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

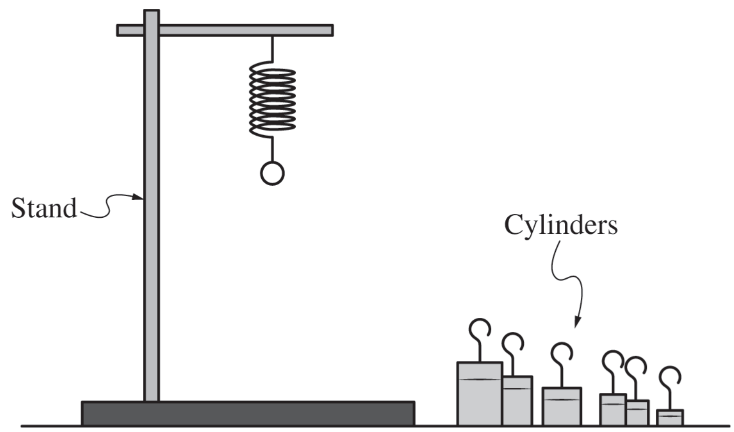

Figure 1

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.

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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.

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

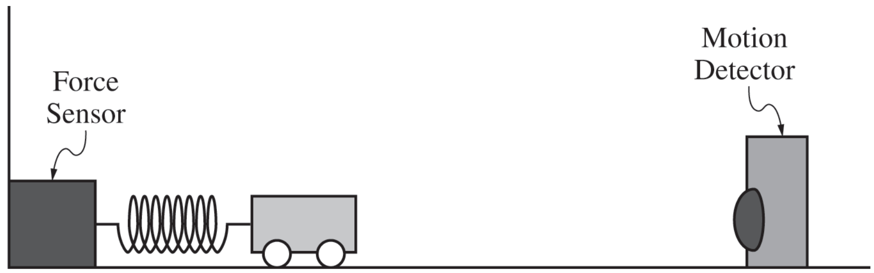
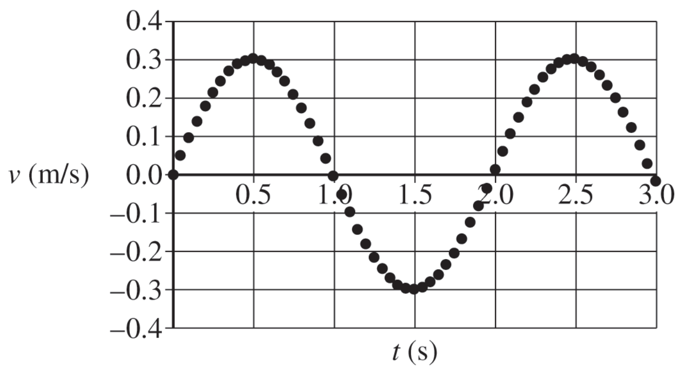
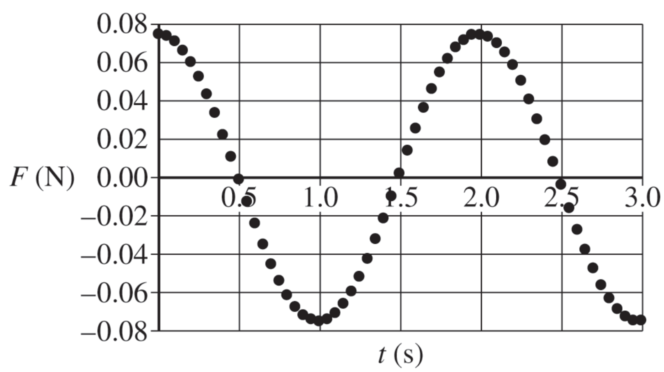


Figure 2

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.





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(c)

i. Using the data in the velocity-time graph, **calculate** the change in kinetic energy of the cart from $t = 0.5\text{ s}$ to $t = 2.0\text{ s}$. Show your steps and substitutions.

ii. Using the data in the force-time graph, **estimate** the change in momentum of the cart from $t = 0.5\text{ s}$ to $t = 2.5\text{ s}$. 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**.

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Question 2: Experimental Design — 12 points

(a) For measuring the mass of at least one cylinder with the digital scale — **1 point**

For measuring the period of oscillation of the cylinder-spring system with the stopwatch — **1 point**

For a procedure that indicates that the cylinder hung on the spring should be set into oscillatory motion — **1 point**

For a procedure that indicates a method to reduce experimental uncertainty — **1 point**

Accept **one** of the following:

- For using multiple masses
- For doing multiple trials with a single mass
- For measuring multiple oscillations and dividing by the number of oscillations

Example Response

Place a cylinder on the digital scale and record the mass. Hang the cylinder from the spring and pull the cylinder down a small distance so that the spring is stretched. Release the cylinder. Use the stopwatch to measure the amount of time necessary for the cylinder to complete ten full cycles (from maximum stretch length back to maximum stretch length). Repeat the procedure for cylinders of different masses.

Total for part (a) — 4 points

(c)(i)	For using the kinetic energy equation $K = \frac{1}{2}mv^2$	**1 point**
	For substituting **one** of the following: • 0.25 kg as the mass • 0.3 m/s as the initial velocity	**1 point**
	For an answer that approximates the change in kinetic energy to be $\Delta K \approx -0.0113\text{ J}$ **Scoring Note:** A correct response with no supporting work earns this point only. **Scoring Note:** The unit and the negative sign are not required to earn this point.	**1 point**

Example Response

$$\Delta K = K_f - K_i$$
$$\Delta K = \frac{1}{2}mv_f{}^2 - \frac{1}{2}mv_i{}^2$$
$$\Delta K = \frac{1}{2}0.25(0)^2 - \frac{1}{2}0.25(0.3)^2$$
$$\Delta K = -0.0113\text{ J}$$

(c)(ii)	For indicating the magnitude of the change in momentum is zero	**1 point**
	For indicating the area under the force-time graph represents the value of the change in momentum	**1 point**

Example Response

The area under the curve for a force vs time graph represents the impulse or change in momentum. The area under the curve for 0.5 s *to* 2.5 s *is zero.*

(c)(iii)	For an explanation that compares the estimated value of the change in momentum from (c)(ii) to the data from the velocity-time graph	**1 point**

Example Response

The velocity-time graph shows that velocity is 0.3 m/s *at both* 0.5 s *and* 2.5 s*, and momentum is mass times velocity, so the momentum is the same at both times. This agrees with my estimation from part (c)(ii) that the change in momentum is zero.*

Total for part (c) **6 points**

Total for question 2 **12 points**