Chapter 4

Energy and Momentum - Ballistic Pendulum

4.1 Purpose

. In this experiment, energy conservation and momentum conservation will be investigated with the ballistic pendulum.

4.2 Introduction

One of the basic underlying principles in all of physics is the concept that the total energy of a system is always conserved. The energy can change forms (i.e. kinetic energy, potential energy, heat, etc.), but the sum of all of these forms of energy must stay constant unless energy is added or removed from the system. This property has enormous consequences, from describing simple projectile motion to deciding the ultimate fate of the universe.

Another important conserved quantity is momentum. Momentum is especially important when one considers the collision between to objects. We generally divide collisions into two types: elastic and inelastic. In an inelastic collision, the colliding objects stick together and move as one object after the collision, whereas in an elastic collision the two objects move independently after the collision. Both types of collisions display conservation of momentum.

In this experiment we will be using both conservation of momentum and conservation of energy to find the velocity of an object (ball) being fired from a spring loaded gun. The apparatus we will be using consists of a spring loaded gun which fires a small metal ball into a hanging pendulum. See Figure 4.1. The momentum and energy of the ball then causes the pendulum to swing up a ramp, which will catch the pendulum so that we can measure how high it swung.

When the metal ball is initially fired from the gun, it will have a kinetic energy, KE_i:

$$KE_i = \frac{1}{2}mv_0^2 \tag{4.1}$$

where m is the mass of the metal ball and v_0 is the initial velocity of the ball before it strikes the hanging pendulum.

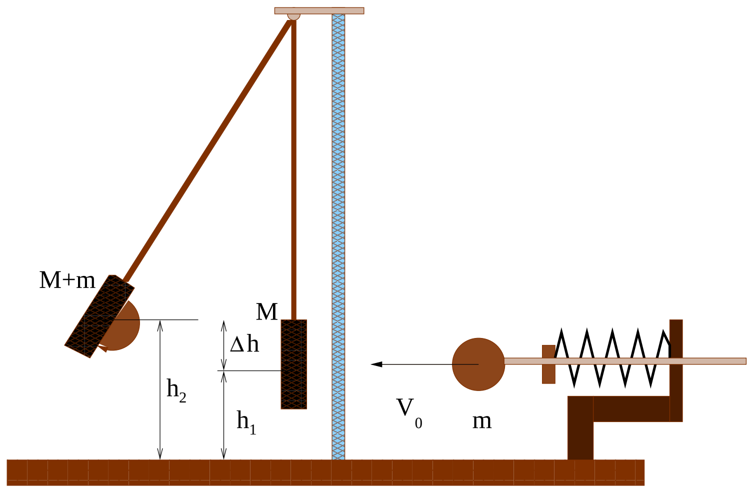

Figure 4.1: Schematic diagram show the components of the ballistic pendulum apparatus

After the collision takes place, and the metal ball is stuck in the pendulum, the pendulum-ball combination has a kinetic energy:

$$KE_f = \frac{1}{2}(m + M)v_f^2 \tag{4.2}$$

where M = mass of the pendulum and v_f is the velocity of the pendulum/ball moving together.

As the pendulum-ball swings, its kinetic energy is converted to potential energy. When it reaches its highest point, all of its energy has been converted to potential energy:

$$PE_f = (m + M)g(\Delta h) \tag{4.3}$$

where g = gravitational acceleration (9.8 m/s^2) and Δh is the change in height of the pendulum-ball combination (final height of pendulum-ball combination - initial height of pendulum-ball combination).

We can look at the entire process in a step-by-step manner and see that, because of conservation of energy and conservation of momentum, all of these steps are related to each other. Therefore, if we can measure the total energy or momentum of the system at any time during the experiment, we can find out everything else about the system. The easiest thing to measure in this setup is the potential energy in Equation 4.3 (mainly because nothing is moving at that point). By doing this, we will work backwards to find out how fast the metal ball is shot out of the gun. Finally for comparison, we will use a photo-gate timing system to measure the speed of the ball when it is shot out of the gun.

4.3 Equipment:

Ballistic pendulum apparatus, ruler, photo-gate timing system.

Figure 4.2: The ballistic pendulum with the pendulum on the ratchet mechanism which prevents the pendulum ring from falling from its maximum height.

4.4 Procedure:

A photograph of the ballistic pendulum is shown in Figure 4.2 with the photo-gate timing system.

In the first part of the experiment, we will measure the final potential energy of the pendulum in order to find the initial velocity of the metal ball. In the second part of the experiment, the initial velocity of the metal ball will be measured using the photo-gate timing apparatus to directly measure the time it takes for the ball to move a fixed distance.

- Using the scales, find the mass of the metal ball,m. The mass of the pendulum, M, is 0.20 kg.
- Using a ruler, measure the distance from table to the center of the pendulum ring. A small red 'dot' marks the center of the pendulum ring.
- Place the ball on the gun and push it against the spring back to the second or third detent position. The first detent position produces insufficient v_o. Always use the same position of the spring gun for all data.
- Fire the metal ball into the ring and measure the distance from the table to the center of the pendulum ring when the pendulum/ball combination is stopped at its highest peak.
- By conservation of energy, the potential energy at the highest peak is equal to the kinetic energy immediately after the collision. Using equation 4.2 and equation 4.3, we have:

$$KE_f = \frac{1}{2}(m+M)v_f^2 = (m+M)g(\Delta h) = PE_f \tag{4.4}$$

solving for v_f we have:

$$v_f = \sqrt{2g(\Delta h)} \tag{4.5}$$

- By conservation of momentum, the momentum of the system after the collision must be equal to the momentum of the system before the collision. Since **Momentum = (mass) x (velocity)**, we have:

$$(m + M)v_f = mv_0 \tag{4.6}$$

This can be used to find the initial velocity v_0:

$$v_0 = \frac{(m + M)}{m} v_f \tag{4.7}$$

Using equation 4.5 for v_f:

$$v_0 = \frac{(m + M)}{m} \sqrt{2g(\Delta h)} \tag{4.8}$$

Using equation 4.8 and the values for M, m, g and Δh, calculate v_0

- Repeat the measurement two more time. Calculate the average (mean) value of the three measurements of v_0.

- Move the ballistic pendulum to the photo-gate setups where your teaching assistant will help you align the apparatus with the photo-gates and timer.

- **Push the pendulum up the ramp and out of the way.** Align the photo-gates so the ball with travel through the photo-gates **without hitting either photo-gate** or other objects like wires when the gun is fired. The first photo-gate should be located just ahead of the position where the ball leaves the spring gun. Use a box to catch the ball after it passes through the second photo-gate.

- Measure the distance between the centers of the two photo-gates. Verify the timer is in 'pulse' mode. Push the reset button on the timer. The timer will start when the ball passes the first photo-gate and stop when the ball passes the second photo-gate.

- Fire the ball into the box. Record the time. Repeat the measurement two more times. (Always check the alignment each time the spring gun is 'reloaded'.)

- Calculate v_0 for each of the time measurements using $v = \frac{distance}{time}$. Calculate the mean (average) of the three values.

- Calculate the percentage difference between v_0 from the first part of the experiment with v_0 measured with the photo-gate timer.

4.5 Questions:

1. How does the mean of your v_0 from the first part of the procedure using energy and momentum conservation compare with the value from the measurement from the photogates and timer. What is the percentage difference between the averages (means) of the two different measurements of v_0?

2. List possible sources of error in each of the two measurements of v_0. Which procedure do you think is more accurate? Why?