PHYS 256 – University Physics I Laboratory

Experiment 3: Collisions

The third experiment is a three-week series of activities designed to investigate momentum and energy of systems in a variety of types of collisions.

- In part 3A: Linear Collisions with a Fixed Object you will study collisions between an air track glider and different objects attached to the fixed end of the air track, and compare the impulse experienced by the glider during the collision to the change in momentum of the glider.
- In part 3B: Linear Collisions between Two Objects you will study one-dimensional collisions between two objects by colliding two gliders on an air track. Collisions ranging from completely inelastic to (nearly) elastic will be studied.
- In part 3C: Rotational Coupling Collision you will study an inelastic collision between a heavy ring dropped onto a rotating disk. The angular momentum and rotational kinetic energy of the system before and after the collision will be compared.
- In part 3D: Peer Review and Report Preparation you will have an opportunity to refine your measurements from the first three weeks, share your results with other students, and polish your laboratory report for this experiment.

Key questions to answer during this series include:

- Under what conditions are linear and/or angular momentum conserved when two objects collide?
- Under what circumstances is kinetic energy conserved when two objects collide?

Once again, you should change to a different lab partner than you worked with for either Experiment 1 or 2 and continue working with this partner for the duration of this experiment. Each of you should continue to make good notes in your laboratory notebooks describing your experimental methods and results and the outcomes of your simulations as you work together to build a portfolio of material that can be used to assemble your report for this experiment. Each of you should prepare your own individual draft report for this experiment and bring it with you the fourth week for a session where you can work on improving it before it is submitted the following week.

Experiment 3: Collisions

3.A. Linear Collisions with a Fixed Object

This week you will begin your study of collisions by investigating the collision of a glider with a fixed object. You will measure the momentum of the glider before and after the collision as well as the force on the glider during the collision, and use these results to investigate the Impulse-Momentum principle.

Background

Impulse-Momentum Principle

When we apply the momentum principle

$$\vec{F}_{\text{net}} = \frac{\mathrm{d}\vec{p}}{\mathrm{d}t}$$

we must always consider the *system* that we are applying it to. In a collision between two objects we often consider the system to consist of *both* objects. In that situation, we understand from reciprocity (Newton's Third Law) that the force on object A by object B during the collision is equal and opposite to the force on object B by object A. So the internal forces on the system cancel in pairs, resulting in no net force on the system due to such interaction forces. ***Only forces external to the system can change the momentum of the system.***

When a small object collides with a large, massive, "fixed" object (think of a ball bouncing off the Earth's surface) the "fixed" object will experience a change in momentum that is exactly opposite the change in momentum of the small object (the momentum of the system will be conserved). But the fixed object has such a large mass that its change in velocity is not noticeable. In these situations, we often consider the system to be just the moving object. We can rearrange the momentum principle as

$$\mathrm{d}\vec{p} = \vec{F}_{\text{net}}\,\mathrm{d}t$$

and integrate over the duration of the collision to obtain

$$\Delta\vec{p} = \int \vec{F}_{\text{net}}\,\mathrm{d}t$$

This is the *impulse-momentum principle*. The left-hand side of this relation is the change in momentum of the object and the right-hand side is the *impulse* exerted on the moving object by the fixed object during the collision. It can be expressed as the average force multiplied by the time during which the force acts. Units are N·s or, equivalently, kg·m s^{-1} (the same as momentum).

Coefficient of Restitution

One parameter that can be used to characterize a collision is called the *coefficient of restitution* ε. It is defined as the ratio of the relative speed of the objects after the collision to the relative speed before the collision. In this week's scenario where we have an object colliding with a massive fixed object this simply reduces to the ratio of the final speed to the initial speed of the moving object. When the coefficient of restitution is 1 the system will have the same speed both before and after the collision. Therefore, it will not lose any kinetic energy. Such a collision is referred to as *elastic*. On the other hand, if there is any loss of kinetic energy, then the collision is classified as *inelastic* and the coefficient of restitution will take on values in the range $0 \le \varepsilon < 1$. A special case of an inelastic collision occurs when the objects stick together. In this situation, the relative speed of the objects after the collision is zero, the coefficient of restitution is zero, there is a maximum loss of kinetic energy, and the collision is referred to as *completely inelastic*.

Equipment/supplies provided:

- Air track, glider, sonic ranger, and interface box.
- Force probe with various attachments

Students are responsible to have:

- A bound laboratory notebook for recording observations and data.

Experimental Tasks:

1. ***Measure and compare the impulse and the change in momentum of a glider colliding with a fixed object.***

   1.1. Set up the air track with a sonic ranger on the side with the air supply hose and a force sensor on the opposite end. Attach a spring to the force sensor in such a way that the glider will collide with the spring. Your goal is to measure (and model) the force on the glider during the collision and its momentum before and after the collision.

   1.2. Set up Lab Assistant to measure the glider position using a sonic ranger channel and the force on the glider using an analog input channel. Enter the mass as a constant and set up derived channels for the velocity and momentum of the glider.

   1.3. Calibrate the position and force channels. To calibrate the force probe you will need to hang the force sensor vertically and attach known masses to it using a hook. You should "tare" (i.e., zero) the sensor (with no mass hanging from it) in between calibration measurements and you should tare it again after you set it back horizontally on the air track support when you are done with calibration.

   1.4. Within Lab Assistant, set up calculated values for the <u>impulse</u> experienced by the glider during the collision as the definite integral of the force, for the <u>average momentum</u> as the mean value of the momentum channel, and for the <u>momentum uncertainty</u> as the standard error of the momentum channel.

   1.5. The force probe can acquire data faster than the sonic ranger. You can use this fact to improve the sensitivity of the force measurement and the impulse calculation. Use the *Timing* button on any of the data waveform tabs (or the *Settings > Timing Parameters* menu option) to set the sonic ranger period to 25 ms and the analog input period to 1 ms. The sonic ranger will make one measurement every 25 ms and the force probe will make one measurement every ms. There will be 25 force measurements for every position measurement.

   1.6. Ensure that the force sensor is firmly secured and that the attachment is not overly tightened onto the sensor. With the air supply on gently push the glider toward the force sensor and acquire data over a period that includes before, during, and after the collision of the glider with the force sensor.

   1.7. View the position, force, and momentum waveforms on the waveform graph and zoom in to focus on the interval that includes before, during, and after the collision. Using the cursors, bracket a region where the momentum is nearly constant BEFORE the collision and use the *Calculate* button to add the momentum (and its uncertainty) before the collision. Repeat this for after the collision by moving the cursors to a region after the collision. Finally, place one cursor just before the collision (where the force is still approximately zero) and the other just after the collision (where the force is back to approximately zero) and calculate the impulse.

You will now have three new rows in your data table. It will be helpful to use the comment field to label these rows as before, after, and during the collision. To do so you can right-click on a row to bring up a pop-up menu that will include an *Edit Comment* option.

1.8. Find the change in momentum as the final momentum minus the initial momentum (and find the uncertainty in this value using error propagation). Compare this result to the impulse. Are these values in agreement using the difference criterion for comparing two measured quantities (see Appendix B, in particular the section titled *Comparing Two Quantities*).

1.9. Compute the coefficient of restitution for this collision as the ratio of the final speed to the initial speed. In this case, since we are just looking at one object, this will be the same as the ratio of the magnitude of the final momentum to the magnitude of the initial momentum.

1.10. Repeat for the rubber bumper attachment on the force probe and then for the modeling clay.

2. ***Model the collision in VPython with the coefficient of restitution as an adjustable parameter.***

2.1. Using a web browser (preferably Chrome), copy the starter code for this experiment provided at physics.wku.edu/up/phys256/ into a new VPython program. This code simply draws a surface (air track) and a glider.

2.2. Add the appropriate physics to this code so that the glider will move if given an initial velocity.

2.3. Use an `if-then` statement test to see if the object has collided with the end of the track. If so, then use the coefficient of restitution to change its velocity (and momentum) to an appropriate new value.

2.4. Based upon your experimental measurements should you include any additional forces such as friction or air resistance into this model to make it more realistic? If so, make necessary changes to the model to make it more realistic.

For Next Lab Session

For next week you and your partner should prepare draft reports describing the data you collected this week. These partial reports will not be graded, but will form the foundation of a subsequent lab report that WILL be part of your course grade. Bring your reports to next week's lab so we can discuss the various results obtained as a group. The report should include Introduction, Experimental Procedure, Data and Analysis, and Conclusion sections.

- Complete the pre-lab questions for next week.