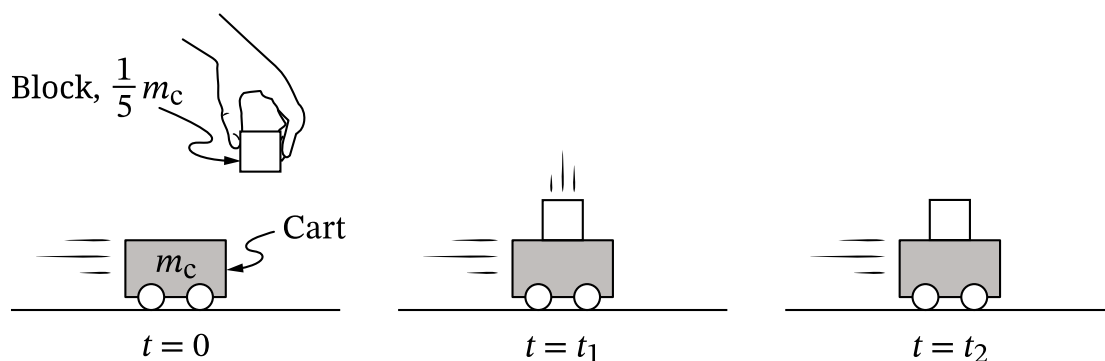


Question 1: Version J

1. A student has a cart of mass m_c and a block of mass $\frac{1}{5}m_c$, as shown in Figure 1.

- At time $t = 0$, the cart is moving to the right across a horizontal surface with constant speed v_c , and the student releases the block from rest.
- At $t = t_1$, the block collides with and sticks to the top of the cart. The block does not slide on the cart.
- At $t = t_2$, the block-cart system continues to move to the right with constant speed v_f .

Figure 1



A.

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

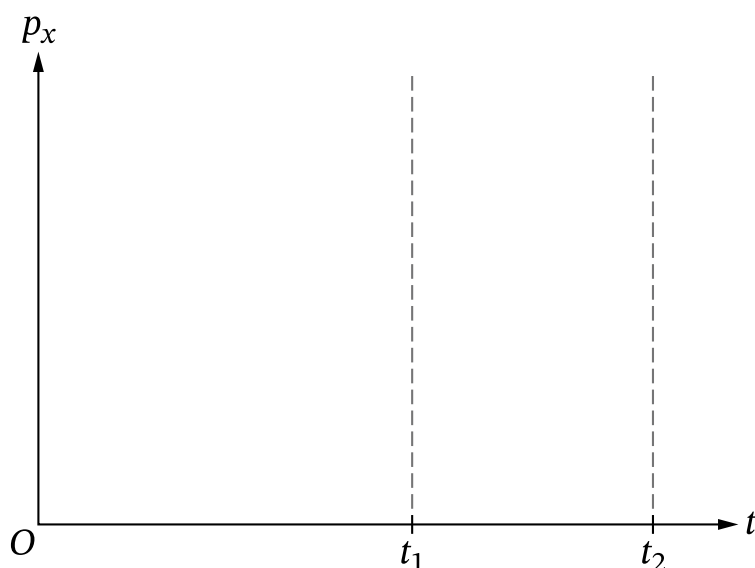


Figure 2

- ii. **Derive** an expression for the speed v_f of the block-cart system after time $t = t_2$ in terms of m_c , v_c , and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.
- iii. **Derive** an expression for the change in the kinetic energy ΔK in the block-cart system from $t = 0$ to $t = t_2$ in terms of m_c , v_c , and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.
- B.** Consider the case where a new block is dropped and collides with the top of the cart. The new block slides along the cart during the collision but does not slide off the cart. The time interval from when the new block collides with the cart and moves together with the cart is Δt . During Δt there is a frictional force between the new block and the cart.
- Indicate** whether the x -component of the momentum of the new block-cart system increases, decreases, or remains constant during Δt .

_____ Increases

_____ Decreases

_____ Remains constant

Justify your response.

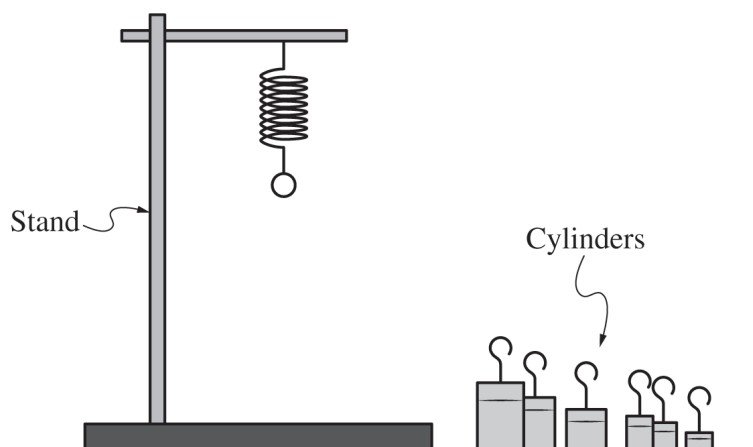
Begin your response to **QUESTION 2** on this page.

Figure 1

2. (12 points, suggested time 25 minutes)

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.

(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 of the setup with your procedure.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 2** on this page.

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

- (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: _____
- ii. Briefly **describe** how the slope of the graph would be analyzed to determine the spring constant k of the spring.

GO ON TO THE NEXT PAGE.

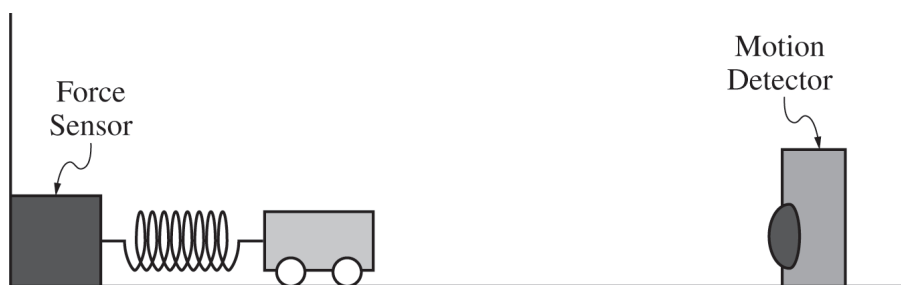
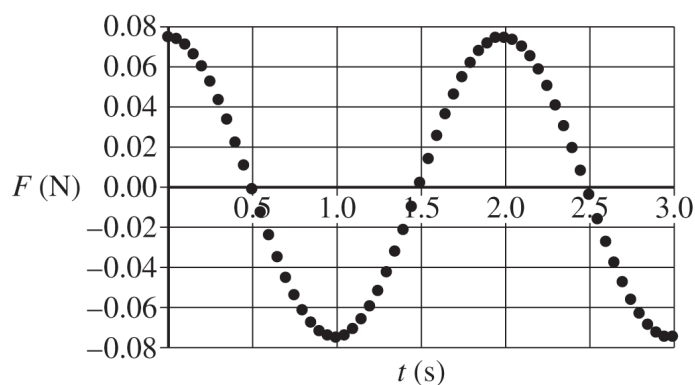
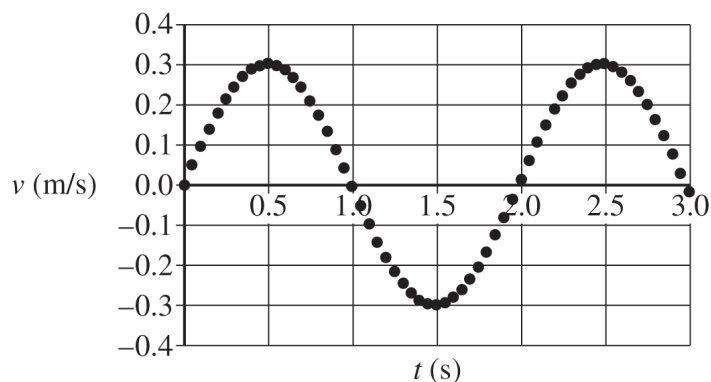
Continue your response to **QUESTION 2** on this page.

Figure 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 .

**GO ON TO THE NEXT PAGE.**

Continue your response to **QUESTION 2** on this page.

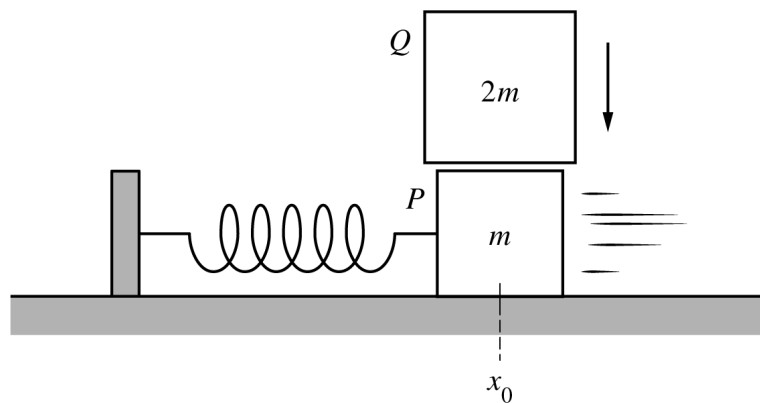
(c)

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.

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.

iii. Do the data from the velocity-time graph confirm your estimation from part (c)(ii) ? Briefly **explain**.

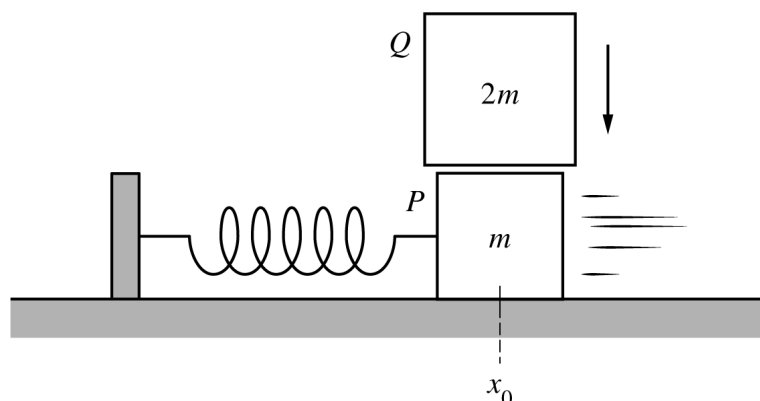
GO ON TO THE NEXT PAGE.



5. (7 points, suggested time 13 minutes)

Block P of mass m is on a horizontal, frictionless surface and is attached to a spring with spring constant k . The block is oscillating with period T_P and amplitude A_P about the spring's equilibrium position x_0 . A second block Q of mass $2m$ is then dropped from rest and lands on block P at the instant it passes through the equilibrium position, as shown above. Block Q immediately sticks to the top of block P , and the two-block system oscillates with period T_{PQ} and amplitude A_{PQ} .

(a) Determine the numerical value of the ratio T_{PQ}/T_P .



(b) The figure is reproduced above. How does the amplitude of oscillation A_{PQ} of the two-block system compare with the original amplitude A_P of block P alone?

_____ $A_{PQ} < A_P$ _____ $A_{PQ} = A_P$ _____ $A_{PQ} > A_P$

In a clear, coherent paragraph-length response that may also contain diagrams and/or equations, explain your reasoning.

STOP

END OF EXAM