points are earned for an incorrect prediction regardless of explanation.