*ILD 4* Name: ____________________ Tutorial section _______

# Why is momentum conserved in collisions?

## I. Introduction

In this ILD, we'll figure out exactly where the equation expressing conservation of momentum comes from and how it relates to other physics concepts.

A. First, let's make sure we agree about what conservation of momentum says. Two students are arguing about this, talking about a collision between object 1 and object 2:

LINDA: Conservation of momentum says that the total momentum of the system before the collision equals the total momentum of the system after the collision:

$$m_1\mathbf{v}_{1\text{ before}} + m_2\mathbf{v}_{2\text{ before}} = m_1\mathbf{v}_{1\text{ after}} + m_2\mathbf{v}_{2\text{ after}}$$

JENNIFER: No, I think conservation of momentum says that, in the collision, the momentum gained by one object equals the momentum lost by the other:

$$m_1\,\Delta\mathbf{v}_1 = -m_2\Delta\mathbf{v}_2.$$

The minus sign says that the *gain* in object 1's momentum equals the *loss* in object 2's momentum, or vice versa; one compensates for the other.

Which student or students do you agree with?

(1) I agree with Linda.
(2) I agree with Jennifer.
(3) I agree with both: They're saying the same thing in different ways.
(4) I agree with both, though they disagree with each other.
(5) I agree with neither.

✯ Rad polling. Class discussion: Are the equations the same?

B. Where do you think conservation of momentum comes from?

(1) Momentum conservation is just another way of writing Newton's laws. So, this isn't really a new topic at all.

(2) The whole point of momentum conservation is that it gives us a way to think about what happens during a collision even when we *don't* know the size of the forces involved. So, momentum conservation is a new topic, based on new concepts, only loosely connected to forces and the like.

(3) I'm torn; I kind of agree with elements of both (i) and (ii).

✯ *POLLING*. Class discussion

## II. Deriving momentum conservation

Let's play the implications game, applying Newton's $2^{nd}$ and $3^{rd}$ laws to a collision between objects 1 and 2, and see where that leads us.

First, as we saw with the truck-and-car scenario, Newton's' $3^{rd}$ law says that objects 1 and 2 exert equally strong forces on each other (though in opposite directions):

$$\vec{F}_{2\to 1} = -\vec{F}_{1\to 2}$$

A. (*Work together*) Suppose that, during the collision, the forces exerted on the objects all balance out except the forces they each other. These then equal the *net forces* felt by each object. Using Newton's $2^{nd}$ law, rewrite the above gray-shaded equation in terms of the masses and accelerations of the objects during the collision ($m_1$, $a_1$, $m_2$, and $a_2$).

B. (*Work together*) Now use the basic definition of acceleration to rewrite the equation in terms of the masses ($m_1$ and $m_2$,), the changes in velocity of each object during the collision ($\Delta v_1$ and $\Delta v_2$), and the time interval over which the collision occurs ($\Delta t$).

C. (*Work together*) Now multiply through by $\Delta t$. Does the result look familiar?

D. (*Work together*) Since you already knew that momentum was conserved before coming to lecture today, what was the point of the mathematical steps we led you through in parts A through C?

E. (*Work together*) Based on the derivation you just did, state a general rule about when momentum is conserved and when it isn't. Hint: In parts A through C, what assumption or assumptions did you make *besides* Newton's laws?

✯ Class discussion

## III. Applying momentum conservation

(*Work together*) Your instructor will do an experiment in which a fan-driven cart of mass 1 kg collides with a stationary second cart of mass 2 kg. The velocity vs. time graph is for the initially moving cart. Figure out the post-collision speed of the heavier cart. (Then we'll test your prediction experimentally.)

✯ Class discussion. Experiment.