

## Frames of Reference, Energy and Momentum, with *Interactive Physics*

### Purpose:

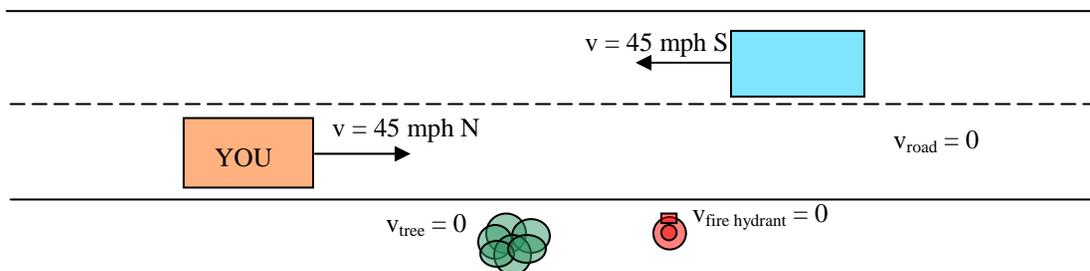
In this lab we will use the Interactive Physics program to simulate elastic collisions in one and two dimensions, and with a ballistic pendulum. We will introduce the concept of viewing an event in different frames of reference, including the “Laboratory” frame and “Center of Mass” frame.

### Equipment:

- Interactive Physics Software
- paper, pencil

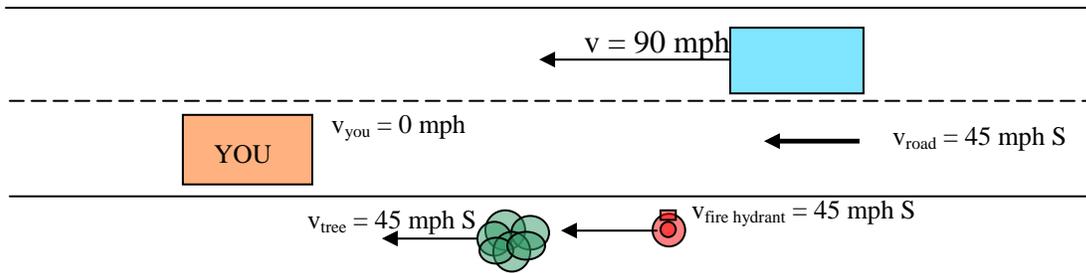
### Theory:

Imagine that you are driving north along a two-lane highway. The speed limit is 45 mph, and you are obeying the speed limit, as are the cars in front of you, and the cars driving south in the other lane. As you look out the right-side window, you notice that you are passing trees and fire hydrants and parked cars. As you look out the left-side window, you see the cars driving south. You notice that the cars on the left go by the window much more quickly than the trees on the right. You realize that this is because the cars are moving, whereas the trees are not...the reason that the trees don't maintain the same position relative to your right-side window is because *you* are moving.



**Figure 1** Two cars driving in opposite directions

Now, imagine the same situation as above, but add one more step: pretend that you're not the one who is moving, it's everything else. What would the world look like then? You would see the south-driving cars coming toward you at 90 mph. You would see the trees and fire hydrants and parked cars coming toward you at 45 mph. You would see the dots of the yellow dividing line coming toward you at 45 mph, for even the road under your wheels is changing position relative to your “stationary” car. You have just *changed your frame of reference!*

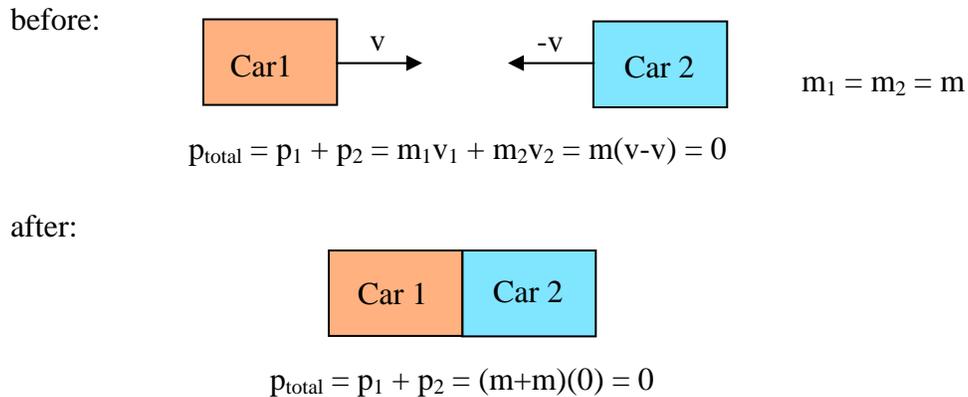


**Figure 2** Imagining that your car is stationary

A *frame of reference* is a particular way of looking at a situation. Up until now we have (without you even realizing it) chosen the Laboratory Frame of Reference. That is, we have measured velocities and movements with respect to the “laboratory”: the classroom, tables, floor, walls, etc.: which, as far as we are concerned, doesn’t move at all. We could, however, choose to look at the world through a view that is moving with a constant velocity – an *inertial* reference frame. As long as we choose an inertial reference frame the laws of physics will remain the same as what we’re used to. If the frame of reference is *accelerating* we call this a *non-inertial reference frame*, and things may get a little weird.

As an example, lets look again at the two cars from before. This time, however, they are driving in the same lane and they tragically collide. Luckily, no one is hurt, so we will use this event to discuss conservation of momentum and energy and changing frames of reference. We’ll first start out with what we’re used to:

The Laboratory Frame:

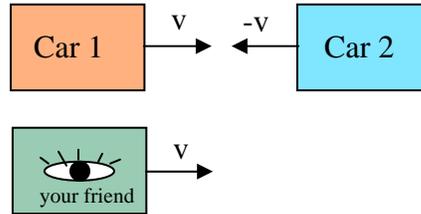


**Figure 3** Collisions in the Laboratory Frame

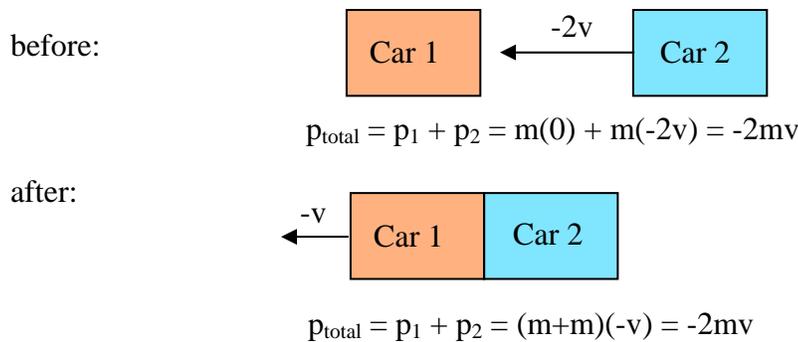
This is the solution we’re familiar with. Our reference point is the “outside world” or “laboratory” which doesn’t move. It’s easy to see that momentum is conserved.

Now imagine that while you're watching the collision from the sidewalk on the side of the road, your friend is standing on a moving platform that happens to have the same velocity as Car 1.

What this looks like to you (i.e. from the lab frame):



What this looks like to your friend (i.e. the observer's reference frame):

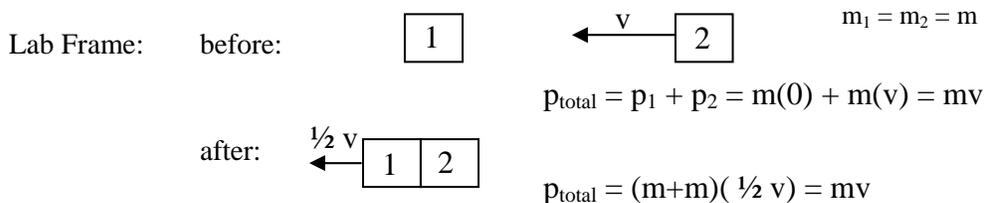


Momentum is Conserved!

**Figure 4 Comparing the same collision in two different reference frames**

Since the observer is moving with the same velocity as Car 1 (before the collision), the car is not moving *relative* to the observer. For simplicity, this is sometimes called “the reference frame of Car 1”. This can lead to confusion, however, because the observer *keeps going* with the same velocity even when Car 1 stops. The observer (reference frame) DOES NOT change its velocity...that would be an *accelerating* or *non-inertial* reference frame, and we would not see momentum conserved in that case!

Another very common frame of reference is the “Center of Mass” (CM) frame, in which the system's center of mass remains stationary. In a case like the one above, where two objects with the same mass approach each other with opposing velocities, the lab frame *is* the CM frame. However, look at what happens when one of the objects is initially stationary...



**Figure 5 Conservation of Momentum in the Laboratory Frame; one object is initially stationary**



Of course, we looked at a very simple collision in the CM frame...the two blocks have the same mass, one is stationary. However, the process works for more complicated systems and collisions as well. We find the objects' velocities in the CM frame as follows:

$$v_1' = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)v_1 \quad \mathbf{a}$$

$$v_2' = \left(\frac{2m_1}{m_1 + m_2}\right)v_1 \quad \mathbf{b}$$

Eq. 1a and b

And, of course, in any new frame, the velocities must follow the rule:

$$\mathbf{v}_{\text{new}} = \mathbf{v}_{\text{old}} - \mathbf{v}_{\text{frame}} \quad \text{Eq. 2}$$

## Experiment:

### Part A: One-Dimensional Collisions

1. Start *Interactive Physics* and select **File > Open > Physics Experiments > Elastic Collisions 3**.
2. You will see a small ball, and a large ball and graphs showing velocities of each object. Run the simulation once and watch what happens. Double click on either object to bring up the properties dialog box, where you will get information about the position, velocity, and mass of the object you select. Be sure the elasticity for each ball is set to one. Reset after you run the simulations.
3. Write down the conservation of momentum and energy equations for this collision, and show that the velocities that you “measure” when running the simulation are correctly predicted by theory

$$v_1' = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)v_1$$

$$v_2' = \left(\frac{2m_1}{m_1 + m_2}\right)v_1$$

Write down the predicted, and measured values.

4. Now we will change reference frames to the frame that initially moves along with the large mass. Draw a small rectangle on the screen above the center of the two objects before the collision (so its out of the way). Double click on the rectangle and assign it the same x-velocity as the large mass. While the rectangle is selected go to **View > New Reference Frame**. Select any title for the new frame you choose (such as “Large Mass Frame”). Run the simulation and observe what happens. Write down a brief statement of what you observe.

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The theory for this experiment was written by Jennifer LK Whalen

5. Open the *Interactive Physics* file: **Elastic Collisions #4** and measure the initial and final velocities of the two pucks. Then repeat Step 3.
6. Now change reference frames to a frame that moves with the smaller ball. Run the simulation and observe what happens. Write down a brief statement of what you observe.
7. Using the transformation:  $\mathbf{v}_{\text{new}} = \mathbf{v}_{\text{old}} - \mathbf{v}_{\text{frame}}$  show that the old and new velocities of the balls agree. Note that Interactive Physics will not give you the proper velocities (in numerical form) in the new frame. You have to measure them by measuring a displacement and dividing by a time interval. “Measuring a displacement” means physically taking a ruler and holding it against the screen to measure how far the large ball moved. You also might be able to use the program “Screen Ruler” to determine how far the ball traveled.
8. Using the velocities you determined in Step 7, show that momentum is also conserved in this frame.
9. Repeat Steps 6 - 8 using the center of mass reference frame. To define the system center of mass as the new reference frame, first select **View > System Center of Mass**, select the center of mass by clicking on it once, and then **View > New Reference Frame** as before.

### **Part B: Two Dimensional Collisions**

1. Open the file entitled “**Strobe Collision**” on the PC, and “**Two dimensions vary elasticity**” on the Mac. If you are working on the Macs, you will have to adjust the position and velocity of one of the balls so that you start with one stationary ball, and get a glancing collision. Run it once and watch what happens. Does this look familiar (only if you did Lab 11A)?
2. **If** you did Lab 11A, click on each object and adjust its mass to match those used in the experiment performed in class. Otherwise, change the masses so that they are different from each other, and different from Step 1. Measure the  $x$  and  $y$  components of the velocity of each mass before and after the Collision. Show that momentum is conserved in both directions. Note that the “Erase Track” command under the edit window will get rid of the previous pictures.
3. Now give the “stationary” puck a tiny velocity in the  $y$ -direction. Run the experiment and see what happens. Measure all the relevant velocities, and show that moment is still conserved.

### **Part C: The Ballistic Pendulum**

1. Open the file called “Ballistic Pendulum.” Run the simulation once, and observe what happens.

2. Derive a formula for the velocity of the target projectile based on the final height of the pendulum. Run the simulation again, and show that the predicted value agrees with the “measured” value from the simulation.

**Results:**

Write at least one paragraph describing the following:

- what you expected to learn about the lab (i.e. what was the reason for conducting the experiment?)
- your results, and what you learned from them
- Think of at least one other experiment might you perform to verify these results
- Think of at least one new question or problem that could be answered with the physics you have learned in this laboratory, or be extrapolated from the ideas in this laboratory.

**Clean-Up:**

Before you can leave the classroom, you must clean up your equipment, and have your instructor sign below. How you divide clean-up duties between lab members is up to you.

Clean-up involves:

- Completely dismantling the experimental setup
- Removing tape from anything you put tape on
- Drying-off any wet equipment
- Putting away equipment in proper boxes (if applicable)
- Returning equipment to proper cabinets, or to the cart at the front of the room
- Throwing away pieces of string, paper, and other detritus (i.e. your water bottles)
- Shutting down the computer
- Anything else that needs to be done to return the room to its pristine, pre lab form.

I certify that the equipment used by \_\_\_\_\_ has been cleaned up.

(student's name)

\_\_\_\_\_, \_\_\_\_\_.

(instructor's name)

(date)