Past-paper walk-through

Gravitational Force ▪ 2.6

eXercise

Questions in this set

- 2025 Q3
- 2021 Set 1 Q1
- 2021 Set 2 Q1
- 2018 Q1
- 2017 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 3

2025 ▪ Q3

A box is connected to one end of a rigid rod. Both the box and the rod have negligible mass. The other end of the rod is connected to a pivot. The box is open on one side, and a block is placed inside the box.

The center of mass of the block is displaced a vertical distance h, as shown in Figure 1. The block-box system is then released from rest and swings downward. There is negligible friction about the pivot. When the system is at the lowest point of its swing, the rod collides with a rigid stopper, as shown in Figure 2. The box comes to rest, and the block is launched horizontally out of the box. The block moves across a horizontal surface toward a motion sensor that measures the speed of the block. All frictional forces are negligible.

[Figure 1: A pivot at top connected by a rod to a box (containing a block) displaced to the left and up, with the center of mass of the block shown a vertical distance h above

Question 3

the box's lowest-point position (dashed horizontal line). A stopper is shown attached near the pivot.]

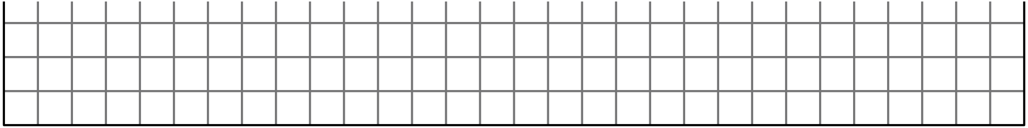
[Figure 2: The rod now hangs vertically straight down from the pivot, with the box (and block) at its lowest point, aligned with the dashed horizontal line.]

(a) Students are asked to experimentally determine the acceleration due to gravity g using a linear graph. To determine g, the students are permitted to use measurements from only a meterstick and the motion sensor.

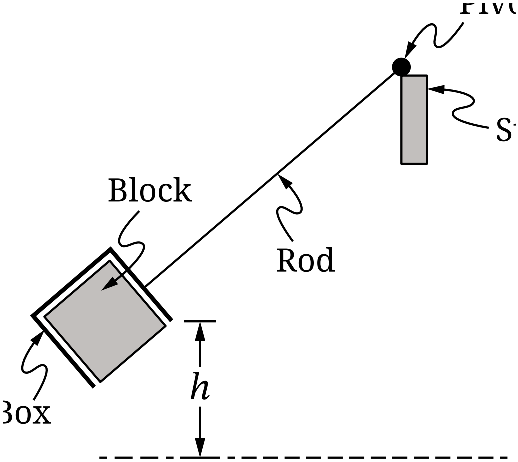
Describe an experimental procedure using the described setup to collect data that would allow the students to determine an experimental value of g using a linear graph. Include any steps necessary to reduce experimental uncertainty.

Question 3

Question 3



Question 3



Question 3

h (m)	x_{max} (m)
0.30	0.76
0.45	1.10
0.60	1.40
0.75	1.90
0.90	2.30

Question 3

2025 ▪ Q3

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The center of mass of the block is displaced a vertical distance h, as shown in Figure 1. The block-box system is then released from rest and swings downward. There is negligible friction about the pivot. When the system is at the lowest point of its swing, the rod collides with a rigid stopper, as shown in Figure 2. The box comes to rest, and the block is launched horizontally out of the box. The block moves across a horizontal surface toward a motion sensor that measures the speed of the block. All frictional forces are negligible.
[Figure 1: A pivot at top connected by a rod to a box (containing a block) displaced to the left and up, with the center of mass of the block shown a vertical distance h above the box's lowest-point position (dashed horizontal line). A stopper is shown attached near the pivot.]

Question 3

[Figure 2: The rod now hangs vertically straight down from the pivot, with the box (and block) at its lowest point, aligned with the dashed horizontal line.]

(b) Describe how the data collected in part A could be graphed and how that graph would be analyzed to determine the value of g.

Question 3

2025 ▪ Q3

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The center of mass of the block is displaced a vertical distance h, as shown in Figure 1. The block-box system is then released from rest and swings downward. There is negligible friction about the pivot. When the system is at the lowest point of its swing, the rod collides with a rigid stopper, as shown in Figure 2. The box comes to rest, and the block is launched horizontally out of the box. The block moves across a horizontal surface toward a motion sensor that measures the speed of the block. All frictional forces are negligible.

[Figure 1: A pivot at top connected by a rod to a box (containing a block) displaced to the left and up, with the center of mass of the block shown a vertical distance h above the box's lowest-point position (dashed horizontal line). A stopper is shown attached near the pivot.]

Question 3

[Figure 2: The rod now hangs vertically straight down from the pivot, with the box (and block) at its lowest point, aligned with the dashed horizontal line.]

(c)(i) The experiment is repeated, but the horizontal surface on which the block slides is replaced with a new rough surface, as shown in Figure 3. The coefficient of kinetic friction between the block and the new surface is μ.

[Figure 3: A rod hanging vertically from a pivot with the box/block at its lowest point on a rough (wavy-line) horizontal surface at position $x = 0$; a dashed square outline is shown further right at position $x = x_{\max}$, indicating where the block comes to rest.]

The block-box system is pulled aside so that the center of mass of the block is displaced various vertical distances h and then released from rest. For each vertical distance, students measure the position $x = x_{\max}$ at which the block comes to rest. The students' measurements of h and $x_{\max}$ are shown in Table 1.

Table 1

Question 3

h (m)	$x_{\max}$ (m)
0.30	0.76
0.45	1.10
0.60	1.40
0.75	1.90
0.90	2.30

Indicate two quantities, either measured quantities from Table 1 or additional calculated quantities, that could be graphed to produce a straight line that could be used to determine μ.

Vertical axis: $H^{orizontalaxis}$:

(c)(ii) On the grid provided, create a graph of the quantities indicated in part C (i).

- Use Table 2 to record the measured or calculated quantities that you will plot.
- Clearly **label** the axes, including units as appropriate.
- **Plot** the points you recorded in Table 2.

[A blank graphing grid (square-ruled) is provided for plotting the chosen quantities.]

(c)(iii) Draw a best-fit line to the data graphed in part C (ii).

Question 3

2025 ▪ Q3

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[Figure 1: A pivot at top connected by a rod to a box (containing a block) displaced to the left and up, with the center of mass of the block shown a vertical distance h above the box's lowest-point position (dashed horizontal line). A stopper is shown attached near the pivot.]

Question 3

[Figure 2: The rod now hangs vertically straight down from the pivot, with the box (and block) at its lowest point, aligned with the dashed horizontal line.]

(d) Using the best-fit line that you drew in part C (iii), **calculate** an experimental value for μ.

Solution 3

(a) Mark scheme

- Describe an experimental procedure (using only a meterstick and a motion sensor) to collect data allowing determination of g from a linear graph, including a step to reduce experimental uncertainty. Model answer: measure the height h from which the block(-box) system is released (using the meterstick). Measure the resulting speed v of the block as it moves across the horizontal surface (using the motion sensor) [Point A1: procedure includes measuring h and the block's speed]. Repeat the speed measurement for multiple different release heights h (or repeat multiple trials at the same h and average) to reduce experimental/random uncertainty [Point A2: any reasonable uncertainty-reduction method, e.g. repeating trials at one h, or repeating across several values of h].

Solution 3

(b) Mark scheme

- Describe how the data from part A could be graphed/analyzed to determine g. Any of the following linear relationships is acceptable, along with their reciprocals: v^2 vs. $2h$ (slope $= g$); $\frac{1}{2}v^2$ vs. h (slope $= g$); v^2 vs. h (slope $= 2g$); v vs. $\sqrt{h}$ (slope $= \sqrt{2g}$) [Point B1: describes a graph with a linear trend usable to find g; may be earned independently of part A]. Model answer: plot v^2 on the vertical axis and $2h$ on the horizontal axis; the slope of the best-fit line equals g [Point B2: correctly relates the best-fit slope to g, per whichever pairing is chosen – see the graph/analysis table above for the correct slope-to-g relationship for each valid axis choice].

Solution 3

(c)(i)

Mark scheme

- New scenario: the horizontal surface is replaced by a rough surface with kinetic friction coefficient μ; the block (released from height h) slides and comes to rest at $x_{\max}$. Indicate quantities that could be plotted to produce a LINEAR graph usable to determine μ. Model answer: plot h vs. $x_{\max}$ (the reciprocal, $x_{\max}$ vs. h, is equally acceptable) [Point C1: any correct linear pairing of measurable quantities that yields μ from the slope, e.g. h vs. x$_max$].

Solution 3

(c)(ii) Mark scheme

- Graph the quantities identified in part C(i) using the data in Table 2. Label both axes, including units, with a linear scale – e.g. h (m) on the vertical axis and x_{max} (m) on the horizontal axis, with evenly-spaced gridlines from 0 upward [Point C2: correctly labeled linear-scale axes with units]. Plot each data point from Table 2 as a dot at its (x_{max}, h) coordinates on the grid, consistent with the axes chosen in part C(i) – the example data trend roughly linearly from about $(0.3\ \mathrm{m}, 0.15\ \mathrm{m})$ through $(1.4, 0.6)$, $(1.9, 0.75)$, up to about $(2.9\ \mathrm{m}, 1.1\ \mathrm{m})$ [Point C3: plotted points consistent with the part-C(i) quantities, Table 2's values, or the grid's own labeled axes].

Solution 3

(c)(iii)

Mark scheme

- Draw a best-fit straight line through the data points plotted in part C(ii) – a single straight line that approximates the overall increasing linear trend of the plotted $(x_{\max}, h)$ points (not simply connecting the dots), extending across the range of the data [Point C4: any reasonable line/curve that approximates the trend of the plotted data].

Solution 3

(d) Mark scheme

- Using the best-fit line from part C(iii), calculate an experimental value of μ. Derivation: by conservation of energy, $mgh - F_f x_{\max} = 0$ where $F_f = \mu mg$ (kinetic friction on a horizontal surface, normal force $= mg$), so $mgh = \mu mg\, x_{\max} \Rightarrow h = \mu x_{\max}$. Comparing to $y = mx + b$ with h vs. $x_{\max}$: the slope of the best-fit line equals μ directly [Point D1: correctly relates the best-fit slope to μ]. Reading two well-separated points off the best-fit line, e.g. $(0.70\text{ m}, 0.30\text{ m})$ and $(2.4\text{ m}, 0.95\text{ m})$: slope $= \dfrac{0.95 - 0.30}{2.4 - 0.70} = 0.38$, so $\mu = 0.38$ [Point D2: award for any value of μ within the acceptable range 0.30 to 0.50, since the exact value depends on the student's own graphed data/line].

Question 1

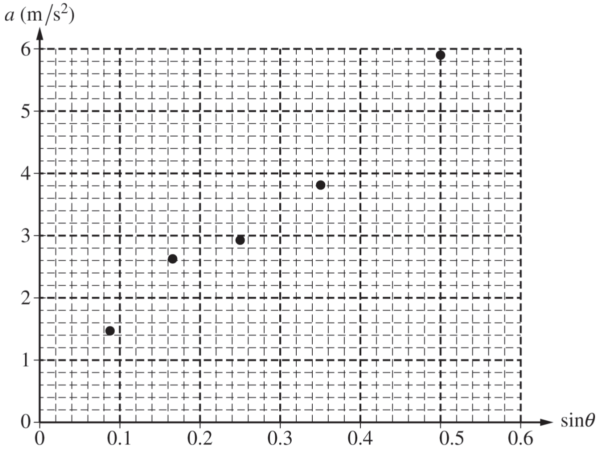
2021 Set 1 ▪ Q1

A 0.50 kg fan cart is placed on a level, horizontal track of negligible friction, as shown. The fan is turned on, and the fan cart is released from rest and moves to the right. The cart travels along the horizontal track and then down an incline. Motion detector 1 measures the acceleration *a* of the cart from time $t = 0$ to $t = 3$ s. At $t = 3$ s, the cart makes a smooth transition to the incline, and motion detector 2 measures the acceleration of the cart after $t = 3$ s. The fan exerts the same magnitude of force on the cart during the entire motion. The graphs below show *a* as functions of *t*. For each motion detector, the positive direction is away from the detector.
[Figure: A fan cart with a fan mounted on top sits on a horizontal track next to Motion Detector 1. The track slopes down into an incline; Motion Detector 2 is positioned at the bottom of the incline facing up the slope at angle θ to the horizontal. Note: Figure not drawn to scale.]

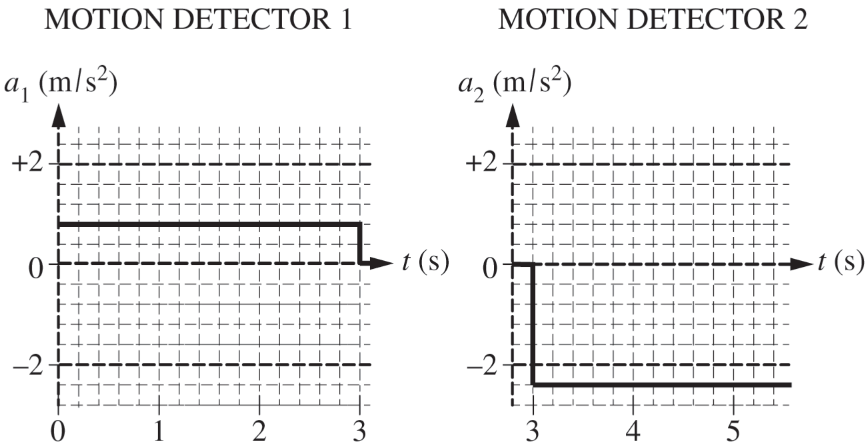
Question 1

[Graph "MOTION DETECTOR 1": axes a_1 ($\mathrm{m/s^2}$) vertical from -2 to $+2$, t (s) horizontal from 0 to 3. The graph shows a constant positive value of $a_1 = +2$ $\mathrm{m/s^2}$ from $t = 0$ to $t = 3$ s, then drops to 0.]
[Graph "MOTION DETECTOR 2": axes a_2 ($\mathrm{m/s^2}$) vertical from -2 to $+2$, t (s) horizontal from 3 to 5. The graph shows a constant value of $a_2 = -2$ $\mathrm{m/s^2}$ from $t = 3$ s to $t = 5$ s.]
(a) On the dots below that represent the cart at two different locations, draw and label the forces (not components) that act on the cart at each location. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.
[Two diagrams: "Cart on Horizontal Track" shows a single dot on a level dashed line. "Cart on Incline" shows a single dot on a dashed line sloping down at angle θ.]

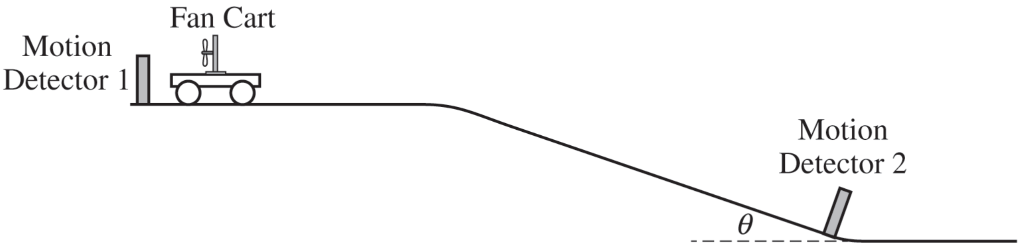
Question 1



Question 1


MOTION DETECTOR 1
a_1 (m/s^2)
+2
0
–2
0
1
2
3
t (s)
MOTION DETECTOR 2
a_2 (m/s^2)
+2
0
–2
3
4
5
t (s)

Question 1



Note: Figure not drawn to scale.

Question 1

2021 Set 1 ▪ Q1

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[Figure: A fan cart with a fan mounted on top sits on a horizontal track next to Motion Detector 1. The track slopes down into an incline; Motion Detector 2 is positioned at the bottom of the incline facing up the slope at angle θ to the horizontal. Note: Figure not drawn to scale.]

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[Graph "MOTION DETECTOR 2": axes a_2 (m/s^2) vertical from -2 to $+2$, t (s) horizontal from 3 to 5. The graph shows a constant value of $a_2 = -2$ m/s^2 from $t = 3$ s to $t = 5$ s.]

(b) Calculate the magnitude of the net force exerted on the fan cart when it is on the horizontal track.

Question 1

2021 Set 1 ▪ Q1

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[Figure: A fan cart with a fan mounted on top sits on a horizontal track next to Motion Detector 1. The track slopes down into an incline; Motion Detector 2 is positioned at the bottom of the incline facing up the slope at angle θ to the horizontal. Note: Figure not drawn to scale.]

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(c) Calculate the angle θ of the incline.

Question 1

2021 Set 1 ▪ Q1

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(d) Suppose careful measurement determines the angle of the incline to be $3°$ larger than that calculated in part (c). Consider the following explanation.

"The scale used to measure the mass of the fan cart was not calibrated properly before the measurement, and this could account for the observed difference in the angle."

Does the explanation sufficiently account for the observed discrepancy?

_______ Yes _______ No

Justify your answer.

Question 1

2021 Set 1 ▪ Q1

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(e)(i) The experiment is repeated for several trials, each with a different angle for the incline. The acceleration of the cart down the incline is measured for each angle. The graph below shows the plot of the acceleration a of the cart as a function of the sine of the angle $\sin\theta$.

[Graph: axes a (m/s^2) vertical from 0 to 6, $\sin\theta$ horizontal from 0 to 0.6. Data points plotted approximately at $(\sin\theta, a)$: $(0.1, 1.6)$, $(0.2, 2.4)$, $(0.25, 3.0)$, $(0.35, 3.9)$, $(0.5, 5.7)$.]

Draw a best-fit line for the data.

Question 1

(e)(ii) Using the straight line, calculate an experimental value for the acceleration due to gravity g.

Question 1

2021 Set 1 ▪ Q1

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(f) If the cart were replaced with a second cart of mass 1.0 kg that has a fan that exerts the same magnitude of force as the original fan, explain how the graph given in part (e) would change.

Solution 1

(a) Mark scheme

- Draw all forces as arrows starting on the dot, pointing away from it. On the horizontal track (1 point, all three vectors must be correct together): normal force F_N pointing straight up, weight mg pointing straight down, and the fan force F_{fan} pointing horizontally forward (the cart's direction of travel). On the incline (1 point each, 3 points total): weight mg pointing straight down; normal force F_N perpendicular to the incline surface, pointing away from it; and the fan force F_{fan} directed along the incline surface, up-slope (same sense as the cart's acceleration). Acceptable labels for weight: F_G, F_g, F_{grav}, W, mg, Mg, 'grav force', 'F Earth on cart', etc. (labels 'G' or 'g' alone are NOT acceptable). Acceptable labels for the normal force: F_n, F_N, N, 'normal force', 'ground force'. Scoring note: a maximum

Solution 1

of 3 of the 4 points can be earned if any extraneous (incorrect/extra) vectors are drawn. No credit for force components – only whole forces.

Solution 1

(b)

Mark scheme

- Apply Newton's second law to the cart on the flat (horizontal) track, where the fan force is the only horizontal force: $F_{fan} = m_{cart}a_1$ (1 point for the correct equation). Substitute $m_{cart} = 0.50$ kg and $a_1 = 0.8$ m/s^2 (the given horizontal-track acceleration): $F_{fan} = (0.50 \text{ kg})(0.8 \text{ m/s}^2) = 0.40$ N (1 point for the correct numeric answer with units).

Solution 1

(c) Mark scheme

- Write Newton's second law along the incline, with the fan force and the component of weight along the incline both contributing to the incline acceleration a_2: $F_{fan} + mg\sin\theta = ma_2$ (1 point for including the correct weight component; 1 point for the fully correct N2L equation – the same equation earns both). Solve for θ and substitute the value $F_{fan} = 0.40$ N found in part (b), with $m = 0.50$ kg, $a_2 = 2.4$ m/s^2, $g = 9.8$ m/s^2 (1 point for correct, part-(b)-consistent substitution):
$\theta = \sin^{-1}\left(\dfrac{ma_2 - F_{fan}}{mg}\right) = \sin^{-1}\left(\dfrac{(0.50)(2.4) - 0.40}{(0.50)(9.8)}\right) = \sin^{-1}(0.163) = 9.4^\circ.$

Solution 1

(d) Mark scheme

- Answer: No – the explanation does not sufficiently account for the observed discrepancy (1 point for selecting 'No' with an attempted justification). Correct justification (1 point): the mass of the cart cancels out of the equation used to find the incline angle – $\theta = \sin^{-1}\left(\frac{ma_2 - F_{fan}}{mg}\right)$ has m as a common factor in every term (since $F_{fan} = ma_1$ too), so $\theta = \sin^{-1}\left(\frac{a_2 - a_1}{g}\right)$ is independent of the cart's mass. A mis-calibrated scale giving a wrong mass value therefore could not have caused the 3-degree discrepancy in the calculated angle.

Solution 1

(e)(i)

Mark scheme

- Draw a straight best-fit line through the five plotted points $(\sin\theta, a)$ – approximately $(0.1, 1.6), (0.2, 2.4), (0.25, 3.0), (0.35, 3.9), (0.5, 5.7)$ in m/s^2 – that reasonably balances points above and below it (roughly running from a y-intercept near 0.6 m/s^2 up through about $(0.5, 5.9)$). This is a graphical (drawing) task; the point is earned for a reasonable, ruled best-fit line through the data, not a specific written value.

Solution 1

(e)(ii) Mark scheme

- Pick two well-separated points on the best-fit line (not data points) and compute its slope (1 point): slope $= \dfrac{\Delta y}{\Delta x} = \dfrac{(5-1)\ \mathrm{m/s^2}}{0.42-0.04} = 10.52\ \mathrm{m/s^2}$. Relate the slope to g (1 point): from Newton's second law, $F_{fan} + mg\sin\theta = ma \Rightarrow a = g\sin\theta + F_{fan}/m$; comparing to $y = mx + b$ with a plotted vs. $\sin\theta$, the slope of the line equals g. Experimental value: $g \approx 10.5\ \mathrm{m/s^2}$ (from the example best-fit line; accept any value consistent with the student's own line and correct slope/g reasoning).

Solution 1

(f)

Mark scheme

- With a 1.0 kg cart producing the same fan-force magnitude, the slope of the a vs. $\sin\theta$ line still equals g and is unchanged, but the y-intercept F_{fan}/m decreases because the larger mass m is in the denominator of the intercept term. So the new line is parallel to the original (same slope g) but shifted below it (smaller y-intercept).

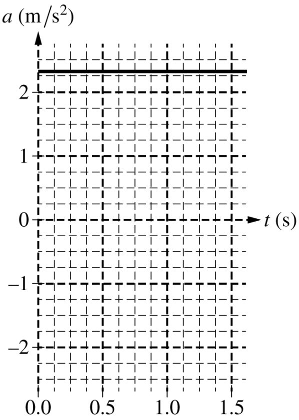
Question 1

2021 Set 2 ▪ Q1

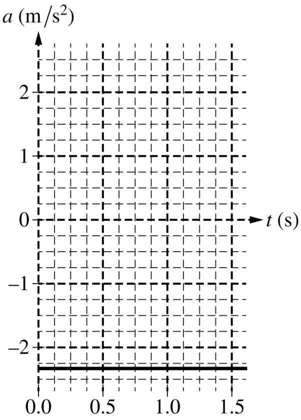
Students design an experiment using blocks of adjustable mass to investigate friction using the setup shown. Block 1 of initial mass 0.44 kg is placed on a rough horizontal surface and connected by a string to block 2 of initial mass 0.20 kg. The string extends over a pulley that has negligible mass and friction.
[Figure: Setup diagram. Motion Detector 1 is at the left, facing right toward Block 1 (0.44 kg), which sits on a horizontal rough surface. A string from Block 1 runs right over a frictionless, massless pulley at the edge of the surface, then down to Block 2 (0.20 kg), which hangs vertically. Motion Detector 2 is below Block 2, facing up toward it.]
(a) Calculate the minimum value of the coefficient of static friction μ_s that would keep the two-block system at rest.

Question 1

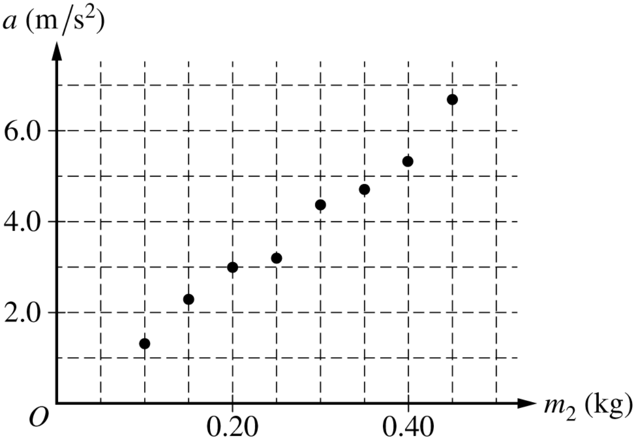
Motion Detector 1



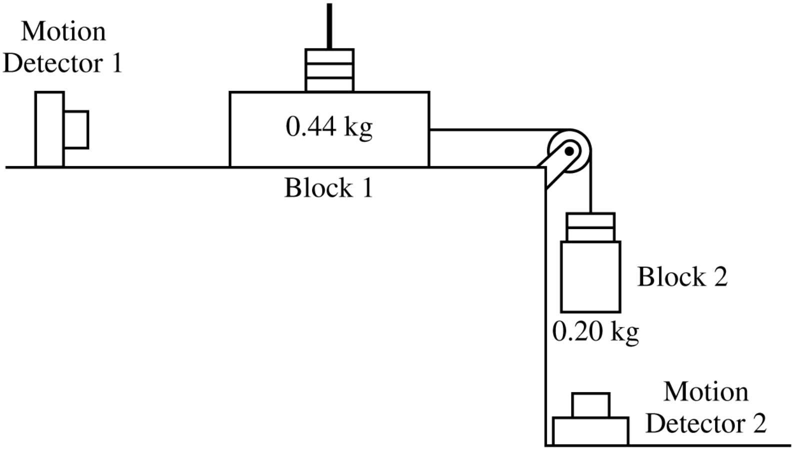
Motion Detector 2



Question 1



Question 1



Motion
Detector 1
0.44 kg
Block 1
Block 2
0.20 kg
Motion
Detector 2

Question 1

2021 Set 2 ▪ Q1

Students design an experiment using blocks of adjustable mass to investigate friction using the setup shown. Block 1 of initial mass 0.44 kg is placed on a rough horizontal surface and connected by a string to block 2 of initial mass 0.20 kg. The string extends over a pulley that has negligible mass and friction.

[Figure: Setup diagram. Motion Detector 1 is at the left, facing right toward Block 1 (0.44 kg), which sits on a horizontal rough surface. A string from Block 1 runs right over a frictionless, massless pulley at the edge of the surface, then down to Block 2 (0.20 kg), which hangs vertically. Motion Detector 2 is below Block 2, facing up toward it.]

(b) The coefficient of friction is such that when block 2 is released from rest, block 1 travels across the surface. The acceleration *a* of each block is recorded with motion detectors 1 and 2, as shown in the figure. The data for the motion detectors as

Question 1

functions of time t are shown on the graphs. For each motion detector, the positive direction is away from the detector.

[Two graphs side by side, each with vertical axis a (m/s^2) ranging from -2 to 2, and horizontal axis t (s) ranging from 0.0 to 1.5, gridlines at intervals of 0.5 s and 1 m/s^2. Left graph "Motion Detector 1": data points scattered near $a \approx 2$ m/s^2 for all shown t from 0.0 to 1.5 s (roughly constant, slightly above the $a = 2$ gridline). Right graph "Motion Detector 2": data points scattered near $a \approx 2$ m/s^2 for all shown t from 0.0 to 1.5 s (roughly constant, similar to the left graph).]

On the dots below, which represent the blocks, draw and label the forces (not components) that act on each block. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

[Two labelled dots are provided for the student to draw on: "Block 1" and "Block 2", each shown as a single black dot with blank space around it for force arrows.]

Question 1

2021 Set 2 ▪ Q1

Students design an experiment using blocks of adjustable mass to investigate friction using the setup shown. Block 1 of initial mass 0.44 kg is placed on a rough horizontal surface and connected by a string to block 2 of initial mass 0.20 kg. The string extends over a pulley that has negligible mass and friction.

[Figure: Setup diagram. Motion Detector 1 is at the left, facing right toward Block 1 (0.44 kg), which sits on a horizontal rough surface. A string from Block 1 runs right over a frictionless, massless pulley at the edge of the surface, then down to Block 2 (0.20 kg), which hangs vertically. Motion Detector 2 is below Block 2, facing up toward it.]

(c) Calculate the coefficient of kinetic friction μ_k between block 1 and the table.

Question 1

2021 Set 2 ▪ Q1

Students design an experiment using blocks of adjustable mass to investigate friction using the setup shown. Block 1 of initial mass 0.44 kg is placed on a rough horizontal surface and connected by a string to block 2 of initial mass 0.20 kg. The string extends over a pulley that has negligible mass and friction.

[Figure: Setup diagram. Motion Detector 1 is at the left, facing right toward Block 1 (0.44 kg), which sits on a horizontal rough surface. A string from Block 1 runs right over a frictionless, massless pulley at the edge of the surface, then down to Block 2 (0.20 kg), which hangs vertically. Motion Detector 2 is below Block 2, facing up toward it.]

(d) Careful measurements determine that the coefficient of kinetic friction is larger than the value calculated in part (c). Does the following explanation sufficiently account for the observed discrepancy?

Question 1

"The horizontal table was not perfectly level before the experiment was conducted. The observed difference in the angle accounts for the difference in the expected and calculated values of μ_k."

$^{Yes}{}_{No}$

Justify your answer.

The experiment is moved to a surface with negligible friction and run for eight trials. In each trial, the students vary the masses m_1 and m_2 of blocks 1 and 2, respectively, while keeping the total mass $(m_1 + m_2) = 0.64$ kg constant. The data for the acceleration a of block 1 as a function of m_2 are shown on the graph below.

[Graph: vertical axis a (m/s^2) with gridlines at 2.0, 4.0, 6.0; horizontal axis m_2 (kg) with gridlines at 0.20, 0.40. Eight data points show an increasing, slightly concave/roughly linear trend: starting near $(0.05, 1.3)$, rising through approximately

Question 1

$(0.10, 2.0)$, $(0.15, 3.0)$, $(0.20, 3.3)$, $(0.25, 4.2)$, $(0.30, 4.9)$, $(0.35, 5.3)$, up to about $(0.40, 5.6)$.]

Question 1

2021 Set 2 ▪ Q1

Students design an experiment using blocks of adjustable mass to investigate friction using the setup shown. Block 1 of initial mass 0.44 kg is placed on a rough horizontal surface and connected by a string to block 2 of initial mass 0.20 kg. The string extends over a pulley that has negligible mass and friction.

[Figure: Setup diagram. Motion Detector 1 is at the left, facing right toward Block 1 (0.44 kg), which sits on a horizontal rough surface. A string from Block 1 runs right over a frictionless, massless pulley at the edge of the surface, then down to Block 2 (0.20 kg), which hangs vertically. Motion Detector 2 is below Block 2, facing up toward it.]

(e)(i) Draw a best-fit line for the data points.

(e)(ii) Using the straight line, calculate an experimental value for the acceleration due to gravity g.

Question 1

2021 Set 2 ▪ Q1

Students design an experiment using blocks of adjustable mass to investigate friction using the setup shown. Block 1 of initial mass 0.44 kg is placed on a rough horizontal surface and connected by a string to block 2 of initial mass 0.20 kg. The string extends over a pulley that has negligible mass and friction.

[Figure: Setup diagram. Motion Detector 1 is at the left, facing right toward Block 1 (0.44 kg), which sits on a horizontal rough surface. A string from Block 1 runs right over a frictionless, massless pulley at the edge of the surface, then down to Block 2 (0.20 kg), which hangs vertically. Motion Detector 2 is below Block 2, facing up toward it.]

(f) The students lift the left end of the surface so that the surface is inclined at an angle to the horizontal, and the experiment for $m_2 = 0.20$ kg is repeated. Would the acceleration of the system be greater than, less than, or equal to the acceleration of the system in the original experiment?

Question 1

$G^{reaterthan}{}_{L^{essthan}{}_{E^{qualto}}}$

Justify your claim.

Solution 1

(a)

Mark scheme

- System held at rest: applying Newton's second law to the two-block system, $m_2 g - f = (m_1 + m_2)a = 0$, so $m_2 g = f$ (1 pt). Substituting static friction $f = \mu_s F_N = \mu_s m_1 g$ gives $\mu_s = m_2/m_1$ (1 pt). Numerically: $\mu_s = (0.20 \text{ kg})/(0.44 \text{ kg}) = 0.45$. Final answer: $\mu_s = 0.45$.

Solution 1

(b) Mark scheme

- Free-body diagrams (not components), 4 points total: (1) horizontal forces on block 1 — friction f and tension F_T, correctly drawn/labeled; (2) vertical forces on block 1 — weight $m_1 g$ and normal force F_N, correctly drawn/labeled; (3) weight $m_2 g$ and tension F_T correctly drawn/labeled on block 2; (4) indicating that the gravitational forces on the two blocks are different ($m_1 g \neq m_2 g$, since $m_1 \neq m_2$). Acceptable gravity labels: F_G, F_g, F_{grav}, W, mg, Mg, 'grav force', 'F Earth on block', etc. (G or g alone are NOT acceptable). Acceptable normal-force labels: F_n, F_N, N, 'normal force', 'ground force'. Block 1 (on the table): F_N up, $m_1 g$ down, f and F_T horizontal (opposite directions). Block 2 (hanging): F_T up, $m_2 g$ down.

Solution 1

(c) Mark scheme

- Newton's 2nd law, block 1: $T - f = m_1 a$ (1 pt). Block 2: $m_2 g - T = m_2 a$ (1 pt) — both points can also be earned via a single correct two-block-system equation $m_2 g - f = (m_1 + m_2)a$. Substituting kinetic friction $f = \mu_k F_N = \mu_k m_1 g$ into the combined equation: $\mu_k = \dfrac{m_2 g - (m_1 + m_2)a}{m_1 g}$ (1 pt). Numerically: $\mu_k = \dfrac{(0.20\ \text{kg})(9.8\ \text{m/s}^2) - (0.44\ \text{kg} + 0.20\ \text{kg})(2.3\ \text{m/s}^2)}{(0.44\ \text{kg})(9.8\ \text{m/s}^2)} = 0.11$. Final answer: $\mu_k = 0.11$.

Solution 1

(d)

Mark scheme

- Select 'Yes' (1 pt for selecting Yes and attempting a relevant justification) with a correct justification (1 pt). Example: 'If the track is not level, the angle of the track must be incorporated into the equation for acceleration, and this could account for the larger coefficient of kinetic friction.' Any justification tying a non-level table to a systematic change in the effective acceleration/friction equation earns the point.

Solution 1

(e)(i)

Mark scheme

- Draw a single straight best-fit line through the a (m/s^2) vs. m_2 (kg) data points, passing close to/through the cluster of points (roughly from near the origin up through about (0.45 kg, 6.7 m/s^2)). No numeric answer required; graded on the reasonableness of the fit to the plotted data.

Solution 1

(e)(ii) Mark scheme

- Calculate the slope using two points on the best-fit line: slope $= \dfrac{\Delta y}{\Delta x} = \dfrac{(6-2)\ \mathrm{m/s^2}}{(0.45-0.15)\ \mathrm{kg}} = 13.3\ \mathrm{m/(kg \cdot s^2)}$ (1 pt). Relate slope to g: since $a = (\text{slope})m_2 + (\text{y-intercept})$ and theoretically $a = \dfrac{m_2 g}{m_1+m_2}$, the slope equals $\dfrac{g}{m_1+m_2}$, so
  $g = \text{slope} \times (m_1+m_2) = (13.3\ \mathrm{m/(kg \cdot s^2)})(0.44\ \mathrm{kg} + 0.20\ \mathrm{kg}) = 8.5\ \mathrm{m/s^2}$ (1 pt). Final answer: $g \approx 8.5\ \mathrm{m/s^2}$.

Solution 1

(f)

Mark scheme

- Select 'Greater than' with a correct justification (1 point total, for the justification). Example: 'The acceleration would be greater because there would be a component of the gravitational force on block 1 along the surface, which would be in the same direction as the tension force.' (Tilting the surface adds a gravity component along the incline on block 1 that adds to the tension force, increasing the net force and thus the acceleration of the system.)

Question 1

2018 ▪ Q1

A student wants to determine the value of the acceleration due to gravity g for a specific location and sets up the following experiment. A solid sphere is held vertically a distance h above a pad by an electromagnet, as shown in the figure above. The experimental equipment is designed to release the sphere when the electromagnet is turned off. A timer also starts when the electromagnet is turned off, and the timer stops when the sphere lands on the pad.

[Diagram: A vertical stand on a table. An electromagnet is mounted at the top of the stand, holding a sphere directly beneath it. The distance from the sphere down to a pad on the table is labeled h. Labels: "Electromagnet", "Sphere", "h" (vertical arrow), "Pad", "Table".]

(a) While taking the first data point, the student notices that the electromagnet actually releases the sphere after the timer begins. Would the value of g calculated

Question 1

from this one measurement be greater than, less than, or equal to the actual value of g at the student's location?

$G^{reaterthan}{}_{L^{essthan}{}_{E^{qualto}}}$

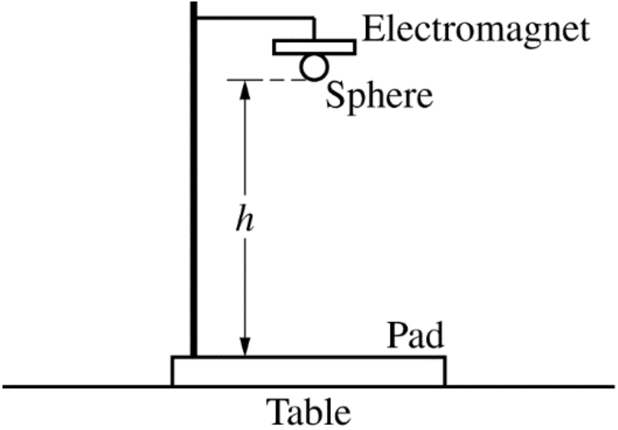
Justify your answer.

The electromagnet is replaced so that the timer begins when the sphere is released. The student varies the distance h. The student measures and records the time Δt of the fall for each particular height, resulting in the following data table.

h (m)	0.10	0.20	0.60	0.80	1.00
Δt (s)	0.105	0.213	0.342	0.401	0.451

Question 1

Question 1



Question 1

h (m)	0.10	0.20	0.60	0.80	1.00
Δt (s)	0.105	0.213	0.342	0.401	0.451

Question 1

2018 ▪ Q1

A student wants to determine the value of the acceleration due to gravity g for a specific location and sets up the following experiment. A solid sphere is held vertically a distance h above a pad by an electromagnet, as shown in the figure above. The experimental equipment is designed to release the sphere when the electromagnet is turned off. A timer also starts when the electromagnet is turned off, and the timer stops when the sphere lands on the pad.

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(b) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for g.

Vertical axis: ________________

Horizontal axis: ________________

Question 1

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given in the table. Label each row you use and include units.

Question 1

2018 ▪ Q1

A student wants to determine the value of the acceleration due to gravity g for a specific location and sets up the following experiment. A solid sphere is held vertically a distance h above a pad by an electromagnet, as shown in the figure above. The experimental equipment is designed to release the sphere when the electromagnet is turned off. A timer also starts when the electromagnet is turned off, and the timer stops when the sphere lands on the pad.

[Diagram: A vertical stand on a table. An electromagnet is mounted at the top of the stand, holding a sphere directly beneath it. The distance from the sphere down to a pad on the table is labeled h. Labels: "Electromagnet", "Sphere", "h" (vertical arrow), "Pad", "Table".]

(c) Plot the data points for the quantities indicated in part (b) on the graph below. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.

Question 1

[Graph: A blank grid (approximately 6 columns $\times$ 16 rows of small squares) provided for the student to plot data and draw a best-fit straight line. No axes, scale, or data are pre-printed.]

Question 1

2018 ▪ Q1

A student wants to determine the value of the acceleration due to gravity g for a specific location and sets up the following experiment. A solid sphere is held vertically a distance h above a pad by an electromagnet, as shown in the figure above. The experimental equipment is designed to release the sphere when the electromagnet is turned off. A timer also starts when the electromagnet is turned off, and the timer stops when the sphere lands on the pad.

[Diagram: A vertical stand on a table. An electromagnet is mounted at the top of the stand, holding a sphere directly beneath it. The distance from the sphere down to a pad on the table is labeled h. Labels: "Electromagnet", "Sphere", "h" (vertical arrow), "Pad", "Table".]

(d) Using the straight line, calculate an experimental value for g.

Another student fits the data in the table to a quadratic equation. The student's equation for the distance fallen y as a function of time t is $y = At^2 + Bt + C$, where

Question 1

$A = 5.75$ m/s^2, $B = -0.524$ m/s, and $C = +0.080$ m. Vertically down is the positive direction.

Question 1

2018 ▪ Q1

A student wants to determine the value of the acceleration due to gravity g for a specific location and sets up the following experiment. A solid sphere is held vertically a distance h above a pad by an electromagnet, as shown in the figure above. The experimental equipment is designed to release the sphere when the electromagnet is turned off. A timer also starts when the electromagnet is turned off, and the timer stops when the sphere lands on the pad.

[Diagram: A vertical stand on a table. An electromagnet is mounted at the top of the stand, holding a sphere directly beneath it. The distance from the sphere down to a pad on the table is labeled h. Labels: "Electromagnet", "Sphere", "h" (vertical arrow), "Pad", "Table".]

(e)(i) Using the student's equation above, derive an expression for the velocity of the sphere as a function of time.

(e)(ii) Using the student's equation above, calculate the new experimental value for g.

Question 1

(e)(iii) Using 9.81 m/s^2 as the accepted value for g at this location, calculate the percent error for the value found in part (e)ii.
(e)(iv) Assuming the sphere is at a height of 1.40 m at $t = 0$, calculate the velocity of the sphere just before it strikes the pad.

Solution 1

(a) Mark scheme

- Less than. Justification: because the electromagnet actually released the sphere after the timer had already begun, the measured time is longer than the true fall time for that height. Since $g = 2h/\Delta t^2$ (i.e. $a \propto 1/t^2$), a longer measured Δt makes the calculated value of g smaller than the true value, so the computed g is LESS THAN the actual g. (1 point for selecting "Less than" with an attempt at a relevant justification; 1 point for a correct justification, e.g. "the measured time to fall the same distance is larger, so the acceleration must be less" or "the time is larger and $a \propto 1/t^2$, so g must decrease.")

Solution 1

(b)

Mark scheme

- Vertical axis: h. Horizontal axis: $(\Delta t)^2$. Since $h = \frac{1}{2}g(\Delta t)^2$, plotting h vs. $(\Delta t)^2$ gives a straight line through the origin with slope $g/2$. Full credit is also given if the axes are reversed (horizontal h, vertical $(\Delta t)^2$, slope $= 2/g$) or for any other combination of quantities that yields a straight line usable to find g.

Solution 1

(c) Mark scheme

- Using the part (b) quantities, compute $(\Delta t)^2$ for each row: $h = 0.10$ m $\rightarrow (\Delta t)^2 = 0.011\ \mathrm{s}^2$; $h = 0.20 \rightarrow 0.045$; $h = 0.60 \rightarrow 0.117$; $h = 0.80 \rightarrow 0.161$; $h = 1.00 \rightarrow 0.203\ \mathrm{s}^2$. Plot h (vertical) vs $(\Delta t)^2$ (horizontal) and draw a best-fit straight line through the points (the official answer graph is linear, passing near the origin, rising from about (0.01,0.10) to (0.20,1.00)). Scoring: 1 point for a scale that uses more than half the grid; 1 point for correctly labeling axes with the part-(b) variables and units; 1 point for correctly plotting the data consistent with part (b); 1 point for drawing a straight line consistent with the plotted data.

Solution 1

(d)

Mark scheme

- Using two points ON THE BEST-FIT LINE (not raw data points): slope $= \dfrac{\Delta h}{\Delta(\Delta t)^2} = \dfrac{(0.80 - 0.20)\ \text{m}}{(0.160 - 0.039)\ \text{s}^2} \approx 4.96\ \text{m/s}^2$ (linear regression on all data gives $4.83\ \text{m/s}^2$). Since slope $= \frac{1}{2}g$, $g = 2 \times$ slope. So $g = 2(4.96) = 9.92$ m/s^2 (linear regression: $9.66\ \text{m/s}^2$). 1 point for using points on the line (not the raw data) to compute the slope; 1 point for correctly relating the slope to g.

Solution 1

(e)(i)

Mark scheme

- Matching $y = At^2 + Bt + C$ to the kinematic form $y = y_0 + v_i t + \frac{1}{2}at^2$ and differentiating: $v(t) = \dfrac{dy}{dt} = 2At + B$. (Credit is also earned for substituting the given numbers: $v(t) = (11.5\ \mathrm{m/s^2})t - 0.524\ \mathrm{m/s}$.)

Solution 1

(e)(ii)

Mark scheme

- Comparing $y = y_0 + v_i t + \frac{1}{2}at^2$ to $y = At^2 + Bt + C$ gives $A = \frac{1}{2}a$, so $a = 2A$. Here the acceleration is g (free fall), so $g = 2A = 2(5.75\ \mathrm{m/s^2}) = 11.5\ \mathrm{m/s^2}$. 1 point for correctly relating the given equation to a correct kinematic equation; 1 point for correctly relating the equation to the value of g (i.e. $g = 2A$).

Solution 1

(e)(iii)

Mark scheme

- $\%\text{error} = \dfrac{|\text{acc} - \text{exp}|}{\text{acc}} \times 100\% = \dfrac{|11.5 - 9.81|\ \text{m/s}^2}{9.81\ \text{m/s}^2} \times 100\% = 17.2\%$. Credit is earned whether the percent error is expressed as positive or negative.

Solution 1

(e)(iv) Mark scheme

- From the fitted equation: $v_i = B = -0.524$ m/s, $a = 2A = 11.5$ m/s^2, $y_0 = C = 0.080$ m, so $\Delta y = 1.40 - 0.080 = 1.32$ m. Using $v^2 = v_i^2 + 2a\Delta y$: $v = \sqrt{(-0.524)^2 + 2(11.5)(1.32)} = 5.54$ m/s. 1 point for relating the equation's coefficients to the kinematic variables v_i, a, y_0; 1 point for correctly using an appropriate kinematics equation to find v. (Equivalent full-credit alternates: solve the quadratic $5.75t^2 - 0.524t - 1.32 = 0$ for $t = 0.53$ s and substitute into part (e)(i)'s $v(t)$; or use conservation of energy $mgh + \frac{1}{2}mv_i^2 = \frac{1}{2}mv^2$ — both give $v = 5.54$ m/s.)

Question 1

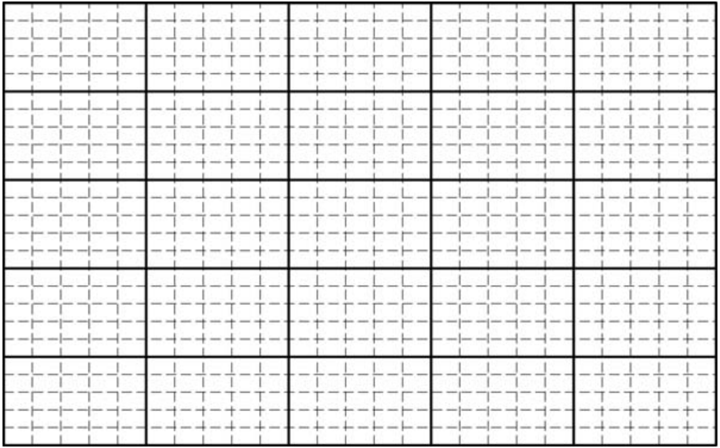
2017 ▪ Q1

An Atwood's machine consists of two blocks connected by a light string that passes over a frictionless pulley of negligible mass, as shown in the figure above. The masses of the two blocks, M_1 and M_2, can be varied. M_2 is always greater than M_1.
[Figure: An Atwood's machine — two blocks M_1 and M_2 hang from a light string over a frictionless pulley of negligible mass mounted on a support stand, above a table/floor surface.]
(a) On the dots below, which represent the blocks, draw and label the forces (not components) that act on the blocks. Each force must be represented by a distinct arrow starting on and pointing away from the appropriate dot. The relative lengths of the arrows should show the relative magnitudes of the forces.

Question 1

[Two dotted grids, each with a single large dot at its center, labeled "Block of Mass M_1" and "Block of Mass M_2" respectively — students draw force vectors from each dot.]

Question 1

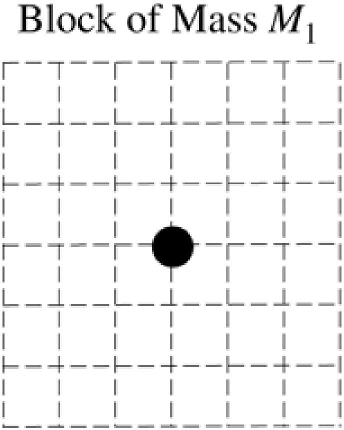


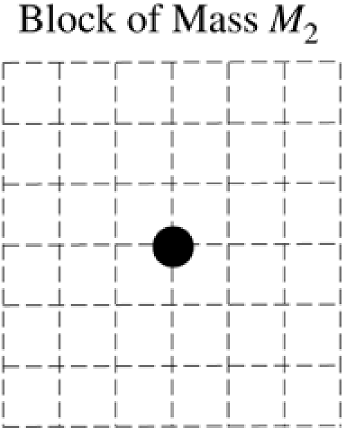
Question 1

The magnitude of the acceleration a was measured for different values of M_1 and M_2, and the data are shown below.

M_1 (kg)	1.0	2.0	5.0	6.0	10.0
M_2 (kg)	2.0	3.0	12.0	8.0	14.0
a (m/s^2)	3.02	1.82	4.21	1.15	1.71

Question 1





Question 1

2017 ▪ Q1

An Atwood's machine consists of two blocks connected by a light string that passes over a frictionless pulley of negligible mass, as shown in the figure above. The masses of the two blocks, M_1 and M_2, can be varied. M_2 is always greater than M_1.

[Figure: An Atwood's machine — two blocks M_1 and M_2 hang from a light string over a frictionless pulley of negligible mass mounted on a support stand, above a table/floor surface.]

(b) Using the forces in your diagrams above, write an equation applying Newton's second law to each block and use these two equations to derive the magnitude of the acceleration of the blocks and show that it is given by the equation:

$$a = \frac{(M_2 - M_1)}{(M_1 + M_2)} g$$

Question 1

The magnitude of the acceleration a was measured for different values of M_1 and M_2, and the data are shown below.

M_1 (kg)	1.0	2.0	5.0	6.0	10.0
M_2 (kg)	2.0	3.0	12.0	8.0	14.0
a (m/s^2)	3.02	1.82	4.21	1.15	1.71

Question 1

2017 ▪ Q1

An Atwood's machine consists of two blocks connected by a light string that passes over a frictionless pulley of negligible mass, as shown in the figure above. The masses of the two blocks, M_1 and M_2, can be varied. M_2 is always greater than M_1.

[Figure: An Atwood's machine — two blocks M_1 and M_2 hang from a light string over a frictionless pulley of negligible mass mounted on a support stand, above a table/floor surface.]

(c) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for the acceleration due to gravity g.

Vertical axis: ____________________

Horizontal axis: ____________________

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given.

Question 1

2017 ▪ Q1

An Atwood's machine consists of two blocks connected by a light string that passes over a frictionless pulley of negligible mass, as shown in the figure above. The masses of the two blocks, M_1 and M_2, can be varied. M_2 is always greater than M_1.

[Figure: An Atwood's machine — two blocks M_1 and M_2 hang from a light string over a frictionless pulley of negligible mass mounted on a support stand, above a table/floor surface.]

(d) Plot the data points for the quantities indicated in part (c) on the graph below. Clearly scale and label all axes including units, if appropriate. Draw a straight line that best represents the data.

[Blank grid for plotting the linearized data from part (c), with a best-fit straight line to be drawn through the plotted points.]

Question 1

2017 ▪ Q1

An Atwood's machine consists of two blocks connected by a light string that passes over a frictionless pulley of negligible mass, as shown in the figure above. The masses of the two blocks, M_1 and M_2, can be varied. M_2 is always greater than M_1.

[Figure: An Atwood's machine — two blocks M_1 and M_2 hang from a light string over a frictionless pulley of negligible mass mounted on a support stand, above a table/floor surface.]

(e) Using your straight line, determine an experimental value for g.

[Figure: The experiment is now modified — block M_1 rests on a smooth, horizontal table, with the string passing over a frictionless pulley mounted at the edge of the table, and block M_2 hangs vertically over the side of the table.]

The experiment is now repeated with a modification. The Atwood's machine is now set up so that the block of mass M_1 is on a smooth, horizontal table and the block of mass M_2 is hanging over the side of the table, as shown in the figure above.

Question 1

2017 ▪ Q1

An Atwood's machine consists of two blocks connected by a light string that passes over a frictionless pulley of negligible mass, as shown in the figure above. The masses of the two blocks, M_1 and M_2, can be varied. M_2 is always greater than M_1.

[Figure: An Atwood's machine — two blocks M_1 and M_2 hang from a light string over a frictionless pulley of negligible mass mounted on a support stand, above a table/floor surface.]

(f) For the same values of M_1 and M_2, is the magnitude of the tension in the string when the blocks are moving higher, lower, or equal to the magnitude of the tension in the string when the blocks are moving in the first experiment?

_____ Higher _____ Lower _____ Equal to

Justify your answer.

Question 1

2017 ▪ Q1

An Atwood's machine consists of two blocks connected by a light string that passes over a frictionless pulley of negligible mass, as shown in the figure above. The masses of the two blocks, M_1 and M_2, can be varied. M_2 is always greater than M_1.

[Figure: An Atwood's machine — two blocks M_1 and M_2 hang from a light string over a frictionless pulley of negligible mass mounted on a support stand, above a table/floor surface.]

(g) The value determined for the acceleration due to gravity g is lower than in the first experiment. Give one physical factor that could account for this lower value and explain how this factor affected the experiment.

Solution 1

(a) Mark scheme

- Each block has two forces: tension F_T (up) and weight (down, M_1g or M_2g). For block M_1: draw F_T and M_1g with the tension arrow LONGER than the weight arrow, since M_1 accelerates upward (net force up) so $F_T > M_1g$. For block M_2: draw F_T and M_2g with the weight arrow LONGER than the tension arrow, since M_2 accelerates downward so $M_2g > F_T$. The tension magnitude must be drawn EQUAL on both blocks (same ideal string over a frictionless, massless pulley). 1 point for M1's diagram (correct forces, tension > weight), 1 point for M2's diagram (correct forces, weight > tension), 1 point for equal tension magnitudes on both blocks. (Max 2 points if extraneous vectors are drawn.)

Solution 1

(b)

Mark scheme

- Newton's second law for block M_1 (taking up as positive, since M_1 accelerates upward): $F_T - M_1 g = M_1 a$. For block M_2 (taking down as positive): $M_2 g - F_T = M_2 a$. Adding the two equations eliminates F_T: $M_2 g - M_1 g = (M_1 + M_2)a$, so $a = \dfrac{(M_2 - M_1)}{(M_1 + M_2)} g$, as required. 1 point for each correct equation (2 total), 1 point for correctly combining them to reach the given result.

Solution 1

(c)

Mark scheme

- Vertical axis: a. Horizontal axis: $\dfrac{(M_2 - M_1)}{(M_1 + M_2)}$. Since $a = g \cdot \dfrac{(M_2 - M_1)}{(M_1 + M_2)}$, plotting these gives a straight line through the origin with slope g. (Full credit is also earned if the axes are reversed, or another combination that correctly linearizes the relation to get g from the slope.)

Solution 1

(d) Mark scheme

- Using the given M_1, M_2 table, compute $(M_2 - M_1)/(M_1 + M_2)$ and the corresponding measured acceleration a for each data row, then plot all points and draw ONE straight best-fit line through them (the scoring guideline's own graph runs from about (0.05, 0.5) up to about (0.42, 4.4) m/s^2, with data points near (0.14,1.1), (0.17-0.19, 1.6-1.7), (0.31,3.0), (0.40,4.3)). 1 point for a scale that uses more than half the grid with correctly labeled axes (including units), 1 point for correctly plotting the data, 1 point for a straight best-fit line consistent with the plotted data.

Solution 1

(e) Mark scheme

- Using two well-separated points on the best-fit line (NOT the raw data points), e.g. (0.12, 1.0) and (0.31, 3.0): slope $= \dfrac{(3.0 - 1.0)\ \mathrm{m/s^2}}{(0.31 - 0.12)} = 10.5\ \mathrm{m/s^2}$. Since $a = g \cdot x$ with $x = (M_2 - M_1)/(M_1 + M_2)$, the slope equals g, so $g \approx 10.5\ \mathrm{m/s^2}$ (linear regression on the data instead gives $g \approx 10.1\ \mathrm{m/s^2}$, also acceptable, but only if the student states linear regression was used). 1 point for correctly calculating the slope from the best-fit line, 1 point for correctly identifying slope $=$ g.

Solution 1

(f) Mark scheme

- Correct answer: Lower. Since M_1 now sits on a frictionless table (instead of hanging), the net driving force on the system increases and so the acceleration increases (Example reasoning from the scoring guideline: 'Because the block M_1 is on the table, the net force on the system increases, and therefore the acceleration increases. Because the acceleration of M_2 increases, the net force on M_2 must increase. Therefore, there must be a greater difference in the magnitude of the two forces on M_2. Because the weight of block M_2 stays the same, the retarding force – the tension in the string – must decrease.') 1 point for a correct statement about the acceleration of the blocks, 1 point for a correct statement about the forces on the blocks (connecting increased acceleration to decreased tension).

Solution 1

(g)

Mark scheme

- Any correct physical factor with a valid explanation for why the experimental g comes out lower than the true value. Example from the scoring guideline: 'Block M_1 will experience friction with the table. The acceleration of the system will decrease and this will decrease the slope of the line; therefore, the value of g determined by the experiment is lower.' Other acceptable factors include rotational inertia of the pulley or air resistance, each with a matching explanation of why it reduces the acceleration/slope. 1 point for a correct justification.

Question 1

2015 ▪ Q1

A block of mass m is projected up from the bottom of an inclined ramp with an initial velocity of magnitude v_0.

The ramp has negligible friction and makes an angle θ with the horizontal. A motion sensor aimed down the ramp is mounted at the top of the incline so that the positive direction is down the ramp. The block starts a distance D from the motion sensor, as shown above. The block slides partway up the ramp, stops before reaching the sensor, and then slides back down.

[Diagram: An inclined ramp making angle θ with the horizontal. A Motion Sensor is mounted at the top of the incline, aimed down the ramp, with a y-axis pointing up-left from the sensor and an x-axis pointing along the ramp surface down and to the right. The point $x = 0$ is at the sensor (top of ramp); the point $x = D$ is at the bottom of the ramp where the block starts. A dashed line labeled D spans from the sensor down

Question 1

to a small dashed box partway down the ramp. A block near the bottom of the ramp (at $x = D$) has an arrow labeled $\vec{v}_0$ pointing up the ramp (toward the sensor).]

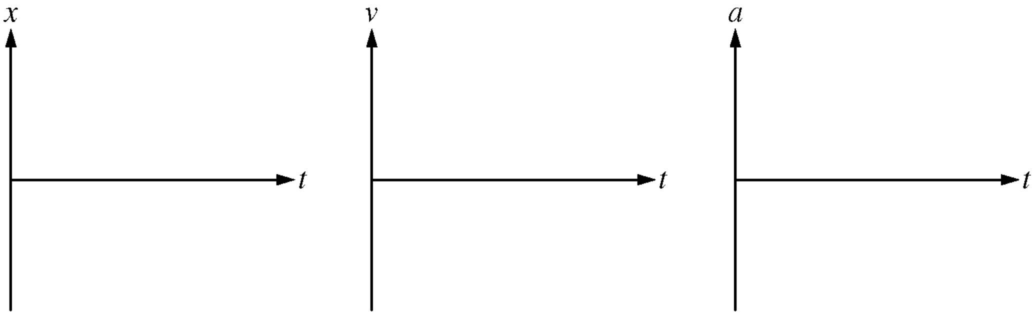
(a) Consider the motion of the block at some time t after it has been projected up the ramp. Express your answers in terms of m, D, v_0, t, θ and physical constants, as appropriate.

(a)(i) Determine the acceleration a of the block.

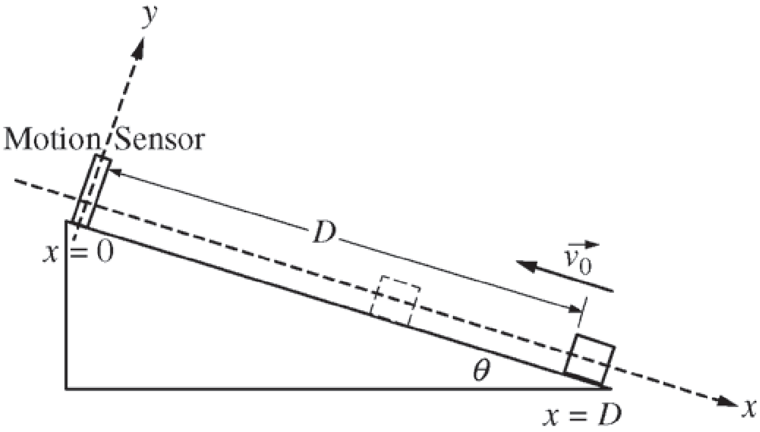
(a)(ii) Determine an expression for the velocity v of the block.

(a)(iii) Determine an expression for the position x of the block.

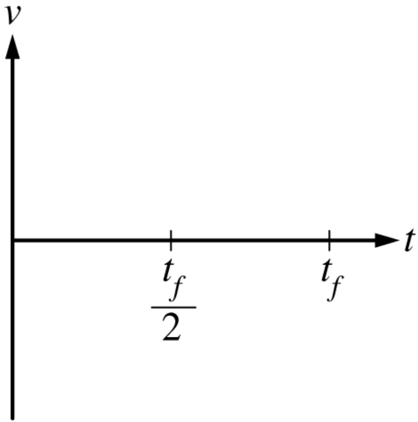
Question 1



Question 1



Question 1



Question 1

2015 ▪ Q1

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Question 1

ramp. A block near the bottom of the ramp (at $x = D$) has an arrow labeled $\vec{v}_0$ pointing up the ramp (toward the sensor).]

(b) Derive an expression for the position x_{min} of the block when it is closest to the motion sensor. Express your answer in terms of m, D, v_0, θ, and physical constants, as appropriate.

Question 1

2015 ▪ Q1

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Question 1

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(c) On the axes provided below, sketch graphs of position x, velocity v, and acceleration a as functions of time t for the motion of the block while it goes up and back down the ramp. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.

[Three blank axes side by side, each with a horizontal t-axis and a vertical axis. The first is labeled x, the second labeled v, the third labeled a. All axes are unlabeled/blank grids for the student to sketch on — no data is plotted.]

Question 1

2015 ▪ Q1

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Question 1

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(d) After the block slides back down and leaves the bottom of the ramp, it slides on a horizontal surface with a coefficient of friction given by μ_k. Derive an expression for the distance the block slides before stopping. Express your answer in terms of m, D, v_0, θ, μ_k, and physical constants, as appropriate.

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2015 ▪ Q1

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Question 1

ramp. A block near the bottom of the ramp (at $x = D$) has an arrow labeled $\vec{v}_0$ pointing up the ramp (toward the sensor).]

(e) Suppose the ramp now has friction. The same block is projected up with the same initial speed v_0 and comes back down the ramp. On the axes provided below, sketch a graph of the velocity v as a function of time t for the motion of the block while it goes up and back down the ramp, arriving at the bottom of the ramp at time t_f. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.

[Blank axes with vertical axis v and horizontal axis t. Two tick marks are pre-labeled on the t-axis: $\frac{t_f}{2}$ and t_f. The graph itself is blank for the student to sketch.]