

LAB #3: COLLISIONS IN TWO DIMENSIONS

BEFORE YOU COME TO LAB

- Read the writeup for this lab, and plan how you will approach it intellectually.
- Consider the optional PreLab problem set attached.

A. Introduction

The two parts to this lab both involve the motion of “hockey pucks” on an essentially frictionless air table. The air flows out through a set of small holes in the surface of the air table, which cancels out the normal force of gravity, and the pucks move freely in the plane. You will use the video camera and VideoPoint software to analyze their motion.

In the first experiment, two pucks are launched with some initial speeds and directions. They then collide, and head off with different speeds and directions of motion. Since there is no external horizontal force acting on the pucks, the sum of their vector momenta should be conserved (*i.e.*, should be the same before and after the collision). Your experiment is to confirm this fundamental fact, by direct measurement of the components of the vector velocity (and vector momenta). You will also check whether kinetic energy was conserved in the collision. Of course, your measurements can only confirm anything to within some experimental uncertainty, which will be part of your analysis.

In the second experiment, you will study a totally inelastic collision, and check whether energy and momentum are conserved in this case.

B. General Instructions

Start by making a video of a simple collision between two pucks. Be sure to include a meter stick in the camera's field of view, for use in scaling your movie. Weigh each puck to determine its mass so that you can later convert its velocity to momentum.

Check that pucks do not glide in any particular direction when placed at “rest” on the air table. If they do, adjust the three leveling feet on which it stands. *Don't spend too much time on this – you'll never make it perfectly level.*

Immediately after opening VideoPoint, you should tell the system that you want to measure the positions of 2 objects in each frame, rather than 1. Then you will want to pick off the coordinates of the 2 pucks. VideoPoint makes it easy to pick off the coordinates of Puck 1 in Frame 1, then of Puck 2 in the same frame, and then Puck 1 and Puck 2 in Frame 2, *etc.*

To do this:

- Check that, in the Options menu item on the movie screen, both the AutoFrame Advance and Auto Point Advance options have check marks beside them.
- Pick off the location of the first puck on the first frame, then click on Edit / Leave/Hide Trails.
- Move to the second puck, and pick off its location. Then click on Edit / Leave/Hide Trails again.
- The movie should automatically advance to the second frame, while showing the “trails” from Frame 1. If you continue to click first on Puck 1, and then on Puck 2, in each frame, the data sequence should continue from frame to frame without help from you. (If, at any time, you want to change whether a puck's trail is displayed or not, just use the Leave/Hide Trails button again, for whichever puck you want to affect.
- If your pickoff sequence gets confused, and you need to remove a point or to start over, you can use the Edit/Clear Selection on Frame and Edit/Clear Selection on All Frames commands to remove erroneous points. (Selecting a point may require carefully clicking on its position in the *Movie* screen. A selected point will appear with a double circle.)

After you have entered all your coordinates, transfer them to an Excel spreadsheet for your analysis. Make the usual graphs of x - and y -position, x - and y - velocity, *etc.* Make separate graphs for each set of points for which you wish to determine a puck's x or y -velocity. Use WPTools and a Linear Fit (or better, Polynomial Fit of order 2) to determine the velocity and the estimate of the uncertainty.

After converting velocities to momenta, you can see if (to within your measurement accuracy) momentum is conserved. Show your logic, and justify your conclusions, in your notebook.

C. Nearly Elastic Collisions

Use pucks **without** Velcro bands in part C. Make and analyze a movie of an “elastic” collisions between the two pucks. Report results as to conservation of momentum of the system of two pucks separately for its x - and y - components.

Do you find that the sum of the kinetic energies of the two pucks is the same after the collision as before (*i.e.*, that kinetic energy is conserved in the collision)? If not, where did the “missing” energy go?

A single movie suffices for the study of both energy and momentum. It's better if the initial velocities of the pucks are not parallel to an edge of the air table.

D. Totally Inelastic Collisions

Use pucks **with** Velcro bands. *If there are **white** Velcro bands at your Lab table, add these to plain pucks. If there are pucks with **black** Velcro bands, do not try to remove the Velcro.*

Make and analyze a movie of the inelastic collision of these pucks. Was momentum conserved here, according to your data? What fraction of the initial kinetic energy remained after the collision?

Appendix: Error Propagation

The total x -momentum in a collision of two pucks of masses m_1 and m_2 is $P_x = m_1 v_{1,x} + m_2 v_{2,x}$, so the uncertainty in P_x is given by

$$\sigma_{P_x} = \sqrt{v_{1,x}^2 \sigma_{m_1}^2 + m_1^2 \sigma_{v_{1,x}}^2 + v_{2,x}^2 \sigma_{m_2}^2 + m_2^2 \sigma_{v_{2,x}}^2}.$$

Likewise, the uncertainty on their kinetic energy, $KE = \frac{m_1(v_{1,x}^2 + v_{1,y}^2)}{2} + \frac{m_2(v_{2,x}^2 + v_{2,y}^2)}{2}$, is given by

$$\sigma_{KE} = \sqrt{\left(v_{1,x}^2 + v_{1,y}^2\right)^2 \frac{\sigma_{m_1}^2}{4} + m_1^2 \left(v_{1,x}^2 \sigma_{v_{1,x}}^2 + v_{1,y}^2 \sigma_{v_{1,y}}^2\right) + \left(v_{2,x}^2 + v_{2,y}^2\right)^2 \frac{\sigma_{m_2}^2}{4} + m_2^2 \left(v_{2,x}^2 \sigma_{v_{2,x}}^2 + v_{2,y}^2 \sigma_{v_{2,y}}^2\right)}.$$

PRELAB Problems for Lab #3: Collisions in Two Dimensions

1. Referring to the figure on the following page, make sketch plots of the behavior of v_x and v_y for *each* of the two pucks as a function of time. Although you don't know the scales of either position or time, be careful to get the signs correct, and to show at least roughly correct relative magnitudes.

2. Avik and Venus are calculating the momentum and kinetic energy of a puck on their air table. The puck is moving parallel to the x axis with a speed of 12.0 ± 0.2 m/sec, and its mass is 30.00 ± 0.01 grams.
 - a) What is the x-component of the momentum of the puck, and what is its uncertainty? How much would the uncertainty change if the mass were precisely known (*i.e.*, if the uncertainty in the mass was negligibly small) ?

 - b) What is the kinetic energy of the puck, and what is its uncertainty? How does the fractional uncertainty in kinetic energy compare to the fractional uncertainty in momentum?

3. Deduce the formulae in the Appendix of this Lab, possibly referring to sec. B.8 of the Appendices to the Lab Manual.



Figure for PreLab #1. This is the final frame of a video of two colliding pucks. The y -axis points toward the top of the page, and the x -axis points to the right.

