Experiment 9: Momentum

Physics is often concerned with what are called "conserved" quantities. Mass and energy are two examples of quantities that must remain conserved for a closed system. Conservation of a quantity is a clue to a physicist that there is some underlying principle to be discovered. Perhaps the oldest and most famous conservation principle is the conservation of momentum. This is embodied in Newton's First Law, written in 1687. It states that an object in motion will remain in motion unless acted upon by a net force. Conservation of momentum will be studied through one dimensional collisions.

One Dimensional Collisions

The concept of momentum is fundamental to an understanding of the motion and dynamics of an object. The momentum of an object is defined to be

$$\overrightarrow{p} = m\overrightarrow{v} \tag{1}$$

For multiple objects in a system, the total momentum is a vector sum of the individual momenta. As a consequence of Newton's second law

$$\overrightarrow{F_{ext}} = \frac{d\overrightarrow{p}}{dt} \tag{2}$$

For a closed system, the total momentum cannot change unless acted upon by an outside force. This conservation of momentum is a powerful tool for physicists to analyze the behaviors of systems of particles. The simplest application of this concept is in the one-dimensional collision between two particles. There are two special kinds of collisions which are particularly easy to analyze: the perfectly elastic and perfectly inelastic collisions. While both of these processes conserve momentum, in the perfectly elastic collision the total kinetic energy, KE, is also conserved. Examples of perfectly inelastic collisions include objects which collide and stick together and objects which break apart due to internal forces.

In the analysis of a perfectly elastic one-dimensional collision, consider two objects with masses m_1 and m_2 and initial velocities v_1 and v_2. After the collision, the objects will have new velocities v_1' and v_2', where all velocities are assumed to be in the positive direction. Conservation of momentum demands that the total momentum must be the same before and after the collision. This can be stated as:

$$m_1 v_1 + m_2 v_2 = m_1 v_1' + m_2 v_2' \tag{3}$$

Since the kinetic energy is also conserved in this kind of collision, we have:

$$\frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 = \frac{1}{2} m_1 v_1'^2 + \frac{1}{2} m_2 v_2'^2 \tag{4}$$

If we know the masses and the initial velocities, it is possible to solve for the final velocities of the two objects. After a number of algebraic manipulations, the solutions are:

$$v_1' = \frac{m_1 - m_2}{m_1 + m_2} v_1 + \frac{2m_2}{m_1 + m_2} v_2 \tag{5}$$

$$v_2' = \frac{2m_1}{m_1 + m_2} v_1 + \frac{m_2 - m_1}{m_1 + m_2} v_2. \tag{6}$$

Again, all velocities are presumed to be along the positive direction. If a velocity is negative, it is then directed along the negative direction.

The perfectly inelastic ("sticky") collision is somewhat easier to analyze as only Equation 3 can be used. The energy equation used in the analysis depends on which case is being studied. If the collision starts with a single object which breaks into two, then we have $v_1 = v_2$. If there are initially two objects which end up stuck together, then we have $v_1' = v_2'$. The analysis is then straightforward.

Most collisions are neither perfectly elastic nor perfectly inelastic but partially elastic. This means that a certain fraction of the kinetic energy is lost to the system but the objects do not stick together. In this case, it is valuable to define a quantity called the coefficient of restitution

$$e = \frac{v_1' - v_2'}{v_2 - v_1} \tag{7}$$

For a perfectly elastic collision, $e = 1$ and for a perfectly inelastic collision (starting with two bodies and ending with one), $e = 0$. For most real collisions $0 < e < 1$.

Experimental Objectives

In the laboratory you have air track, two gliders, *two* photogates, a scale, and additional masses that can be placed on the gliders. The glider carts have velcro on the ends to create a "sticky" collision or rubber bands for an elastic collision. The photogates are connected to a computer data acquisition system and velocity data can be collected using the Data Studio software (ask your TA about using this software in your experiment and setting up the two photogates). Remember, velocity is a vector, so *you* must assign it a direction - the Data Studio software cannot do this. Using this equipment:

- Devise an experimental procedure to observe and verify linear momentum and energy conservation laws. Repeat your experiment for different masses and different velocities of the glider (including zero initial velocity for one of the gliders). Do five different collisions and repeat each one to get consistent data.
- Devise an experiment to study "perfectly" inelastic collisions. Verify whether or not momentum and energy are conserved in this type of collision.

A full lab report is not necessary for this lab. Answer the questions on the following page and turn it in with your signed datasheet.

PHYS 123, Lab 9 Questions

Name: **CWID:**

Write your answers on a separate sheet and attach your signed datasheet when turning it in. You must show all of your work for full credit. Make it clear to me you understand what you're doing. Any graphs or tables should be made via computer software and attached to this handout.

1. Answer the following questions using the data you acquired in this experiment:

   (a) For the two experiments, create data tables for the different cart masses (M_1, M_2), the initial cart velocities, the final velocities, the initial and final momentums and kinetic energies. Give a brief description of the collisions.

   (b) Explain if momentum and kinetic energy are conserved in the collisions. What are the sources of error?

   (c) Determine if the collisions are perfectly elastic or inelastic by using the concept of the coefficient of restitution.