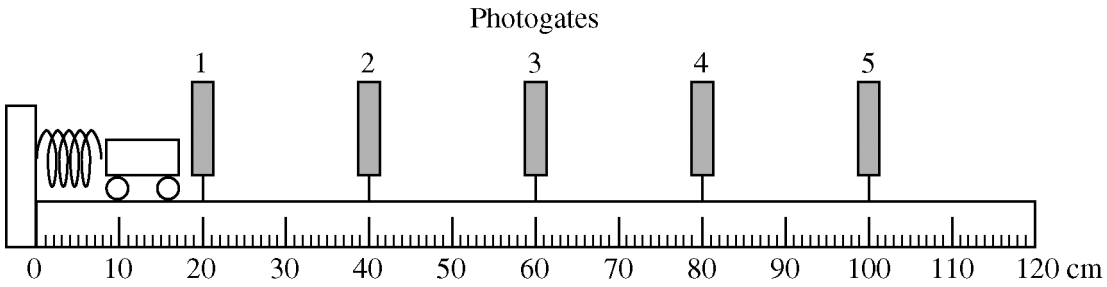
PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



Mech. 1.

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.

(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.

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, $A = 200\ \text{N/m}^2$ and $B = 150\ \text{N/m}$. 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.

(b) Calculate the following:

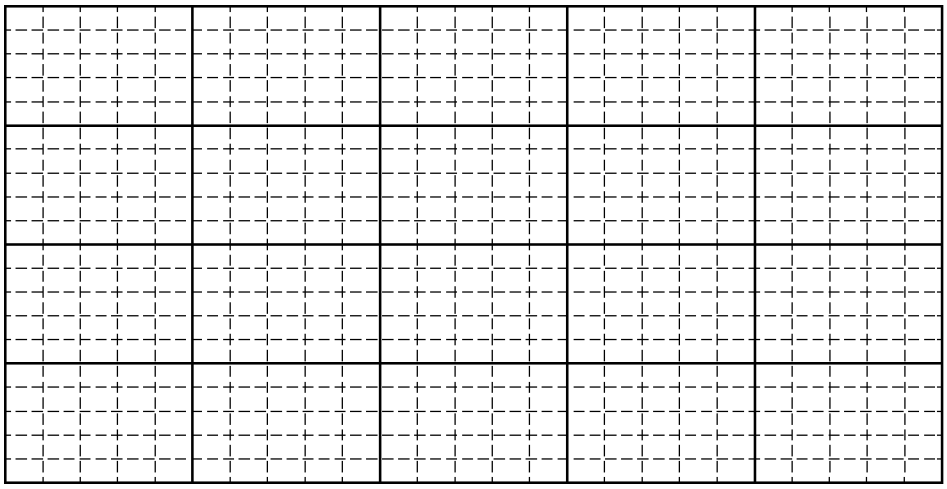
i. The speed of the cart immediately after it loses contact with the spring

ii. The impulse given to the cart by the spring

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 $0.320\ \text{m/s}$ after 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 $\pm 0.002\ \text{m/s}$. 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

(c) 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.



(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.

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

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Question 1

15 points total **Distribution of points**

(a) 2 points

For using a correct expression for the potential energy of a spring expressed as the integral of the force 1 point

$U_S = \int F(x)dx$

$U_S = \int_0^s \left(Ax^2 + Bx\right)dx$

Evaluate the definite integral to get an answer with the correct magnitude.

$U_S = \left[\frac{1}{3}Ax^3 + \frac{1}{2}Bx^2\right]_0^s$

For any correct answer with a local minimum at $x = 0$ 1 point

$U_S = \frac{1}{3}As^3 + \frac{1}{2}Bs^2$

Note: Full credit is given for any consistent use of sign, since the guidelines are concerned with the magnitude. Full credit is also given if there is a constant term added to the correct expression.

(b)

i. 3 points

For any statement of conservation of mechanical energy 1 point

$U_S = K$

For using the expression for potential energy from part (a) and a correct expression for kinetic energy 1 point

$\frac{1}{3}As^3 + \frac{1}{2}Bs^2 = \frac{1}{2}mv^2$

Solve for v^2

$v^2 = 2\left(\frac{1}{3}As^3 + \frac{1}{2}Bs^2\right)\Big/m$

For correct substitution 1 point

$v^2 = 2\left(\left(\frac{1}{3}\right)\left(200\,\text{N/m}^2\right)(0.040\text{ m})^3 + \left(\frac{1}{2}\right)(150\,\text{N/m})(0.040\text{ m})^2\right)\Big/(0.30\text{ kg})$

$v^2 = 0.828\ \text{m}^2/\text{s}^2$

$v = 0.91\ \text{m/s}$

Question 1 (continued)

Distribution of points

(b) continued

ii. 3 points

For using a correct expression for impulse in terms of change in velocity — 1 point

$J = \Delta p = m(v_2 - v_1)$

For substitution of values consistent with the answer in part (b)i — 1 point

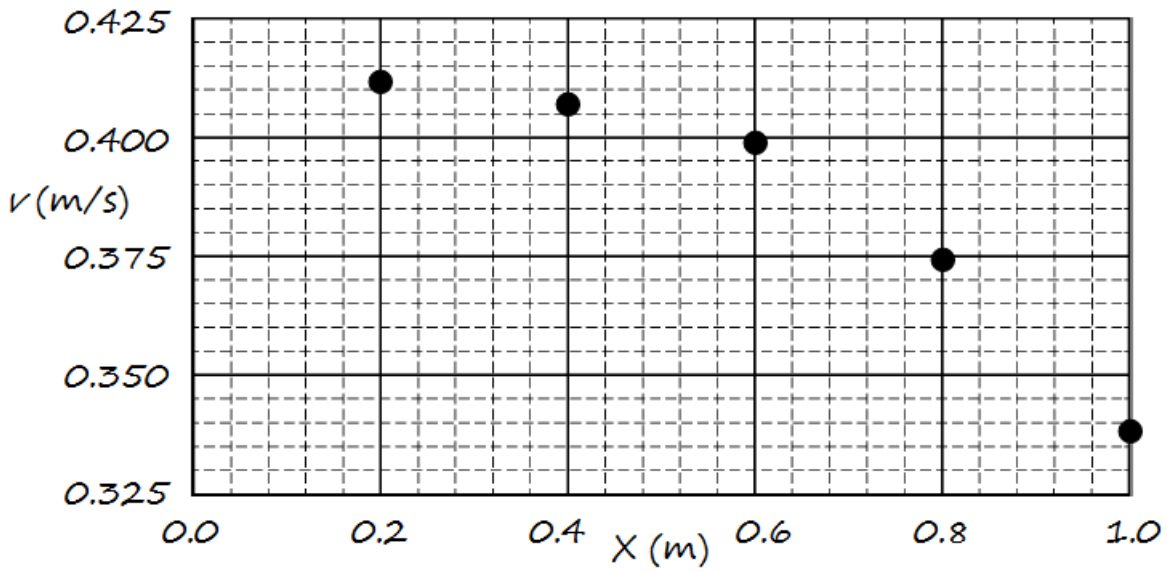
$J = (0.30\ \text{kg})(0.91\ \text{m/s} - 0)$

$J = 0.27\ \text{kg•m/s}$ or N•s

Units 1 point

For correct units in both answers in part (b) — 1 point

(c) 3 points



For correctly labeling both axes with variables and units — 1 point

For correctly scaling both axes with scales that are linear and such that the curvature in the data is apparent — 1 point

For correctly plotting the data points — 1 point

Question 1 (continued)

Distribution of points

(d) i. 2 points

For stating that the measured initial speed of the cart is greater than the predicted value — 1 point

For correctly identifying a source of error regarding the initial speed of the cart — 1 point

Examples:

The student compressed the spring more than was determined. This would lead to more potential energy in the spring and greater kinetic energy for the cart. The cart would therefore move faster than predicted.

The table is not level, sloping downward would result in a greater measured speed.

The constants A and B for the spring are not accurate. The true values are larger than what is given. This would lead to smaller predicted potential energy of the spring and a smaller predicted value for the kinetic energy of the cart. Therefore, the cart would move faster than predicted

ii. 2 points

For correctly identifying the trend — 1 point

For a correct physical explanation for the cart slowing down — 1 point

Examples:

Friction in the axles and air resistance against the cart are slowing it down.

The track is not perfectly level and the cart is going uphill. This is slowing down the cart.