Past-paper walk-through

Linear Momentum ▪ 4.1

eXercise

Questions in this set

- 2024 Q2

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

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.

Question 2

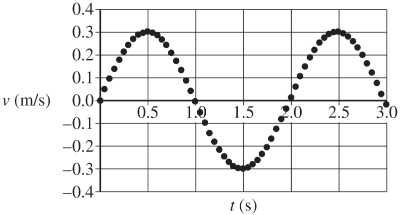
(a) (a) Design an experimental procedure the student could use to determine the spring constant k of the spring.
In the following table, list the quantities that would be measured using only the provided equipment in your experiment. Define a symbol to represent each quantity.
In the space below the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

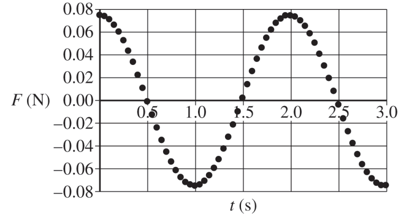
Question 2

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

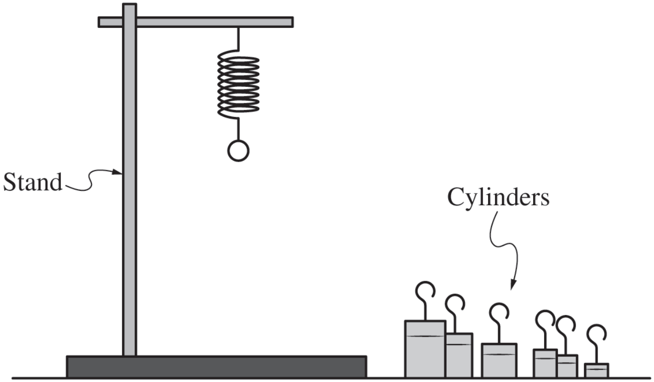


Figure 1

Question 2

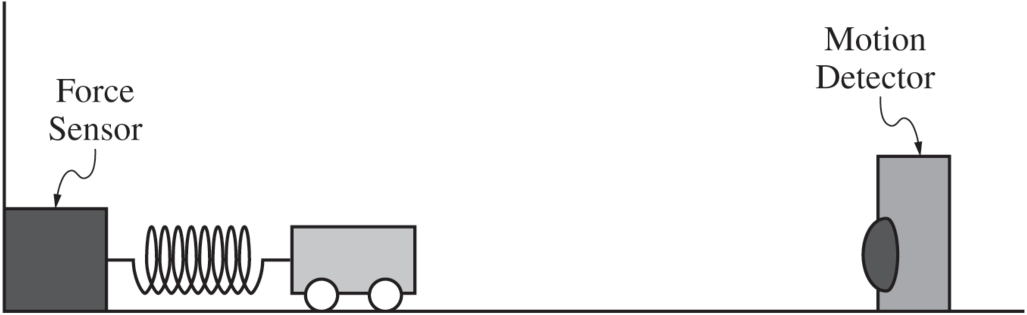


Figure 2

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.]

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(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.]

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(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.]

Question 2

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

Question 2

$t \approx 2.2$–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.