I. Everyday collisions

A. Two physicists, Anne and Brady, are facing one another while sitting at rest on two longboards with very low-friction bearings. Anne tosses a large, heavy ball to Brady, as shown in the series of pictures at right.

1. Anne begins to move in the direction opposite the ball’s motion.
   a. Explain this observation in terms of momentum, including a diagram showing the momentum of each object at two relevant instants.

   Momentum diagram for _______ at instant ____

   Momentum diagram for _______ at instant ____

   Momentum diagram for _______ at instant ____

   Momentum diagram for _______ at instant ____

   Force diagram for _______ at instant ___

   Force diagram for _______ at instant ___

   Force diagram for _______ at instant ___

b. Explain this observation in terms of forces, including a force diagram at the relevant instant(s). These need not be the same instants you chose in part (a).
c. Check your thinking with an instructor. Based on your diagrams in (a) and (b), what can you infer about the relationship between force and momentum?

2. Brady begins to move in the direction that the ball was originally moving. Both he and the ball move more slowly than the ball was moving just before he caught it.
   a. Explain this observation in terms of momentum, including diagrams showing the momentum of each object at two relevant instants.

   Momentum diagram for ________ at instant __
   Momentum diagram for ________ at instant __
   Momentum diagram for ________ at instant __
   Momentum diagram for ________ at instant __

   b. Explain this observation in terms of forces, including a force diagram at the relevant instant(s).

   Force diagram for _________ at instant ___
   Force diagram for _________ at instant ___
B. Imagine you want to shut two identical drawers quickly but can’t reach them. You have a rubber bouncy ball and a piece of clay of the same weight. You throw the clay at one drawer and the bouncy ball at the other drawer (with the same speed); the bouncy ball bounces back toward you, whereas the clay ball drops to the ground. You observe that the drawer hit by the bouncy ball shuts faster than the drawer hit by the clay.

1. Explain this observation in terms of momentum, including diagrams showing the momentum of each object at two relevant instants. (It may be helpful to number the instants you’re referring to.)

2. Explain this observation in terms of forces, including a free-body diagram at the relevant instant(s).
C. Considering your reasoning so far, how do you think the quantities force and momentum (or change in momentum) are related? Write a rule (or a set of rules) that expresses this relationship. *Discuss your rules with an instructor or TA.*
II. Experiments

A. Consider the following experiment: A moving cart with mass 1.25 kg collides with a 1.25 kg stationary cart. A stiff spring is attached to the front of the stationary cart and both carts have sensors that record the force by the spring during the collision, as shown in the photo. Below are graphs of each cart’s velocity and the force measured by each sensor over time.

Coordinate the graphs provided with the experiment, as follows:
1. Which object is which?
2. Where is the force probe located and what force(s) is it measuring?
3. What do the horizontal and vertical axes represent?
4. What does it mean for each graph to be positive or negative?
5. What does it mean for the slope of each graph to be steeper or less steep?
6. Does the area under the graph represent anything?
7. How could you use the information given by these graphs draw force and momentum diagrams like the ones you drew in part I?

Your instructor has provided you with videos of a number of experiments that measure force and velocity for carts undergoing various collisions. You may also use a simulation to create your own collisions. The goal of this section is to make observations to find out more about the relationship between force and momentum. Complete the table below for at least three experiments.

1. Select an experiment that you think will demonstrate (or contradict?) part of your rule.
2. Examine the video of the experiment and the graphs provided for the experiment:
   a. Which object is which?
   b. Where is the force probe located and what force(s) is it measuring?
   c. What do the horizontal and vertical axes represent?
   d. What does it mean for each graph to be positive or negative?
   e. What does it mean for the slope of each graph to be steeper or less steep?
   f. Does the area under the graph represent anything interesting?
3. Use the table on the next page to explain what this evidence suggests about the rule you wrote in part I.C.

**Description of experiment 1:**

How your rule applies to this experiment (what should happen, based on your rule?):

Measurements that verify, disprove, or refine the rule:

**Description of experiment 2:**

How your rule applies to this experiment (what should happen, based on your rule?)
Measurements that verify, disprove, or refine the rule:

<table>
<thead>
<tr>
<th>Description of experiment 3:</th>
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<tbody>
<tr>
<td>How your rule applies to this experiment (what should happen, based on your rule?)</td>
</tr>
<tr>
<td>Measurements that verify, disprove, or refine the rule:</td>
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### III. Conceptual rule

Now that you’ve tested and refined your ideas, write down a (revised, improved) rule for the relationship between forces and momentum.