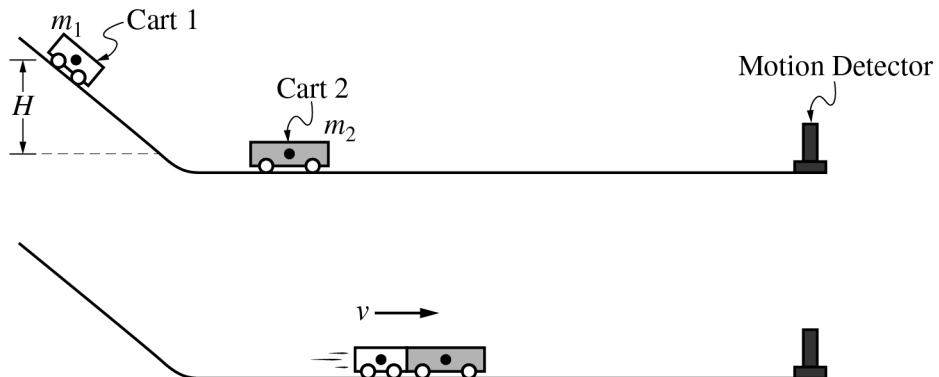


Begin your response to **QUESTION 2** on this page.



2. Cart 1 of mass m_1 is held at rest above the bottom of an 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 smoothly transitions to the horizontal section. The center of mass of Cart 1 moves a vertical distance of H , as shown. At time t_C , Cart 1 reaches the bottom of the 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.

- (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

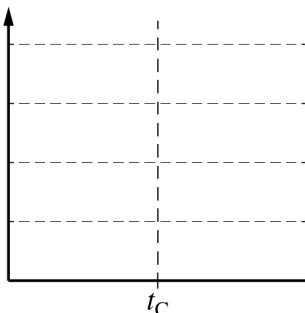
Justify your answer.

GO ON TO THE NEXT PAGE.

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

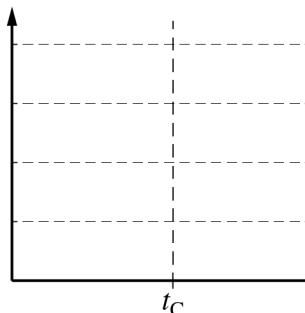
- (b) On the following axes, draw graphs of the magnitude of the momentum of each cart as a function of time t , before and after t_C . The collision occurs in a negligible amount of time. The grid lines on each graph are drawn to the same scale.

Momentum



Cart 1

Momentum



Cart 2

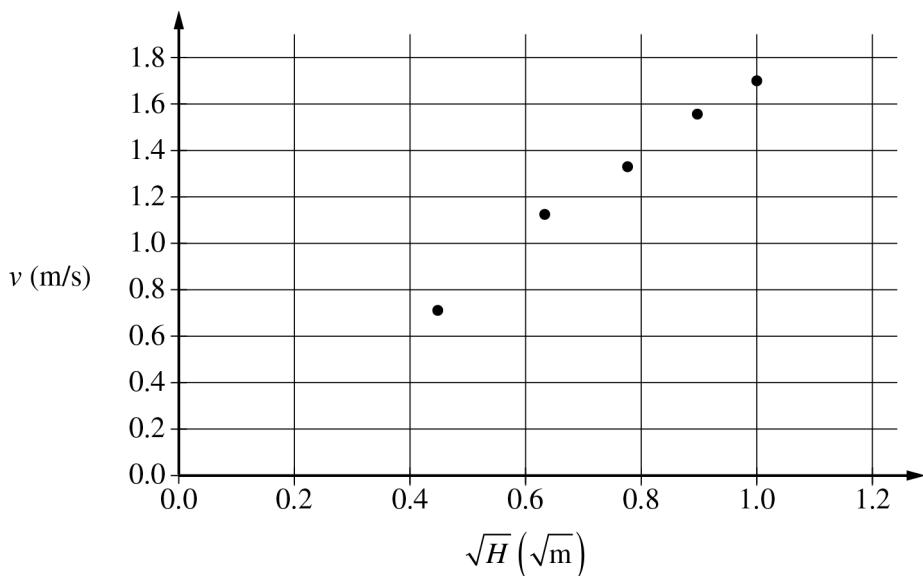
- (c) Show that the velocity v of the two-cart system after the collision is given by the equation

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

GO ON TO THE NEXT PAGE.

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

- (d) A group of students use the setup to perform an experiment. They measure the mass of Cart 1 to be $m_1 = 0.250 \text{ kg}$. 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.



- Draw a line that represents the best fit to the data points shown.
- Use the best-fit line to calculate the mass of Cart 2.

GO ON TO THE NEXT PAGE.

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

- (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?

$m_1' > 0.250 \text{ kg}$ $m_1' < 0.250 \text{ kg}$ $m_1' = 0.250 \text{ kg}$

Justify your answer.

GO ON TO THE NEXT PAGE.

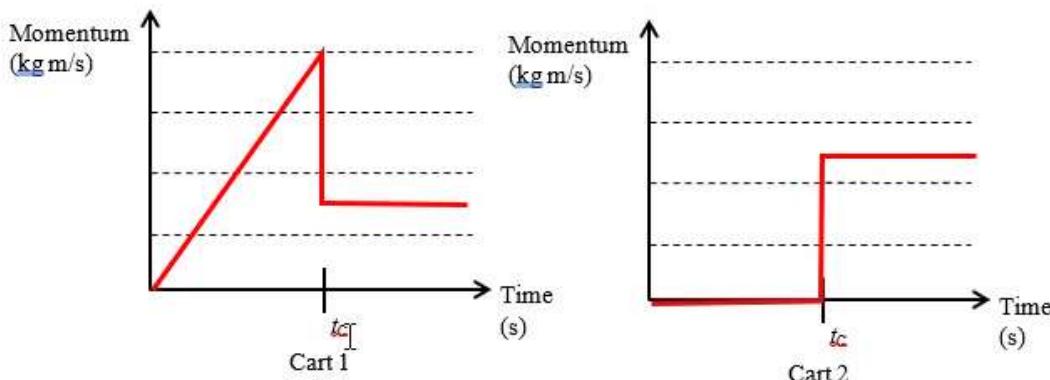
Question 2: Free-Response Question**15 points**

- (a) For selecting “Equal to” with an attempt at a relevant justification **1 point**
 For a correct justification **1 point**

Example Response

Newton’s third law says equal/opposite forces, time intervals are same during same collision, so magnitudes of impulse must be equal.

- | | Total for part (a) 2 points |
|---|------------------------------------|
| (b) For correctly drawing the momentum for carts 1 and 2 for the time interval $0 < t < t_C$: | 1 point |
| Linear increasing momentum for Cart 1 and zero for Cart 2 | |
| For drawing a horizontal line for Cart 1 when $t > t_C$ that is smaller in magnitude than the momentum of Cart 1 at time $t = t_C$ | 1 point |
| For drawing a horizontal line for Cart 2 when $t > t_C$ that is greater in magnitude than the momentum of Cart 1 after time $t = t_C$ | 1 point |
| For carts 1 and 2 having a change in momentum that is equal in magnitude, such that Cart 1 loses momentum and Cart 2 gains momentum or a response with changes in momentum consistent with the response in part (a) | 1 point |

Example Response

- | | Total for part (b) 4 points |
|---|------------------------------------|
| (c) For using conservation of energy to find the speed of Cart 1 at the bottom of the incline | 1 point |
| OR | |
| For a correct substitution of acceleration and displacement in a kinematics equation to find the speed of Cart 1 at the bottom of the incline | |
| For using conservation of momentum to find the speed of the two-cart system after the collision | 1 point |
| For combining correct equations from above | 1 point |

(e) For selecting “ $m_1' < 0.250 \text{ kg}$ ” with an attempt at a relevant justification	1 point
---	----------------

For a correct justification	1 point
-----------------------------	----------------

Example Response

A smaller m_2 indicates that the initial energy and momentum was smaller. With identical slope and height H this means that the mass m_1' must be smaller.

Total for part (e) 2 points

Total for question 2 15 points