COLLISIONS-I

PURPOSE: To investigate the relationship of impulse to change of momentum

APPARATUS: ULI, force probe, golf ball, clay balls, Pasco track with carts, motion detector

Introduction: In a collision it is difficult to use Newton's Second Law, $\mathbf{F} = m\,\mathbf{a}$ because the force varies with time in some generally unknown manner. (Note: a bold letter for $\mathbf{F}$ means it is a vector unlike mass, m, which is a scalar.) We can rewrite the second law in a manner more useful for collisions by using the impulse $\mathbf{I} = \int \mathbf{F} dt$.

Integrating both sides of the second law,

$$\mathbf{I} = \int \mathbf{F} dt = \int m\,\mathbf{a}\,dt = \int m(d\mathbf{v}/dt)dt = \int m\,d\mathbf{v} = m\mathbf{v_f} - m\mathbf{v_i},$$

where $\mathbf{v_f}$ and $\mathbf{v_i}$ are the velocities of m before and after the collision. We define the **linear momentum** of m as $\mathbf{P} = m\,\mathbf{v}$. Then the second law says that the change of momentum of a body during a collision equals the impulse it receives,

$$\mathbf{I} = \Delta\mathbf{P}.$$

Now consider two colliding objects, m_1 and m_2. By Newton's Third Law they exert equal and opposite forces, and hence impulses, on each other when they collide.

$$\mathbf{I_1} + \mathbf{I_2} = \Delta\mathbf{P_1} + \Delta\mathbf{P_2} = 0.$$

The law of conservation of linear momentum states that the total momentum of a system remains constant <u>if there is no net external force:</u>

$$\sum \mathbf{P} = \sum(m\,\mathbf{v}) = \mathbf{constant}.$$

<u>**Example**</u> Consider two masses (called carts) m_1 and m_2 sliding towards one another along a track (assumed frictionless) with velocities $\mathbf{v_1}$ and $\mathbf{v_2}$ respectively, as shown in Fig. 1 below:

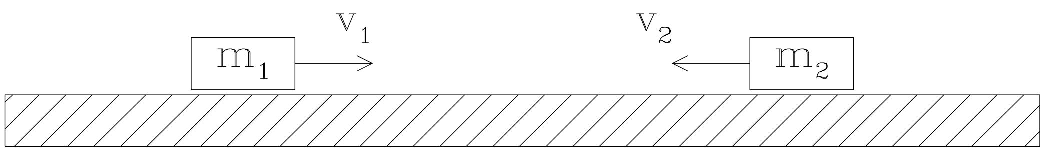

FIGURE 1.

At some point the masses collide and stick. What is the final velocity, $\mathbf{v_f}$, of the composite mass?

<u>Before collision</u> $\mathbf{p_1} = m_1\,\mathbf{v_1}$ $\mathbf{p_2} = m_2\,\mathbf{v_2}$

Total momentum: $\mathbf{P} = \sum_i \mathbf{p_i} = \mathbf{p_1} + \mathbf{p_2} = m_1\,\mathbf{v_1} + m_2\,\mathbf{v_2}$

<u>After collision</u> $\mathbf{p_f} = (m_1 + m_2)\,\mathbf{v_f}$

Total momentum before collision = total momentum after collision

$$m_1\,\mathbf{v_1} + m_2\,\mathbf{v_2} = (m_1 + m_2)\,\mathbf{v_f}$$

Hence,

$$\mathbf{v_f} = \frac{m_1\,\mathbf{v_1} + m_2\,\mathbf{v_2}}{m_1 + m_2}$$

Note that the two terms in the numerator may have opposite signs if the velocities are in opposite directions

EXPERIMENT: In this experiment we will explore momentum, mechanical energy conservation (or non-conservation) and impulse in several types of collisions.

Impulse: When a dropped ball hits something it exerts a force on it (and by Newton's third law an equal force is exerted on it). We will use the force probe to measure that force. You will drop a clay ball and golf ball with the same mass from the same height. The golf ball undergoes a nearly elastic collision while the clay ball has an inelastic collision. Which do you expect to exert the greater force?

Weigh the golf ball and then make a clay ball with about the same mass (within a gram). Open `LoggerPro`. (If necessary set Port to COM2.) Setup the Force probe sensor with a sampling speed of 4000 Hz for 0.5 s, trigger level of 1 N, and 100 pre-trigger data. Adjust the plot window to display Force vs. time (you may close the text window). Zero the probe (do this before each measurement). First drop the golf ball from the top of the tube. Be sure to note the height of the bottom of the ball to the top of the hook. (It might be easier to remove the hook and let the ball bounce off the flat part of the probe.) Record the time at the start of the first bounce (t-initial), the time when the first bounce ends (t-final), the integral of the force between t-initial and t-final, and the time that the second bounce starts. If the force is not close to zero before the ball first hits, zero the force probe and repeat. In any case, record the force before the bounce (F-initial) and correct the integral for any non-zero value. Record the force after the ball comes to rest (F-final). Be sure there is a clear second bounce, with a peak force height of at least 40% of the original bounce. Also, be sure the force is not saturating (you can check this by pushing on the probe with your finger and determining whether you are near the maximum force recorded). Save the result (under **Data** select **Store latest run**).

Repeat for the clay ball. Record the same information as above (except that there will be no second bounce). You will have to correct for the mass of the ball (you will see the force has a non-zero value after the clay ball sticks to it due to the weight of the ball). Does the force after the collision equal the weight of the ball? Do you have to make any correction to the impulse to account for the mass of the golf ball? Discuss the corrections in your report. Include in your report a copy of the force plot showing the curve for each ball in the same plot.

After making the plot with one golf ball bounce and one clay ball fall and printing the two together, repeat each measurement (clay and golf ball) at least once (twice is better). You don't need to print any more plots. Does the second set agree with the first? What information does this gives on the uncertainty of the measurement?

From the height the ball was dropped you can determine its speed when it hits the force probe. Calculate the expected impulse for both completely elastic and inelastic collisions. You can use the time between bounces of the golf ball to find its speed after the bounce. Use this information to calculate the impulse and compare to the integral of the bounce. Estimate the uncertainty on the initial velocity and discuss how that affects your conclusions.

For your report describe the setup and your analysis. Compare the expected and measured impulses. Discuss experimental or physical reasons for any differences and estimate the uncertainty in the result. Include a discussion on the degree to which you have confirmed that impulse equals change in momentum. Calculate the degree of inelasticity of the golf ball bounce. The report should be typed and written in complete sentences. Discuss why the following two statements are incorrect:

1. The clay ball will exert the greater force because it has to be stopped, while the golf ball retains most of its speed.

2. The balls will exert the same force because they have the same mass and are moving at the same speed.

(**II**) In the second part we will make a similar measurement with a rolling cart hitting the force probe. The velocity will be measured using the motion detector. The motion detector cannot take data at the high rate we need for the force detector, so you will have to use an independent motion detector (i.e., not the one connected to the same ULI as the force probe). Record the mass of the car and indicate whether the run corresponds to an inelastic (with clay) or elastic (no clay) collision.

Move the force detector such that it is parallel to the track at a position such that it will hit the cart close to the center. Set the motion detector of the group at the adjacent table on the track. Make a few test runs and be sure the motion detector follows the cart until it hits the force probe. **BE GENTLE!** Do not push the car too quickly. Make the car bounce off the hook. You may want to hold the force probe to make it more rigid during the collision. Record the integral of the impulse, as well as the peak value and width (at the bottom). Find the change of momentum from the change in velocity just before and just after the collision. Next mount some clay on the front of the car. Make the clay in the form of an elongated "nose" such that it will be greatly deformed when it hits the hook, and stop the car. This may take a few trials. Be sure to zero the force probe before each trial. Again, record the total impulse, peak force, and width of the force peak. Discuss in your report the agreement of impulse and change of momentum in the two cases. Does the time of the collision seem to matter?

For both parts, give a typewritten discussion of the experiment with the questions answered in the text.