PHY 251
Lab 8 – Conservation of Momentum and Energy

Objectives:
The objective of this lab is to determine the velocity of a projectile using the law of conservation of momentum and the law of conservation of energy.

Theory:
Newton's second law of motion states that the time rate of change of momentum for an object is equal to the net force acting on the object. In a collision between two objects, each one exerts a force on the other. These forces are equal and opposite, hence the net force acting on the system at impact is zero, and the total momentum of the system remains unchanged. Momentum is therefore conserved in a collision, regardless of the nature of the collision.

During the collision, the objects become deformed and a certain amount of energy is required to deform them. If the objects are not elastic, they will remain permanently deformed and the energy used to deform them cannot be recovered. Inelastic impact can be illustrated by the ballistic pendulum in which a ball is fired into a pendulum bob, with the ball remaining embedded in the bob after the collision. If the pendulum bob is initially at rest and the projectile strikes the pendulum with a velocity v (note the lowercase), then conservation of momentum requires that the momentum of the system immediately before the collision equal the momentum of the system immediately after the collision.

$$mv = (m+M)V \qquad \text{(Eq. 1)}$$

In this expression, m is the mass of the ball, v is the velocity of the ball before the collision, M is the mass of the pendulum bob, and V is the velocity of the bob with embedded ball after the collision (note the uppercase).

As a result of the collision, the pendulum with embedded ball swings about its point of support and the bob rises to a height h above its initial position. By the law of conservation of energy, we therefore must have the kinetic energy of the pendulum bob and ball system immediately after the collision equal to the potential energy of the pendulum bob and ball system after the collision.

$$\frac{1}{2}(M+m)V^2 = (M+m)gh \qquad \text{(Eq. 2)}$$

This equation gives a way to determine V. By substituting this value of V and the values of the masses m and M into the momentum equation, the value v of the speed of the ball can be determined. This method is one which is often used to determine the velocity of a rifle bullet with a heavy block of wood as a pendulum bob.

The apparatus used in this experiment is a combination of a ballistic pendulum and spring gun. The pendulum bob consists of a massive cylinder hollowed out to receive the ball. This bob is suspended by a strong, lightweight rod pivoted at its upper end. The projectile is a metal ball which is fired into the pendulum bob and held in place. A marker must be placed on the pendulum bob to indicate the location of the center of mass of the loaded pendulum. When the projectile is fired into the bob, the pendulum arm swings upward and is caught at its highest point by a pawl which engages a tooth in the curved rack.

<u>Procedure:</u>

1. Measure and record the mass M of the pendulum (in kilograms) by removing it from the stand (be careful not to lose the nut) and placing it on a digital balance.

2. Measure and record the mass m of the ball (in kilograms).

3. Determine the center of mass of the pendulum and ball system by balancing the pendulum with embedded ball on a sharp edge (this point may already be marked from previous uses, but you should confirm it).

4. Reconnect the pendulum to the stand and allow it to hang freely. With the pendulum hanging in its lowest position, measure and record the distance L (in meters) from the center of the pivot point to the center of mass determined from Procedure 3.

5. With the pendulum at rest, fire the ball from the first setting of the spring gun into the pendulum bob and determine the number of the notch on the curved scale reached by the pawl when it catches the pendulum. Do this four more times.

6. From these measurements, compute the average value of the position of the pendulum on the rack. Set the pendulum with the pawl engaged in the notch with corresponds most closely with this value. Measure the angle θ with respect to the vertical.

7. Repeat Procedures 5 and 6 with the second setting.

<u>Calculations:</u>

1. From the data of Procedures 4-6, compute the vertical distance h ($= L - L\cos\theta$) through which the center of mass of the loaded pendulum was raised as a result of the collisions.

2. Using h and the law of conservation of energy, compute the value of the velocity of the pendulum bob and ball just after collision.

3. By use of the law of conservation of momentum, calculate the velocity of the ball before the collision.

4. Repeat Calculations 1-3 for the data from Procedure 7.

<u>Questions:</u>

1. Using the data of your experiment, calculate
    a. the kinetic energy of the ball just before impact
    b. the kinetic energy of the loaded pendulum bob just after impact
    c. the loss of energy during this impact

2. What is the fractional loss of energy during this impact? What became of the energy loss?