Past-paper walk-through

Spring Forces ▪ 2.8

eXercise

Questions in this set

- 2025 Q2
- 2024 Q2
- 2024 Q4
- 2023 Q3
- 2022 Q1
- 2022 Q5
- 2019 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 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

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

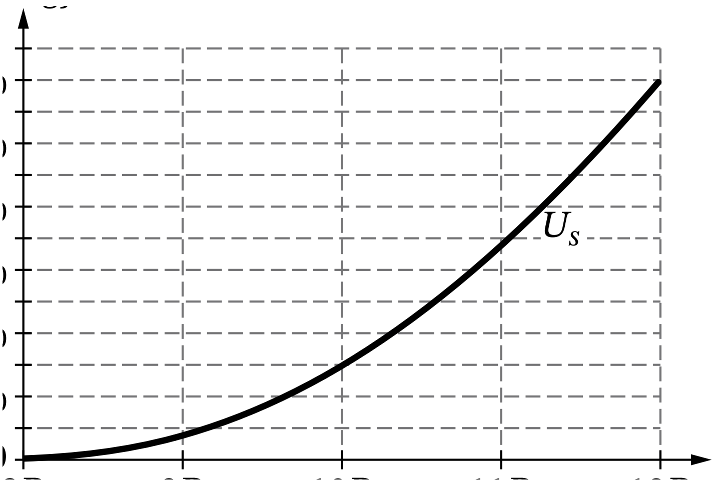
(a) Figure 4 shows an energy bar chart that represents the kinetic energy K of the block, the gravitational potential energy U_g of the block-spring-Earth system, and the spring potential energy U_s of the block-spring-Earth system at the instant that the block is at $x = 10D$. The gravitational potential 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



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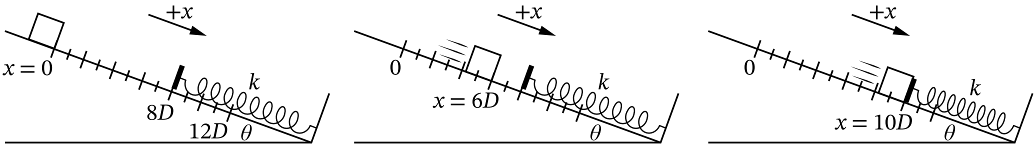

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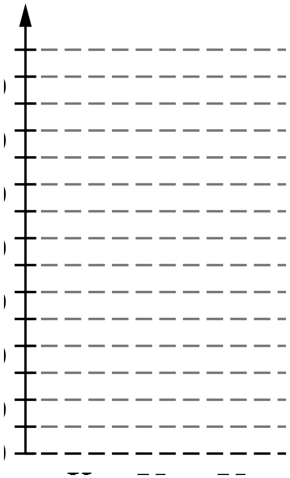

Question 2

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.

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2025 ▪ Q2

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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 2

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[Figure 1: A stand with a horizontal support arm (labeled "Stand") has a spring hanging vertically from the arm, with a small loop at the bottom of the spring. To the right, a set of stacked cylindrical masses of various sizes (labeled "Cylinders") sits on the table, available for hanging on the spring's loop.]

A student hangs a spring of unknown spring constant k vertically by attaching one end to a stand, as shown in Figure 1. The other end of the spring has a small loop from which small cylinders can be hung. In addition to the spring, the student has access only to a variety of cylinders of unknown masses, a stopwatch, and a digital scale.

Question 2

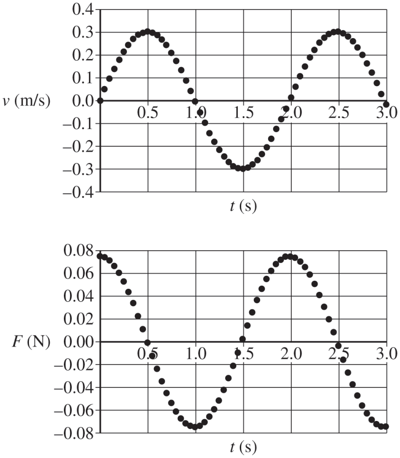
(a) (a) Design an experimental procedure the student could use to determine the spring constant k of the spring.
In the following table, list the quantities that would be measured using only the provided equipment in your experiment. Define a symbol to represent each quantity.
In the space below the 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 with your procedure.

Quantity to Be Measured	Symbol for Quantity	Equipment for Measurement
		Stopwatch Digital scale

Question 2

Procedure (and diagram, if needed):

Question 2



0.4
0.3
0.2
0.1
0.0
–0.1
–0.2
–0.3
–0.4
v (m/s)
0.5
1.0
1.5
2.0
2.5
3.0
t (s)
0.08
0.06
0.04
0.02
0.00
–0.02
–0.04
–0.06
–0.08
F (N)
0.5
1.0
1.5
2.0
2.5
3.0
t (s)

Question 2

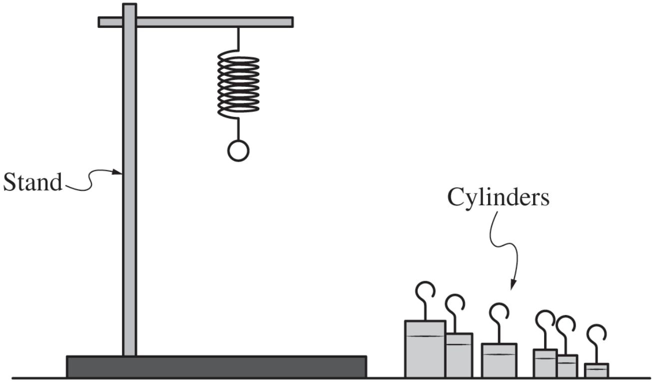


Figure 1

Question 2

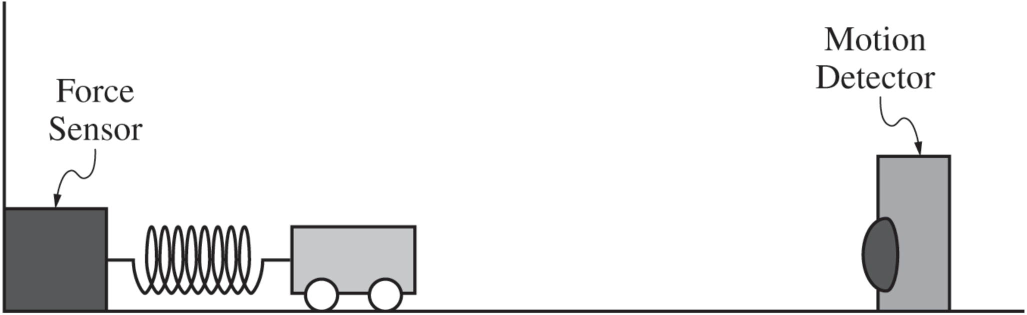


Figure 2

Question 2

2024 ▪ Q2

[Figure 1: A stand with a horizontal support arm (labeled "Stand") has a spring hanging vertically from the arm, with a small loop at the bottom of the spring. To the right, a set of stacked cylindrical masses of various sizes (labeled "Cylinders") sits on the table, available for hanging on the spring's loop.]

A student hangs a spring of unknown spring constant k vertically by attaching one end to a stand, as shown in Figure 1. The other end of the spring has a small loop from which small cylinders can be hung. In addition to the spring, the student has access <u>only</u> to a variety of cylinders of unknown masses, a stopwatch, and a digital scale.

(b)(i) (b)

i. **Indicate** the quantities that could be plotted to produce a linear graph whose slope can be used to determine the spring constant k of the spring.

Vertical axis: ____________________ Horizontal axis: ____________________

Question 2

(b)(ii) ii. Briefly **describe** how the slope of the graph would be analyzed to determine the spring constant k of the spring.

Question 2

2024 ▪ Q2

[Figure 1: A stand with a horizontal support arm (labeled "Stand") has a spring hanging vertically from the arm, with a small loop at the bottom of the spring. To the right, a set of stacked cylindrical masses of various sizes (labeled "Cylinders") sits on the table, available for hanging on the spring's loop.]

A student hangs a spring of unknown spring constant k vertically by attaching one end to a stand, as shown in Figure 1. The other end of the spring has a small loop from which small cylinders can be hung. In addition to the spring, the student has access only to a variety of cylinders of unknown masses, a stopwatch, and a digital scale.

(c)(i) [Figure 2: A force sensor is mounted on a wall on the left. A spring connects the force sensor to a cart of mass $m = 0.25$ kg on wheels, sitting on a horizontal track. To the right of the cart is a motion detector facing the cart.]

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In a different experiment, the student attaches one end of a spring to a force sensor that is attached to a wall. The other end of the spring is attached to a cart with mass $m = 0.25$ kg. The student places a motion detector to the right of the cart, as shown in Figure 2, and pulls the cart to the right a small distance so that the spring is stretched. The student releases the cart from rest, and the cart-spring system oscillates.

The following graphs show the velocity v of the cart and the force F exerted on the cart by the spring as functions of time t.

[Graph 1: velocity v (m/s) vs. time t (s); y-axis from -0.4 to 0.4 in increments of 0.1; x-axis from 0 to 3.0 s with gridlines at $0.5, 1.0, 1.5, 2.0, 2.5, 3.0$. The curve is a smooth cosine-like oscillation: starting near $v \approx 0$ at $t = 0$, rising to a positive peak near $v \approx 0.3$–0.35 around $t \approx 0.5$ s, back down through zero near $t \approx 1.0$–1.2 s, down to a negative peak near $v \approx -0.3$–-0.35 around $t \approx 1.7$ s, back up through zero near

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$t \approx 2.2$–2.4 s, and up to another positive peak near $t \approx 2.9$–3.0 s. Period of oscillation is approximately 1.7–1.8 s.]
[Graph 2: force F (N) vs. time t (s); y-axis from -0.08 to 0.08 in increments of 0.02; x-axis from 0 to 3.0 s with gridlines at $0.5, 1.0, 1.5, 2.0, 2.5, 3.0$. The curve is a smooth oscillation with the same period as the velocity graph, appearing approximately $90°$ out of phase with $v(t)$: starting near $F \approx 0.06$–0.07 (near a peak) at $t = 0$, decreasing through zero around $t \approx 0.4$–0.5 s, reaching a negative peak near $F \approx -0.07$ around $t \approx 0.8$–0.9 s, back through zero near $t \approx 1.3$ s, reaching a positive peak near $t \approx 1.7$–1.8 s, and continuing to oscillate with the same period through $t = 3.0$ s.]
i. Using the data in the velocity-time graph, **calculate** the change in kinetic energy of the cart from $t = 0.5$ s to $t = 2.0$ s. Show your steps and substitutions.

Question 2

(c)(ii) ii. Using the data in the force-time graph, **estimate** the change in momentum of the cart from $t = 0.5$ s to $t = 2.5$ s. Briefly **explain** how you arrived at your estimation.
(c)(iii) iii. Do the data from the velocity-time graph confirm your estimation from part (c)(ii)? Briefly **explain**.

Solution 2

(a) Mark scheme

- Procedure: place a cylinder on the digital scale and record its mass. Hang the cylinder from the spring and pull it down a small distance so the spring is stretched, then release it so it oscillates. Use the stopwatch to measure the time for the cylinder to complete many (e.g. ten) full cycles (from maximum stretch back to maximum stretch), then divide by the number of oscillations to get the period. Repeat the procedure for cylinders of different masses. Points (4 total, 1 each): measuring the mass of at least one cylinder with the digital scale; measuring the period of oscillation with the stopwatch; a procedure that indicates the cylinder is set into oscillatory motion; a procedure that reduces experimental uncertainty (accept any one of: using multiple masses, doing multiple trials with a

Solution 2

single mass, or measuring multiple oscillations and dividing by the number of oscillations).

Solution 2

(b)(i) Mark scheme

- List a linear-izing pair of axes whose slope gives k, e.g. Vertical axis: m, Horizontal axis: T^2 (from $T = 2\pi\sqrt{m/k}$, so $m = \frac{k}{4\pi^2}T^2$). Any of the following pairs earns the point: m vs. T^2; T^2 vs. m; $4\pi^2 m$ vs. T^2; T^2 vs. $4\pi^2 m$; $\frac{T^2}{4\pi^2}$ vs. m; m vs. $\frac{T^2}{4\pi^2}$; T vs. $\sqrt{m}$; $\sqrt{m}$ vs. T; $\frac{T}{2\pi}$ vs. $\sqrt{m}$; $\sqrt{m}$ vs. $\frac{T}{2\pi}$; T vs. $2\pi\sqrt{m}$; $2\pi\sqrt{m}$ vs. T (any bullet may also substitute $1/f$ for T).

Solution 2

(b)(ii) Mark scheme

- Describe how the slope relates to k, consistent with the axes chosen in (b)(i). Using $T = 2\pi\sqrt{m/k}$: e.g. for m (vertical) vs. T^2 (horizontal), slope $= \dfrac{k}{4\pi^2}$, so $k = (\text{slope})\, 4\pi^2$. (Other axis choices give the corresponding relation, e.g. T^2 vs. m gives slope $= 4\pi^2/k$ so $k = 4\pi^2/\text{slope}$; $4\pi^2 m$ vs. T^2 gives slope $= k$; etc.) Full credit (1 point) for correctly relating the slope of the best-fit line to k given the student's chosen axes.

Solution 2

(c)(i)

Mark scheme

- Estimate the change in kinetic energy of the cart using $K = \frac{1}{2}mv^2$:
  $\Delta K = K_f - K_i = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = \frac{1}{2}(0.25)(0)^2 - \frac{1}{2}(0.25)(0.3)^2 \approx -0.0113$ J.
  Points: using the kinetic energy equation $K = \frac{1}{2}mv^2$ (1 point); substituting one of the given values — mass 0.25 kg or initial velocity 0.3 m/s (1 point); an answer that approximates $\Delta K \approx -0.0113$ J (unit and sign not required) — a correct numeric answer with no supporting work earns this point alone (1 point).

Solution 2

(c)(ii)

Mark scheme

- Because the cart's speed returns to the same value (0.3 m/s) before and after the interaction, the magnitude of the change in momentum is zero. This is estimated from the force-time graph: the area under a force-vs-time curve equals the impulse, i.e. the change in momentum; the area under the curve from $t = 0.5$ s to $t = 2.5$ s is zero (equal positive and negative areas cancel), so $\Delta p \approx 0$. Points: indicating the magnitude of the change in momentum is zero (1 point); indicating that the area under the force-time graph represents the value of the change in momentum (1 point).

Solution 2

(c)(iii)

Mark scheme

- Yes — the velocity-time graph confirms the estimate from (c)(ii): it shows the velocity is 0.3 m/s at both $t = 0.5$ s and $t = 2.5$ s, and since momentum is mass times velocity, the momentum is the same at both times, giving a change in momentum of zero. This agrees with the (c)(ii) estimate that $\Delta p \approx 0$. Full credit (1 point) for an explanation that compares the (c)(ii) estimate to the velocity-time data in this way.

Question 4

2024 ▪ Q4

[Figure showing a pendulum: a rigid horizontal support bracket attached to a wall/ceiling structure, from which a string hangs. The string makes angle θ with the vertical dashed line. At the end of the string is a small sphere labeled "Small Sphere", at position A. A dashed circle labeled B marks the lowest point of the swing, directly below the pivot along the vertical dashed line.]

A simple pendulum consists of a small sphere that hangs from a string with negligible mass. The top end of the string is fixed. The sphere is pulled to Point A so that the string makes a small angle θ with the vertical, as shown. The sphere is then released from rest and swings through its lowest point at Point B. The work done on the sphere by Earth between points A and B is W_E.

The pendulum is then taken to Planet X. The mass of Planet X is the same as the mass of Earth, but the radius of Planet X is greater than the radius of Earth. The

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sphere is again brought to Point A (displaced θ from the vertical), released from rest, and swings through its lowest point at Point B. The work done on the sphere by Planet X between points A and B is W_X.

(a) (a) **Justify** why W_X is less than W_E.

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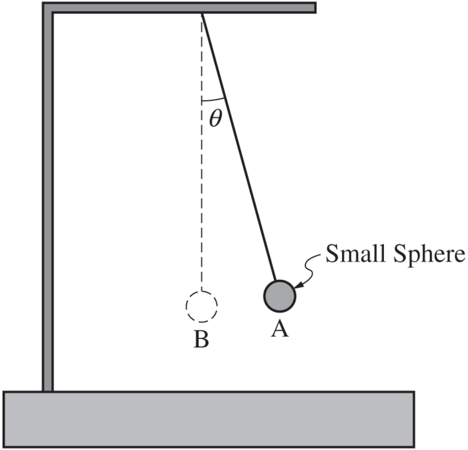

Question 4

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[Figure showing a pendulum: a rigid horizontal support bracket attached to a wall/ceiling structure, from which a string hangs. The string makes angle θ with the vertical dashed line. At the end of the string is a small sphere labeled "Small Sphere", at position A. A dashed circle labeled B marks the lowest point of the swing, directly below the pivot along the vertical dashed line.]

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The pendulum is then taken to Planet X. The mass of Planet X is the same as the mass of Earth, but the radius of Planet X is greater than the radius of Earth. The sphere is again brought to Point A (displaced θ from the vertical), released from rest, and swings through its

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lowest point at Point B. The work done on the sphere by Planet X between points A and B is W_X.

(b) A new pendulum is made by hanging the same small sphere from a different string with negligible mass. The new string is slightly elastic, and the length of the string may increase or decrease depending on the tension applied to the string. On Earth, when the sphere is again displaced θ from the vertical and released from rest, the new pendulum oscillates with period T_E.

The new pendulum is then taken to a different planet, Planet Y. The radius of Planet Y is the same as the radius of Earth, but the mass of Planet Y is larger than the mass of Earth. On Planet Y, when the sphere is again displaced from the vertical and released from rest, the new pendulum oscillates with period T_Y.

(b) In a clear, coherent paragraph-length response that may also contain drawings, **explain** how T_Y <u>could be larger</u> than T_E but also <u>could be smaller</u> than T_E.

Solution 4

(a) Mark scheme

- Because Planet X has a larger radius than Earth (same mass sphere/planet setup), the gravitational force (equivalently the gravitational field strength or acceleration due to gravity) is smaller on Planet X. Since the sphere travels the same vertical distance in both scenarios, and work done equals force times distance, the smaller gravitational force on Planet X means less work is done on the sphere there — so $W_X < W_E$. Points: indicating one of — gravitational force, gravitational field strength, or acceleration due to gravity would be smaller for the greater radius (1 point); indicating one of — the sphere travels the same vertical distance in both scenarios, the work done depends on the magnitude of the gravitational force, or the change in gravitational potential energy is less on Planet X (1 point).

Solution 4

(b) Mark scheme

- Argument: the pendulum period is $T = 2\pi\sqrt{\ell/g}$. On Planet Y, since the planet's mass is larger, the gravitational force on the sphere (and hence its weight, and the gravitational field strength g) is larger than on Earth, so the sphere experiences a larger acceleration due to gravity on Planet Y. Because g is in the denominator of the period equation, a larger g alone would tend toward a smaller period. However, the larger gravitational force on the sphere also means a greater stretching force on the (slightly elastic) string, so the string — and hence the pendulum length ℓ — could increase. Since T increases with ℓ, a longer string could push the period back up. So the net effect on T depends on which change (larger g vs. longer ℓ) dominates. Points (5 total, 1 each): relating a larger

Solution 4

planetary mass to a larger weight of the sphere / larger g / larger gravitational field strength; indicating the period is inversely related to g (or gravitational field strength); indicating the amount of string stretch depends on the weight of the sphere / g / gravitational field strength; relating the length of the string to the period of the pendulum; and an overall logical, relevant, internally consistent argument that addresses the question and follows the paragraph-response format.

Question 3

2023 ▪ Q3

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

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

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

Question 3

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

(a)(i) At time $t = t_1$, the rod is spinning such that the block moves in a circular path with a constant tangential speed v_1 and the spring is stretched a distance d_1 from the spring's unstretched length, as shown in Figure 1. At time $t = t_2$, the rod is spinning such that the block moves in a circular path with a constant tangential speed v_2 and the spring is stretched a distance d_2 from the spring's unstretched length, where $d_2 > d_1$, as shown in Figure 2.

i. On the following dots, which represent the block at the locations shown in Figure 1 and Figure 2, draw the force that is exerted on the block by the spring at times $t = t_1$ and $t = t_2$. The spring force must be represented by a distinct arrow starting on, and

Question 3

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

Question 3

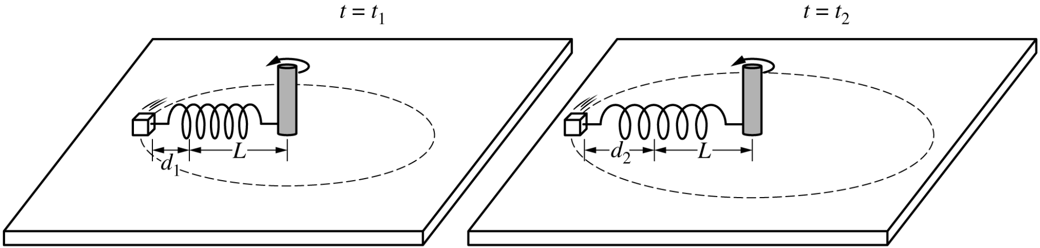
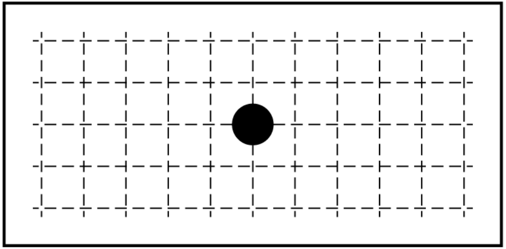


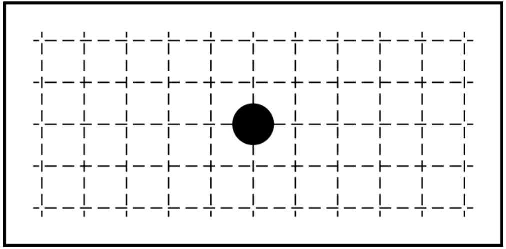
Figure 1

Figure 2

Question 3

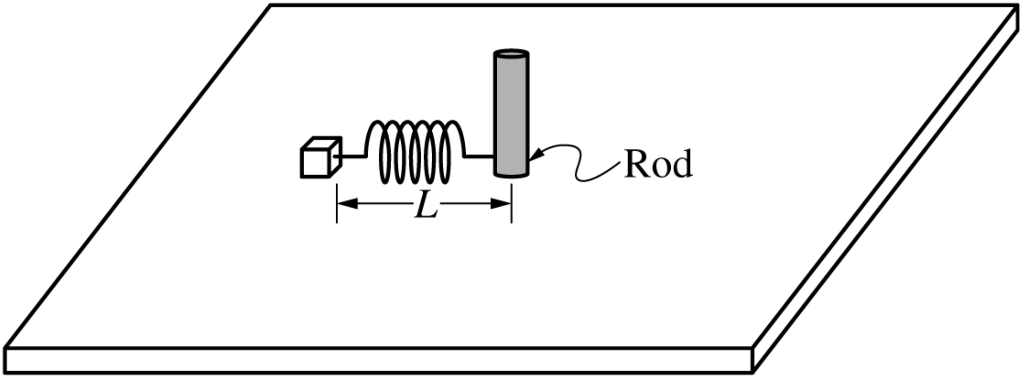


$t = t_1$



$t = t_2$

Question 3



Question 3

2023 ▪ Q3

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

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

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

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

Question 3

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

Question 3

2023 ▪ Q3

[Figure: A small block attached to one end of a spring, the spring's other end attached to a short post; the post is mounted via a rod of length L to a vertical rod ("Rod") fixed on a horizontal rotating table.]
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[Figure 1 (labeled "$t = t_1$"): Top view of the rotating table; the post/rod is at the center, a dashed circular path is shown, the block sits on the spring at distance L from the center plus a stretch d_1 (spring stretched a distance d_1 from its unstretched length).]
[Figure 2 (labeled "$t = t_2$"): Same top-view setup, dashed circular path shown, block at distance L from the center plus a stretch d_2 from unstretched length, with d_2 drawn longer than d_1.]

Question 3

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

_______ Yes _______ No

Explain your reasoning.

Solution 3

(a)(i) Mark scheme

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

Solution 3

(a)(ii)

Mark scheme

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

Solution 3

(a)(iii) Mark scheme

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

Solution 3

(b)(i)

Mark scheme

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

Solution 3

(b)(ii) Mark scheme

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

Solution 3

(c) Mark scheme

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

Question 1

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

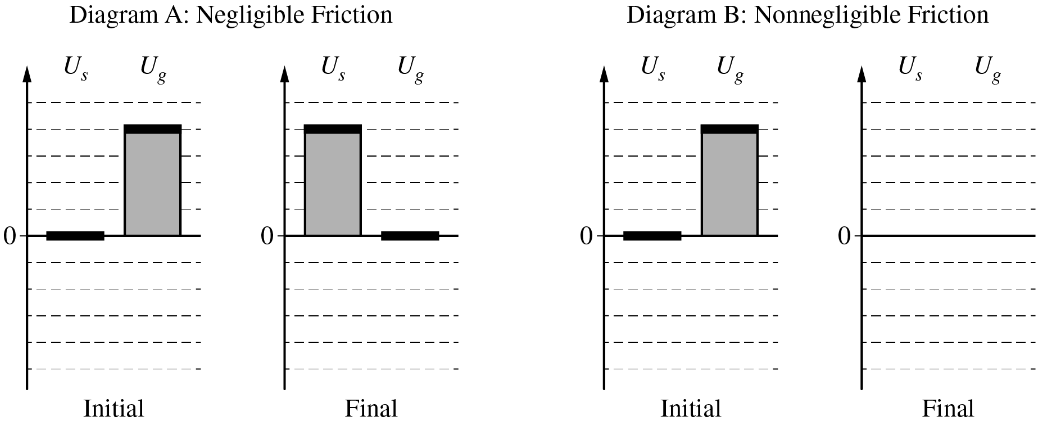
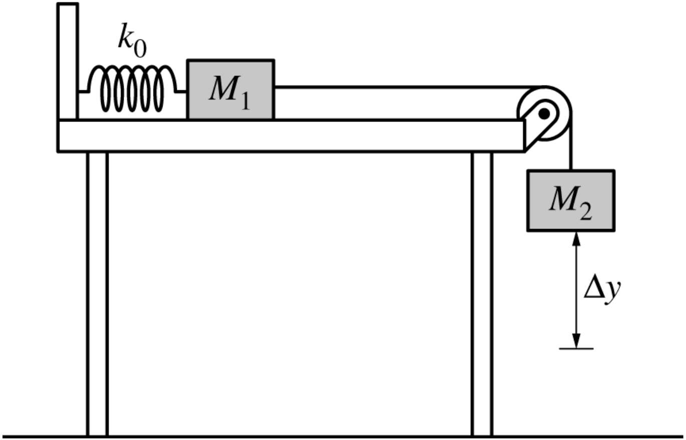


Diagram A: Negligible Friction
U_s
U_g
0
Initial
Final
Diagram B: Nonnegligible Friction
Initial
Final

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.]

Question 1

(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

Question 1

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$_i = K_f = 0) : U_{g,i} + M_2g\Delta y = U_{g,f} + \frac{1}{2}k_0\Delta y^2, i.e. M_2g\Delta y = \frac{1}{2}k_0\Delta y^2, so M_2g = \frac{1}{2}k_0\Delta y, giving \Delta y = \frac{2M_2g}{k_0}. Scoring : 1 point for a correct energy - conservation equation including both a gravitational PE term and a spring PE term; 1 point for the corr$ $2M_2g/k_0 depending only on M_2, k_0, and g.$

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 5

2022 ▪ Q5

[Figure: A spring hangs vertically from a ceiling (shown as a hatched surface at top). A lightweight hanger is attached to the lower end of the spring. Below the hanger, a vertical distance of “1.00 m” is marked down to a “Motion Detector” resting on the floor, facing upward directly under the hanger.]

A spring of unknown spring constant k_0 is attached to a ceiling. A lightweight hanger is attached to the lower end of the spring, and a motion detector is placed on the floor facing upward directly under the hanger, as shown in the figure above. The bottom of the hanger is 1.00 m above the motion detector.

A 0.50 kg object is placed on the hanger and allowed to come to rest at the equilibrium position. The spring is then stretched downward a distance d_0 from equilibrium and released at time $t = 0$. The motion detector records the height of the

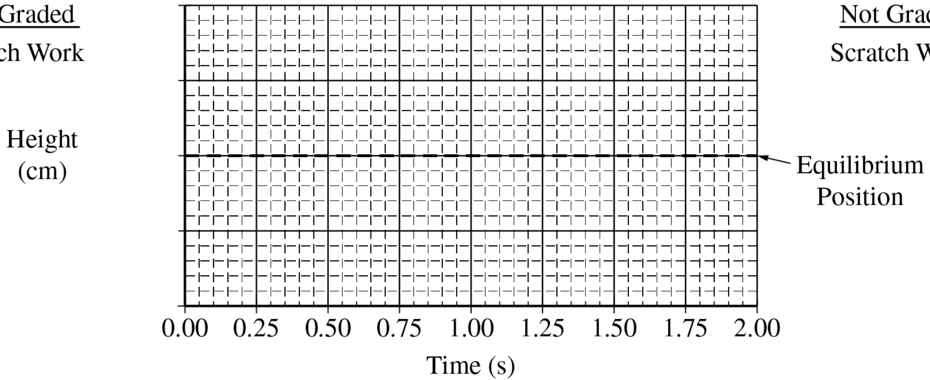
Question 5

bottom of the hanger as a function of time. The output from the motion detector is shown in the graph on the following page.
[Graph: "Height (cm)" on the y-axis from 50 to 70 cm (gridlines at 50, 55, 60, 65, 70), "Time (s)" on the x-axis from 0.00 to 2.00 s (gridlines at 0.00, 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00). A smooth sinusoidal curve oscillates between about 55 cm and 65 cm, starting near a minimum around $t = 0$, with "Equilibrium Position" labeled at the horizontal midline around 60 cm. The curve appears to have a period of about 1.00 s.]
(a) Using the information given and information taken from the graph, calculate the spring constant.

Question 5

Not Graded

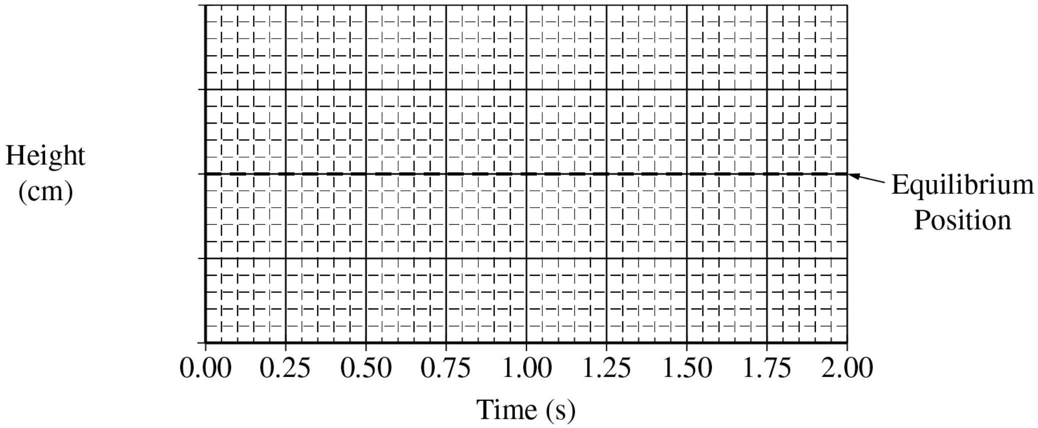
Scratch Work



Not Graded

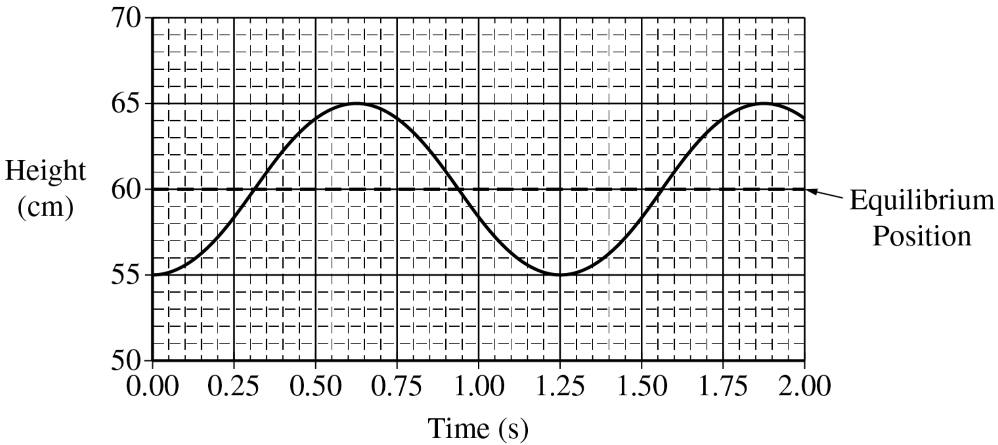
Scratch Work

Question 5



Height (cm)
Equilibrium Position
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Time (s)

Question 5


Height (cm)
70
65
60
55
50
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Time (s)
Equilibrium Position

Question 5

2022 ▪ Q5

[Figure: A spring hangs vertically from a ceiling (shown as a hatched surface at top). A lightweight hanger is attached to the lower end of the spring. Below the hanger, a vertical distance of “1.00 m” is marked down to a “Motion Detector” resting on the floor, facing upward directly under the hanger.]

A spring of unknown spring constant k_0 is attached to a ceiling. A lightweight hanger is attached to the lower end of the spring, and a motion detector is placed on the floor facing upward directly under the hanger, as shown in the figure above. The bottom of the hanger is 1.00 m above the motion detector.

A 0.50 kg object is placed on the hanger and allowed to come to rest at the equilibrium position. The spring is then stretched downward a distance d_0 from equilibrium and released at time $t = 0$. The motion detector records the height of the bottom of the hanger as a function of time. The output from the motion detector is shown in the graph on the following page.

Question 5

[Graph: "Height (cm)" on the y-axis from 50 to 70 cm (gridlines at 50, 55, 60, 65, 70), "Time (s)" on the x-axis from 0.00 to 2.00 s (gridlines at 0.00, 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00). A smooth sinusoidal curve oscillates between about 55 cm and 65 cm, starting near a minimum around $t = 0$, with "Equilibrium Position" labeled at the horizontal midline around 60 cm. The curve appears to have a period of about 1.00 s.]

(b)(i) At time 0.75 s, the object-spring-Earth system has a total kinetic energy K_0 and a total potential energy U_0. At 1.13 s, the object-spring-Earth system again has a total kinetic energy K_0 and a total potential energy U_0.

Explain how a feature of the graph indicates that the total kinetic energy of the system is the same at these two times.

(b)(ii) Briefly explain why the total potential energy of the system is the same at these two times.

Question 5

2022 ▪ Q5

[Figure: A spring hangs vertically from a ceiling (shown as a hatched surface at top). A lightweight hanger is attached to the lower end of the spring. Below the hanger, a vertical distance of "1.00 m" is marked down to a "Motion Detector" resting on the floor, facing upward directly under the hanger.]

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Question 5

[Graph: "Height (cm)" on the y-axis from 50 to 70 cm (gridlines at 50, 55, 60, 65, 70), "Time (s)" on the x-axis from 0.00 to 2.00 s (gridlines at 0.00, 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00). A smooth sinusoidal curve oscillates between about 55 cm and 65 cm, starting near a minimum around $t = 0$, with "Equilibrium Position" labeled at the horizontal midline around 60 cm. The curve appears to have a period of about 1.00 s.]

(c) The experiment is repeated with a spring of spring constant $4k_0$ and that has the same length as the original spring. The 0.50 kg object is hung from the new spring and allowed to come to rest at a new equilibrium position.

(c)(i) Determine the new equilibrium position above the motion detector.

(c)(ii) The object is again pulled down the same distance d_0 from the equilibrium position and released. On the following graph, draw a curve representing the motion of the object after it is released. Label the vertical axis with an appropriate numerical scale. A grid for scratch (practice) work is also provided.

Question 5

[Graph: “Height (cm)” on the y-axis (unlabeled scale, to be filled in by student), “Time (s)” on the x-axis from 0.00 to 2.00 s (gridlines at 0.00, 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00). “Equilibrium Position” labeled at the horizontal midline. Blank grid for the student to draw the curve.]

The following graph is provided for scratch work only and will not be graded.

[Two “Not Graded / Scratch Work” grids follow, each labeled “Height (cm)” vs. “Time (s)” from 0.00 to 2.00 s, with “Equilibrium Position” marked at the midline — for student scratch work, not graded.]

Solution 5

(a) Mark scheme

- From the graph, the period is T = 1.25 s. Using T = $2\pi\sqrt{m/k}, solve for k: k_0 = \frac{m}{(T/2\pi)^2} = \frac{0.50\ \text{kg}}{(1.25\ \text{s}/2\pi)^2} \approx 12.6\ \text{N/m}.(Alternate solution: the spring stretches 0.40 m to reach equilibrium -- since the equilibrium height is 60 cm and the original unstretched height was 100 cm -- and at equilibrium mg = kx, so k = mg/x = 5\ \text{N}/0.40\ \text{m} = 12.5\ \text{N/m}.) Scoring: 1 point for obtaining a period of 1.25 s from the graph (or, in the alternate method, 1 point for correctly fin$

Solution 5

(b)(i)

Mark scheme

- The magnitude of the slope of the height-vs-time graph (the object's speed) is the same at t=0.75 s and t=1.13 s, so the kinetic energy (which depends only on speed) is the same at both times. (Equivalently: the object is the same distance from the equilibrium position at both times, so its speed – and hence KE – must be the same.) Scoring: 1 point for a valid reason why the kinetic energy is the same at both times.

Solution 5

(b)(ii)

Mark scheme

- The total mechanical energy of the object-spring-Earth system is constant, so since the kinetic energy K_0 is the same at both times, the potential energy U_0 (= total energy minus K_0) must also be the same at both times. (Equivalently: equal energy is transferred between gravitational and spring potential energy as the object oscillates.) Scoring: 1 point for a valid reason why the total potential energy is the same at both times.

Solution 5

(c)

Mark scheme

- This is the introductory stem describing the repeated experiment with a new spring of constant 4k_0 (same natural length) – it poses no scorable question itself; the two scored sub-parts are (c)(i) and (c)(ii), which together carry all 3 points allocated to part (c) in the scoring guidelines.

Solution 5

(c)(i)

Mark scheme

- The new equilibrium position is 90 cm (0.90 m) above the motion detector – with a spring 4 times stiffer, the same weight stretches it only 1/4 as far (0.10 m instead of 0.40 m), so the equilibrium position rises from 60 cm to 90 cm. Scoring: 1 point for writing 90 cm or 0.90 m.

Solution 5

(c)(ii) Mark scheme

- Draw a sinusoidal curve centered on the new equilibrium height of 90 cm, with the same amplitude as the original graph (the object is pulled down the same distance $d_0 fromequilibrium), andwithhalftheperiodoftheoriginalmotion(since T = 2\pi\sqrt{m/k} andkincreasedbyafactorof 4, T_new = T_old/2). Labeltheverticalaxiswithanappropriatenumericalscalereflectingthe 90 cmcenterandsamea$
$1 pointforboth(agraphwiththesameamplitudeastheoriginal AND centeredonthenew 90 cmequilibriu$

Question 3

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[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

Question 3

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

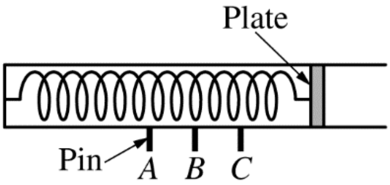

Figure 1. Uncompressed spring

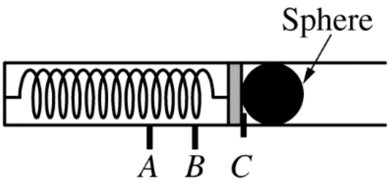

Figure 2. Compressed spring

Question 3