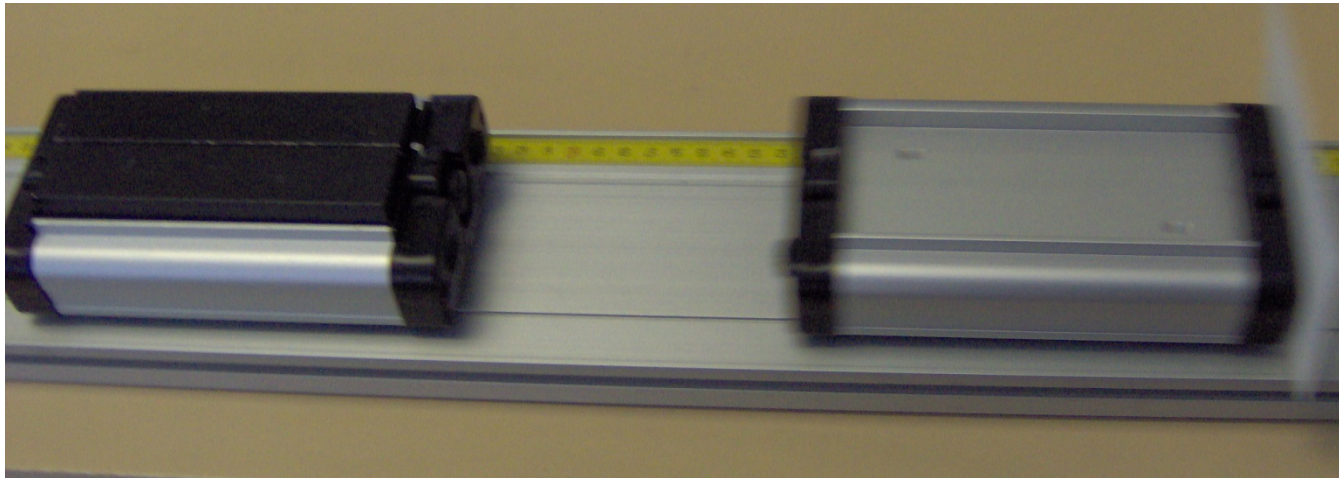


Momentum and Impulse



Momentum

Momentum is a vector quantity which is a product of a mass of the object and its velocity. Therefore

$$\vec{p} = m\vec{v}$$

The units of momentum are *kg m/s*. Momentum has the same direction as the velocity.

If your system consists of more than one object (for example if it consists of two carts), then in order to find its total momentum you will have to calculate momenta of individual objects and then add them together (just remember that you will be adding vectors here). Therefore

$$\vec{p}_{sys} = \vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \dots$$

Impulse

Impulse is very closely related to momentum. Impulse is a vector, \vec{I} , defined as the change in the momentum of an object:

$$\vec{I} = \Delta\vec{p} = \vec{p}_f - \vec{p}_i$$

Where \vec{p}_f and \vec{p}_i are the final and initial momentum respectively. It can be shown that impulse is the average force, \vec{F}_{avg} , multiplied by the change in time Δt :


$$\vec{I} = \vec{F}_{avg} \Delta t$$

Note: Since this experiment only involves one dimension, the sign of the impulse and momentum vectors will indicate direction.


Momentum Conservation

To talk about momentum conservation and impulse on a group of objects we need to first mention two concepts;

1. System,
2. External Force.



The **system** is the set of objects or single object that we are considering. For example, if we have two cars colliding, we can consider the two cars as our system. Alternatively we could consider one of the two cars as our system.



An **external force** is defined using the idea of a **system**. It is any force that is applied on the system from outside the system. For example, if our two cars collide and we choose our system to be the two cars, there is no external force (the force between them is internal because it is between two objects in the system). If we choose our system to be one car on the other hand, there will be an external force since the other car is outside the system and it provides a force.

Momentum Conservation

The momentum of a system is defined as the sum of all the momenta of all the objects in the system:

$$\vec{p}_{sys} = \vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \dots$$

The next two statements are the most important for this lab and you should refer back to them throughout the lab.

If a system has no net external force, then momentum is conserved, $\vec{p}_{sysi} = \vec{p}_{sysf}$.

If a system has a net external force, then momentum is not conserved, $\vec{p}_{sysi} \neq \vec{p}_{sysf}$.

Objectives

In this experiment, you will investigate the relationship between force and the change of momentum in a simple two cart collision case. This relation is expressed by the following equation

$$\vec{F}_{avg} \Delta t = \Delta \vec{p} = \vec{p}_f - \vec{p}_i$$


which means that

If an average force \vec{F}_{avg} acts on a system over a period of time Δt , then the momentum of this system will change as a result


Or, if you notice that the momentum of a system changed, then you know that there had to be a net external force acting on this system.

Today's Experiment

Today you will measure momentum of two carts before as well as after they collide with each other. There are two possible outcomes of this experiment.



Outcome 1: The momentum before the collision is the same as the momentum after the collision, i.e., $\vec{p}_f = \vec{p}_i$. In this case, momentum is conserved during the collision. Therefore there is no net external force acting on the system.



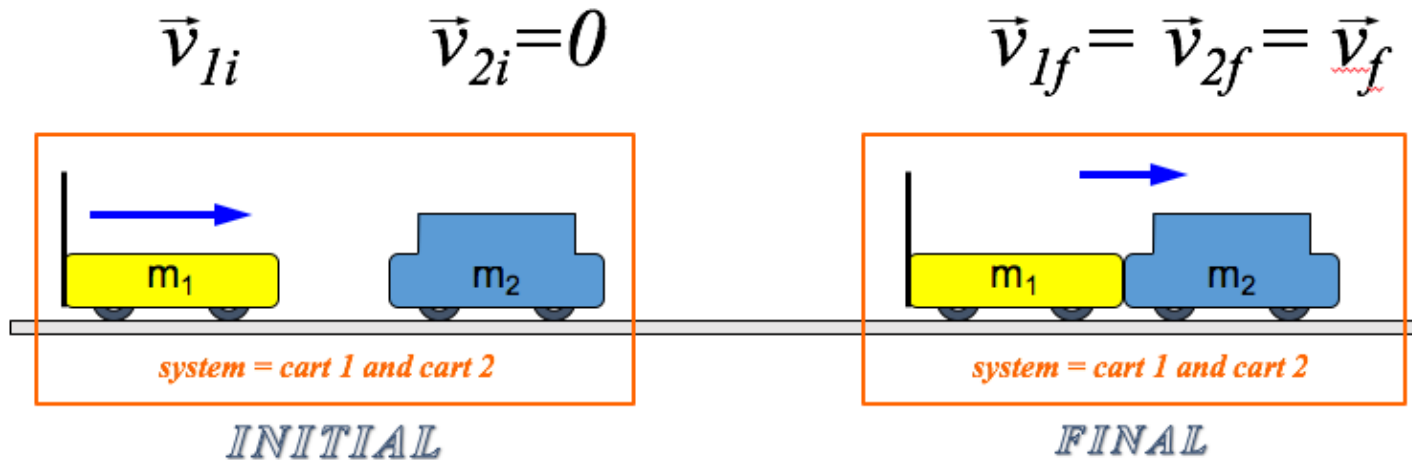
Outcome 2: The momentum before the collision is different from the momentum after the collision, i.e., $\vec{p}_f \neq \vec{p}_i$. In this case, momentum is not conserved during the collision. Therefore there is net external force acting on the system which can be calculated from $\vec{F}_{av}\Delta t = \Delta\vec{p}$

You will have to decide which outcome applies to your results after you analyze them

Prediction

Q

QUESTION 1: If a cart of mass m_1 and initial velocity \vec{v}_{i1} collides with a stationary cart of mass m_2 , then they get stuck together and move with a common final velocity \vec{v}_f . Do you expect the \vec{v}_f to be larger, equal to or smaller than the initial velocity \vec{v}_{i1} ?



Finding m_1 and m_2

Your masses and carts are labeled.

Cart 1 will have 1 plastic card. Cart 2 (with the plunger) will have 1 black block. Mass of plastic card is $(14.3 \pm 0.2)g$.

Click [here](#) to open a file containing the masses of the rectangular black masses. (Units are grams and uncertainty is $0.1 g$)

Find your values and record them in Tables 1.

Click [here](#) to open a file containing the masses of the carts.

Search for your values and record them in Tables 1 .

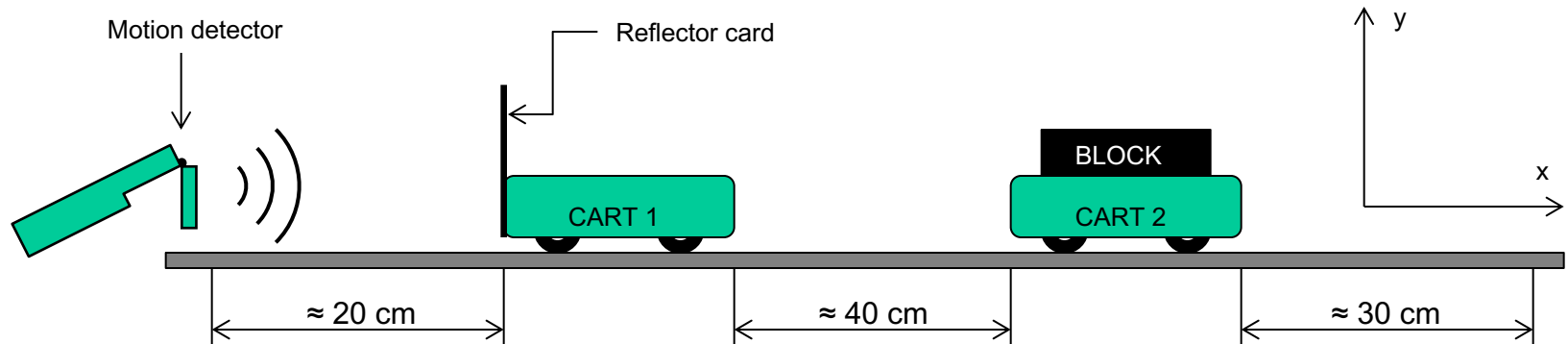
Place the carts **UPSIDE DOWN** when not using them.

Find the total mass for each cart and record your result in Tables 1.

You may need to depress the plunger on Cart 2 by pushing in and up on the plunger.

Experimental Setup

Below is a schematic drawing of the experimental setup



- Remember to level the track as best you can using the leveling screw.
- The metal bumper on one of the carts should face the other cart.
- Fasten the reflector card to cart 1 with masking tape. Make sure that the card is not touching the track.
- The distances between objects in the above drawing are guides only.
- Perform a quick test run of the experiment without data collection to see if everything is arranged in the right way. **The carts should get stuck together after the collision.**



Data Collection

- Before collecting any data make sure that the motion detector is plugged in into **DIG/SONIC 1** port on the side of the LabPro.
- Launch *Logger Pro* by clicking on the icon below.



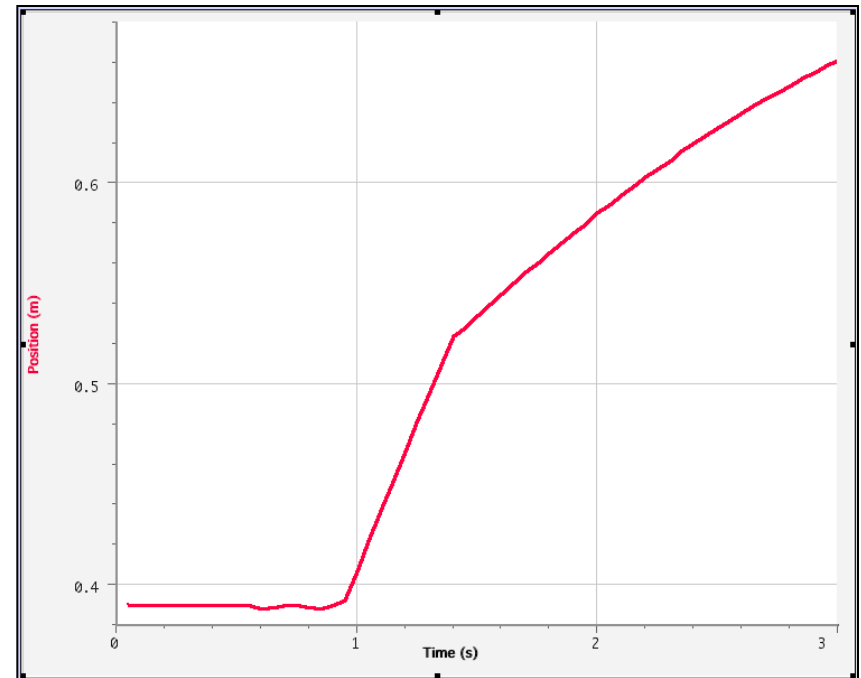
Logger Pro should open with a window containing a graph of Position vs. Time. The time axis should have a maximum value of 3 seconds.

If your graph does not look as expected, consult an instructor now.



Data Collection (cont.)

- Click collect in your *Logger Pro* window. Wait for the motion detector to make a clicking noise.
- Apply a gentle push to cart 1 with the card attached towards the direction of cart 2. It should hit it and **they should stick together**.
- Inspect your graph. It should resemble the graph shown here. If it does not, repeat the experiment. If you are not satisfied with the appearance of your graph after 5 - 10 attempts, consult instructor.



Data Collection

Q

QUESTION 2: Sketch your position vs. time graph in your laboratory workbook. Identify the point where the collision occurred and circle it. Describe in words what happened to the velocity of the carts before and after the collision, how is this represented on the graph, and is it consistent with your answer to Question 1?

Measuring Initial Velocities

- To determine the velocity of cart 1 before the collision
 - Click and drag your mouse from the collision point to highlight about 10 data points **immediately before the collision** on your graph. Look at the data table to the left of your screen to see the number of points selected.
 - Click on “**Analyze**” and then “**Linear Fit**”. A box will pop up displaying the slope and intercept of the highlighted portion of your graph.
 - Double click on that box and check the option “**show uncertainties**”.
 - Enter your results in **Table 2** for \vec{v}_{1i} .
- Decide what was the velocity of cart 2 before the collision. Enter that value in **Table 2** for \vec{v}_{2i} . (Hint: it is not the same as \vec{v}_{1i})

Measuring Final Velocities

- To determine the velocity of cart 1 after the collision
 - Click and drag your mouse from **the collision point** to highlight about 10 data points **immediately after the collision** on your graph. Again check the number of points selected by looking at the data table.
 - Click on “**Analyze**” and then “**Linear Fit**”. A box will pop up displaying the slope and intercept of the highlighted portion of your graph.
 - Double click on that box and check the option “**show uncertainties**”.
 - Enter your results in **Table 1** for \vec{v}_{1f} .
- Decide what was the velocity of cart 2 after the collision. Enter that value in **Table 2** for \vec{v}_{2f} .

Have an Instructor check your data in Table 1 & 2 before you proceed.

Add a title, label your axes and include the fit boxes to your graph and print it.

LW

LW

CP

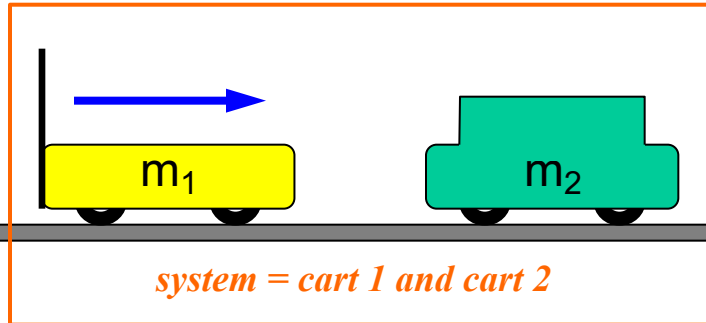
P

Data Analysis (2 carts system)

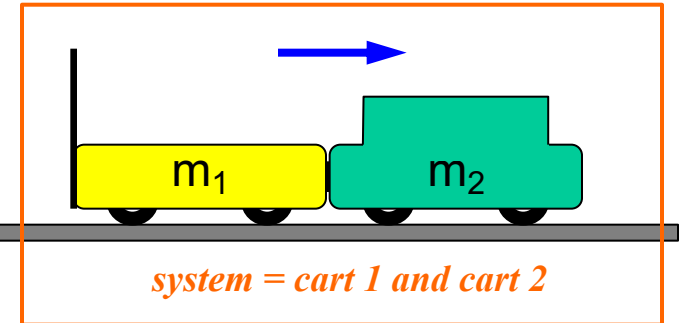
$$\vec{v}_{1i}$$

$$\vec{v}_{2i}=0$$

$$\vec{v}_{1f} = \vec{v}_{2f}$$



INITIAL



FINAL

In this part of the analysis you will consider the momentum of both carts before and after the collision.

2 cart system (cont.)

We need to calculate the total momentum, both initial and final, of the system consisting of two carts, therefore we will have to calculate the momentum of cart 1 and add it to the momentum of cart 2.

Q

QUESTION 3: Using the notation from the diagram shown on slide 16 write down an expression (no numbers) for the total **initial momentum** of a system consisting of cart 1 and cart 2.

Q

QUESTION 4: Using the equation you just wrote as an answer to previous question and your data from **Table 1 & 2**, calculate the **initial momentum** of your system and its uncertainty.

Q

QUESTION 5: Similarly, write down an expression (no numbers) for the total **final momentum** of the system consisting of cart 1 and cart 2.

Q

QUESTION 6: Using the equation you just wrote as an answer to previous question and your data from **Table 1 & 2**, calculate the **final momentum** of your system and its uncertainty.

2 carts system (cont.)

Q

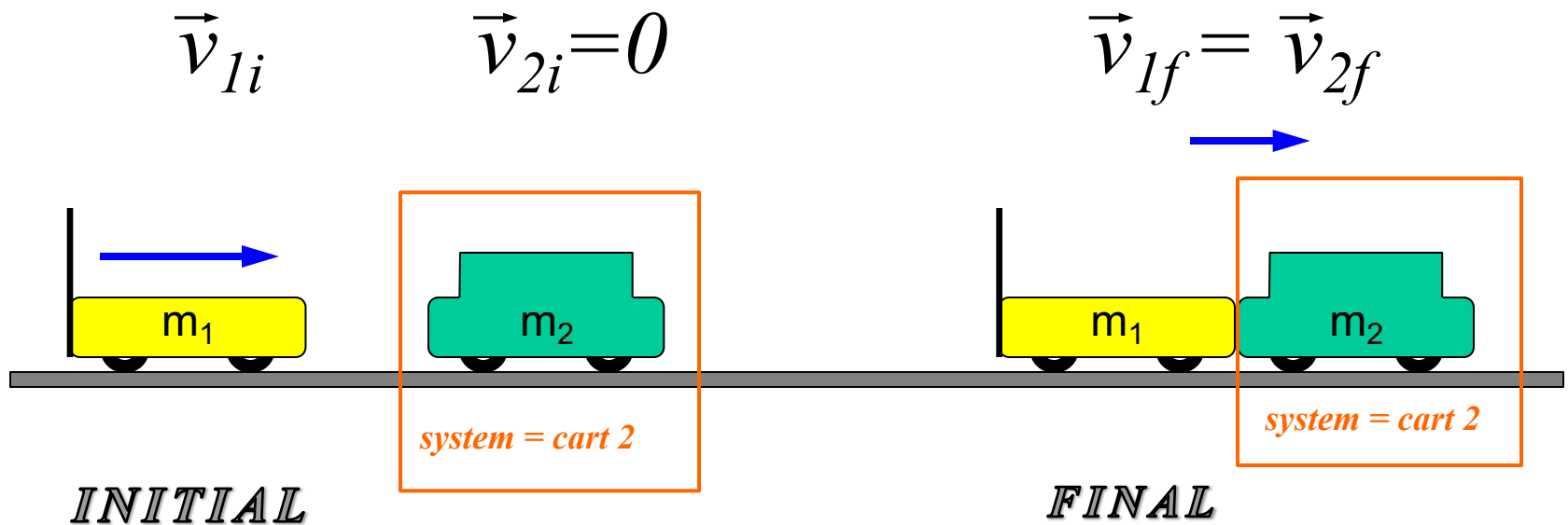
QUESTION 7: Is the momentum before the collision equal to the momentum after the collision within the experimental uncertainty? Support your answer by calculating appropriate ranges of values.

Q

QUESTION 8: Using the relation between average force \vec{F}_{avg} and the change of momentum $\Delta\vec{p}$ shown on slide 6 calculate the average force acting on the system during collision. Assume that $\Delta t = 0.200\text{ s}$ exactly ($\delta\Delta t = 0$). Write your final answer in a form $\vec{F}_{avg} \pm \delta\vec{F}_{avg}$. Where might this force come from?

Data Analysis (1 cart system)

For this part use *the same data* from Table 1 & 2. However this time your system consists of *only cart 2*.



1 Cart system (cont.)

Q

QUESTION 9: Neglecting friction, draw the free body diagram for cart 2 during the collision. Carefully label the direction of each force.

Q

QUESTION 10: Calculate the **initial** momentum (i.e. momentum **before** the collision) and its uncertainty for cart 2 only. Write your final answer in the correct form, i.e. $p_i \pm \delta p_i$.

Q

QUESTION 11: Calculate the **final** momentum (i.e. momentum **after** the collision) and its uncertainty for cart 2 only. Write your final answer in the correct form, i.e. $p_f \pm \delta p_f$.

Q

QUESTION 12: Using the relation between average force F_{avg} and the change of momentum Δp shown on slide 3 calculate the average force acting on cart 2 during collision. Assume that $\Delta t = 0.200 \text{ s}$ exactly ($\delta \Delta t = 0$).

1 cart system (cont.)

Q

QUESTION 13: You just calculated the average force on cart 2. What would you expect the force on cart 1 to be? Support your answer.

Q

QUESTION 14: Is momentum conserved during the collision for cart 2 (i.e. is the momentum before equal to the momentum after within uncertainty)? Would you expect it to be conserved?

Q

QUESTION 15: We have ignored friction so far. What role does friction play in this experiment?

Summary

Q

QUESTION 16: Identify two sources of uncertainty in this experiment. Are these random or systematic?

- Close all applications and log out.
- Submit your laboratory workbook with the graph attached.

!