Past-paper walk-through

Change in Momentum and Impulse ▪ 4.2

eXercise

Questions in this set

- 2025 Q1
- 2023 Set 2 Q1
- 2022 Set 1 Q2
- 2022 Set 2 Q2
- 2019 Set 2 Q2
- 2018 Q2
- 2014 Q1

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 1

2025 ▪ Q1

Two blocks, 1 and 2, slide toward each other on a horizontal surface. Block 1 has mass m and slides in the $+x$-direction with constant speed $2v_0$. Block 2 has mass $6m$ and slides in the $-x$-direction with constant speed v_0, as shown in Figure 1. The blocks then collide and stick together. The collision occurs from time $t = 0$ to $t = t_c$. After the collision, where $t > t_c$, the blocks move together with the same constant speed. [Figure 1: Horizontal surface with a $+x$ arrow pointing right. Block 1 (mass m) on the left, moving in the $+x$-direction with speed $2v_0$ (arrow pointing right labeled $2v_0$). Block 2 (mass $6m$) on the right, moving in the $-x$-direction with speed v_0 (arrow pointing left labeled v_0).]

(a)(i) The diagrams in Figure 2 can be used to represent the momentum of blocks 1 and 2 before and after the collision. The momentum vector diagram for Block 1 before the collision is shown.

Question 1

[Figure 2: A table titled “Momentum Before Collision” / “Momentum After Collision” with rows for Block 1, Block 2, and Two-Block System. Each cell shows a horizontal zero-momentum grid line labeled “0”. The “Block 1, Before Collision” cell already shows an arrow starting at 0 and pointing right (+x-direction), representing the momentum of Block 1 before the collision. All other cells (Block 2 before collision; Block 1 after collision [shaded, not applicable]; Block 2 after collision [shaded, not applicable]; Two-Block System before collision; Two-Block System after collision) are blank grids to be filled in.]

Draw arrows on the grids to represent the momentum vectors of Block 2 before the collision and the two-block system before and after the collision.

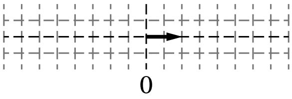
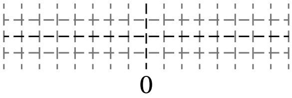
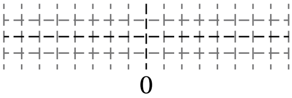
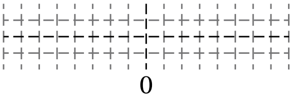
- Arrows should start at the zero-momentum line.
- The length of the arrows should be proportional to the relative magnitudes of the vectors.

Question 1

- Represent an arrow of zero length by drawing a dot at zero.

(a)(ii) During the time interval $0 \leq t \leq t_c$, a force F is exerted on Block 2 by Block 1 along the x-direction as a function of t that is modeled by $F(t) = F_{\max}\sin(At)$, where A is a positive constant and $F_{\max}$ is the magnitude of the maximum force exerted on Block 2 by Block 1 during the collision.
Derive an expression for $F_{\max}$. Express your answer in terms of m, v_0, A, t_c, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

Question 1

	Momentum Before Collision	Momentum After Collision
Block 1		
Block 2		
Two-Block System		

Question 1

Question 1

2025 ▪ Q1

Two blocks, 1 and 2, slide toward each other on a horizontal surface. Block 1 has mass m and slides in the $+x$-direction with constant speed $2v_0$. Block 2 has mass $6m$ and slides in the $-x$-direction with constant speed v_0, as shown in Figure 1. The blocks then collide and stick together. The collision occurs from time $t = 0$ to $t = t_c$. After the collision, where $t > t_c$, the blocks move together with the same constant speed.

[Figure 1: Horizontal surface with a $+x$ arrow pointing right. Block 1 (mass m) on the left, moving in the $+x$-direction with speed $2v_0$ (arrow pointing right labeled $2v_0$). Block 2 (mass $6m$) on the right, moving in the $-x$-direction with speed v_0 (arrow pointing left labeled v_0).]

(b) Consider a new scenario where Block 1 initially slides in the $+x$-direction with a new constant speed v_1 and Block 2 again initially slides in the $-x$-direction with constant speed v_0. The blocks collide and stick together. In this new scenario, the two-block system has constant speed v_0 after the collision.

Question 1

Derive an expression for v_1 in terms of v_0. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

Solution 1

(a)(i) Mark scheme

- Momentum vector diagram (Figure 2). Using the scale already set by the given Block 1 arrow (2 units right, i.e. magnitude $2v_0$ for mass m, since Block 1's momentum is $m(2v_0)$): draw ONE arrow for Block 2's momentum before the collision pointing in the $-x$ direction (leftward) and 6 units long (magnitude $6mv_0$, consistent with Block 2's mass $6m$ and speed v_0) [Point A1]. Draw identical arrows – same length and direction – for the momentum of the two-block system both BEFORE and AFTER the collision, since total momentum is conserved; the length equals the vector sum of the Block 1 and Block 2 arrows: 2 units right + 6 units left = 4 units left, i.e. pointing in the $-x$ direction with magnitude $4mv_0$ (matches $m(2v_0) + 6m(-v_0) = -4mv_0 = 7m(-\frac{4}{7}v_0)$) [Point

Solution 1

A2]. Award A1 for the correctly-directed 6-unit Block 2 arrow; award A2 for two IDENTICAL two-block-system arrows (before and after) of the correct length/direction, independent of A1.

Solution 1

(a)(ii) Mark scheme

- Derive F_{max}. Begin with the impulse-momentum theorem or Newton's second law: $\vec{J} = \int_{t_1}^{t_2} \vec{F}_{net}(t)\, dt = \Delta\vec{p}$, or equivalently $\vec{F}_{net} = \dfrac{d\vec{p}}{dt}$ [Point A3: multistep derivation using the integral form of impulse or the differential form of N2L]. Apply conservation of momentum to the original collision: $\sum \vec{p}_0 = \sum \vec{p}_f \Rightarrow (m)(2v_0) + (6m)(-v_0) = (m + 6m)(v_f) \Rightarrow v_f = -\frac{4}{7}v_0$ [Point A4: award for stating any ONE equivalent fact – final speed of Block 1 or 2 is $\frac{4}{7}v_0$, $\Delta p_{Block2} = +\frac{18}{7}mv_0$, $\Delta p_{Block1} = -\frac{18}{7}mv_0$, $\Delta v_{Block2} = +\frac{3}{7}v_0$, or $\Delta v_{Block1} = -\frac{18}{7}v_0$]. Then $\Delta p_{Block2} = -\Delta p_{Block1} = 6m\left(-\frac{4}{7}v_0 - (-v_0)\right) = \frac{18}{7}mv_0$. Substitute the given force into the impulse integral:

Solution 1

$\Delta p_{Block2} = \int_0^{t_c} F_{\max}\sin(At)\,dt$ [Point A5: substituting F(t) into the impulse/N2L expression]. Evaluate: $\frac{18}{7}mv_0 = \dfrac{F_{\max}}{A}\big[-\cos(At)\big]_0^{t_c} = \dfrac{F_{\max}}{A}\big[1-\cos(At_c)\big]$ [Point A6: definite integral with correct limits, or an equivalent indefinite integral plus a constant of integration]. Solve: $F_{\max} = \dfrac{18}{7}\left(\dfrac{Amv_0}{1-\cos(At_c)}\right)$ [Point A7: final correct expression in terms of m, v_0, A, t_c].

Solution 1

(b) Mark scheme

- New scenario: Block 1 (mass m) slides at speed v_1 in the $+x$ direction, Block 2 (mass $6m$) slides at speed v_0 in the $-x$ direction; they collide and stick, and the combined system moves afterward at constant speed v_0. Using conservation of momentum (a multistep derivation) [Point B1]: $\sum \vec{p}_0 = \sum \vec{p}_f$. The final momentum magnitude of the combined $7m$ system is $7mv_0$ [Point B2]. $mv_1 + 6m(-v_0) = 7m(v_0) \Rightarrow mv_1 = 13mv_0 \Rightarrow v_1 = 13v_0$ [Point B3: correct final expression for v_1 in terms of v_0].

Question 1

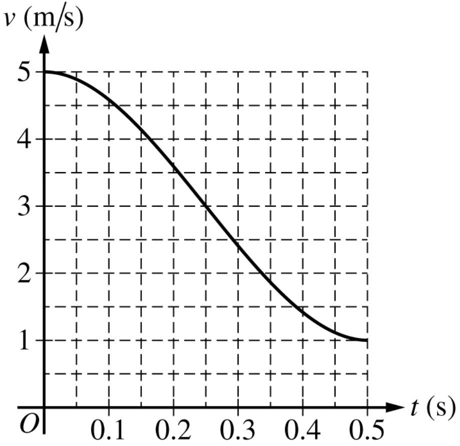
2023 Set 2 ▪ Q1

Scientists have created a new type of lightweight foam and are performing experiments to investigate the properties of the foam. The mass of Cart A is 1000 kg and the mass of Cart B is 2000 kg. A piece of foam with negligible mass is attached to the front of Cart A, as shown. Cart A moves with a constant speed toward Cart B, which is initially at rest. At time $t = 0$ s, the foam connected to Cart A makes contact with Cart B. The foam remains in contact with Cart B for 0.5 s, after which the carts separate and both carts move with constant velocities.
[Diagram: Cart A (with a block labeled "Foam" attached to its front) approaching Cart B along a horizontal track, both carts shown as boxes on wheels.]
(a)(i) The graph shows the velocity v of Cart A as a function of time t for the time interval when the foam and Cart B are in contact.

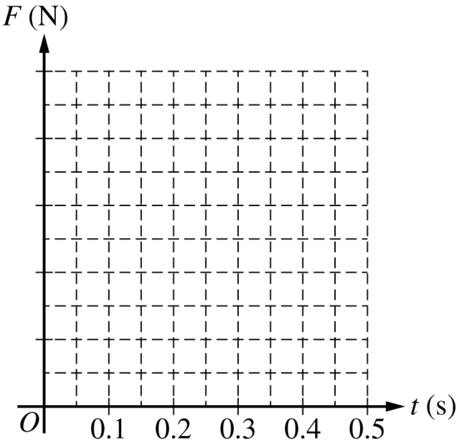
Question 1

[Graph: *v* (m/s) vs. *t* (s); y-axis from 0 to 5 m/s in increments of 1, x-axis from 0 to 0.5 s in increments of 0.1 s; curve starts at $(0, 5)$ and decreases smoothly, concave up, leveling off toward approximately $(0.5, 1)$.]
What feature(s) of the graph could be used to estimate the displacement of Cart A during the collision?
(a)(ii) Using the information shown in the graph, determine the speed of Cart B at $t = 0.5$ s.
(a)(iii) On the following grid, draw a smooth curve of the velocity of Cart B as a function of time.
[Grid: *v* (m/s) vs. *t* (s); y-axis from 0 to 5 m/s in increments of 1, x-axis from 0 to 0.5 s in increments of 0.1 s; the curve for Cart A is already plotted and labeled "Cart A," starting at $(0, 5)$ and decreasing to approximately $(0.5, 1)$.]

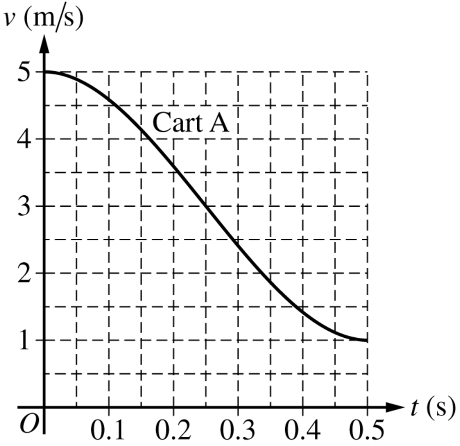
Question 1



Question 1



Question 1



Question 1

2023 Set 2 ▪ Q1

Scientists have created a new type of lightweight foam and are performing experiments to investigate the properties of the foam. The mass of Cart A is 1000 kg and the mass of Cart B is 2000 kg. A piece of foam with negligible mass is attached to the front of Cart A, as shown. Cart A moves with a constant speed toward Cart B, which is initially at rest. At time $t = 0$ s, the foam connected to Cart A makes contact with Cart B. The foam remains in contact with Cart B for 0.5 s, after which the carts separate and both carts move with constant velocities.

[Diagram: Cart A (with a block labeled “Foam” attached to its front) approaching Cart B along a horizontal track, both carts shown as boxes on wheels.]

(b)(i) For $0 \leq t \leq 0.50$ s, the velocity v of Cart A can be described by the function $v(t) = 64t^3 - 48t^2 + 5$.

Calculate the magnitude of the maximum net force acting on Cart A during this interval.

Question 1

(b)(ii) On the following grid, draw a smooth curve of the magnitude of the force acting on Cart A as a function of time. Clearly indicate the value of the maximum force on the vertical axis.
[Grid: F (N) vs. t (s); x-axis from 0 to 0.5 s in increments of 0.1 s; y-axis unlabeled/blank for the student to fill in.]

Question 1

2023 Set 2 ▪ Q1

Scientists have created a new type of lightweight foam and are performing experiments to investigate the properties of the foam. The mass of Cart A is 1000 kg and the mass of Cart B is 2000 kg. A piece of foam with negligible mass is attached to the front of Cart A, as shown. Cart A moves with a constant speed toward Cart B, which is initially at rest. At time $t = 0$ s, the foam connected to Cart A makes contact with Cart B. The foam remains in contact with Cart B for 0.5 s, after which the carts separate and both carts move with constant velocities.

[Diagram: Cart A (with a block labeled "Foam" attached to its front) approaching Cart B along a horizontal track, both carts shown as boxes on wheels.]

(c) The foam is removed from the front of Cart A and the experiment is repeated. The carts collide, with both Cart A and Cart B having the same initial and final velocities as in the original collision. The time intervals during which the carts are in contact are different in the collision with the foam and the collision without the foam.

Question 1

In the collision without the foam, Cart A is in contact with Cart B for a shorter duration than in the original collision, when the foam was present.
For the original collision when the foam is present, the magnitude of the average net force exerted on Cart B is F_1. For the collision without the foam, the magnitude of the average net force exerted on Cart B is F_2.
What is the relationship between the magnitude of the average net force F_1 exerted on Cart B for the collision with the foam and the magnitude of the average net force F_2 exerted on Cart B for the collision without the foam?
_____ $F_1 > F_2$ _____ $F_1 < F_2$ _____ $F_1 = F_2$
Justify your answer.

Question 2

2022 Set 1 ▪ Q2

[Diagram, Figure setup: Cart 1 of mass m_1 sits at the top of an incline (marked "Cart 1"), held at rest at a height H above the bottom of the incline. The incline descends and transitions smoothly into a horizontal section. Cart 2, of mass m_2, sits at rest on the horizontal section further along, marked "Cart 2". A Motion Detector is mounted vertically at the far right end of the horizontal track, facing left toward the carts. A second diagram below shows the two-cart system, now combined, moving to the right with velocity v (arrow labeled "v" pointing right) toward the Motion Detector.]

Cart 1 of mass m_1 is held at rest above the bottom of the incline. Cart 2 has mass m_2, where $m_2 > m_1$, and is at rest at the bottom of the incline. At time $t = 0$, Cart 1 is released and then travels down the incline and transitions to the horizontal section. The center of mass of Cart 1 moves a vertical distance H, as shown. At time t_C, Cart 1 reaches the bottom of the incline and immediately collides with and sticks to Cart 2.

Question 2

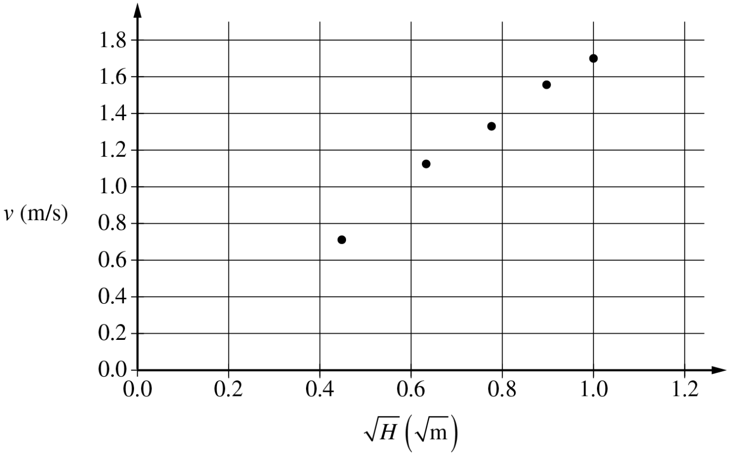
After the collision, the two-cart system moves with constant speed v. Frictional and rotational effects are negligible.

(a) During the collision, is the impulse on Cart 1 from Cart 2 greater than, less than, or equal to the magnitude of the impulse on Cart 2 from Cart 1 ?

______ Greater than   ______ Less than   ______ Equal to

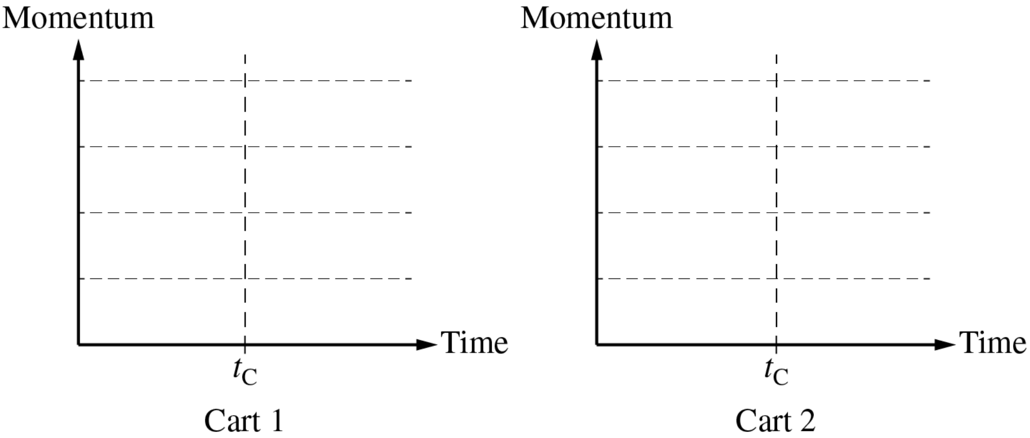
Justify your answer.

Question 2

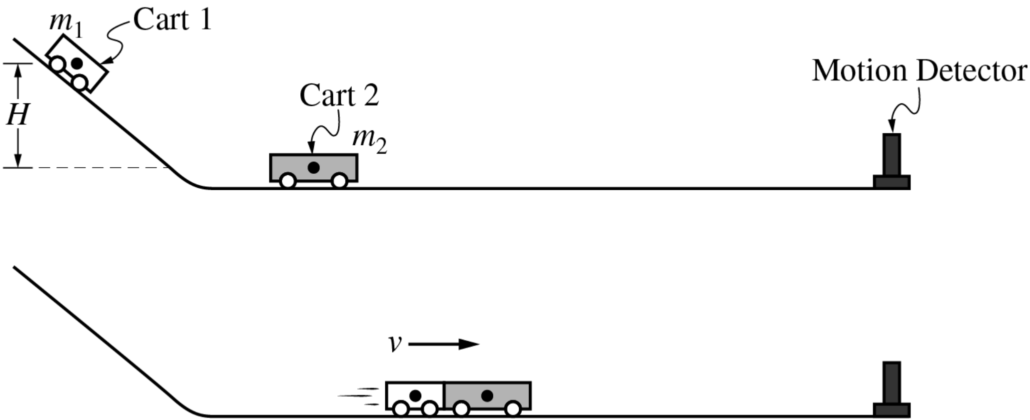


v (m/s)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
$\sqrt{H}\ \left(\sqrt{\text{m}}\right)$

Question 2



Question 2



Question 2

2022 Set 1 ▪ Q2

[Diagram, Figure setup: Cart 1 of mass m_1 sits at the top of an incline (marked "Cart 1"), held at rest at a height H above the bottom of the incline. The incline descends and transitions smoothly into a horizontal section. Cart 2, of mass m_2, sits at rest on the horizontal section further along, marked "Cart 2". A Motion Detector is mounted vertically at the far right end of the horizontal track, facing left toward the carts. A second diagram below shows the two-cart system, now combined, moving to the right with velocity v (arrow labeled "v" pointing right) toward the Motion Detector.]

Cart 1 of mass m_1 is held at rest above the bottom of the incline. Cart 2 has mass m_2, where $m_2 > m_1$, and is at rest at the bottom of the incline. At time $t = 0$, Cart 1 is released and then travels down the incline and transitions to the horizontal section. The center of mass of Cart 1 moves a vertical distance H, as shown. At time t_C, Cart 1 reaches the bottom of the

Question 2

incline and immediately collides with and sticks to Cart 2. After the collision, the two-cart system moves with constant speed v. Frictional and rotational effects are negligible.

(b) On the following axes, draw graphs of the magnitude of the momentum of each cart as a function of time t, before and after t_C. The collision occurs in a negligible amount of time. The grid lines on each graph are drawn to the same scale.

[Graph 1, titled "Cart 1": axes labeled "Momentum" (vertical) vs. "Time" (horizontal); a dashed vertical gridline is marked at t_C on the time axis; horizontal dashed gridlines are evenly spaced on the momentum axis; no data plotted, blank axes for the student to draw on.]

[Graph 2, titled "Cart 2": axes labeled "Momentum" (vertical) vs. "Time" (horizontal); a dashed vertical gridline is marked at t_C on the time axis; horizontal dashed gridlines are evenly spaced on the momentum axis; no data plotted, blank axes for the student to draw on.]

Question 2

2022 Set 1 ▪ Q2

[Diagram, Figure setup: Cart 1 of mass m_1 sits at the top of an incline (marked "Cart 1"), held at rest at a height H above the bottom of the incline. The incline descends and transitions smoothly into a horizontal section. Cart 2, of mass m_2, sits at rest on the horizontal section further along, marked "Cart 2". A Motion Detector is mounted vertically at the far right end of the horizontal track, facing left toward the carts. A second diagram below shows the two-cart system, now combined, moving to the right with velocity v (arrow labeled "v" pointing right) toward the Motion Detector.]

Cart 1 of mass m_1 is held at rest above the bottom of the incline. Cart 2 has mass m_2, where $m_2 > m_1$, and is at rest at the bottom of the incline. At time $t = 0$, Cart 1 is released and then travels down the incline and transitions to the horizontal section. The center of mass of Cart 1 moves a vertical distance H, as shown. At time t_C, Cart 1 reaches the bottom of the

Question 2

incline and immediately collides with and sticks to Cart 2. After the collision, the two-cart system moves with constant speed v. Frictional and rotational effects are negligible.

(c) Show that the velocity v of the two-cart system after the collision is given by the equation

$$v = \sqrt{2g}\left(\frac{m_1}{m_1 + m_2}\right)\sqrt{H}.$$

Question 2

2022 Set 1 ▪ Q2

[Diagram, Figure setup: Cart 1 of mass m_1 sits at the top of an incline (marked "Cart 1"), held at rest at a height H above the bottom of the incline. The incline descends and transitions smoothly into a horizontal section. Cart 2, of mass m_2, sits at rest on the horizontal section further along, marked "Cart 2". A Motion Detector is mounted vertically at the far right end of the horizontal track, facing left toward the carts. A second diagram below shows the two-cart system, now combined, moving to the right with velocity v (arrow labeled "v" pointing right) toward the Motion Detector.]

Cart 1 of mass m_1 is held at rest above the bottom of the incline. Cart 2 has mass m_2, where $m_2 > m_1$, and is at rest at the bottom of the incline. At time $t = 0$, Cart 1 is released and then travels down the incline and transitions to the horizontal section. The center of mass of Cart 1 moves a vertical distance H, as shown. At time t_C, Cart 1 reaches the bottom of the

Question 2

incline and immediately collides with and sticks to Cart 2. After the collision, the two-cart system moves with constant speed v. Frictional and rotational effects are negligible.

(d)(i) A group of students use the setup to perform an experiment. They measure the mass of Cart 1 to be $m_1 = 0.250$ kg. The mass of Cart 2 is unknown. The students perform several trials and in each trial, Cart 1 is released from a different height H and the final velocity of the two-cart system is measured. The students graph v as a function of $\sqrt{H}$, as shown below.

[Graph: scatter plot; vertical axis "v (m/s)" ranges from 0.0 to 1.8 in increments of 0.2; horizontal axis "$\sqrt{H}\,(\sqrt{\text{m}})$" ranges from 0.0 to 1.2 in increments of 0.2; plotted points approximately at $(0.45, 0.75)$, $(0.65, 1.05)$, $(0.65, 1.25)$, $(0.85, 1.35)$, $(1.0, 1.55)$, $(1.0, 1.65)$, showing a roughly linear increasing trend; no line drawn yet.]

Draw a line that represents the best fit to the data points shown.

(d)(ii) Use the best-fit line to calculate the mass of Cart 2.

Question 2

2022 Set 1 ▪ Q2

[Diagram, Figure setup: Cart 1 of mass m_1 sits at the top of an incline (marked "Cart 1"), held at rest at a height H above the bottom of the incline. The incline descends and transitions smoothly into a horizontal section. Cart 2, of mass m_2, sits at rest on the horizontal section further along, marked "Cart 2". A Motion Detector is mounted vertically at the far right end of the horizontal track, facing left toward the carts. A second diagram below shows the two-cart system, now combined, moving to the right with velocity v (arrow labeled "v" pointing right) toward the Motion Detector.]

Cart 1 of mass m_1 is held at rest above the bottom of the incline. Cart 2 has mass m_2, where $m_2 > m_1$, and is at rest at the bottom of the incline. At time $t = 0$, Cart 1 is released and then travels down the incline and transitions to the horizontal section. The center of mass of Cart 1 moves a vertical distance H, as shown. At time t_C, Cart 1 reaches the bottom of the

Question 2

incline and immediately collides with and sticks to Cart 2. After the collision, the two-cart system moves with constant speed v. Frictional and rotational effects are negligible.

(e) After the experiment, the students use a balance to measure the mass of Cart 2 and find it to be less than what was determined in part (d). To explain this discrepancy, one of the students proposes that the mass of Cart 1 was incorrectly measured at the beginning of the experiment. The students measure the mass of Cart 1 again and record a new value, m_1'.

Should the students expect that m_1' will be greater than 0.250 kg, less than 0.250 kg, or equal to 0.250 kg?

$\mathrm{m}_1' > 0.250$ kg $\quad$ $\mathrm{m}_1' < 0.250$ kg $\quad$ $\mathrm{m}_1' = 0.250$ kg

Justify your answer.

Solution 2

(a)

Mark scheme

- Answer: Equal to (1 point for selecting this with an attempted justification). Justification: By Newton's third law, the force Cart 2 exerts on Cart 1 and the force Cart 1 exerts on Cart 2 are equal in magnitude (and opposite in direction) at every instant during the collision; since both carts experience the collision over the same time interval, the impulses ($\int F\,dt$) on each cart must be equal in magnitude (1 point).

Solution 2

(b) Mark scheme

- Momentum (p) vs. time (t) graphs, before/after t_C (collision assumed instantaneous). Cart 1: for $0 < t < t_C$, a straight line increasing linearly from zero (Cart 1 accelerates down the incline); at t_C its momentum drops abruptly to a smaller constant (horizontal) value for $t > t_C$ (1 point for the $0 < t < t_C$ portion: linear increasing for Cart 1 and zero for Cart 2; 1 point for Cart 1's post-collision horizontal line being smaller in magnitude than its momentum at $t = t_C$). Cart 2: zero (flat on the axis) for $0 < t < t_C$, then jumps at t_C to a constant (horizontal) value for $t > t_C$ that is GREATER in magnitude than Cart 1's post-collision momentum (1 point). The magnitude of Cart 1's momentum loss at the collision

Solution 2

must equal the magnitude of Cart 2's momentum gain (equal and opposite changes), consistent with the equal-impulse answer in part (a) (1 point).

Solution 2

(c) Mark scheme

- Derivation of $v = \sqrt{2g}\left(\frac{m_1}{m_1 + m_2}\right)\sqrt{H}$. Conservation of energy (or equivalently kinematics) gives Cart 1's speed at the bottom of the incline: $m_1 gH = \frac{1}{2}m_1 v_1^2 \Rightarrow v_1 = \sqrt{2gH}$ (1 point). Conservation of momentum for the perfectly inelastic collision: $m_1 v_1 = (m_1 + m_2)v \Rightarrow v = \frac{m_1}{m_1 + m_2}v_1$ (1 point). Combining: $v = \frac{m_1}{m_1 + m_2}\sqrt{2gH} = \sqrt{2g}\left(\frac{m_1}{m_1 + m_2}\right)\sqrt{H}$, as required (1 point).

Solution 2

(d)(i)

Mark scheme

- Draw a straight best-fit line through the v vs. $\sqrt{H}$ scatter plot with approximately equal numbers of data points above and below the line (through or near the origin).

Solution 2

(d)(ii) Mark scheme

- Use the best-fit line to find m_2. Calculate the slope using two well-separated points on the best-fit line, e.g. slope $= \dfrac{(1.20 - 0.60)\ \text{m/s}}{(0.70 - 0.35)\sqrt{\text{m}}} = 1.72\ \sqrt{\text{m}}/\text{s}$ (1 point). Relate the slope to the masses via the part (c) result, $\textit{slope} = \dfrac{m_1}{m_1 + m_2}\sqrt{2g}$, and solve for m_2: $m_2 = \dfrac{m_1\sqrt{2g}}{\textit{slope}} - m_1$ (1 point). Substituting $m_1 = 0.250$ kg and $g = 9.8\ \text{m/s}^2$: $m_2 = \dfrac{(0.25\ \text{kg})\sqrt{2(9.8)}}{1.72} - 0.25\ \text{kg} \approx 0.39\ \text{kg}$ (1 point). Any value in the range 0.30–0.60 kg is acceptable given a valid best-fit slope.

Solution 2

(e)

Mark scheme

- Answer: $m_1' < 0.250$ kg (1 point for selecting this with an attempted justification). Justification: The directly-measured mass of Cart 2 came out smaller than the value calculated in part (d). A smaller true m_2 corresponds to a smaller initial energy/momentum for the same drop height H; since the best-fit slope (and hence the computed relationship) stays the same, this discrepancy is explained if the actual mass of Cart 1 is smaller than the recorded 0.250 kg — i.e., $m_1' < 0.250$ kg (1 point).

Question 2

2022 Set 2 ▪ Q2

[Figure (top): A spring with spring constant k is attached to a wall on the left, compressed by an amount Δx from its natural length, holding Block 1 (mass m_1). Block 2 (mass m_2) sits at rest at position $x = 0$, to the right of Block 1, in front of a Motion Detector mounted on a wall at the far right.]
[Figure (bottom): After release, the spring is no longer compressed (uncompressed length shown), and the combined Block 1 + Block 2 system moves to the right with speed v, starting from $x = 0$.]
Block 1 of mass m_1 is held at rest while compressing an ideal spring an amount Δx. The spring constant of the spring is k. Block 2 has mass m_2, where $m_2 < m_1$. At time $t = 0$, Block 1 is released. At time t_C, the spring is no longer compressed and Block 1 immediately collides with and sticks to Block 2. The blocks stick together and the

Question 2

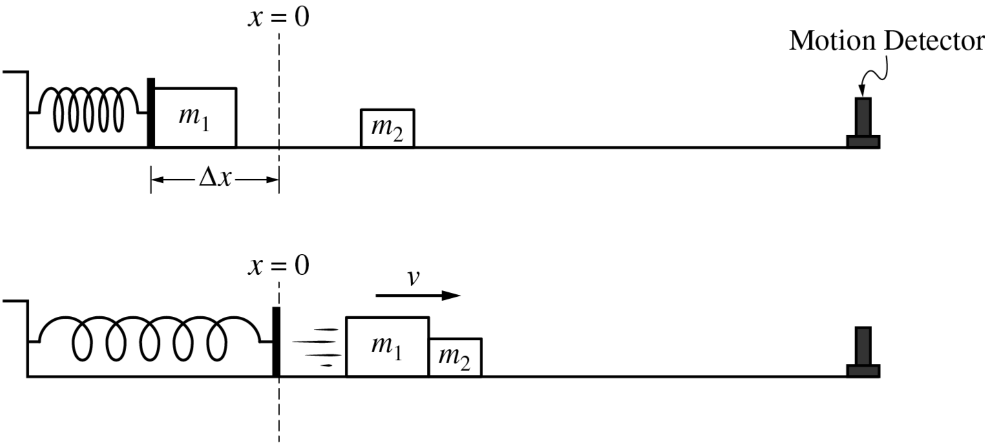
two-block system moves with constant speed v, as shown. Frictional effects are negligible.

(a) The impulse on Block 1 from the spring during the time interval $0 < t < t_C$ is J_S. The impulse on Block 1 from Block 2 during the collision is J_2. Which of the following expressions correctly compares the magnitudes of J_S and J_2 ?

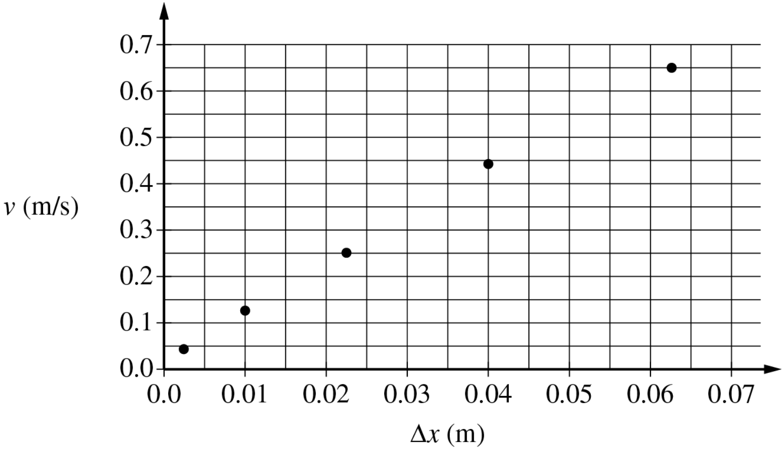
____ $J_S > J_2$ ____ $J_S < J_2$ ____ $J_S = J_2$

Justify your answer.

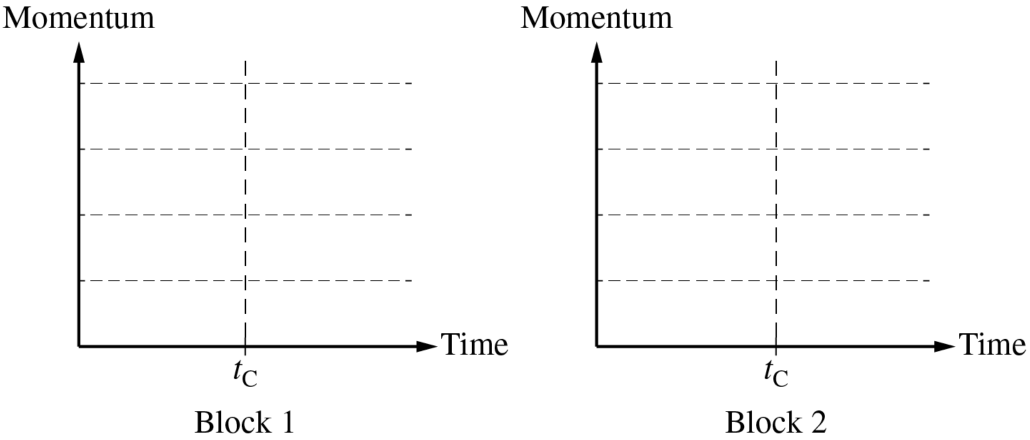
Question 2



Question 2



Question 2



Question 2

2022 Set 2 ▪ Q2

[Figure (top): A spring with spring constant k is attached to a wall on the left, compressed by an amount Δx from its natural length, holding Block 1 (mass m_1). Block 2 (mass m_2) sits at rest at position $x = 0$, to the right of Block 1, in front of a Motion Detector mounted on a wall at the far right.]
[Figure (bottom): After release, the spring is no longer compressed (uncompressed length shown), and the combined Block 1 + Block 2 system moves to the right with speed v, starting from $x = 0$.]

Block 1 of mass m_1 is held at rest while compressing an ideal spring an amount Δx. The spring constant of the spring is k. Block 2 has mass m_2, where $m_2 < m_1$. At time $t = 0$, Block 1 is released. At time t_C, the spring is no longer compressed and Block 1 immediately collides with and sticks to Block 2. The blocks stick together and the two-block system moves with constant speed v, as shown. Frictional effects are negligible.

Question 2

(b) On the following axes, draw graphs of the magnitude of the momentum of each block as a function of time, before and after t_C. The collision occurs in a negligible amount of time. The grid lines on each graph are drawn to the same scale.
[Two blank graphs labeled "Momentum" on the vertical axis and "Time" on the horizontal axis, each with a marked point t_C on the time axis and dashed gridlines; left graph labeled "Block 1", right graph labeled "Block 2", for the student to sketch momentum vs. time before and after t_C.]

Question 2

2022 Set 2 ▪ Q2

[Figure (top): A spring with spring constant k is attached to a wall on the left, compressed by an amount Δx from its natural length, holding Block 1 (mass m_1). Block 2 (mass m_2) sits at rest at position $x = 0$, to the right of Block 1, in front of a Motion Detector mounted on a wall at the far right.]

[Figure (bottom): After release, the spring is no longer compressed (uncompressed length shown), and the combined Block 1 + Block 2 system moves to the right with speed v, starting from $x = 0$.]

Block 1 of mass m_1 is held at rest while compressing an ideal spring an amount Δx. The spring constant of the spring is k. Block 2 has mass m_2, where $m_2 < m_1$. At time $t = 0$, Block 1 is released. At time t_C, the spring is no longer compressed and Block 1 immediately collides with and sticks to Block 2. The blocks stick together and the two-block system moves with constant speed v, as shown. Frictional effects are negligible.

Question 2

(c) Show that the velocity v of the two-block system after the collision is given by the equation $v = \dfrac{\sqrt{km_1}}{m_1 + m_2}\Delta x$.

Question 2

2022 Set 2 ▪ Q2

[Figure (top): A spring with spring constant k is attached to a wall on the left, compressed by an amount Δx from its natural length, holding Block 1 (mass m_1). Block 2 (mass m_2) sits at rest at position $x = 0$, to the right of Block 1, in front of a Motion Detector mounted on a wall at the far right.]
[Figure (bottom): After release, the spring is no longer compressed (uncompressed length shown), and the combined Block 1 + Block 2 system moves to the right with speed v, starting from $x = 0$.]

Block 1 of mass m_1 is held at rest while compressing an ideal spring an amount Δx. The spring constant of the spring is k. Block 2 has mass m_2, where $m_2 < m_1$. At time $t = 0$, Block 1 is released. At time t_C, the spring is no longer compressed and Block 1 immediately collides with and sticks to Block 2. The blocks stick together and the two-block system moves with constant speed v, as shown. Frictional effects are negligible.

Question 2

(d)(i) A group of students use the setup to perform an experiment. They measure the mass of Block 1 to be $m_1 = 0.500$ kg, and the spring constant k of the spring to be 150 N/m. The mass of Block 2 is unknown. They perform several trials and in each trial the spring is compressed a different distance Δx and the final velocity v of the two-block system is measured. They graph v as a function of Δx, as shown below. Draw a line that represents the best fit to the data points shown.
[Scatter plot: vertical axis v (m/s) from 0.0 to 0.7 in increments of 0.1; horizontal axis Δx (m) from 0.0 to 0.07 in increments of 0.01. Data points approximately at $(0.01, 0.08)$, $(0.02, 0.16)$, $(0.035, 0.28)$, $(0.05, 0.45)$, $(0.06, 0.58)$, $(0.065, 0.62)$, for the student to draw a best-fit line through.]
(d)(ii) Use the best-fit line to calculate the mass of Block 2.

Question 2

2022 Set 2 ▪ Q2

[Figure (top): A spring with spring constant k is attached to a wall on the left, compressed by an amount Δx from its natural length, holding Block 1 (mass m_1). Block 2 (mass m_2) sits at rest at position $x = 0$, to the right of Block 1, in front of a Motion Detector mounted on a wall at the far right.]
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Question 2

(e) After the experiment, the students use a balance to measure the mass of Block 2 and find it to be greater than what was determined in part (d). To explain this discrepancy, one of the students proposes that the spring constant was incorrectly measured at the beginning of the experiment. The students measure the spring constant again and record a new value, k'.

Should the students expect that k' be greater than 150 N/m, less than 150 N/m, or equal to 150 N/m ?

k' $>$ 150 N/m k' $<$ 150 N/m k' $=$ 150 N/m

Justify your answer.

Solution 2

(a) Mark scheme

- Answer: $J_S > J_2$ — select this choice with an attempt at a relevant justification (1 point), plus a fully correct justification (1 point). Example justification: By Newton's third law, the impulse Block 2 exerts on Block 1 during the collision has the same magnitude as the impulse Block 1 exerts on Block 2. Since Block 1 is still moving forward (nonzero momentum) after the collision, the impulse from the spring J_S (which accelerated Block 1 from rest up to its pre-collision speed) must be greater in magnitude than the impulse J_2 from the collision (which only reduces, not zeroes, Block 1's momentum).

Solution 2

(b) Mark scheme

- Full-credit sketch, 1 point per criterion: (1) For $0 < t < t_C$: Block 1's momentum rises along a concave-down (decreasing-slope) curve up to its maximum at $t = t_C$, while Block 2's momentum stays at zero (flat on the time axis) throughout. (2) For $t > t_C$: Block 1's momentum is a horizontal line at a value smaller in magnitude than its momentum at $t = t_C$ (it lost momentum in the collision). (3) For $t > t_C$: Block 2's momentum is a horizontal line at a value smaller in magnitude than Block 1's momentum at $t = t_C$ (Block 2 now moves, but with less momentum than Block 1 had just before the collision). (4) Blocks 1 and 2 have an equal-magnitude change in momentum at t_C — Block 1's drop equals Block 2's rise (momentum conservation in the collision).

Solution 2

(c) Mark scheme

- Use conservation of energy (spring PE converts to KE of Block 1) to find Block 1's speed at $x = 0$ — 1 point: $\frac{1}{2}k(\Delta x)^2 = \frac{1}{2}m_1 v_1^2 \Rightarrow v_1 = \sqrt{\frac{k}{m_1}}\Delta x$. Use conservation of momentum for the perfectly inelastic collision to find the speed of the combined two-block system — 1 point: $m_1 v_1 = (m_1 + m_2)v \Rightarrow v = \dfrac{m_1 v_1}{m_1 + m_2}$. Combine the two equations — 1 point: $v = \dfrac{\Delta x\sqrt{km_1}}{m_1 + m_2}$, as required to show.

Solution 2

(d)(i)

Mark scheme

- Draw a straight best-fit line through the plotted v vs. Δx data, with approximately the same number of data points above the line as below it (need not pass exactly through any single point). 1 point for a reasonable best-fit line satisfying this balance criterion.

Solution 2

(d)(ii) Mark scheme

- Calculate the slope of the best-fit line using two well-separated points on it — 1 point, e.g. slope $= \dfrac{(0.60 - 0.02)\ \mathrm{m/s}}{(0.055 - 0.0175)\ \mathrm{m}} \approx 10.67\ \mathrm{s}^{-1}$. Correctly relate the slope to m_2 using the part (c) result $v = \dfrac{\sqrt{km_1}}{m_1 + m_2}\Delta x$ — 1 point: slope $= \dfrac{\sqrt{km_1}}{m_1 + m_2} \Rightarrow m_2 = \dfrac{\sqrt{km_1}}{\text{slope}} - m_1$. Compute a correct numeric mass — 1 point: $m_2 = \dfrac{\sqrt{(150\ \mathrm{N/m})(0.500\ \mathrm{kg})}}{10.67\ \mathrm{s}^{-1}} - 0.500\ \mathrm{kg} \approx 0.31\ \mathrm{kg}$ (acceptable range $0.27\ \mathrm{kg}$ to $0.37\ \mathrm{kg}$, since it depends on the student's own graph read).

Solution 2

(e) Mark scheme

- Answer: $k' > 150$ N/m — select this choice with an attempt at relevant justification (1 point), plus a fully correct justification (1 point). Example justification: A balance shows the true mass of Block 2 is greater than the value determined in part (d). From slope $= \dfrac{\sqrt{k' m_1}}{m_1 + m_2}$, the measured slope of the graph (an experimental result) stays the same, so for a larger true m_2 the spring constant k' needed to keep that same slope must be greater than the originally assumed 150 N/m.

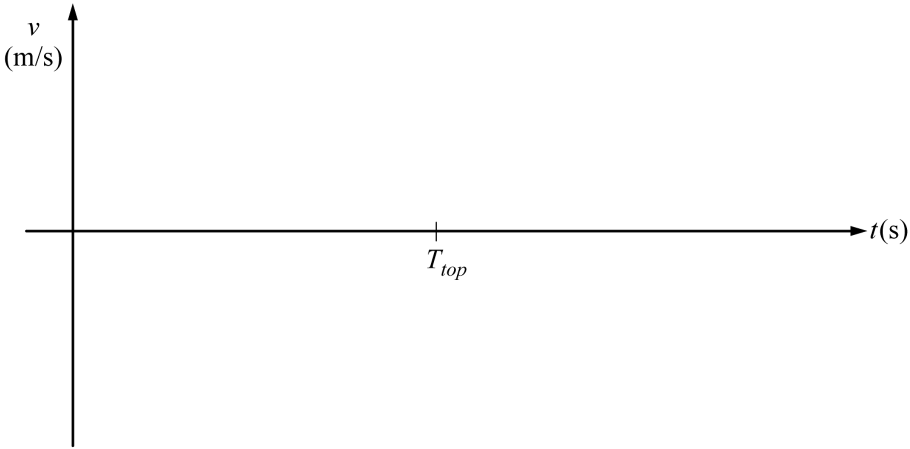
Question 2

2019 Set 2 ▪ Q2

A toy rocket of mass 0.50 kg starts from rest on the ground and is launched upward, experiencing a vertical net force. The rocket's upward acceleration a for the first 6 seconds is given by the equation $a = K - Lt^2$, where $K = 9.0$ m/s^2, $L = 0.25$ m/s^4, and t is the time in seconds. At $t = 6.0$ s, the fuel is exhausted and the rocket is under the influence of gravity alone. Assume air resistance and the rocket's change in mass are negligible.

(a) Calculate the magnitude of the net impulse exerted on the rocket from $t = 0$ to $t = 6.0$ s.

Question 2



Question 2

2019 Set 2 ▪ Q2

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(b) Calculate the speed of the rocket at $t = 6.0$ s.

Question 2

2019 Set 2 ▪ Q2

A toy rocket of mass 0.50 kg starts from rest on the ground and is launched upward, experiencing a vertical net force. The rocket's upward acceleration a for the first 6 seconds is given by the equation $a = K - Lt^2$, where $K = 9.0 \text{ m/s}^2$, $L = 0.25 \text{ m/s}^4$, and t is the time in seconds. At $t = 6.0$ s, the fuel is exhausted and the rocket is under the influence of gravity alone. Assume air resistance and the rocket's change in mass are negligible.

(c)(i) Calculate the kinetic energy of the rocket at $t = 6.0$ s.

(c)(ii) Calculate the change in gravitational potential energy of the rocket-Earth system from $t = 0$ to $t = 6.0$ s.

Question 2

2019 Set 2 ▪ Q2

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(d) Calculate the maximum height reached by the rocket relative to its launching point.

Question 2

2019 Set 2 ▪ Q2

A toy rocket of mass 0.50 kg starts from rest on the ground and is launched upward, experiencing a vertical net force. The rocket's upward acceleration a for the first 6 seconds is given by the equation $a = K - Lt^2$, where $K = 9.0\ \text{m/s}^2$, $L = 0.25\ \text{m/s}^4$, and t is the time in seconds. At $t = 6.0$ s, the fuel is exhausted and the rocket is under the influence of gravity alone. Assume air resistance and the rocket's change in mass are negligible.

(e) On the axes below, assuming the upward direction to be positive, sketch a graph of the velocity v of the rocket as a function of time t from the time the rocket is launched to the time it returns to the ground. T_{top} represents the time the rocket reaches its maximum height. Explicitly label the maxima with numerical values or algebraic expressions, as appropriate.

Question 2

[Graph axes: vertical axis labeled v (m/s), horizontal axis labeled t(s); the origin is at the intersection, with a tick mark labeled T_{top} on the horizontal axis to the right of the origin. The axes are otherwise unscaled and blank for the student to sketch on.]

Solution 2

(a)

Mark scheme

- $J = \int F(t)\,dt = \int ma(t)\,dt = (0.50)\int_0^6 (9.0 - 0.25t^2)\,dt$ (1 pt for the correct expression and substitution of $a(t)$ and m). Integrating with the correct limits: $J = (0.50)\left[9.0t - \frac{1}{12}t^3\right]_0^6 = (0.50)\left[(9.0)(6) - \frac{1}{12}(6)^3\right] = (0.50)(54 - 18)$ (1 pt for correct integration/limits). Final answer: $J = 18\ \mathrm{N}\cdot\mathrm{s}$.

Solution 2

(b)

Mark scheme

- Relate impulse to the change in momentum: $J = \Delta p = m(v_2 - v_1)$ (1 pt for correctly relating impulse to speed). Substitute $J = 18$ N $\cdot$ s from part (a): $(18$ N $\cdot$ s$) = (0.50$ kg$)(v_2 - 0)$ (1 pt for correct substitution), giving $v_2 = 36$ m/s.

Solution 2

(c)(i)

Mark scheme

- $K = \frac{1}{2}mv^2$. Substitute the mass of the rocket (1 pt) and the speed $v = 36$ m/s found in part (b) (1 pt): $K = \frac{1}{2}(0.50\text{ kg})(36\text{ m/s})^2 = 324$ J.

Solution 2

(c)(ii)

Mark scheme

- Integrate the acceleration twice to obtain position. First: $v(t) = \int a(t)\,dt = \int (9.0 - 0.25t^2)\,dt = 9.0t - \frac{1}{12}t^3 + v_0 = 9.0t - \frac{1}{12}t^3$ (1 pt for integrating with correct limits/constant of integration, since $v_0 = 0$). Then integrate again: $\Delta y = \int_0^6 v(t)\,dt = \left[\frac{9}{2}t^2 - \frac{1}{48}t^4\right]_0^6 = \frac{9}{2}(36) - \frac{1}{48}(1296) = 135$ m (1 pt for the second integration with correct limits). Substitute into $\Delta U_g = mg\Delta y = (0.50\text{ kg})(9.8\text{ m/s}^2)(135\text{ m}) \approx 660$ J (1 pt for substituting into the potential-energy equation).

Solution 2

(d) Mark scheme

- Use $v_2^2 = v_1^2 + 2a(y_2 - y_1)$ with $a = g = -9.8\ \mathrm{m/s^2}$ after burnout and $v_2 = 0$ at maximum height: $y_2 - y_1 = -\frac{v_1^2}{2a}$ (1 pt for using $a = g$ in a correct kinematics equation). Substitute the speed $v_1 = 36\ \mathrm{m/s}$ from part (b) (1 pt): $y_2 - y_1 = -\frac{(36\ \mathrm{m/s})^2}{2(-9.8\ \mathrm{m/s^2})} \approx 66\ \mathrm{m}$. Add the height already gained by $t = 6.0$ s, $\Delta y = 135\ \mathrm{m}$ from part (c)(ii) (1 pt for substituting the height from part (c)): $y_2 = 66\ \mathrm{m} + 135\ \mathrm{m} = 201\ \mathrm{m}$ (199.8 m if $g = 10\ \mathrm{m/s^2}$). [Equivalent alternate solutions using energy conservation, $mg\Delta y = \frac{1}{2}mv^2$, or $K_1 + U_1 = U_{top}$ with parts (c)(i)/(c)(ii): $324 + 660 = (0.5)(9.8)\Delta y$, also earn full credit.]

Solution 2

(e) Mark scheme

- Sketch: for $0 \leq t \leq 6.0$ s, an initial concave-down curve starting at the origin $(0, 0)$ that rises to a maximum of $v = 36$ m/s at $t = 6.0$ s (1 pt, for an initial concave-down curve starting at the origin, consistent with the decreasing-but-positive acceleration $a = 9.0 - 0.25t^2$). The curve then transitions, before T_{top}, into a straight line with constant negative slope $-g$ (1 pt, for a transition before T_{top} into a straight line of negative slope). Label the maximum value 36 m/s (consistent with part (b)) with the line crossing the time axis exactly at $t = T_{top}$, continuing to negative v as the rocket falls back to the ground (1 pt, for labeling the maximum consistent with part (b) and crossing the axis at T_{top}).

Question 2

2018 ▪ Q2

Two carts are on a horizontal, level track of negligible friction. Cart 1 has a sensor that measures the force exerted on it during a collision with cart 2, which has a spring attached. Cart 1 is moving with a speed of $v_0 = 3.00$ m/s toward cart 2, which is at rest, as shown in the figure above. The total mass of cart 1 and the force sensor is 0.500 kg, the mass of cart 2 is 1.05 kg, and the spring has negligible mass. The spring has a spring constant of $k = 130$ N/m. The data for the force the spring exerts on cart 1 are shown in the graph below. A student models the data as the quadratic fit $F = \left(3200\ \text{N/s}^2\right) t^2 - (500\ \text{N/s})t$.

[Diagram: Cart 1 (mass $m = 0.500$ kg) with a Force Sensor attached at its right side, moving right with $v_0 = 3.00$ m/s toward a spring ($k = 130$ N/m) connected to Cart 2 (mass $m = 1.05$ kg, initially at rest, $v = 0$), all on a horizontal track.]

Question 2

[Graph: Force F (N) on the vertical axis (marked at 5, 0, -5, -10, -15, -20, -25) versus time t (s) on the horizontal axis (marked 0.02, 0.04, 0.06, 0.08, 0.10, 0.12, 0.14, 0.16, 0.18). Data points start near $F = 0$ at small t, dip down to a minimum of about -20 N around $t = 0.08$–0.10 s, then rise back up toward $F = 0$ by about $t = 0.16$–0.18 s, tracing a roughly parabolic (U-shaped, inverted) curve consistent with the quadratic fit given.]

(a) Using integral calculus, calculate the total impulse delivered to cart 1 during the collision.

(b)(i) Calculate the speed of cart 1 after the collision.

(b)(ii) In which direction does cart 1 move after the collision?

______ Left ______ Right

______ The direction is undefined, because the speed of cart 1 is zero after the collision.

(c)(i) Calculate the speed of cart 2 after the collision.

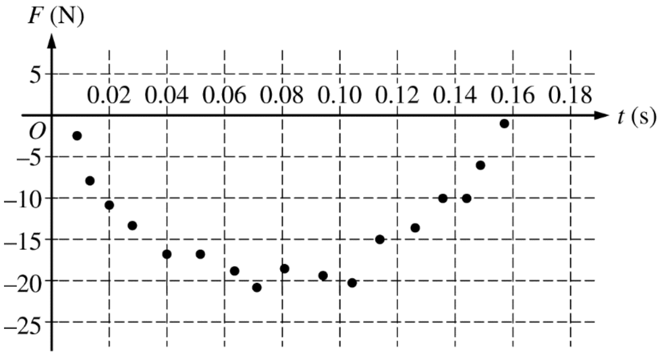
Question 2

(c)(ii) Show that the collision between the two carts is elastic.
(d)(i) Calculate the speed of the center of mass of the two-cart-spring system.
(d)(ii) Calculate the maximum elastic potential energy stored in the spring.

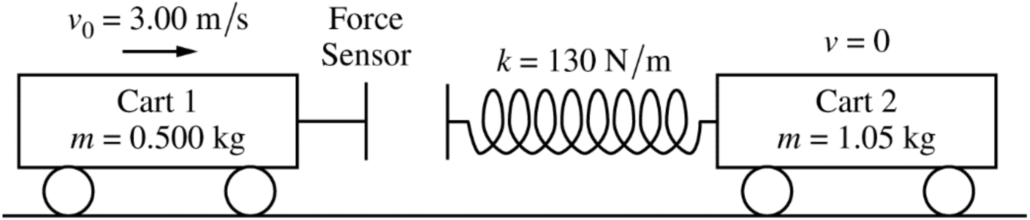
Question 2

a spring constant of $k = 130$ N/m. The data for the force the spring exerts on cart 1 are sho

below. A student models the data as the quadratic fit $F = \left(3200\ \text{N/s}^2\right)t^2 - (500\ \text{N/s})t$.



Question 2



Solution 2

(a)

Mark scheme

- $J = \int F\,dt = \int_0^{0.16} (3200t^2 - 500t)\,dt = \left[\frac{3200}{3}t^3 - 250t^2\right]_0^{0.16} = \frac{3200}{3}(0.16)^3 - 250(0.16)^2 = -2.03$ N·s. 1 point for using the given force equation in the impulse integral; 1 point for integrating with correct limits (or constant of integration); 1 point for the correct final numeric answer $J = -2.03$ N·s.

Solution 2

(b)(i)

Mark scheme

- $J = m_1(v_{1f} - v_{1i}) \;\Rightarrow\; v_{1f} = \dfrac{J}{m_1} + v_{1i} = \dfrac{-2.03\ \mathrm{N \cdot s}}{0.500\ \mathrm{kg}} + 3.00\ \mathrm{m/s} = -1.06\ \mathrm{m/s}.$

Solution 2

(b)(ii)

Mark scheme

- Left. Since $v_{1f} = -1.06$ m/s is negative (opposite the original direction of motion), cart 1 moves to the left after the collision.

Solution 2

(c)(i) Mark scheme

- By Newton's third law on the spring force, $-J = -m_1(v_{1f} - v_{1i}) = m_2 v_{2f} \;\Rightarrow\; v_{2f} = \dfrac{-J}{m_2} = \dfrac{2.03\ \text{N}\cdot\text{s}}{1.05\ \text{kg}} = 1.93$ m/s. (Equivalent alternate via momentum conservation: $m_1 v_{1i} = m_1 v_{1f} + m_2 v_{2f} \Rightarrow v_{2f} = \dfrac{m_1(v_{1i} - v_{1f})}{m_2} = \dfrac{(0.500)(3.00 - (-1.06))}{1.05} = 1.93$ m/s.) 1 point for a correct equation to find v_{2f}; 1 point for correct substitution.

Solution 2

(c)(ii)

Mark scheme

- An elastic collision requires initial KE = final KE: $K_{ii} = K_{1f} + K_{2f}$. Check: $\frac{1}{2}(0.500)(3.00)^2 = \frac{1}{2}(0.500)(-1.06)^2 + \frac{1}{2}(1.05)(1.93)^2 \Rightarrow 2.25\ \mathrm{J} \approx 2.24\ \mathrm{J}$ — equal within rounding, so the collision is elastic. 1 point for indicating that initial and final kinetic energies must be equal; 1 point for correct substitution/numeric verification.

Solution 2

(d)(i)

Mark scheme

- $m_1 v_{1i} = (m_1 + m_2) v_{cm} \;\Rightarrow\; v_{cm} = \dfrac{m_1 v_{1i}}{m_1 + m_2} = \dfrac{(0.500 \text{ kg})(3.00 \text{ m/s})}{0.500 \text{ kg} + 1.05 \text{ kg}} = 0.97$ m/s. 1 point for the correct equation for the center-of-mass speed; 1 point for correct substitution.

Solution 2

(d)(ii) Mark scheme

- Using conservation of energy: $K_i = K_f + U_{Sf} \Rightarrow U_{Sf} = \frac{1}{2}m_1 v_{1i}^2 - \frac{1}{2}(m_1 + m_2)v_{cm}^2 = \frac{1}{2}(0.500)(3.00)^2 - \frac{1}{2}(1.55)(0.97)^2 = 1.52$ J. (Alternate: from $dF/dt = 0$, $t = 0.078$ s gives $|F_{max}| = 19.5$ N (accept 20-21 N from the graph); $x_{max} = F_{max}/k = 0.15$ m (accept 0.15-0.16 m); $U_S = \frac{1}{2}kx_{max}^2 = 1.46$ J, accept 1.46-1.70 J if estimated from the graph.) Scoring: 1 point for using conservation of energy to find the max elastic PE; 1 point for using the center-of-mass speed for the system's translational KE; 1 point for correct substitution/final numeric answer. Q2 also carries an overall 1-point "units" credit (correct units on all calculated answers through the question) — folded into this final part so Q2's 15 points are fully accounted for.

Question 1

2014 ▪ Q1

[Figure: A horizontal track marked in centimeters from 0 to 120 cm. A cart with a spring attached to the left end of the track sits near the 0 cm mark, with two wheels shown. Five vertical photogates labelled 1, 2, 3, 4, 5 are mounted on the track at positions 20 cm, 40 cm, 60 cm, 80 cm, and 100 cm respectively, labelled "Photogates" above.]

In an experiment, a student wishes to use a spring to accelerate a cart along a horizontal, level track. The spring is attached to the left end of the track, as shown in the figure above, and produces a nonlinear restoring force of magnitude $F_s = As^2 + Bs$, where s is the distance the spring is compressed, in meters. A measuring tape, marked in centimeters, is attached to the side of the track. The student places five photogates on the track at the locations shown.

Question 1

(a) Derive an expression for the potential energy U as a function of the compression s. Express your answer in terms of A, B, s, and fundamental constants, as appropriate.

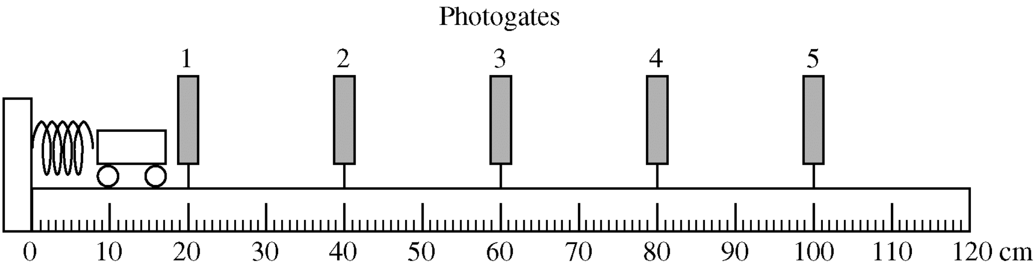
Question 1

Question 1

the spring, compressing the spring the calculated distance, and releasing the cart. The speeds are measured with a precision of ± 0.002 m/s. The positions are measured with a precision of ± 0.005 m.

Photogate	1	2	3	4	5
Cart speed (m/s)	0.412	0.407	0.399	0.374	0.338
Photogate position (m)	0.20	0.40	0.60	0.80	1.00

Question 1



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[Figure: A horizontal track marked in centimeters from 0 to 120 cm. A cart with a spring attached to the left end of the track sits near the 0 cm mark, with two wheels shown. Five vertical photogates labelled 1, 2, 3, 4, 5 are mounted on the track at positions 20 cm, 40 cm, 60 cm, 80 cm, and 100 cm respectively, labelled "Photogates" above.]

In an experiment, a student wishes to use a spring to accelerate a cart along a horizontal, level track. The spring is attached to the left end of the track, as shown in the figure above, and produces a nonlinear restoring force of magnitude $F_s = As^2 + Bs$, where s is the distance the spring is compressed, in meters. A measuring tape, marked in centimeters, is attached to the side of the track. The student places five photogates on the track at the locations shown.

(b)(i) In a preliminary experiment, the student pushes the cart of mass 0.30 kg into the spring, compressing the spring 0.040 m. For this spring, $A = 200\ \mathrm{N/m^2}$ and

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$B = 150$ N/m. The cart is released from rest. Assume friction and air resistance are negligible only during the short time interval when the spring is accelerating the cart. Calculate the following: The speed of the cart immediately after it loses contact with the spring

(b)(ii) Calculate the following: The impulse given to the cart by the spring

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(c) In a second experiment, the student collects data using the photogates. Each photogate measures the speed of the cart as it passes through the gate. The student calculates a spring compression that should give the cart a speed of 0.320 m/s after

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the cart loses contact with the spring. The student runs the experiment by pushing the cart into the spring, compressing the spring the calculated distance, and releasing the cart. The speeds are measured with a precision of ± 0.002 m/s. The positions are measured with a precision of ± 0.005 m.
| Photogate | 1 | 2 | 3 | 4 | 5 | |—|—|—|—|—|—| | Cart speed (m/s) | 0.412 | 0.407 | 0.399 | 0.374 | 0.338 | | Photogate position (m) | 0.20 | 0.40 | 0.60 | 0.80 | 1.00 |
On the axes below, plot the data points for the speed *v* of the cart as a function of position *x*. Clearly scale and label all axes, as appropriate.
[Blank grid of axes for plotting speed *v* vs. position *x*, ruled in a 4x4 arrangement of major squares each subdivided into a 5x5 fine grid, no pre-printed scale numbers or labels.]

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[Figure: A horizontal track marked in centimeters from 0 to 120 cm. A cart with a spring attached to the left end of the track sits near the 0 cm mark, with two wheels shown. Five vertical photogates labelled 1, 2, 3, 4, 5 are mounted on the track at positions 20 cm, 40 cm, 60 cm, 80 cm, and 100 cm respectively, labelled "Photogates" above.]

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(d)(i) Compare the speed of the cart measured by photogate 1 to the predicted value of the speed of the cart just after it loses contact with the spring. List a physical source of error that could account for the difference.

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(d)(ii) From the measured speed values of the cart as it rolls down the track, give a physical explanation for any trend you observe.