Past-paper walk-through

Conservation of Energy ▪ 3.4

eXercise

Questions in this set

- 2026 Q3
- 2025 Q1
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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

2026 ▪ Q3

The following information applies to parts A and B.

A group of students are investigating friction using the following procedure. The students release a block of unknown mass near the top of a curved ramp. The block slides down the ramp. The block then transitions to a horizontal surface, as shown in Figure 1. Frictional forces are negligible between the block and the curved ramp, but there is friction between the block and the horizontal surface.

[Figure 1: A side-view diagram showing a curved ramp descending from upper left to a horizontal surface at the bottom. A small shaded square labeled "Block" sits at the top of the curve. The curve smoothly transitions into a horizontal line extending to the right, on which another small shaded square (the block, later position) sits partway along.]

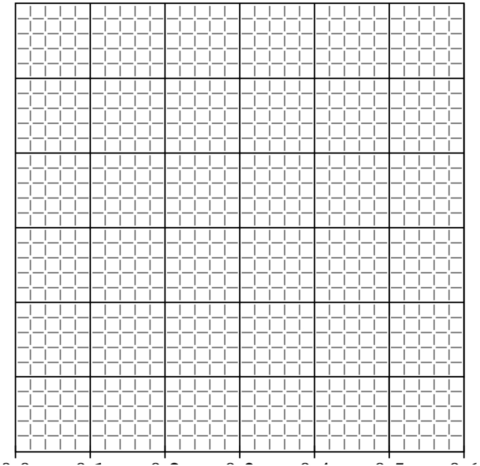
Question 3

The students are asked to perform an experiment in which a single quantity is varied in order to collect data that could be graphed to determine the value μ_k of the coefficient of kinetic friction between the block and the horizontal surface. The students have access to only a meterstick.

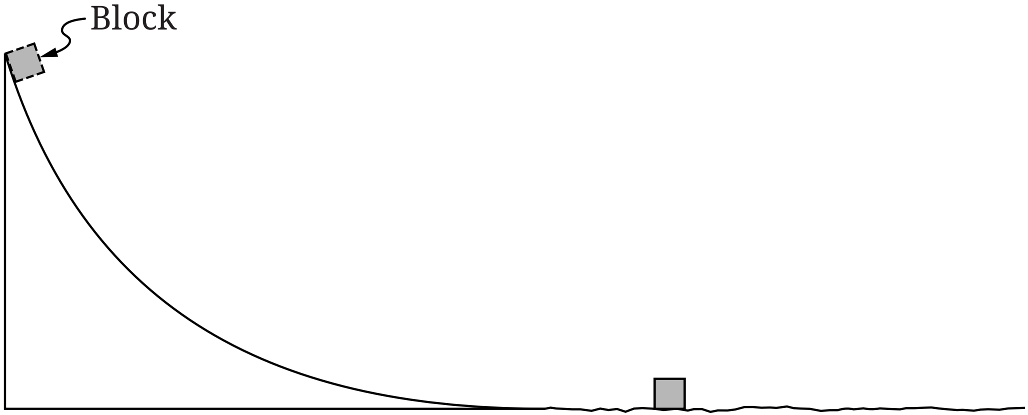
(a)(i) Indicate quantities that could be measured by the students that would allow them to determine μ_k using a linear graph.

(a)(ii) Briefly **describe** a method to reduce experimental uncertainty for the measured quantities.

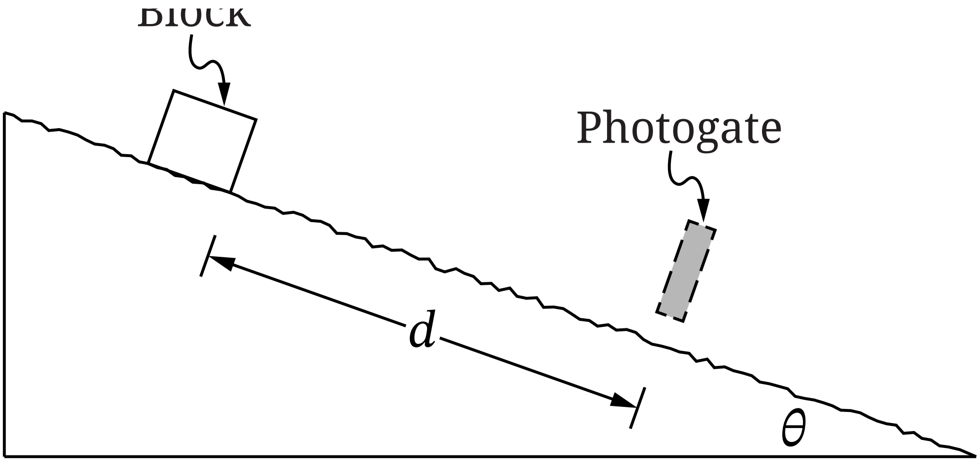
Question 3



Question 3



Question 3



Question 3

2026 ▪ Q3

The following information applies to parts A and B.

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The students are asked to perform an experiment in which a single quantity is varied in order to collect data that could be graphed to determine the value μ_k of the coefficient of kinetic friction between the block and the horizontal surface. The students have access to only a meterstick.

Question 3

(b)(i) Indicate what quantities the students could graph on the horizontal and vertical axes to create a linear graph that can be used to determine μ_k. Clearly state which quantity will be graphed on each axis.
(b)(ii) Briefly **describe** the relationship between μ_k and a feature of the graph from part B (i). Your answer may include an equation that relates μ_k and the chosen feature of the graph.

Question 3

2026 ▪ Q3

The following information applies to parts A and B.

A group of students are investigating friction using the following procedure. The students release a block of unknown mass near the top of a curved ramp. The block slides down the ramp. The block then transitions to a horizontal surface, as shown in Figure 1. Frictional forces are negligible between the block and the curved ramp, but there is friction between the block and the horizontal surface.

[Figure 1: A side-view diagram showing a curved ramp descending from upper left to a horizontal surface at the bottom. A small shaded square labeled "Block" sits at the top of the curve. The curve smoothly transitions into a horizontal line extending to the right, on which another small shaded square (the block, later position) sits partway along.]

The students are asked to perform an experiment in which a single quantity is varied in order to collect data that could be graphed to determine the value μ_k of the coefficient of kinetic friction between the block and the horizontal surface. The students have access to only a meterstick.

Question 3

(c)(d)(i)(n)(t)(r)(o) The following information applies to parts C and D.
In a different experiment, the students release a block from rest on a rough ramp. The block is released a distance d from a photogate. The ramp is inclined at an angle θ above the horizontal, as shown in Figure 2. The block slides down the ramp and passes through the photogate, which is positioned near the bottom of the ramp. The photogate determines the speed v of the block as it passes through the photogate. The unknown coefficient of kinetic friction between the block and the ramp is μ_k.
[Figure 2: A side-view diagram of a ramp inclined at angle θ above the horizontal (a right-triangle shape). A block sits on the incline near the top, with a dashed double-headed arrow labeled d running down the slope from the block to a photogate device (shown as a small hatched rectangle) positioned further down the incline near the bottom. The angle θ is marked at the base of the incline.]

Question 3

The experiment is repeated several times with different release distances d for the same block. Table 1 shows the measured values of d and v.

Table 1

d (m)	v (m/s)
0.20	0.29
0.30	0.38
0.40	0.41
0.50	0.49
0.60	0.52

The students correctly determine that the relationship between d and v is given by

$$v^2 = [2g(\sin\theta - \mu_k \cos\theta)]d,$$

where $\theta = 30^\circ$. The students want to determine μ_k. The students create a graph with d plotted on the horizontal axis.

Question 3

(c)(i) Label the vertical axis of Figure 3 with a measured or calculated quantity. Include units, as appropriate. The graphed quantities should yield a linear graph that can be used to determine μ_k.

(c)(ii) On the grid provided in Figure 3, create a graph that can be used to determine μ_k.

- Clearly **label** the vertical axis with a numerical scale.
- **Plot** the corresponding data points on the grid.
- Table 2 is provided in your booklet for scratch work and will not be scored.

[Figure 3: A blank grid for plotting, with the vertical axis unlabeled (headed "Quantity (units, if appropriate)" with two blank lines above it for the student to write the quantity and units) and the horizontal axis labeled d (m), with tick marks at 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6.]

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

Question 3

2026 ▪ Q3

The following information applies to parts A and B.

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The students are asked to perform an experiment in which a single quantity is varied in order to collect data that could be graphed to determine the value μ_k of the coefficient of kinetic friction between the block and the horizontal surface. The students have access to only a meterstick.

Question 3

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

Question 1

2025 ▪ Q1

A student has a cart of mass m_c and a block of mass $\frac{1}{5}m_c$, as shown in Figure 1.
- At time $t = 0$, the cart is moving to the right across a horizontal surface with constant speed v_c, and the student releases the block from rest. - At $t = t_1$, the block collides with and sticks to the top of the cart. The block does not slide on the cart. - At $t = t_2$, the block-cart system continues to move to the right with constant speed v_f.
Figure 1
[Figure 1: Three snapshots of a cart of mass m_c on a horizontal surface. At $t = 0$, a hand holds a block of mass $\frac{1}{5}m_c$ above the moving cart labeled "Cart"; the cart moves to the right with speed lines shown. At $t = t_1$, the block is shown just above/contacting the top of the cart (falling onto it), cart still moving right. At $t = t_2$, the block rests on top of the cart, and the block-cart system moves to the right together.]

Question 1

(a)(i) On the axes shown in Figure 2, **sketch** a graph of the magnitude p_x of the x-component of the momentum of the block-cart system as a function of time t from $t = 0$ until $t > t_2$.

Figure 2

[Figure 2: A blank set of axes with vertical axis labeled p_x and horizontal axis labeled t, origin O. Two vertical dashed reference lines are drawn at $t = t_1$ and $t = t_2$. The student is to sketch the momentum curve on these axes.]

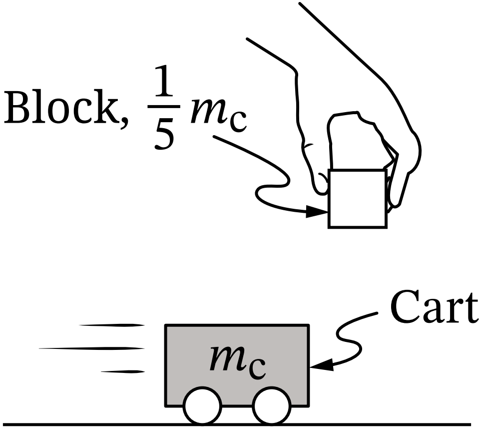
(a)(ii) **Derive** an expression for the speed v_f of the block-cart system after time $t = t_2$ in terms of m_c, v_c, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

(a)(iii) **Derive** an expression for the change in the kinetic energy ΔK in the block-cart system from $t = 0$ to $t = t_2$ in terms of m_c, v_c, and physical constants, as

Question 1

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

Question 1



Question 1

2025 ▪ Q1

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[Figure 1: Three snapshots of a cart of mass m_c on a horizontal surface. At $t = 0$, a hand holds a block of mass $\frac{1}{5}m_c$ above the moving cart labeled "Cart"; the cart moves to the right with speed lines shown. At $t = t_1$, the block is shown just above/contacting the top of the cart (falling onto it), cart still moving right. At $t = t_2$, the block rests on top of the cart, and the block-cart system moves to the right together.]

Question 1

(b) Consider the case where a new block is dropped and collides with the top of the cart. The new block slides along the cart during the collision but does not slide off the cart. The time interval from when the new block collides with the cart and moves together with the cart is Δt. During Δt there is a frictional force between the new block and the cart.
Indicate whether the x-component of the momentum of the new block-cart system increases, decreases, or remains constant during Δt.

$I^{ncreases}$

$D^{ecreases}$

$R^{emainsconstant}$
Justify your response.

Solution 1

(a)(i)

Mark scheme

- Sketch a single continuous, nonzero, horizontal line for p_x across the whole graph from $t = 0$ through $t = t_2$ (and beyond). Since no net external horizontal force acts on the block-cart system, the x-momentum is conserved throughout — constant before the collision ($t < t_1$), unchanged during the collision, and constant after ($t > t_1$), at the same height. Point A1: sketch a constant, nonzero p_x segment for $t < t_1$ OR for $t > t_1$. Point A2: sketch a continuous, nonzero, horizontal line from $t = 0$ to $t = t_2$ (or beyond), showing momentum stays constant the entire time.

Solution 1

(a)(ii) Mark scheme

- Begin with conservation of momentum: $p_i = p_f$. The falling block (mass $m_b = \frac{1}{5}m_c$) collides with the cart (mass m_c, speed v_c) and they move together afterward: $m_c v_c = (m_c + m_b)v_f = \left(m_c + \frac{1}{5}m_c\right) v_f = \frac{6}{5}m_c v_f$. Solving gives $v_f = \frac{5}{6}v_c$. Point A3 is earned for including a conservation-of-momentum equation; Point A4 for setting $m_c v_c$ equal to the post-collision momentum $(m_c + m_b)v_f$. A correct, isolated final expression $v_f = \frac{5}{6}v_c$ earns both A3 and A4.

Solution 1

(a)(iii) Mark scheme

- $\Delta K = K_f - K_0$, with $K_0 = \frac{1}{2}m_c v_c^2$, and using $v_f = \frac{5}{6}v_c$ from part A(ii) with final mass $\frac{6}{5}m_c$: $K_f = \frac{1}{2}\left(\frac{6}{5}m_c\right)\left(\frac{5}{6}v_c\right)^2 = \frac{5}{12}m_c v_c^2$. So $\Delta K = \frac{5}{12}m_c v_c^2 - \frac{1}{2}m_c v_c^2 = -\frac{1}{12}m_c v_c^2$ (kinetic energy decreases in the collision). Point A5 for a multistep derivation using $K = \frac{1}{2}mv^2$ (minimum: show an expression for K or ΔK that goes beyond the given reference equation); Point A6 for identifying m_c and $\frac{6}{5}m_c$ as the initial and final masses moving horizontally; Point A7 for using a v_f expression consistent with part A(ii). A correct, isolated final expression $\Delta K = -\frac{1}{12}m_c v_c^2$ earns points A3, A4, A6, and A7 as well.

Solution 1

(b) Mark scheme

- The x-momentum of the new block-cart system remains constant throughout Δt (Point B1). Justification: the frictional force between the new block and the cart is an internal force — it acts equally and oppositely on the two objects, so it produces no net external force on the system (Point B2: e.g. "the frictional force is internal to the new block-cart system" or "the net external force is still zero"). Consequently, the change in momentum of the new block is equal in magnitude and opposite in direction to the change in momentum of the cart — the impulses on each are equal and opposite (Point B3). Example response: "The momentum of the new block-cart system will remain constant because the frictional force

Solution 1

exerted on the new block by the cart is internal to the system and only a net external force will cause a change in momentum of the system."

Question 2

2025 ▪ Q2

A block of mass M is released from rest at position $x = 0$ near the top of a ramp. The ramp makes an angle of θ with the horizontal. The block slides down the ramp with negligible friction. At $x = 8D$ the block makes contact with an uncompressed spring with spring constant k. The spring is then compressed and the block momentarily comes to rest at $x = 12D$. Figure 1 shows the instants when the block is at $x = 0$, $x = 6D$, and $x = 10D$, respectively.
[Figure 1: Three diagrams of a ramp inclined at angle θ to the horizontal, with a spring of constant k fixed at the bottom of the ramp. The $+x$ direction points down the incline. Left diagram: block at $x = 0$ at the top of the ramp, with marks at $8D$ (where the spring begins, uncompressed) and $12D$ (spring fully compressed position) shown along the incline. Middle diagram: block shown partway down the ramp at

Question 2

$x = 6D$, moving toward the spring (motion lines shown). Right diagram: block shown further down, in contact with/compressing the spring, at $x = 10D$.]

(a) Figure 4 shows an energy bar chart that represents the kinetic energy K of the block, the gravitational potential energy U_g of the block-spring-Earth system, and the spring potential energy U_s of the block-spring-Earth system at the instant that the block is at $x = 10D$. The gravitational potential energy U_g of the block-spring-Earth system is defined to be zero when the block momentarily comes to rest at $x = 12D$. **Draw** shaded bars that represent K, U_g, and U_s to complete the energy bar charts in Figure 2 and Figure 3 for when the block is released from rest at $x = 0$ and for when the block is at $x = 6D$, respectively.

- Shaded bars should start at the dashed line that represents zero energy. - Represent any energy that is equal to zero with a distinct line on the zero-energy line. - The

Question 2

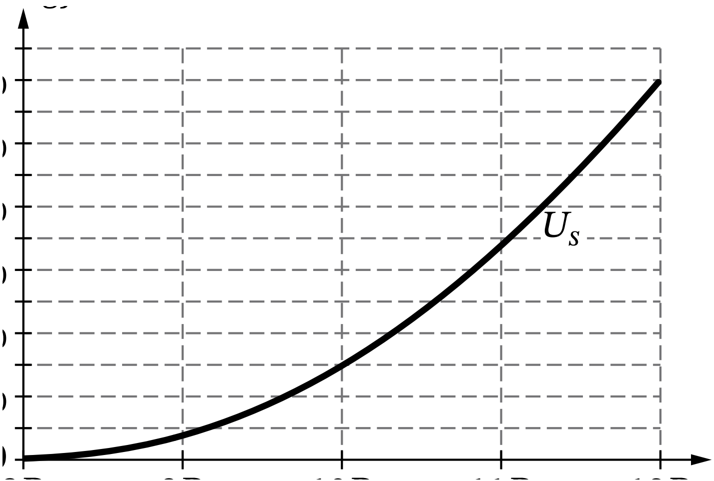
relative heights of each shaded bar should reflect the magnitude of the respective energy consistent with the scale used in Figure 4.

[Figure 2: Bar chart titled "$x = 0$", vertical axis "Energy" gridded in increments of $2E_0$ from 0 to $14E_0$, with three empty bar slots labeled K, U_g, U_s on the horizontal axis — bars to be drawn by the student.]

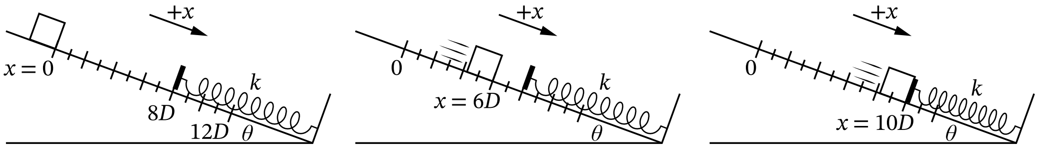
[Figure 3: Bar chart titled "$x = 6D$", vertical axis "Energy" gridded in increments of $2E_0$ from 0 to $14E_0$, with three empty bar slots labeled K, U_g, U_s on the horizontal axis — bars to be drawn by the student.]

[Figure 4: Bar chart titled "$x = 10D$", vertical axis "Energy" gridded in increments of $2E_0$ from 0 to $14E_0$. Three shaded bars are shown: $K \approx 7E_0$, $U_g \approx 1.5E_0$, $U_s \approx 3E_0$.]

Question 2



Question 2



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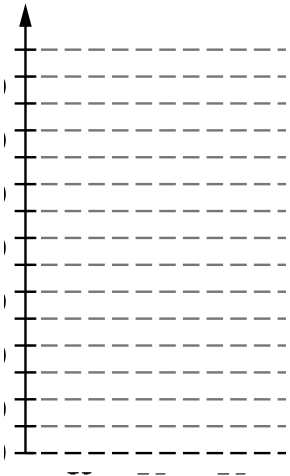

Question 2

2025 ▪ Q2

A block of mass M is released from rest at position $x = 0$ near the top of a ramp. The ramp makes an angle of θ with the horizontal. The block slides down the ramp with negligible friction. At $x = 8D$ the block makes contact with an uncompressed spring with spring constant k. The spring is then compressed and the block momentarily comes to rest at $x = 12D$. Figure 1 shows the instants when the block is at $x = 0$, $x = 6D$, and $x = 10D$, respectively.

[Figure 1: Three diagrams of a ramp inclined at angle θ to the horizontal, with a spring of constant k fixed at the bottom of the ramp. The $+x$ direction points down the incline. Left diagram: block at $x = 0$ at the top of the ramp, with marks at $8D$ (where the spring begins, uncompressed) and $12D$ (spring fully compressed position) shown along the incline. Middle diagram: block shown partway down the ramp at $x = 6D$, moving toward the spring (motion lines shown). Right diagram: block shown further down, in contact with/compressing the spring, at $x = 10D$.]

Question 2

(b) Figure 5 shows the block at $x = 0$ when the block is released from rest and the block at $x = 12D$ when the block momentarily comes to rest against the compressed spring.
Figure 5
[Figure 5: Two diagrams of the same ramp at angle θ with spring constant k at the bottom. Left: block at $x = 0$ at the top, $+x$ direction down the incline, mark at $12D$ shown along the incline. Right: block at $x = 12D$, resting against the fully compressed spring at the bottom of the incline.]
Starting with conservation of energy, **derive** an equation for the spring constant k. Express your answer in terms of M, θ, D, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

Question 2

2025 ▪ Q2

A block of mass M is released from rest at position $x = 0$ near the top of a ramp. The ramp makes an angle of θ with the horizontal. The block slides down the ramp with negligible friction. At $x = 8D$ the block makes contact with an uncompressed spring with spring constant k. The spring is then compressed and the block momentarily comes to rest at $x = 12D$. Figure 1 shows the instants when the block is at $x = 0$, $x = 6D$, and $x = 10D$, respectively.

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Question 2

(c)(i) Figure 6 shows a graph of the energy of the system as a function of the position of the block from $x = 8D$ to $x = 12D$. The spring potential energy U_s of the block-spring-Earth system is shown on the graph.

On the axes shown in Figure 6, **sketch** and **label** a line or curve that represents the total mechanical energy E for the block-spring-Earth system as a function of the position of the block from $x = 8D$ to $x = 12D$.

Figure 6

[Figure 6: Graph with vertical axis "Energy" gridded in increments of $2E_0$ from 0 to $12E_0$, horizontal axis "Position" marked $8D, 9D, 10D, 11D, 12D$. A curve labeled U_s is plotted starting at $(8D, 0)$ and increasing with upward curvature (quadratic-like shape) to reach $(12D, 12E_0)$. The student must add curves for E and U_g on the same axes.]

Question 2

(c)(ii) Sketch and **label** a line or curve that represents the gravitational potential energy U_g for the block-spring-Earth system as a function of the position of the block from $x = 8D$ to $x = 12D$.

Question 2

2025 ▪ Q2

A block of mass M is released from rest at position $x = 0$ near the top of a ramp. The ramp makes an angle of θ with the horizontal. The block slides down the ramp with negligible friction. At $x = 8D$ the block makes contact with an uncompressed spring with spring constant k. The spring is then compressed and the block momentarily comes to rest at $x = 12D$. Figure 1 shows the instants when the block is at $x = 0$, $x = 6D$, and $x = 10D$, respectively.

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Question 2

(d) Indicate whether the speed v_{9D} of the block at $x = 9D$ is greater than, less than, or equal to the speed v_{8D} of the block at $x = 8D$.

________ $v_{9D} > v_{8D}$

________ $v_{9D} < v_{8D}$

________ $v_{9D} = v_{8D}$

Justify how your response is consistent with the energy lines or curves you drew in Figure 6 in part C.

Solution 2

(a) Mark scheme

- Complete two energy bar charts, each totaling the constant mechanical energy $12E_0$. Figure 2 (block at $x = 0$, released from rest, not yet touching the spring): draw a single bar for U_g at height $12E_0$; the K and U_s bars are at zero. Figure 3 (block at $x = 6D$, partway down, still not touching the spring): draw bars for K and U_g only (no U_s), each at height $6E_0$. Point A1 for drawing one bar in Figure 2 that shows only U_g (the correct height is not required for this point); Point A2 for including only K and U_g bars in Figure 3 (correct heights not required); Point A3 for the bars in Figures 2 and 3 each totaling $12E_0$.

Solution 2

(b) Mark scheme

- By conservation of energy, the initial gravitational PE converts entirely into spring PE at the point where the block is momentarily at rest against the fully compressed spring: $E_0 = E_f \Rightarrow U_g = U_s \Rightarrow mg\Delta y = \frac{1}{2}k(\Delta x)^2$. Substituting $\Delta y = 12D\sin\theta$ (the height dropped along the incline from $x = 0$ to $x = 12D$) and $\Delta x = 4D$ (the spring compression, from $x = 8D$ to $x = 12D$): $Mg(12D\sin\theta) = \frac{1}{2}k(4D)^2$, which gives $k = \frac{3}{2}\frac{Mg\sin\theta}{D}$. Point B1 for a multistep derivation that includes conservation of energy; B2 for equating U_g to U_s; B3 for substituting $12D\sin\theta$ for Δy OR $4D$ for Δx in the respective energy expression; B4 for a correct expression for k (any algebraic equivalent of $k = \frac{3}{2}\frac{Mg\sin\theta}{D}$). A correct, isolated final expression for k earns B2, B3, and B4.

Solution 2

(c)(i)

Mark scheme

- Sketch a horizontal line at $E = 12E_0$, drawn continuously from $x = 8D$ to $x = 12D$, labeled to indicate it is the total mechanical energy E of the block-spring-Earth system (constant, since no non-conservative forces act). Point C1.

Solution 2

(c)(ii)

Mark scheme

- Sketch a straight, decreasing line (linear, since $U_g = Mg(12D - x)\sin\theta$ is linear in x) from $x = 8D$ to $x = 12D$, labeled to indicate gravitational potential energy U_g, starting at the point $(8D,\ 4E_0)$ and decreasing to $(12D,\ 0)$. Point C2 for a decreasing straight line labeled as gravitational potential energy; Point C3 for starting that line at $(8D, 4E_0)$.

Solution 2

(d) Mark scheme

- $v_{9D} > v_{8D}$. Justification: from the total-energy line ($E = 12E_0$ everywhere) and the U_g line drawn in part C, at $x = 8D$, $U_g = 4E_0$, so $K = 12E_0 - 4E_0 = 8E_0$ (with $U_s \approx 0$ there). At $x = 9D$, U_g has dropped to about $3E_0$ and U_s is still less than E_0, so $K = E - U_g - U_s > 12E_0 - 3E_0 - E_0 = 8E_0$. Since the kinetic energy — and therefore the speed — is greater at $x = 9D$ than at $x = 8D$, $v_{9D} > v_{8D}$. Point D1 for the comparison consistent with the student's part-C graph (whichever position has the smaller $U_g + U_s$ has the larger speed); Point D2 for a justification consistent with that graph that correctly relates speed to U_g, U_s, and either K or total energy E.

Question 1

2024 ▪ Q1

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

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

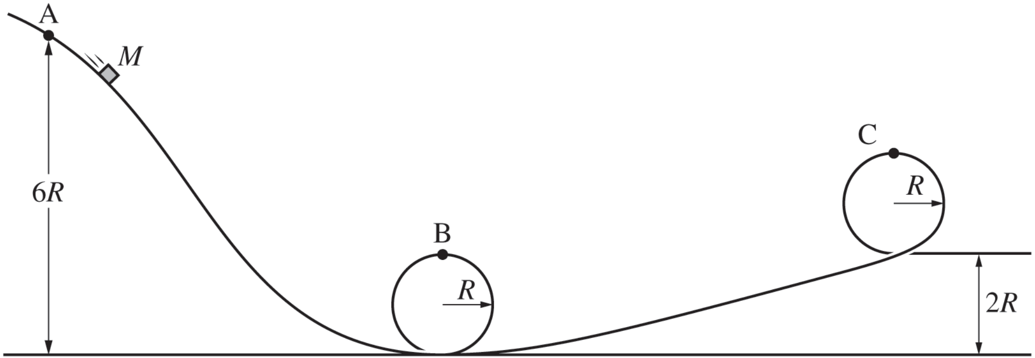
Question 1

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

Question 1

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

Question 1



Question 1

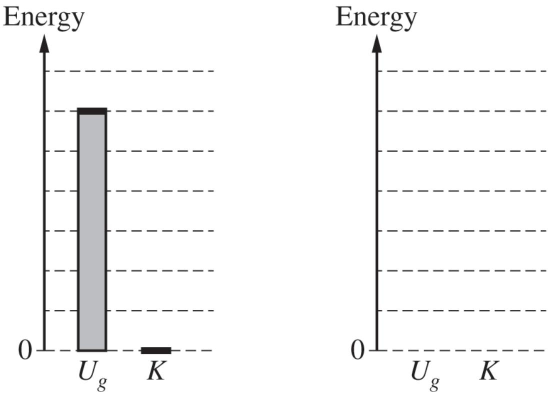


Diagram A

Diagram B

Question 1

2024 ▪ Q1

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

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

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

Question 1

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

Question 1

2024 ▪ Q1

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

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

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

Question 1

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

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

Solution 1

(a)

Mark scheme

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

Solution 1

(b)

Mark scheme

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

Solution 1

(c)(i)

Mark scheme

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

Solution 1

(c)(ii) Mark scheme

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

Question 1

2023 ▪ Q1

A cart on a horizontal surface is attached to a spring. The other end of the spring is attached to a wall. The cart is initially held at rest, as shown in Figure 1. When the cart is released, the system consisting of the cart and spring oscillates between the positions $x = +L$ and $x = -L$. Figure 2 shows the kinetic energy of the cart-spring system as a function of the system's potential energy. Frictional forces are negligible.
[Figure 1: A cart attached to a spring coiled between a wall on the left and the cart on the right, resting on a horizontal surface. Positions marked below: $x = -L$ (at the wall end), $x = 0$ (middle), $x = +L$ (at the cart's rest position shown).]
[Figure 2: Graph of kinetic energy K (J) on the vertical axis, from 0 to 6, versus potential energy U (J) on the horizontal axis, from 0 to 6. A straight diagonal line runs from approximately $(0, 4)$ down to $(4, 0)$, i.e., the line has x-intercept and y-intercept both equal in value.]

Question 1

(a) On the graph of kinetic energy K versus potential energy U shown in Figure 2, the values for the x-intercept and y-intercept are the same. Briefly explain why this is true, using physics principles.

Question 1

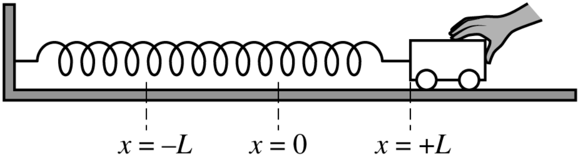


Figure 1

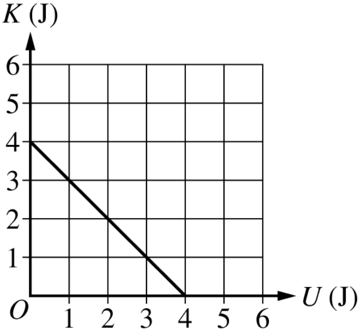


Figure 2

Question 1

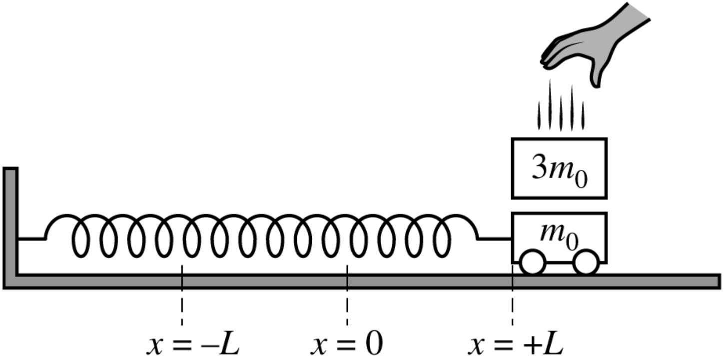


Figure 3

Question 1

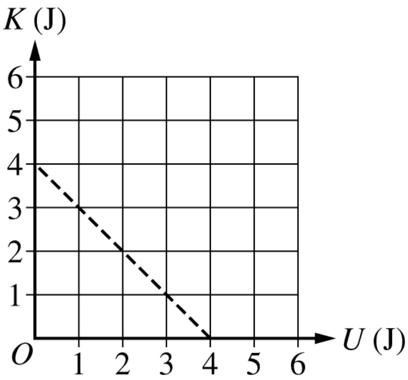


Figure 4

Question 1

2023 ▪ Q1

A cart on a horizontal surface is attached to a spring. The other end of the spring is attached to a wall. The cart is initially held at rest, as shown in Figure 1. When the cart is released, the system consisting of the cart and spring oscillates between the positions $x = +L$ and $x = -L$. Figure 2 shows the kinetic energy of the cart-spring system as a function of the system's potential energy. Frictional forces are negligible.

[Figure 1: A cart attached to a spring coiled between a wall on the left and the cart on the right, resting on a horizontal surface. Positions marked below: $x = -L$ (at the wall end), $x = 0$ (middle), $x = +L$ (at the cart's rest position shown).]

[Figure 2: Graph of kinetic energy K (J) on the vertical axis, from 0 to 6, versus potential energy U (J) on the horizontal axis, from 0 to 6. A straight diagonal line runs from approximately $(0, 4)$ down to $(4, 0)$, i.e., the line has x-intercept and y-intercept both equal in value.]

Question 1

(b) [Continuation of Question 1.] When the cart is at $+L$ and momentarily at rest, a block is dropped onto the cart, as shown in Figure 3. The block sticks to the cart, and the block-cart-spring system continues to oscillate between $-L$ and $+L$. The masses of the cart and the block are m_0 and $3m_0$, respectively.
[Figure 3: Same spring-and-wall setup as Figure 1, but now a block labeled $3m_0$ falls (shown with motion marks) onto a cart labeled m_0 sitting atop the cart at position $x = +L$. Positions marked: $x = -L$, $x = 0$, $x = +L$.]
The frequency of oscillation before the block is dropped onto the cart is f_1. The frequency of oscillation after the block is dropped onto the cart is f_2. Calculate the numerical value of the ratio $\dfrac{f_2}{f_1}$.

Question 1

2023 ▪ Q1

A cart on a horizontal surface is attached to a spring. The other end of the spring is attached to a wall. The cart is initially held at rest, as shown in Figure 1. When the cart is released, the system consisting of the cart and spring oscillates between the positions $x = +L$ and $x = -L$. Figure 2 shows the kinetic energy of the cart-spring system as a function of the system's potential energy. Frictional forces are negligible.

[Figure 1: A cart attached to a spring coiled between a wall on the left and the cart on the right, resting on a horizontal surface. Positions marked below: $x = -L$ (at the wall end), $x = 0$ (middle), $x = +L$ (at the cart's rest position shown).]

[Figure 2: Graph of kinetic energy K (J) on the vertical axis, from 0 to 6, versus potential energy U (J) on the horizontal axis, from 0 to 6. A straight diagonal line runs from approximately $(0, 4)$ down to $(4, 0)$, i.e., the line has x-intercept and y-intercept both equal in value.]

Question 1

(c)(i) [Continuation of Question 1.] The dashed line in Figure 4 shows the kinetic energy K versus potential energy U of the block-cart-spring system after the block is dropped onto the cart. This graph is identical to the graph shown in Figure 2 for the cart-spring system before the block is dropped onto the cart.
[Figure 4: Graph of kinetic energy K (J), vertical axis 0 to 6, versus potential energy U (J), horizontal axis 0 to 6. A dashed diagonal line runs from approximately $(0, 4)$ down to $(4, 0)$ — identical to the solid line in Figure 2.]
i. Briefly explain why the two graphs must be the same, using physics principles.
(c)(ii) ii. After the block is dropped onto the cart, consider a system that consists only of the cart and the spring. On Figure 4, sketch a solid line that shows the kinetic energy of the system that consists of the cart and the spring but not the block after the block is dropped onto the cart.

Solution 1

(a)

Mark scheme

- Maximum kinetic energy equals maximum potential energy (both 4 J) because energy is conserved in the cart-spring system: the graph's x-intercept (max U, $K = 0$) and y-intercept (max K, $U = 0$) both represent the same total mechanical energy. Full credit for simply stating 'conservation of energy.'

Solution 1

(b) Mark scheme

- Set up the ratio of frequencies (or periods): $T = 2\pi\sqrt{m/k}$, $f = \frac{1}{2\pi}\sqrt{k/m}$, so $\frac{f_2}{f_1} = \sqrt{\frac{m_1}{m_2}}$ (1 point for using the frequency/period equation in a valid ratio — any equivalent orientation of f_1/f_2, T_1/T_2, etc. is accepted). Substitute the total mass after the block sticks, $4m_0$ (since $m_0 + 3m_0 = 4m_0$), for m_2: $\frac{f_2}{f_1} = \sqrt{\frac{m_0}{4m_0}} = \frac{1}{2}$ (1 point for correctly substituting the total mass $4m_0$ into the ratio). Final answer: the new frequency is half the old frequency, $f_2/f_1 = 1/2$ (equivalently $T_1/T_2 = 1/2$).

Solution 1

(c)(i)

Mark scheme

- Accept any one valid explanation: (1) no (net external) work is done on the system, so its total mechanical energy is unchanged; (2) the maximum spring potential energy does not depend on the mass of the system, so it is unchanged when the block is added; (3) the force exerted on the system (by the wall/spring at the point of interest) is perpendicular to the direction of motion. Example: 'The maximum potential energy of the system does not depend upon the mass of the system, therefore there will be no change when the block is added.'

Solution 1

(c)(ii) Mark scheme

- Sketch a single solid straight line on the K vs U graph from $(U, K) = (0, 1)$ to $(4, 0)$. Three points: (1) the line's horizontal (U) intercept is the same as the original dashed graph's, at $U = 4$ J (max spring PE is unchanged — it doesn't depend on mass); (2) the line's vertical (K) intercept is less than the original graph's vertical intercept (max KE decreases, since the perfectly inelastic collision between the block and cart dissipates some kinetic energy); (3) the vertical intercept is the exact, correct value of 1 J (total mechanical energy after the collision, found from conservation of momentum in the collision then energy conservation in the subsequent oscillation).

Question 3

2022 ▪ Q3

[Figure: A wheel mounted on a horizontal axle, standing on a support post above a floor. A string is wrapped around the wheel's rim and hangs down to a small hanging block. Labels: "Wheel" (top, pointing to the wheel), "Axle" (pointing to the horizontal axle at the wheel's center), "Hanging Block" (pointing to the small block hanging from the string), "Floor" (the ground below).]

A wheel is mounted on a horizontal axle. A light string is attached to the wheel's rim and wrapped around it several times, and a small block is attached to the free end of the string, as shown in the figure. When the block is released from rest and begins to fall, the wheel begins to rotate with negligible friction.

Question 3

Two students are discussing how different forms of energy change as the block falls. One student says that the kinetic energy of the block increases as it falls. The second student says that this is because gravitational potential energy is converted to kinetic energy. The students decide to test whether the decrease in gravitational potential energy is equal to the increase in the block's kinetic energy from when the block starts moving to immediately before it reaches the floor.

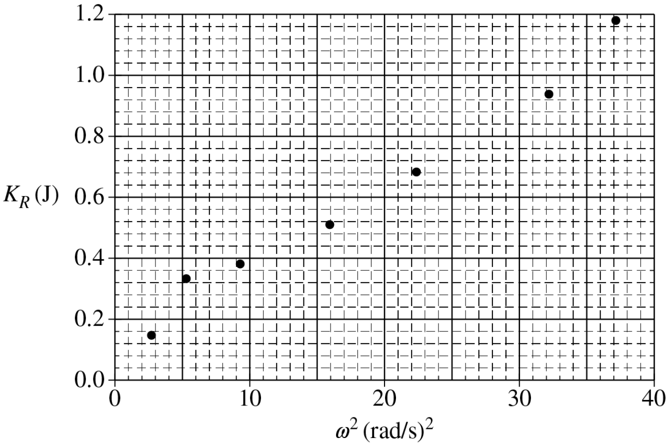
(a) Design an experimental procedure that the students could use to compare the increase in the block's translational kinetic energy with the decrease in the gravitational potential energy of the block-Earth system as the block falls.

Question 3

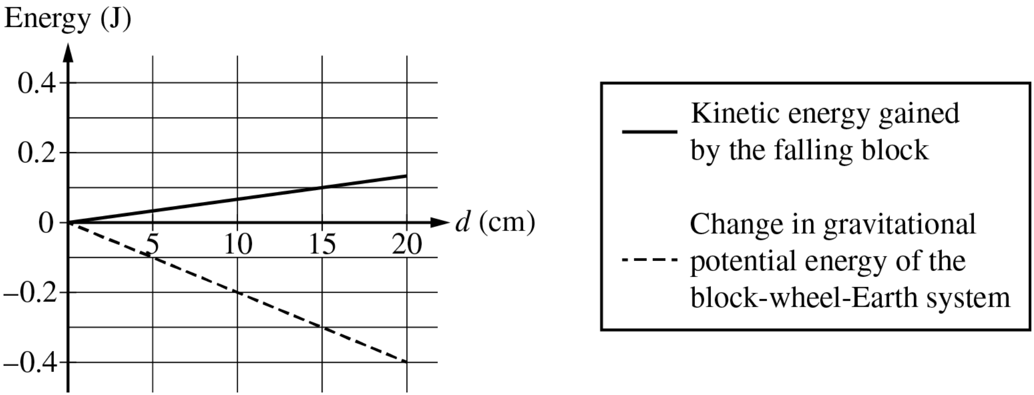
In the table, list the quantities that would be measured in your experiment. Define a symbol to represent each quantity and list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them in the space just below the table.
In the space to the right of the table, describe the overall procedure. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table.
If needed, you may include a simple diagram of the setup with your procedure.

Quantity to Be Measured	**Symbol for Quantity**	**Equipment for Measurement**	**Procedure (and diagram, if needed)**

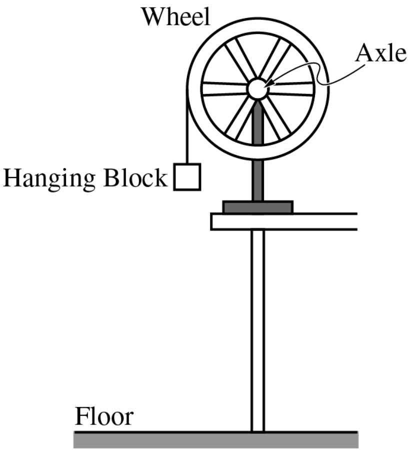
Question 3



Question 3


Energy (J)
0.4
0.2
0
–0.2
–0.4
5
10
15
20
d (cm)
Kinetic energy gained by the falling block
Change in gravitational potential energy of the block-wheel-Earth system

Question 3



Question 3

2022 ▪ Q3

[Figure: A wheel mounted on a horizontal axle, standing on a support post above a floor. A string is wrapped around the wheel's rim and hangs down to a small hanging block. Labels: "Wheel" (top, pointing to the wheel), "Axle" (pointing to the horizontal axle at the wheel's center), "Hanging Block" (pointing to the small block hanging from the string), "Floor" (the ground below).]

A wheel is mounted on a horizontal axle. A light string is attached to the wheel's rim and wrapped around it several times, and a small block is attached to the free end of the string, as shown in the figure. When the block is released from rest and begins to fall, the wheel begins to rotate with negligible friction.

Two students are discussing how different forms of energy change as the block falls. One student says that the kinetic energy of the block increases as it falls. The second student says that this is because gravitational potential energy is converted to kinetic energy. The students decide to test whether the decrease in gravitational potential energy is equal to the increase in

Question 3

the block's kinetic energy from when the block starts moving to immediately before it reaches the floor.

(b) Explain how the students could determine the kinetic energy of the block immediately before it reaches the floor using the quantities you indicated in the table in part (a).

Question 3

2022 ▪ Q3

[Figure: A wheel mounted on a horizontal axle, standing on a support post above a floor. A string is wrapped around the wheel's rim and hangs down to a small hanging block. Labels: "Wheel" (top, pointing to the wheel), "Axle" (pointing to the horizontal axle at the wheel's center), "Hanging Block" (pointing to the small block hanging from the string), "Floor" (the ground below).]

A wheel is mounted on a horizontal axle. A light string is attached to the wheel's rim and wrapped around it several times, and a small block is attached to the free end of the string, as shown in the figure. When the block is released from rest and begins to fall, the wheel begins to rotate with negligible friction.

Two students are discussing how different forms of energy change as the block falls. One student says that the kinetic energy of the block increases as it falls. The second student says that this is because gravitational potential energy is converted to kinetic energy. The students decide to test whether the decrease in gravitational potential energy is equal to the increase in

Question 3

the block's kinetic energy from when the block starts moving to immediately before it reaches the floor.

(c) [Graph: "Energy (J)" on the y-axis from -0.4 to 0.4 J (gridlines at $-0.4, -0.2, 0, 0.2, 0.4$), "*d* (cm)" on the x-axis from 0 to 20 cm (gridlines at 5, 10, 15, 20). A solid line labeled "Kinetic energy gained by the falling block" starts near $(0, 0)$ and rises gently to about $(20, 0.15)$. A dashed line labeled "Change in gravitational potential energy of the block-wheel-Earth system" starts near $(0, 0)$ and falls to about $(20, -0.35)$.]

The graph above represents both the change in the gravitational potential energy of the block-wheel-Earth system and the translational kinetic energy gained by the block as functions of the block's falling distance *d*. On the graph, draw a line or curve to represent the rotational kinetic energy of the wheel as a function of the block's falling distance *d*.

Question 3

2022 ▪ Q3

[Figure: A wheel mounted on a horizontal axle, standing on a support post above a floor. A string is wrapped around the wheel's rim and hangs down to a small hanging block. Labels: "Wheel" (top, pointing to the wheel), "Axle" (pointing to the horizontal axle at the wheel's center), "Hanging Block" (pointing to the small block hanging from the string), "Floor" (the ground below).]

A wheel is mounted on a horizontal axle. A light string is attached to the wheel's rim and wrapped around it several times, and a small block is attached to the free end of the string, as shown in the figure. When the block is released from rest and begins to fall, the wheel begins to rotate with negligible friction.

Two students are discussing how different forms of energy change as the block falls. One student says that the kinetic energy of the block increases as it falls. The second student says that this is because gravitational potential energy is converted to kinetic energy. The students decide to test whether the decrease in gravitational potential energy is equal to the increase in

Question 3

the block's kinetic energy from when the block starts moving to immediately before it reaches the floor.

(d)(i) The students also measure the angular velocity ω of the wheel as the block falls and determine the rotational kinetic energy K_R of the wheel. The students then make a graph of K_R as a function of ω^2, as shown.

[Graph: "K_R (J)" on the y-axis from 0.0 to 1.2 J (gridlines at 0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2), "ω^2 (rad/s)^2" on the x-axis from 0 to 40 (gridlines at 0, 10, 20, 30, 40). Data points (approximate): $(5, 0.15)$, $(8, 0.28)$, $(10, 0.35)$, $(17, 0.5)$, $(24, 0.65)$, $(32, 0.95)$, $(35, 1.15)$.]

On the above graph, draw a straight line that best represents the data.

(d)(ii) Using the line you drew for part (d)(i), calculate an experimental value for the rotational inertia of the wheel.

Solution 3

(a) Mark scheme

- Design: measure the mass m_B of the block with a mass balance; hold the block with the string taut and measure the fall distance d (initial height above the floor) with a meterstick; release the block and use a stopwatch to measure the fall time t_B (start at release, stop when the block hits the floor); repeat 3 trials at the same d and repeat for several different values of d to reduce uncertainty (e.g. by averaging). Table: Mass of block m_B – mass balance; Distance block falls d – meterstick; Time for block to fall t_B – stopwatch. Scoring (1 point each): listing relevant equipment matching the measured quantities; listing measurements sufficient to determine the block's kinetic energy; listing measurements sufficient to determine the gravitational PE of the block-Earth system; a plausible procedure

Solution 3

(can be done in a typical school physics lab); attempting to reduce uncertainty (e.g. repeated trials/averaging).

Solution 3

(b)

Mark scheme

- Compute the block's average speed as d/t_B; $sinceitfallsfromrestwithconstantacceleration, thef$ $2d/t_B. ThenthefinalkineticenergyisK = \frac{1}{2}m_B v_F^2 = \frac{1}{2}m_B(2d/t_B)^2.Scoring :$ $1pointforindicatingthatmassandvelocityareneeded(neednotbethefinalvelocity); 1pointforavalic$

Solution 3

(c) Mark scheme

- On the Energy vs. d graph, draw a straight line through the origin with positive slope representing the kinetic energy gained by the falling block, and a line representing the change in gravitational PE such that the total energy sum is (approximately) zero at all values of d – the correct line passes through the origin and through (15 cm, 0.2 J), so that KE gained plus the (negative) change in PE sums to zero, showing energy conservation. Scoring: 1 point for drawing a straight line that passes through the origin and has a positive slope; 1 point for drawing a line that yields a total energy sum of zero at all values of d.

Solution 3

(d)(i)

Mark scheme

- On the $K_R vs. \omega^2 graph, draw a reasonable best-fit straight line through the plotted data points. Scor$
  $1 point for drawing a reasonable best - fit line.$

Solution 3

(d)(ii)

Mark scheme

- From the best-fit line, slope $= \dfrac{1.04 - 0.20}{35 - 2.5} = 0.0258$ kg · m$^2 .SinceK_R = \dfrac{1}{2} I\omega^2, theslopeofK_R vs.\omega^2 equals \dfrac{1}{2} I, so I = 2 \times$ slope $= 0.0517$ kg · m$^2 .Scoring : 1 pointforcorrectlycalculatingavaluefortheslopeusingpointsonthedrawnline(orstatingacalculatc$

Question 1

2022 ▪ Q1

Two blocks are connected by a string that passes over a pulley, as shown above. Block 1 is on a horizontal surface and is attached to a spring that is at its unstretched length. Frictional forces are negligible in the pulley's axle and between the block and the surface. Block 2 is released from rest and moves downward before momentarily coming to rest.

k_0 is the spring constant of the spring.

M_1 is the mass of block 1.

M_2 is the mass of block 2.

Δy is the distance block 2 moves before momentarily coming to rest.

[Figure: A horizontal tabletop with a spring of constant k_0 attached to a wall on the left, connected to Block 1 (M_1) resting on the table. A string runs from Block 1

Question 1

horizontally to a pulley at the right edge of the table, then down to a hanging Block 2 (M_2), which is shown displaced a distance Δy downward from its initial position.]

(a)(i) Block 2 starts from rest and speeds up, then it slows down and momentarily comes to rest at a position below its initial position. In terms of only the forces directly exerted on block 2, explain why block 2 initially speeds up and explain why it slows down to a momentary stop.

(a)(ii) Derive an expression for the distance Δy that block 2 travels before momentarily coming to rest. Express your answer in terms of k_0, M_1, M_2, and physical constants, as appropriate.

Question 1

Diagram A: Negligible Friction

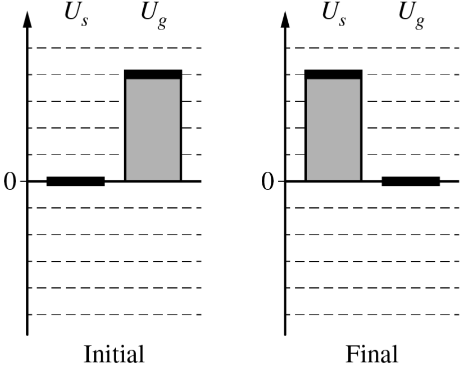
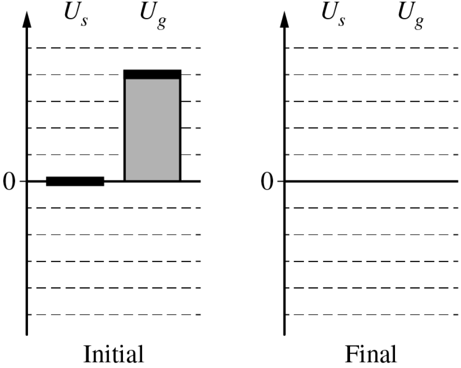
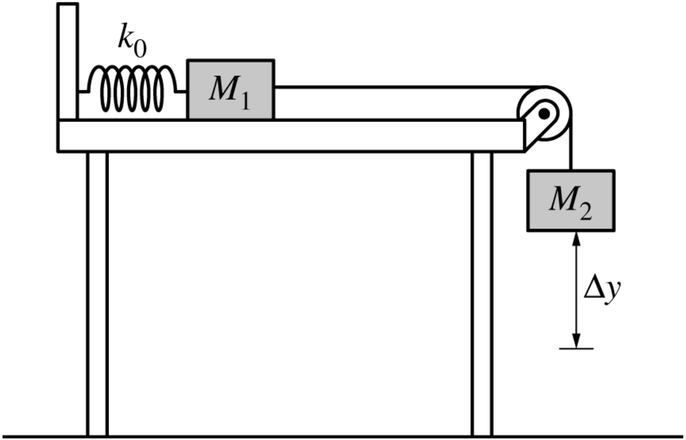


Diagram B: Nonnegligible Friction



Question 1



Question 1

2022 ▪ Q1

Two blocks are connected by a string that passes over a pulley, as shown above. Block 1 is on a horizontal surface and is attached to a spring that is at its unstretched length. Frictional forces are negligible in the pulley's axle and between the block and the surface. Block 2 is released from rest and moves downward before momentarily coming to rest.
k_0 is the spring constant of the spring.
M_1 is the mass of block 1.
M_2 is the mass of block 2.
Δy is the distance block 2 moves before momentarily coming to rest.
[Figure: A horizontal tabletop with a spring of constant k_0 attached to a wall on the left, connected to Block 1 (M_1) resting on the table. A string runs from Block 1 horizontally to a pulley at the right edge of the table, then down to a hanging Block 2 (M_2), which is shown displaced a distance Δy downward from its initial position.]

Question 1

(b) Indicate whether the total mechanical energy of the blocks-spring-Earth system changes as block 2 moves downward.

____ Changes   ____ Does not change

Briefly explain your reasoning.

Question 1

2022 ▪ Q1

Two blocks are connected by a string that passes over a pulley, as shown above. Block 1 is on a horizontal surface and is attached to a spring that is at its unstretched length. Frictional forces are negligible in the pulley's axle and between the block and the surface. Block 2 is released from rest and moves downward before momentarily coming to rest.

k_0 is the spring constant of the spring.

M_1 is the mass of block 1.

M_2 is the mass of block 2.

Δy is the distance block 2 moves before momentarily coming to rest.

[Figure: A horizontal tabletop with a spring of constant k_0 attached to a wall on the left, connected to Block 1 (M_1) resting on the table. A string runs from Block 1 horizontally to a pulley at the right edge of the table, then down to a hanging Block 2 (M_2), which is shown displaced a distance Δy downward from its initial position.]

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(c) Consider the system that includes the spring, Earth, both blocks, and the string, but not the surface. Let the initial state be when the blocks are at rest just before they start moving, and let the final state be when the blocks first come momentarily to rest. Diagram A below is a bar chart that represents the energies in the scenario where there is negligible friction between block 1 and the surface.

The shaded-in bars in the energy bar charts represent the potential energy of the spring and the gravitational potential energy of the blocks-Earth system, U_s and U_g, respectively, in the initial and final states. Positive energy values are above the zero-point line ("0") and negative energy values are below the zero-point line.

[Diagram A: Negligible Friction — two bar charts labeled "Initial" and "Final", each with two bars U_s and U_g, on a vertical axis with a zero-point line "0". Initial: U_s bar is a thin sliver just above 0 (near zero), U_g bar is tall, extending well above 0. Final: U_s

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bar extends above 0 to a moderate height, U_g bar is a thin sliver just below 0 (near zero, slightly negative).]
[Diagram B: Nonnegligible Friction — two bar charts labeled "Initial" and "Final", each with two bars U_s and U_g. Initial state already provided: U_s bar is a thin sliver just above 0, U_g bar is tall extending well above 0 (same as Diagram A's initial state). Final state is blank/empty, to be completed by the student.]
Complete diagram B (at right above) for the scenario in which friction is nonnegligible. The energies for the initial state are already provided. Shade in the energies in the final state using the same scale as in diagram A.

- Shaded regions should start at the solid line representing the zero-point line.
- Represent any energy that is equal to zero with a distinct line on the zero-point line.

Solution 1

(a)(i) Mark scheme

- Block 2 speeds up while the gravitational force (weight, W) exerted on it is greater than the tension (T) in the string (net force and acceleration point downward, in the direction of motion). As Block 2 falls, the spring (connected to Block 1) stretches further, increasing the tension until T becomes greater than W; the net force and acceleration then point upward (opposite the velocity), decelerating Block 2 until it momentarily stops. Scoring: 1 point for relating the net force to acceleration/change in velocity; 1 point for a correct description of the relative magnitudes of T and W during the motion (both $T>W$ initially and $T<W$ later) – the spring force must be connected to the string tension, not treated as acting directly on Block 2.

Solution 1

(a)(ii)

Mark scheme

- Conservation of energy for the blocks-spring-Earth system (K$_i = K_f = 0)$: $U_{g,i} + M_2 g\Delta y = U_{g,f} + \frac{1}{2}k_0\Delta y^2, i.e. M_2 g\Delta y = \frac{1}{2}k_0\Delta y^2, so M_2 g = \frac{1}{2}k_0\Delta y, giving \Delta y = \frac{2M_2 g}{k_0}. Scoring : 1 point for a correct energy - conservation equation including both a gravitational PE term and a spring PE term; 1 point for the corr$
  $2M_2 g/k_0 depending only on M_2, k_0, and g.$

Solution 1

(b)

Mark scheme

- Does not change. There are no external forces doing work on the system and no energy is dissipated by friction, so the total mechanical energy of the blocks-spring-Earth system stays the same (energy only transforms between gravitational PE, spring PE, and KE). Scoring: 1 point for selecting ”Does not change” with a correct explanation.

Solution 1

(c)

Mark scheme

- With non-negligible friction between Block 1 and the surface, mechanical energy is lost to friction as the blocks move, so at the final state (Block 2 momentarily at rest, $K_f=0$) the total spring PE (U_s) plus gravitational PE (U_g) must be less than the initial total of 4 units. The final bar chart must show both $U_s>0$ and $U_g>0$ (both bars positive), with $U_s+U_g < 4$ units. Scoring: 1 point for a final bar chart where both U_s and U_g are positive; 1 point for a final bar chart where the sum of U_s and U_g is less than four units.

Question 3

2019 ▪ Q3

[Figure 1: "Uncompressed spring" — a coiled spring attached at its left end to a fixed wall, with a plate attached at its free (right) end. Below the spring, a pin is shown pointing to position A; positions A, B, C are marked along the axis of the spring near the plate, with A closest to the wall/spring and C closest to the plate's resting position, in increasing order of compression.]
[Figure 2: "Compressed spring" — the same spring shown compressed, with a steel sphere placed against the plate. Positions A, B, C are marked along the same axis; the plate (and sphere) is shown pinned at position C, indicating maximum compression among the three shown positions.]
A projectile launcher consists of a spring with an attached plate, as shown in Figure 1. When the spring is compressed, the plate can be held in place by a pin at any of three positions A, B, or C. For example, Figure 2 shows a steel sphere placed against the

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plate, which is held in place by a pin at position C. The sphere is launched upon release of the pin.

A student hypothesizes that the spring constant of the spring inside the launcher has the same value for different compression distances.

(a)(i) The student plans to test the hypothesis by launching the sphere using the launcher.

State a basic physics principle or law the student could use in designing an experiment to test the hypothesis.

(a)(ii) Using the principle or law stated in part (a)(i), determine an expression for the spring constant in terms of quantities that can be obtained from measurements made with equipment usually found in a school physics laboratory.

Question 3

Quantity to be Measured	Symbol for Quantity	Equipment for Measurement

Question 3

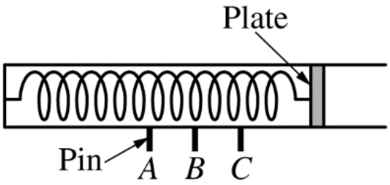

Figure 1. Uncompressed spring

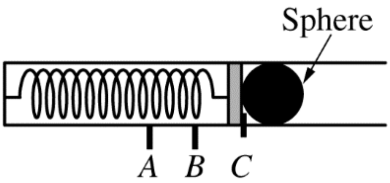

Figure 2. Compressed spring

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