Since there is no net force on the system of the two carts, momentum is conserved:

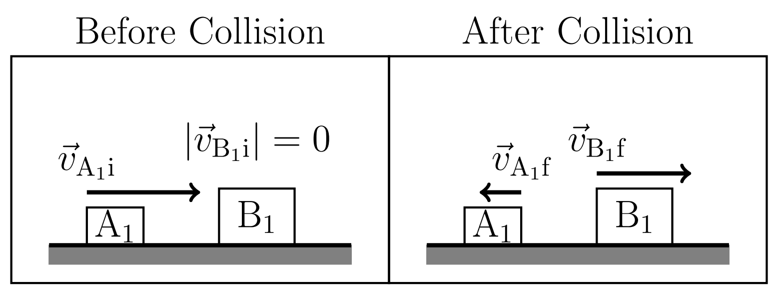
$$\vec{p}_{\mathrm{S}_1} = \vec{p}_{\mathrm{A}_1\mathrm{i}} = \vec{p}_{\mathrm{A}_1\mathrm{f}} + \vec{p}_{\mathrm{B}_1\mathrm{f}}$$
$$p_{\mathrm{S}_1} = p_{\mathrm{A}_1\mathrm{i}} = -p_{\mathrm{A}_1\mathrm{f}} + p_{\mathrm{B}_1\mathrm{f}} < p_{\mathrm{B}_1\mathrm{f}}$$

When A_1 reverses direction, its change in momentum has a larger magnitude than its initial momentum (which was the entire system's momentum). The change in the momentum of B_1 is equal and opposite the change in the momentum of A_1, so A_1 gives B_1 an amount of momentum which is greater than the initial momentum of the system.

Lecture 21: Collisions

Prediction

- Experiment 1 is conducted with two carts, A_1 and B_1, on a level, frictionless track. The mass of cart B_1 is greater than that of cart A_1 (*i.e.* $m_{\mathrm{B}_1} > m_{\mathrm{A}_1}$).
- In experiment 1, cart A_1 moves toward cart B_1, which is initially at rest. Magnets are attached to the carts so that the carts repel each other without touching. After the collision, cart A_1 has reversed direction and cart B_1 moves to the right.
- *Predict* whether the magnitude of the final momentum of cart B_1 is *greater than*, *less than*, or *equal to* that of the system S_1 of both carts. Briefly explain.



Experiment 1

(A) Greater than

(B) Less than

(C) Equal to

(D) Not enough information

Experiment 1

	A_1	B_1	A_1 & B_1
$\vec{p}_i$	$\longrightarrow$	$\bullet$	$\longrightarrow$
$\Delta\vec{p}$	$\longleftarrow$	$\longrightarrow$	$\bullet$
$\vec{p}_f$	$\leftarrow$	$\longrightarrow$	$\longrightarrow$

Experiment 2

	A_2	B_2	A_2 & B_2
$\vec{p}_i$	$\longrightarrow$	$\bullet$	$\longrightarrow$
$\Delta\vec{p}$	$\longleftarrow$	$\longrightarrow$	$\bullet$
$\vec{p}_f$	$\leftarrow$	$\longrightarrow$	$\longrightarrow$

Experiment 3

	A_3	B_3	A_3 & B_3
$\vec{p}_i$	$\longrightarrow$	$\bullet$	$\longrightarrow$
$\Delta\vec{p}$	$\longleftarrow$	$\longrightarrow$	$\bullet$
$\vec{p}_f$	$\longleftarrow$	$\longrightarrow$	$\longrightarrow$

From the diagrams, we can see that

$$p_{B_1 f} < p_{B_2 f} < p_{B_3 f}.$$

Even though v_{Bf} is decreasing with each experiment, p_{Bf} is increasing.

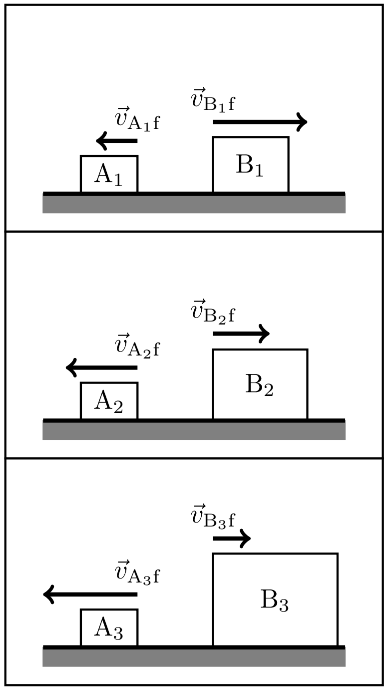
The increase in m_B must be faster than the decrease in v_{Bf} to keep $p_{Bf} = m_B v_{Bf}$ increasing. Still, v_{Bf} could be decreasing fast enough that $K_{Bf} = \frac{1}{2} m_B v_{Bf}^2$ would decrease, thanks to the square.

If $m_B \gg m_A$, object A will reflect at its original speed and object B will barely move. ($v_{Bf} \to 0$ at minimum, and $v_{Af} \to v_{Ai}$ at most, otherwise energy would not be conserved.)

L21-1: Collision Experiments

- Two additional experiments are performed that are identical to experiment 1 with one exception: the mass of the target cart is larger in each subsequent experiment (*i.e.* $m_{B_3} > m_{B_2} > m_{B_1}$).
- In each experiment, cart A moves toward cart B, which is initially at rest.
- The incoming carts A_1–A_3 are identical and have the same initial velocity to the right.
  - Create momentum vector diagrams for experiments 1, 2, and 3 (your vectors only need to be qualitatively accurate).
  - Use your vector diagrams to rank the final momenta of the B carts according to magnitude.
  - Consider what would happen in the special case that the mass of cart B is made *very large*.

After Collision



Experiment 1

Experiment 2

Experiment 3

We should choose the bouncy ball, as it will have a greater momentum change when rebounding, which means it will impart more momentum to the post.

In this momentum vector diagram, I will assume there is no significant external impulse during the brief collision. Also, I will assume the clay ball comes to a stop after the collision (in keeping with the in-class demonstration).

	Ball Clay Rubber	Post	System
$\vec{p}_i$	$\longrightarrow$	$\bullet$	$\longrightarrow$
$\Delta\vec{p}$	$\longleftarrow$ $\longleftarrow$	$\longrightarrow$ $\longrightarrow$	$\bullet$
$\vec{p}_f$	$\bullet$ $\leftarrow$	$\longrightarrow$ $\longrightarrow$	$\longrightarrow$

Looking at $\vec{p}_f$ for the post, the rubber ball gives more momentum to the post, making it more likely to tip over.

If the ball were to stick to the post and move with it after the collision, the diagram would instead look like this:

	Ball	Post	System
$\vec{p}_i$	$\longrightarrow$	$\bullet$	$\longrightarrow$
$\Delta\vec{p}$	$\longleftarrow$	$\longrightarrow$	$\bullet$
$\vec{p}_f$	$\rightarrow$	$\longrightarrow$	$\longrightarrow$

The poste gets even less speed from the collision, as the momentum is shared between both masses.

L21-2: Carnival Game

A carnival game requires you to knock over a wood post by throwing a ball at it. You're offered a very bouncy rubber ball and a very sticky clay ball of equal mass. Assume that you can throw them with equal speed and equal accuracy. You only get one throw.

- Which ball do you choose? Why?
- Create a momentum vector diagram for this situation to defend your answer.
- Ask someone on the instructional team to help you check your answers.

Main Ideas

- Momentum and impulse are useful quantities for solving dynamics problems.
- The impulse is always equal to the change in momentum for a system.
- When the impulse is zero (because the net force is zero), the momentum of the system is constant—it is *conserved*.