MOMENTUM CONSERVATION IN 2D COLLISIONS

I. Introduction: Collisions happen in cars, between football players, hockey pucks, your feet and the floor, and uncountable every day phenomena. It is often not practical to analyze the motion of a system using forces. Since momentum is always conserved, in collisions and motion in general, it is a useful way to study many dynamic systems. This week, you will measure the linear momentum of two pucks colliding on a frictionless surface. Linear momentum is simply defined as $\vec{p} = m\vec{v}$.

II. Required Equipment
- Air table, pucks, camera
- **VideoPoint Capture/Fundamentals**

III. Data Recording – Study I: Elastic Collision
1. Open **VideoPoint Capture** (orange C icon) and click on **[Capture]**. A recording window will be activated and a live video display will appear.

Figure 1 : All dimensions are in CCD pixels - (There is no scale to measure)

2. The video cameras in this lab often go into "effects" mode. This involves shaking, funny colors, and other obnoxious effects. If you notice this, turn the camera off and on again. **Be careful not to disturb the alignment of the video camera.**

3. **Elastic collision:** Start with two light pucks (black bottoms) without velcro. Place the target puck using the camel's hair brush. Put the projectile puck in the launcher and hold down on the pressure key. Make sure that the target puck is near the center of the field of view.

4. Turn on the air table. Start recording with **[REC]**. Fire!

5. [DT1] Record the masses of the pucks (distinguish between the projectile and the target).

6. Stop the movie after the collision has occurred and the pucks have reached the retaining wires at the edge of the table. Play the movie to see if it has provided acceptable video data.

7. If the images look good you have a proper collision, reduce video size with **[Confirm Edit]:** By moving the triangles (see below), set the video to start just after the puck leaves the launcher and end just as the pucks reach the retaining wires.
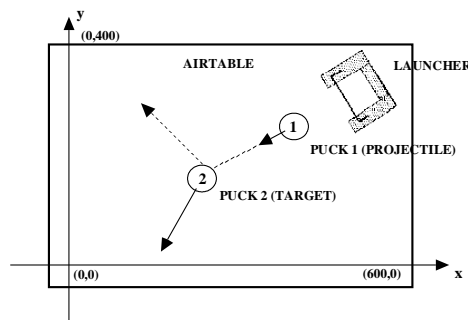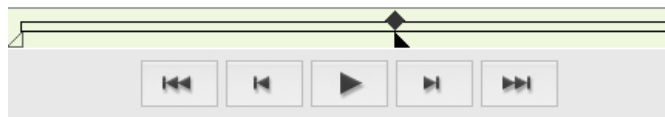

8. Save the movie to the desktop and copy it to your computer with a memory stick.

Digitization of the Movies and Tabulation of Data
1. Begin data analysis when the projectile puck clears the rubber band – it can rub on the surface of the projectile as it leaves the launcher. Make sure the video ends when the puck hits the retaining wire. *If you need to re-edit your video using **VideoPoint Capture**, please do so.*

2. Open **VideoPoint Fundamentals** (the black/green eye), then **File->Open->Movie**.

3. ***You do not need to calibrate your distance or rotate the coordinate system. Here's why:***
   Simplifying Assumptions about units/calibration: Since there is no absolute value (such as g) to find in this experiment, we will use CCD pixel values directly as distance. The time interval of 1/30 sec between successive images is also fixed so we will work in terms of frame number instead.

4. [DT1] Note where the origin is located (you will have negative x and y velocities in this lab, this is why!). Sketch your video collision and mark where the origin is located.

5. **Digitize points:** Click on the magnifying glass. Take S1 (Series 1) to be the projectile puck. Position the cursor at the center of S1 and click. You can see the point marked and the cursor moves to the next position. Continue to click the center of S1 until you have data for each frame and a message box informs you that you have completed the data series.

6. Chose the option "Track another point." Center the cursor on puck S2 (Series 2) and click. The new data points will have a new color. *Note: Until the collision occurs, S2 doesn't move. Keep clicking, S2 will begin to move.* Stop when the movie ends (dialog appears).

7. Click continue – this will bring you to the data page. In **File -> Export** select **LoggerPro(*.txt)**. Save the file.

Graphical Analysis – Study I: Elastic Collision
1. Open **Graphical Analysis**, select **File -> Import**, and open your data file.

2. Plot X and Y for both pucks on the y-axis and Frames on the x-axis.   Your plot will have 4 distinct lines. Be sure to name your columns so can distinguish between these values.

3. [DT2] Examine your data. Where does the collision between pucks occur? Where do the pucks hit the retaining wire? Write down the locations/time. *As for units, remember it's Frame number for time and pixels for distance. It is more convenient and we can still see momentum conservation.*

4. [DT2] Write down a few observations about your video and how it corresponds to the data. Does anything look funny with your data? Does this correspond to anything you noticed in the video? What should be the velocity of puck 2 before the collision?

5. [DT3] Find the velocity before the collision. Highlight (click-and-drag) the portion of the data before the collision that is good for X and Y for both pucks. Find the slope (+/- error) with a linear fit. Repeat this procedure to find the velocity after the collision.

6. [DT3] What are the outstanding features of your data? When is the velocity constant? Why?

7. [DT4] Momentum is a vector $\vec{p}=m\vec{v}$ and can easily be broken into components. For example the component in the x-direction of puck 1 can be calculated as $p_{x1}=m v_{x1}$. Calculate the momenta before/after the collision in both directions.

8. Assume mass is without uncertainty and calculate δp_{x1} (same relative uncertainty as v_{x1}).

9. [DT5] The momenta of individual objects are not conserved, the TOTAL momentum always is (as long as you take the ENTIRE system into account). Add up the momentum in each direction before/after the collision. For example $p_{xi} = p_{x1i} + p_{x2i}$, $\delta p_{xi} = \sqrt{(\delta p_{x1i})^2 + (\delta p_{x2i})^2}$.

10. [DT5] Is momentum conserved in the x-direction? In the y-direction?

11. [DT6] Is kinetic energy conserved? Remember that energy ISN'T a vector quantity, so work with the total velocity before/after the collision. You can skip the error calculation here.

Study II: Other collisions *Choose ONE of the following.*

1. **The Bounce:** Fire a single puck off a retaining wire (just one collision) – don't use the launcher, just push the puck so it cleanly bounces off one wall. **As you perform the analysis, you will notice that this case is clearly different than the collision.** Please describe how and why. Remember momentum is ALWAYS conserved as long as you've taken the entire system into account.

2. **Inelastic Collisions:** Using a light set of pucks (black bottoms) equipped with velcro, examine inelastic collisions. Make a video that ends after the joined pucks hit the retaining wires. **Is momentum conserved in an inelastic collision?**

3. **Small mass/big mass:** Unless you performed Study I with two obviously different sized pucks, do so now.

Study II (all cases): Use the same analysis procedure as the elastic collision in Study I
- Remember to measure the new masses!
- Make a new data tables as needed.
- Determine whether momentum and energy are conserved in your collision.

You have now completed data collection required in the laboratory.
Study I: You should have filled in the data tables and determined whether momentum/energy were conserved.
Study II: You should have repeated the analysis from **Study I** (adjusting as necessary) to determine whether LINEAR momentum/energy were conserved. You do not need to quantify any angular motion in this system.

IV. Discussion
1. **For each study:** Was momentum conserved? If not why? HINT: what other types of momentum are there? Did you observe any behavior consistent with angular momentum?

2. **For each study:** Was kinetic energy conserved? If not why? When answering these questions, be sure to use the vocabulary of collisions (elastic vs. inelastic).

3. Why didn't we treat potential energy in our calculations?

4. What role did friction play in the lab?

Study I: Elastic Collision

TABLE 1	Puck Masses (grams)	Sketch Puck Trajectories:
Puck 1 (projectile)		
Puck 2 (target)		

TABLE 2: Record positions (ignore uncertainty)

	Collision position	Wire Collision (if any)	Observations:
Frame #			
X1 (px)			
Y1 (px)			
X2 (px)			
Y2 (px)			

TABLE 3: Velocity (include uncertainty from slope)

Before Collision		After Collision		Outstanding Features:
v_{x1}		v_{x1}		
v_{y1}		v_{y1}		
v_{x2}		v_{x2}		
v_{y2}		v_{y2}		

TABLE 4: Individual Momenta of Pucks 1&2 (include uncertainty calculation)

Before Collision		After Collision	
p_{x1}		p_{x1}	
p_{y1}		p_{y1}	
p_{x2}		p_{x2}	
p_{y2}		p_{y2}	

TABLE 5: System Momentum

Before Collision		After Collision		Conserved (y/n)?
P_x:		P_x:		
P_y:		P_y:		

TABLE 6: Conservation of Energy (remember it isn't a vector! ignore uncertainty)

Kinetic Energy	Before Collision	After Collision	Conserved (y/n)?
$K = 1/2 mv^2$			

Study II: _____ **(please indicate your choice)**

TABLE 1	Puck Masses (grams)	Sketch Puck Trajectories:
Puck 1 (projectile)		
Puck 2 (target)		

TABLE 2: Record positions (ignore uncertainty)

	Collision position	Wire Collision (if any)	Observations:
Frame #			
X1 (px)			
Y1 (px)			
X2 (px)			
Y2 (px)			

TABLE 3: Velocity (include uncertainty from slope)

Before Collision		After Collision		Outstanding Features:
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