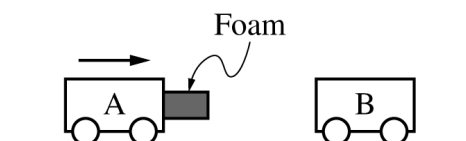


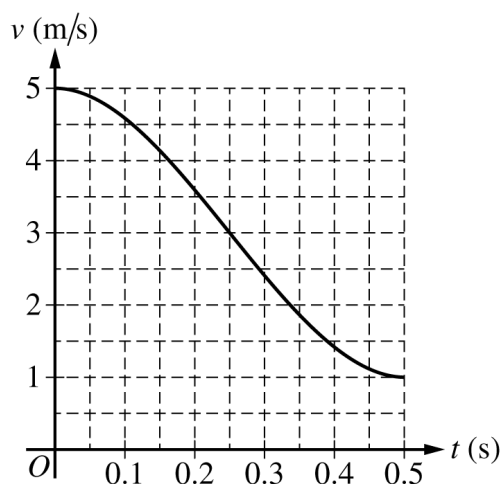
PHYSICS C: MECHANICS**SECTION II****Time—45 minutes****3 Questions**

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.



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.

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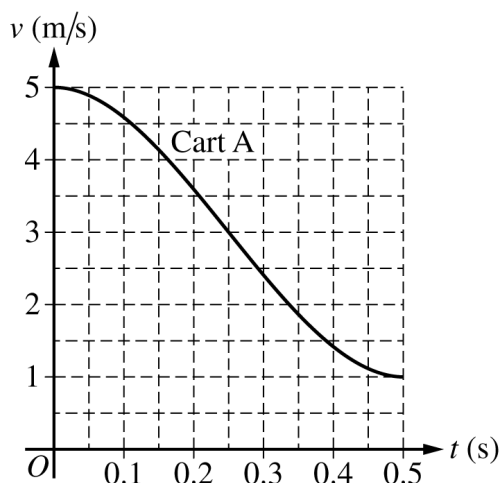
Continue your response to **QUESTION 1** on this page.

(a) 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.

i. What feature(s) of the graph could be used to estimate the displacement of Cart A during the collision?

ii. Using the information shown in the graph, determine the speed of Cart B at $t = 0.5$ s.

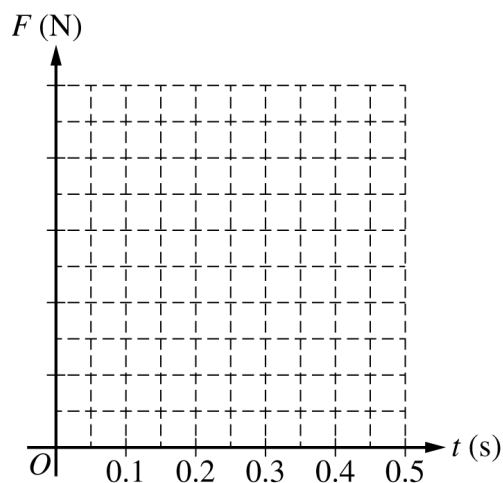
iii. On the following grid, draw a smooth curve of the velocity of Cart B as a function of time.

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

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

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.



GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

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. 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 .

- (c) 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?

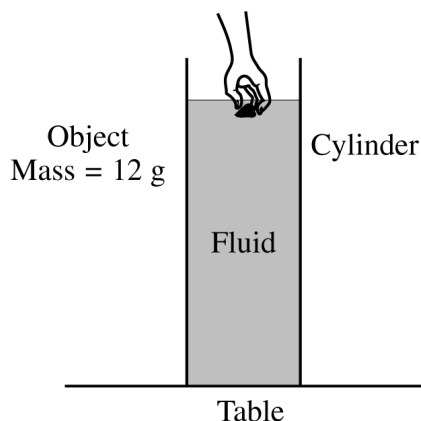
_____ $F_1 > F_2$ _____ $F_1 < F_2$ _____ $F_1 = F_2$

Justify your answer.

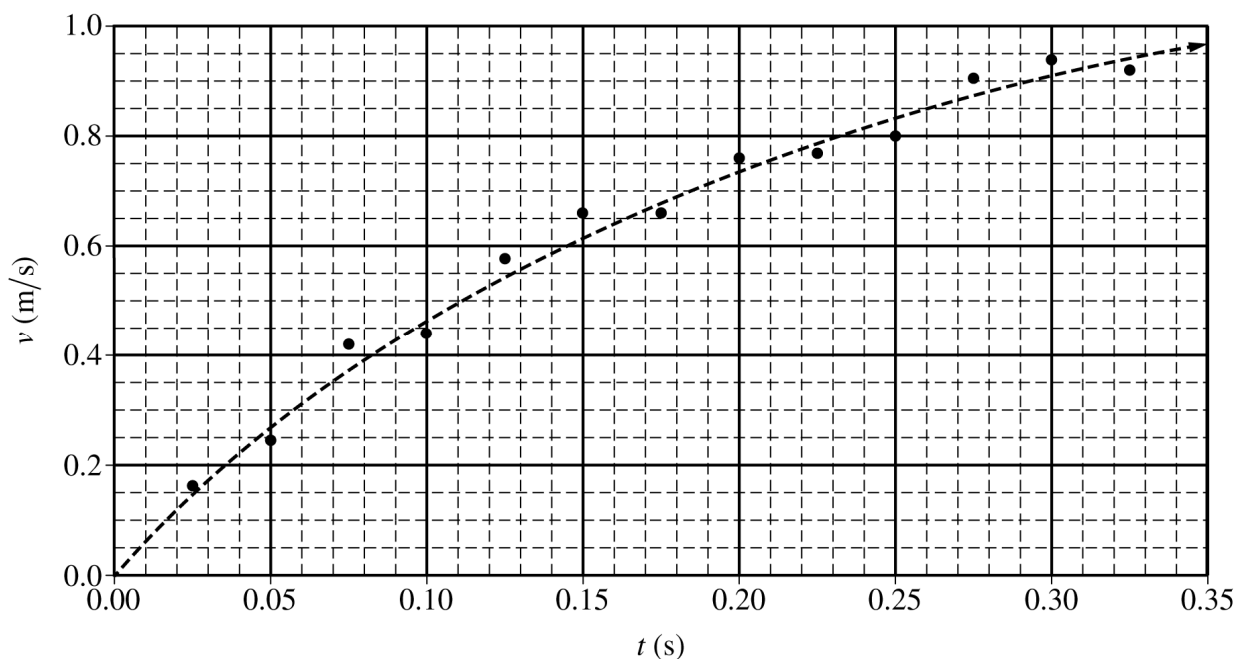
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1. In an experiment, students used video analysis to track the motion of an object falling vertically through a fluid in a glass cylinder. The object of $m = 12\text{ g}$ is released from rest at the top of the column of fluid, as shown above. The data for the speed v of the falling object as a function of time t are graphed on the grid below. The dashed curve represents the best fit chosen by the students for these data.



(a)

- i. Does the speed of the object increase, decrease, or remain the same?

_____ Increase _____ Decrease _____ Remain the same

- ii. In a brief statement, describe the direction of the object's acceleration and how the magnitude of this acceleration changed as the object fell.
- iii. Using the graph, calculate an approximate value for the magnitude of the acceleration of the object at $t = 0.20$ s.

The students use the equation $v = A(1 - e^{-Bt})$ to model the speed of the falling object and find the best fit coefficients to be $A = 1.18$ m/s and $B = 5$ s⁻¹.

(b) Use the above equation to:

- i. Derive an expression for the magnitude of the vertical displacement $y(t)$ of the falling object as a function of time t .
- ii. Derive an expression for the magnitude of the net force $F(t)$ exerted on the object as it falls through the fluid as a function of time t .

The students repeat the experiment with a taller glass cylinder that is filled with the same fluid. The cylinder is tall enough so that the object reaches a constant speed.

(c)

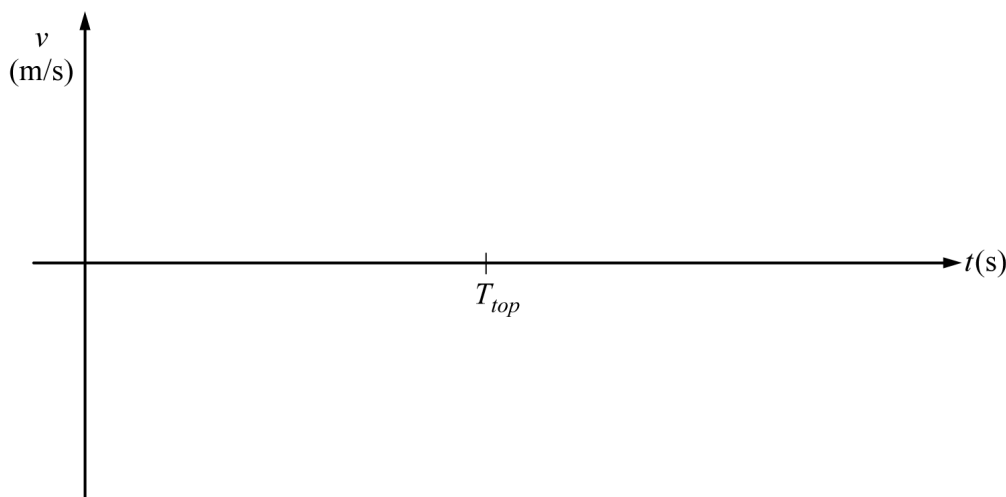
- i. Determine the constant speed of the object.

Justify your answer.

- ii. Determine the force exerted by the fluid on the object at this time.

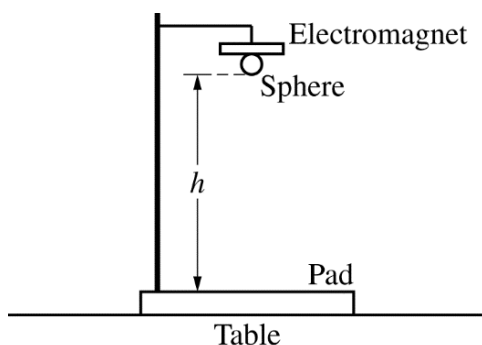
Justify your answer.

2. 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 $t = 6.0\text{ s}$, 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 $t = 6.0\text{ s}$.
- (b) Calculate the speed of the rocket at $t = 6.0\text{ s}$.
- (c)
- Calculate the kinetic energy of the rocket at $t = 6.0\text{ s}$.
 - Calculate the change in gravitational potential energy of the rocket-Earth system from $t = 0$ to $t = 6.0\text{ s}$.
- (d) Calculate the maximum height reached by the rocket relative to its launching point.
- (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.



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

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1. A student wants to determine the value of the acceleration due to gravity g for a specific location and sets up the following experiment. A solid sphere is held vertically a distance h above a pad by an electromagnet, as shown in the figure above. The experimental equipment is designed to release the sphere when the electromagnet is turned off. A timer also starts when the electromagnet is turned off, and the timer stops when the sphere lands on the pad.
- (a) While taking the first data point, the student notices that the electromagnet actually releases the sphere after the timer begins. Would the value of g calculated from this one measurement be greater than, less than, or equal to the actual value of g at the student's location?
- ____ Greater than ____ Less than ____ Equal to

Justify your answer.

The electromagnet is replaced so that the timer begins when the sphere is released. The student varies the distance h . The student measures and records the time Δt of the fall for each particular height, resulting in the following data table.

h (m)	0.10	0.20	0.60	0.80	1.00
Δt (s)	0.105	0.213	0.342	0.401	0.451

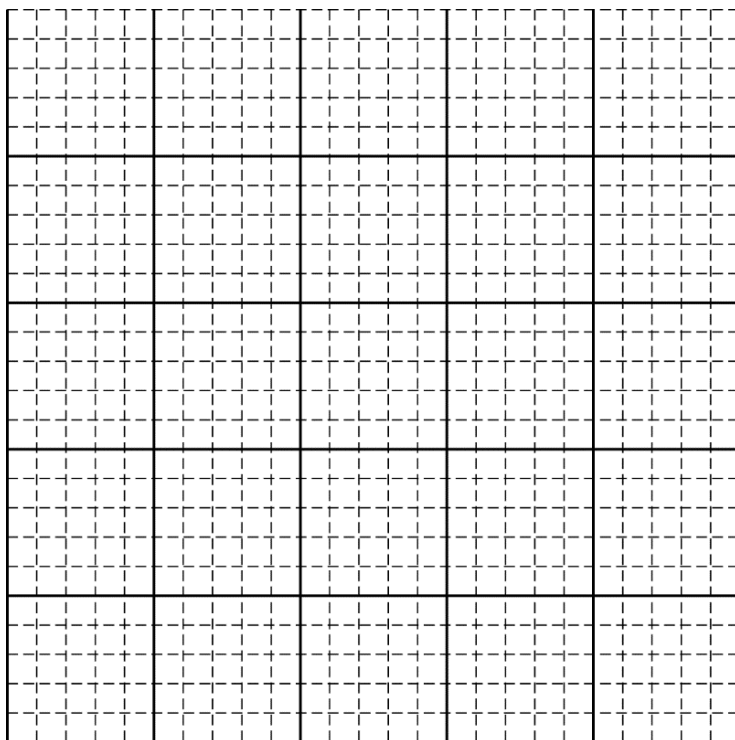
- (b) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for g .

Vertical axis: _____

Horizontal axis: _____

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given in the table. Label each row you use and include units.

- (c) Plot the data points for the quantities indicated in part (b) on the graph below. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



- (d) Using the straight line, calculate an experimental value for g .

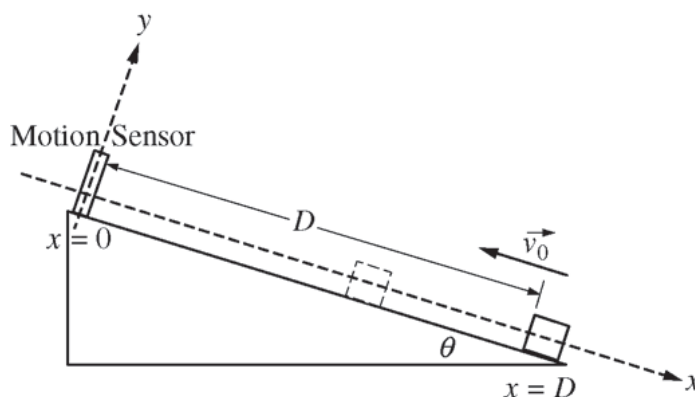
Another student fits the data in the table to a quadratic equation. The student's equation for the distance fallen y as a function of time t is $y = At^2 + Bt + C$, where $A = 5.75 \text{ m/s}^2$, $B = -0.524 \text{ m/s}$, and $C = +0.080 \text{ m}$. Vertically down is the positive direction.

- (e) Using the student's equation above, do the following.

- Derive an expression for the velocity of the sphere as a function of time.
- Calculate the new experimental value for g .
- Using 9.81 m/s^2 as the accepted value for g at this location, calculate the percent error for the value found in part (e)ii.
- Assuming the sphere is at a height of 1.40 m at $t = 0$, calculate the velocity of the sphere just before it strikes the pad.

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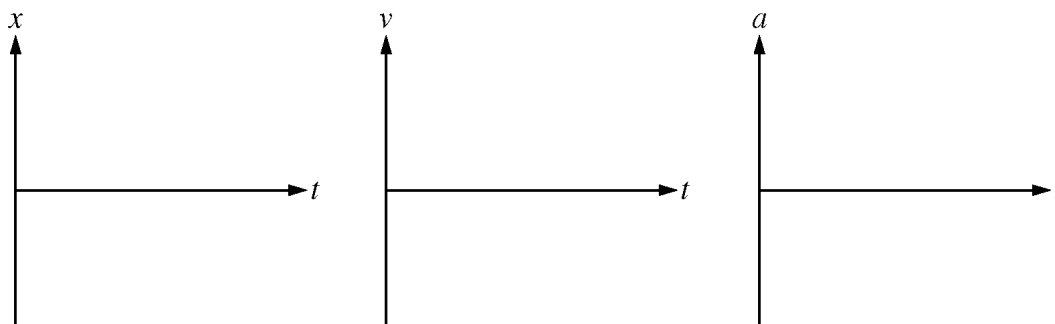


Mech.1.

A block of mass m is projected up from the bottom of an inclined ramp with an initial velocity of magnitude v_0 . The ramp has negligible friction and makes an angle θ with the horizontal. A motion sensor aimed down the ramp is mounted at the top of the incline so that the positive direction is down the ramp. The block starts a distance D from the motion sensor, as shown above. The block slides partway up the ramp, stops before reaching the sensor, and then slides back down.

- (a) Consider the motion of the block at some time t after it has been projected up the ramp. Express your answers in terms of m , D , v_0 , t , θ and physical constants, as appropriate.
- Determine the acceleration a of the block.
 - Determine an expression for the velocity v of the block.
 - Determine an expression for the position x of the block.
- (b) Derive an expression for the position x_{min} of the block when it is closest to the motion sensor. Express your answer in terms of m , D , v_0 , θ , and physical constants, as appropriate.

- (c) On the axes provided below, sketch graphs of position x , velocity v , and acceleration a as functions of time t for the motion of the block while it goes up and back down the ramp. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.



- (d) After the block slides back down and leaves the bottom of the ramp, it slides on a horizontal surface with a coefficient of friction given by μ_k . Derive an expression for the distance the block slides before stopping. Express your answer in terms of m , D , v_0 , θ , μ_k , and physical constants, as appropriate.

- (e) Suppose the ramp now has friction. The same block is projected up with the same initial speed v_0 and comes back down the ramp. On the axes provided below, sketch a graph of the velocity v as a function of time t for the motion of the block while it goes up and back down the ramp, arriving at the bottom of the ramp at time t_f . Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.

