Past-paper walk-through

Kinetic and Static Friction ▪ 2.7

eXercise

Questions in this set

- 2026 Q3
- 2019 Q1
- 2017 Q2
- 2015 Q3

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.]

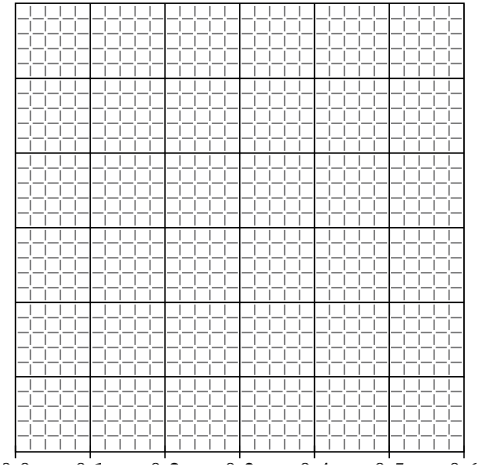
Question 3

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.

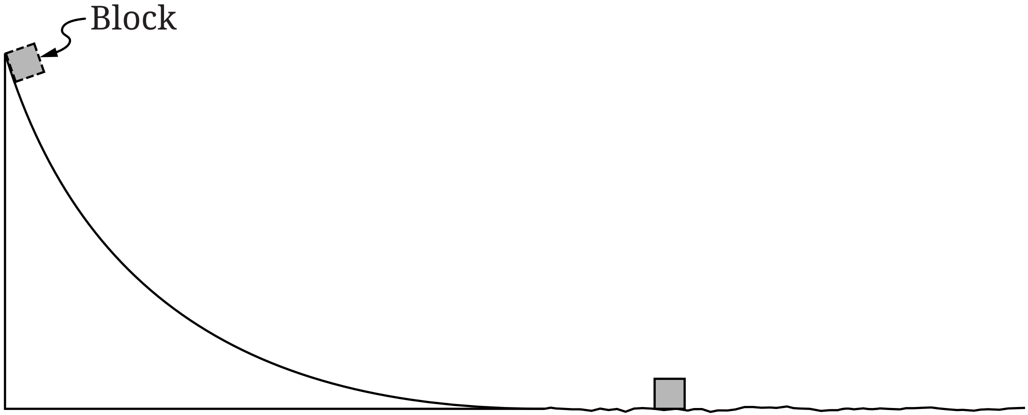
(a)(i) Indicate quantities that could be measured by the students that would allow them to determine μ_k using a linear graph.

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

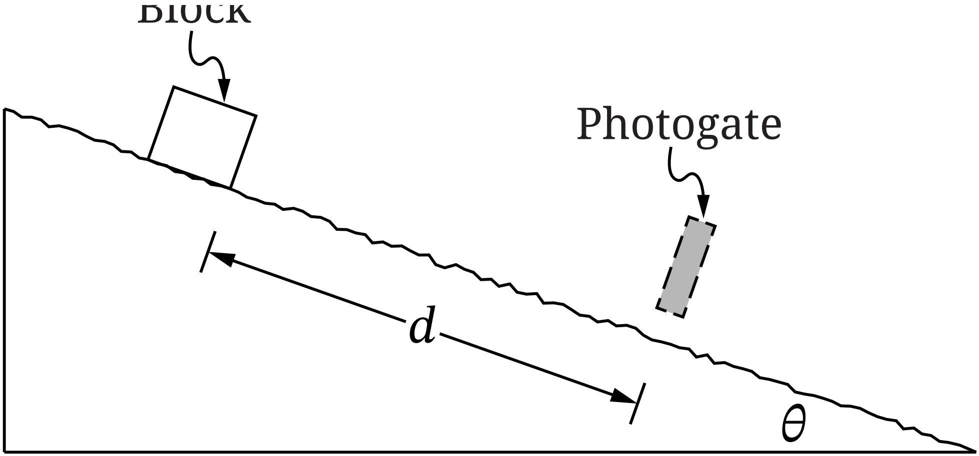
Question 3



Question 3



Question 3



Question 3

2026 ▪ Q3

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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

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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

(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 $\theta = 30°$. 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

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Question 3

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

Question 1

2019 ▪ Q1

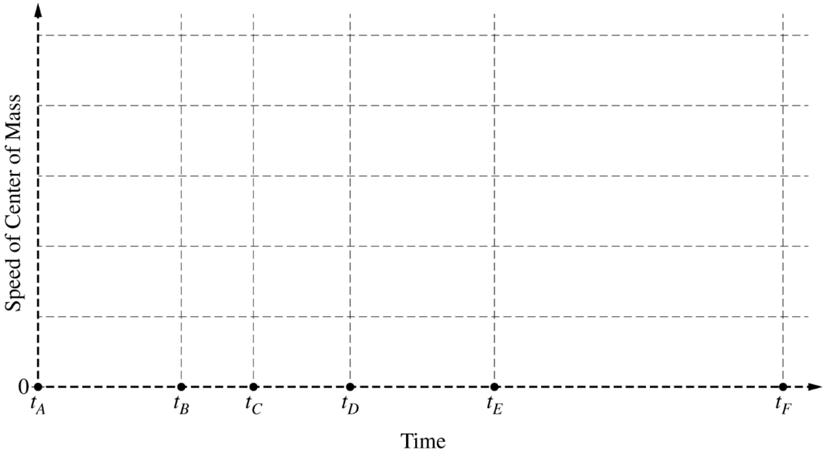
Identical blocks 1 and 2 are placed on a horizontal surface at points A and E, respectively, as shown. The surface is frictionless except for the region between points C and D, where the surface is rough. Beginning at time t_A, block 1 is pushed with a constant horizontal force from point A to point B by a mechanical plunger. Upon reaching point B, block 1 loses contact with the plunger and continues moving to the right along the horizontal surface toward block 2. Block 1 collides with and sticks to block 2 at point E, after which the two-block system continues moving across the surface, eventually passing point F.

[Diagram: A plunger (with block 1 loaded against it) sits at the left, followed by a horizontal line marked with points A, B, C, D, E, F from left to right. Block 2 sits at point E. The region between C and D is hatched, indicating it is rough (roughened surface). The plunger pushes block 1 from A to B.]

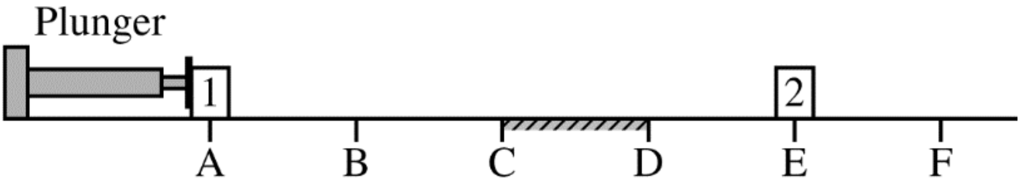
Question 1

(a) On the axes below, sketch the speed of the center of mass of the two-block system as a function of time, from time t_A until the blocks pass point F at time t_F. The times at which block 1 reaches points A through F are indicated on the time axis.
[Graph: y-axis "Speed of Center of Mass" starting at 0, no numeric scale shown; x-axis "Time" with labeled tick marks at t_A, t_B, t_C, t_D, t_E, t_F (unevenly spaced, t_E noticeably farther from t_D than the others); axes are otherwise blank dashed gridlines for the student to sketch on.]

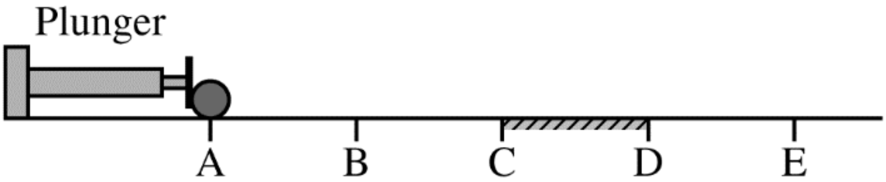
Question 1



Question 1



Question 1



Question 1

2019 ▪ Q1

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[Diagram: A plunger (with block 1 loaded against it) sits at the left, followed by a horizontal line marked with points A, B, C, D, E, F from left to right. Block 2 sits at point E. The region between C and D is hatched, indicating it is rough (roughened surface). The plunger pushes block 1 from A to B.]

Question 1

(b) The plunger is returned to its original position, and both blocks are removed. A uniform solid sphere is placed at point A, as shown. The sphere is pushed by the plunger from point A to point B with a constant horizontal force that is directed toward the sphere's center of mass. The sphere loses contact with the plunger at point B and continues moving across the horizontal surface toward point E. In which interval(s), if any, does the sphere's angular momentum about its center of mass change? Check all that apply.
[Diagram: A plunger with a sphere loaded against it sits at the left, followed by a horizontal line marked with points A, B, C, D, E from left to right. The region between C and D is hatched, indicating it is rough.]
_____ A to B _____ B to C _____ C to D _____ D to E _____ None
Briefly explain your reasoning.

Solution 1

(a) Mark scheme

- Correct graph of center-of-mass speed vs time has 5 required features (1 pt each): (1) a straight line beginning at 0 at t_A and increasing to t_B (block 1 accelerates under the plunger's constant external force, block 2 stationary, so $v_{cm} = v_1/2$ rises linearly); (2) a horizontal, nonzero segment from t_B to t_C (frictionless surface, block 1 moves at constant velocity, so v_{cm} constant); (3) a segment decreasing linearly from t_C to t_D (friction between C and D is an external force decelerating block 1, so v_{cm} decreases); (4) a horizontal, nonzero, constant segment from t_D through t_F at a DIFFERENT (lower) value than the t_B-t_C plateau, with NO change at t_E; (5) a curve continuous from t_A through t_F, with the only possible exception being a jump at t_E. Note: if the speed changes at t_E, point (4) is not

Solution 1

earned but point (5) may still be earned. No credit for a flat line along the time axis. Physical reasoning: the collision between block 1 and block 2 at E is an INTERNAL interaction of the two-block system, so it does not change the system's center-of-mass velocity (momentum conservation) – the correct graph shows the D-to-F plateau passing smoothly through t_E with no jump, at a lower speed than the B-to-C plateau because the mass tracked (2 blocks) is now effectively combined.

Solution 1

(b) Mark scheme

- Correct answer: the sphere's angular momentum about its center of mass changes ONLY in the interval C to D (not A-B, not B-C, not D-E). Point 1: for reasoning that a change in angular momentum is caused by a net external torque. Point 2: for correctly identifying that friction acting between C and D is the only force producing an external torque over the entire interval A to E. Full reasoning: the plunger's force (A to B) is directed toward the sphere's center of mass, so it produces zero torque about the center of mass; the surface is frictionless everywhere except C to D, so no other external force can exert a torque about the center of mass; therefore only the friction force acting in the rough region C to D changes the sphere's angular momentum about its center of mass (this point is

Solution 1

NOT earned if the response claims angular momentum/angular speed decreases between C and D or that the sphere stops rotating at D – friction here INcreases/changes the spin from zero, since the sphere arrives at C already translating without spin).

Question 2

2017 ▪ Q2

A student wants to determine the coefficient of static friction between a long, flat wood board and a small wood block.

(a)(i) Describe an experiment for determining the coefficient of static friction between the wood board and the wood block. Assume equipment usually found in a school physics laboratory is available.

Draw a diagram of the experimental setup of the board and block. In your diagram, indicate each quantity that would be measured and draw or state what equipment would be used to measure each quantity.

(a)(ii) Describe the overall procedure to be used, including any steps necessary to reduce experimental uncertainty. Give enough detail so that another student could replicate the experiment.

Question 2

Lab Group Number	Coefficient of Kinetic Friction	Coefficient of Static Friction
1	0.45	0.54
2	0.46	0.52
3	0.42	0.56
4	0.43	0.55
5	0.74	0.23
6	0.44	0.54
Average	0.49	0.49

Question 2

2017 ▪ Q2

A student wants to determine the coefficient of static friction between a long, flat wood board and a small wood block.

(b) Derive an equation for the coefficient of static friction in terms of quantities measured in the procedure from part (a).

A physics class consisting of six lab groups wants to test the hypothesis that the coefficient of static friction between the board and the block equals the coefficient of kinetic friction between the board and the block. Each group determines the coefficients of kinetic and static friction between the board and the block. The groups' results are shown below, with the class averages indicated in the bottom row.

Lab Group Number	Coefficient of Kinetic Friction	Coefficient of Static Friction
1	0.45	0.54
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Average	0.49	0.49

Question 2

2017 ▪ Q2

A student wants to determine the coefficient of static friction between a long, flat wood board and a small wood block.

(c) Based on these data, what conclusion should the students make about the hypothesis that the coefficients of static and kinetic friction are equal?

______ The static and kinetic coefficients are equal.

______ The static and kinetic coefficients are not equal.

Briefly justify your reasoning.

Question 2

2017 ▪ Q2

A student wants to determine the coefficient of static friction between a long, flat wood board and a small wood block.

(d) A metal disk is glued to the top of the wood block. The mass of the block-disk system is twice the mass of the original block. Does the coefficient of static friction between the bottom of the block and the board increase, decrease, or remain the same when the disk is added to the block?

_____ Increase _____ Decrease _____ Remain the same

Briefly state your reasoning.

Solution 2

(a)(i) Mark scheme

- Set up the wood board as an incline: hinge/rest one end of the board on the table so the other end can be raised, with the wood block placed on the board. Slowly raise the free end (increasing the angle θ between board and table) until the block is on the verge of sliding, and measure that critical angle θ with a protractor. Diagram should show: the board tilted at angle θ above the horizontal table, the block resting on the board, θ marked at the pivot between board and table, and a protractor indicated as the instrument used to measure θ. Points: 1 pt for a diagram of an experimental setup to measure the coefficient of friction that is feasible in a school physics lab; 1 pt for indicating the measurement(s) necessary

Solution 2

for calculating the coefficient of friction (the critical angle θ); 1 pt for indicating the equipment necessary for measuring that quantity (a protractor).

Solution 2

(a)(ii) Mark scheme

- With the block at rest on the board (board initially near horizontal), slowly lift one end of the board, increasing the angle θ, until the block just begins to slide, and record θ at that instant. Repeat this measurement several times, and/or with the block placed at different locations on the board, then average the resulting angles to reduce experimental (random) error. Points: 1 pt for a description consistent with the diagram in part (a)(i), in enough detail that another student could replicate the experiment; 1 pt for a description that is a conceptually valid method to find quantities allowing calculation of the friction coefficient; 1 pt for including a valid method for reducing experimental uncertainty (e.g., repeating trials at different board locations and averaging).

Solution 2

(b) Mark scheme

- At the critical angle θ (block on the verge of sliding) the block is in equilibrium. Newton's second law perpendicular to the board's surface: $N - mg\cos\theta = 0 \Rightarrow N = mg\cos\theta$. Newton's second law parallel to the board's surface: $mg\sin\theta - f_{s,max} = 0 \Rightarrow f_{s,max} = mg\sin\theta$. Since $f_{s,max} = \mu_s N$, dividing gives $\mu_s = \frac{f_{s,max}}{N} = \frac{mg\sin\theta}{mg\cos\theta} = \tan\theta$. Final answer: $\mu_s = \tan\theta$, where θ is the critical sliding angle measured in part (a). Points: 1 pt for using Newton's second law (or zero-net-force reasoning) parallel to the board's surface, explicitly or implicitly; 1 pt for using Newton's second law (or zero-net-force reasoning) perpendicular to the board's surface, explicitly or implicitly (replacing the normal

Solution 2

force with *mg* alone is only valid/implicit for a horizontal surface; a tilted surface must show the $\cos\theta$ term); 1 pt for a correctly derived expression $\mu_s = \tan\theta$ in terms of quantities from part (a). Full credit requires all variables to be defined in the diagram/procedure of part (a).

Solution 2

(c) Mark scheme

- Correct answer: the static and kinetic coefficients are NOT equal (reasoning only earns credit if this option is selected). Group 5's data is an outlier compared to the other five lab groups' results (its measured coefficients deviate substantially from the pattern of the rest of the class). Once Group 5 is identified as an outlier and excluded (or simply noted), the remaining groups' data show $\mu_s \neq \mu_k$ (or the coefficients differ from group to group rather than clustering at a common equal value), supporting the conclusion that static and kinetic friction coefficients are not equal. Points: 1 pt for identifying Group 5's results as an outlier, or indicating the presence of an outlier; 1 pt for a conclusion that the coefficients are not the

Solution 2

same, justified either by removing the outlier or by noting the coefficients are different for each group.

Solution 2

(d) Mark scheme

- Correct answer: Remain the same. The coefficient of static friction is a property of the two surfaces in contact (the block's bottom surface and the board's surface), not of the normal force or the masses of the objects pressing them together. Gluing the metal disk to the block doubles the mass (and hence the normal force between block and board), but since $\mu_s = f_{s,max}/N$ is a ratio that depends only on the nature/roughness of the two contacting surfaces, μ_s remains unchanged even though the normal force and the maximum static friction force both double. Points: 1 pt for a valid argument that the coefficient of static friction is a property of the two surfaces, consistent with the selected answer ("Remain the same," justified via μ_s's independence from mass/normal force, is

Solution 2

the credited reasoning; e.g. referring to the equation from part (b) showing $\mu_s = \tan\theta$ does not depend on mass).

Question 3

2015 ▪ Q3

[Figure: A block is held against a spring of negligible mass attached to a wall, on a frictionless surface, at position $x = -D$. Position $x = 0$ marks the end of the frictionless surface and the start of a rough (shaded) track extending to the right. A dashed box near $x = 0$ and another dashed box further right (near $x = 3D$) mark reference positions. The x-axis is labeled with $-D$, 0, and $3D$.]

A block is initially at position $x = 0$ and in contact with an uncompressed spring of negligible mass. The block is pushed back along a frictionless surface from position $x = 0$ to $x = -D$, as shown above, compressing the spring by an amount $\Delta x = D$. The block is then released. At $x = 0$ the block enters a rough part of the track and eventually comes to rest at position $x = 3D$. The coefficient of kinetic friction between the block and the rough track is μ.

Question 3

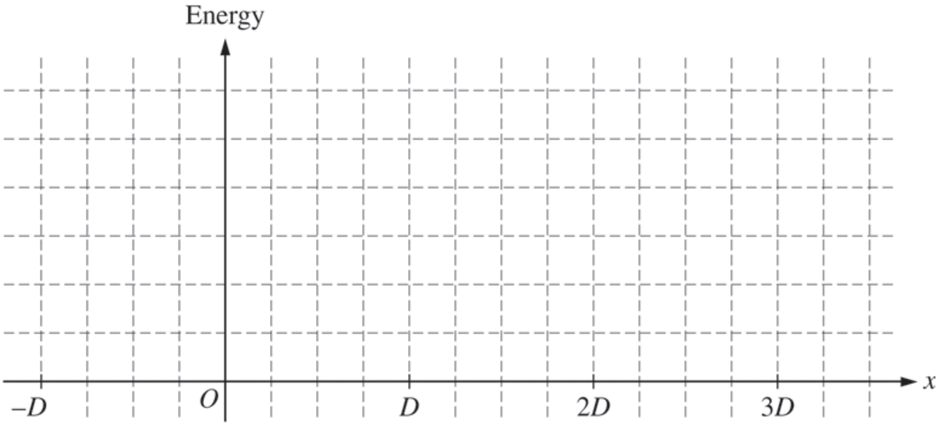
(a) On the axes below, sketch and label graphs of the following two quantities as a function of the position of the block between $x = -D$ and $x = 3D$. You do not need to calculate values for the vertical axis, but the same vertical scale should be used for both quantities.

i. The kinetic energy K of the block

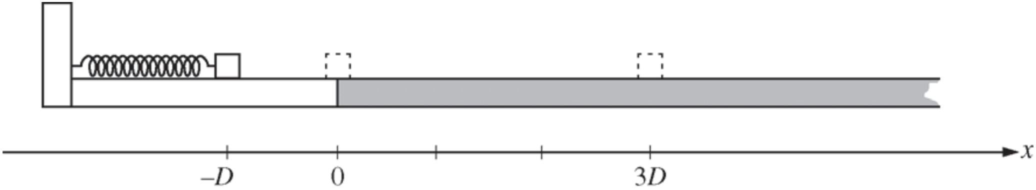
ii. The potential energy U of the block-spring system

[Blank grid: vertical axis labeled "Energy" (unmarked scale), horizontal axis labeled x with gridlines/tick labels at $-D$, O, D, $2D$, $3D$, for the student to sketch the two graphs on.]

Question 3



Question 3



Question 3

2015 ▪ Q3

[Figure: A block is held against a spring of negligible mass attached to a wall, on a frictionless surface, at position $x = -D$. Position $x = 0$ marks the end of the frictionless surface and the start of a rough (shaded) track extending to the right. A dashed box near $x = 0$ and another dashed box further right (near $x = 3D$) mark reference positions. The x-axis is labeled with $-D$, 0, and $3D$.]

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(b)(i) The spring is now compressed twice as much, to $\Delta x = 2D$. A student is asked to predict whether the final position of the block will be twice as far at $x = 6D$. The

Question 3

student reasons that since the spring will be compressed twice as much as before, the block will have more energy when it leaves the spring, so it will slide farther along the track before stopping at position $x = 6D$.

Which aspects of the student's reasoning, if any, are correct? Explain how you arrived at your answer.

(b)(ii) Which aspects of the student's reasoning, if any, are incorrect? Explain how you arrived at your answer.

Question 3

2015 ▪ Q3

[Figure: A block is held against a spring of negligible mass attached to a wall, on a frictionless surface, at position $x = -D$. Position $x = 0$ marks the end of the frictionless surface and the start of a rough (shaded) track extending to the right. A dashed box near $x = 0$ and another dashed box further right (near $x = 3D$) mark reference positions. The x-axis is labeled with $-D$, 0, and $3D$.]

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(c) Use quantitative reasoning, including equations as needed, to develop an expression for the new final position of the block. Express your answer in terms of D.

Question 3

2015 ▪ Q3

[Figure: A block is held against a spring of negligible mass attached to a wall, on a frictionless surface, at position $x = -D$. Position $x = 0$ marks the end of the frictionless surface and the start of a rough (shaded) track extending to the right. A dashed box near $x = 0$ and another dashed box further right (near $x = 3D$) mark reference positions. The x-axis is labeled with $-D$, 0, and $3D$.]

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(d) Explain how any correct aspects of the student's reasoning identified in part (b) are expressed by your mathematical relationships in part (c). Explain how your

Question 3

relationships in part (c) correct any incorrect aspects of the student's reasoning identified in part (b). Refer to the relationships you wrote in part (c), not just the final answer you obtained by manipulating those relationships.

Solution 3

(a) Mark scheme

- Sketch Energy vs. position x from $x = -D$ to $x = 3D$. Region $x \in [-D, 0]$ (block still compressing/leaving the spring): kinetic energy K starts at 0 at $x = -D$ and rises to a maximum at $x = 0$; potential energy U (spring) starts at a maximum at $x = -D$ and falls to 0 at $x = 0$, with $K + U$ constant throughout (energy conservation while on the spring). Region $x \in [0, 3D]$ (block on the rough track, spring no longer in contact): potential energy $U = 0$ for the entire interval; kinetic energy K decreases LINEARLY from its maximum value at $x = 0$ to zero at $x = 3D$ (constant kinetic friction force removes energy linearly with distance). Scoring (4 points, 1 each): (1) either energy curve sketched with a reasonably correct shape from $x = -D$ to $x = 0$, with zero and maximum values at the

Solution 3

correct locations; (2) both curves sketched from $x = -D$ to $x = 0$ with shapes/values such that total energy is constant (even if the individual curve shapes are imperfect); (3) potential energy sketched as zero from $x = 0$ to $x = 3D$; (4) kinetic energy sketched as a linear function decreasing from its maximum at $x = 0$ to zero at $x = 3D$.

Solution 3

(b)(i)

Mark scheme

- The student is CORRECT that the block will have more energy when it leaves the spring: compressing the spring twice as far (to $\Delta x = 2D$) stores spring potential energy $U = \frac{1}{2}k(\Delta x)^2$, which scales with the SQUARE of the compression, so doubling the compression gives $4\times$ the stored (and hence kinetic) energy. 1 point for identifying this aspect of the student's reasoning as correct, with a valid explanation.

Solution 3

(b)(ii)

Mark scheme

- The student is INCORRECT that the block will travel exactly twice as far (predicting $x = 6D$): this conclusion assumes energy scales LINEARLY with compression, but spring potential energy actually scales with the SQUARE of the compression ($U \propto \Delta x^2$), so the relationship between compression and final sliding distance is not simply proportional. 1 point for identifying this aspect as incorrect, with a valid explanation.

Solution 3

(c) Mark scheme

- Quantitative derivation: original spring energy $U_1 = \frac{1}{2}kD^2$; with double compression, $U_2 = \frac{1}{2}k(2D)^2 = 4\left(\frac{1}{2}kD^2\right) = 4U_1$. Original friction work to stop the block over distance $3D$ (from $x = 0$ to $x = 3D$): $W_1 = \mu mg(3D)$; in the new case, work to stop over the new (unknown) sliding distance Δx_2: $W_2 = \mu mg\,\Delta x_2$. By energy conservation $W_1 = U_1$ and $W_2 = U_2 = 4U_1 = 4W_1$, so $\mu mg\,\Delta x_2 = 4(\mu mg(3D)) \Rightarrow \Delta x_2 = 4(3D) = 12D$. The new final position is $x = 12D$ (NOT $6D$ – four times, not twice, the original stopping distance). Scoring (3 points, 1 each): (1) indicating that the final spring energy (mechanical energy of the block as it reaches the rough track) is four times the original spring energy; (2) indicating that the frictional force is unchanged; (3) equating the

Solution 3

initial spring energy to an expression showing the friction-dissipated energy is proportional to sliding distance, and solving for the new distance ($\Delta x_2 = 12D$).

Solution 3

(d) Mark scheme

- The student's correct reasoning that the block has more energy in the second situation is expressed by the part (c) comparison of initial spring energies ($U_2 = 4U_1$). The student's correct reasoning that the block slides farther is expressed by the part (c) equation showing that the friction work needed to stop the block in the second situation is a factor ($4\times$) greater than in the first ($W_2 = 4W_1$). The student's incorrect reasoning – that distance scales LINEARLY with compression (so doubling compression should double the distance to $6D$) – is corrected by the part (c) expression for spring energy, $U = \frac{1}{2}kx^2$, which shows energy (and hence stopping distance) scales with the SQUARE of the compression, giving $4\times$ the distance ($12D$) rather than $2\times$ ($6D$). Scoring (3

Solution 3

points, 1 each): (1) linking the 'more energy' correct reasoning to the part (c) energy comparison; (2) linking the 'slides farther' correct reasoning to the part (c) friction-work equation; (3) showing how the part (c) spring-energy expression corrects the student's incorrect linear-scaling assumption. Must reference the relationships from part (c), not just the final numeric answer.