Ballistic Pendulum

Name:	Teammates:

Introduction

The last two weeks have shown us the importance of conservation laws. These laws provide extra “tools” that allow us to analyze certain aspects of physical systems and be able to predict the motion of objects in the systems without using more complicated analysis. Even in situations wherein we cannot exactly solve the motion, these laws are quite useful.

When we did run the last two experiments, we found that the data did not support a 100% conservation of energy. We attributed the discrepancy to experimental errors and to losses to friction and air resistance. Actually, that there is another law at work that limits these conservation laws: the Second Law of Thermodynamics.

The Second Law of Thermodynamics

While the total amount of energy does not change, the second law of thermodynamics puts limits on the amount of usable energy that can be transferred. One of the consequences of this law is that the total amount of usable energy that comes out of any process will be less than the total amount of energy that went into the process. The difference between the total amount of energy input and the usable energy output is expended as waste heat. Take, for example, a ball that is dropped from some height above the ground. As it falls, air acts upon the ball to slow it down. In doing so, some of the initial potential energy of the ball is converted to greater kinetic energy of the molecules of air, which makes them slightly warmer.

This brings us to the issue of efficiency, which is a measure of the amount of usable energy that is generated during any type of transfer. If a transfer is very efficient, then the amount of usable energy that is generated is almost equal to the total amount of energy that went into the transfer. This means that very little waste energy will be produced. An inefficient transfer is one in which most of the energy going into the process is converted to waste heat. For example, a fluorescent light bulb converts about 20% of the electrical energy that runs through it into visible light energy.

Ballistic Pendulum

Fig. 1: Ballistic pendulum

In lab this week, we are going to look at a series of energy conversions to see how efficiency works. Figure 1 shows a picture of the ballistic pendulum that we will use in this activity. The device is quite simple to operate. Pushing back the spring-loaded piston on the projectile section stores potential energy that can be used to propel a ball. Once the ball has been propelled out of the launcher by pulling the trigger, it collides inelastically with the pendulum, thus transferring momentum to it. The pendulum then swings upward until all of its kinetic energy is converted to potential energy. The angle measuring system on the side of the device stops it at this height, allowing for measurements of the amount of potential energy stored. This potential energy can be compared to the initial kinetic energy to see how efficient the energy is converted.

To find out what the theoretical efficiency of this process is, taking the velocity of the ball leaving the gun piston to be v_{b1} the mass of the ball to be m_b, the mass of the pendulum to be m_p, and the height to which the ball-pendulum rises to be h_f. With this, the efficiency of the energy transfers will be

$$\text{Efficiency} = \frac{PE_{final}}{KE_{initial}} = \frac{2(m_b + m_p)gh_f}{m_b v_{bi}^2}$$

By using conservation of energy and conservation of momentum, show that:

$$\text{Efficiency} = \frac{m_b}{m_b + m_p}$$

Activity

In order to test our model, we will first need to know the velocity of the ball leaving the end of the plunger (v_{bi}). In a previous lab, we did this by projecting the ball horizontally from the table top, measuring how far the ball traveled before hitting the ground, and then calculating the velocity. This week, we are going to use the photogates to measure this quantity, which we will then use in the second half of the activity to measure the efficiency.

1. Place the ballistic pendulum on the tabletop such that the shot ball will have an unobstructed path to the floor. Remove the pendulum portion of the equipment.
2. Place the photogate near the end of the plunger such that the released ball will sail through the photogate opening, with the middle of the ball passing between the LED light/detector.
3. Turn on the Science Workshop software and run the program "ballistic".
4. Place the ball on the plunger and cock the mechanism for firing.
5. Click the "Start" button on the software.
6. Fire the gun, making sure that no one is in the path of the ball and that appropriate measures have been taken to stop the ball after it hits the ground.
7. Record the velocity of the ball
8. Repeat this procedure 4 times and average the velocities. Record these results.

Velocity of ball

	Run 1	Run 2	Run 3	Run 4	Run 5	Avg.
Velocity v_{bi}						

1. What are the systematic errors in this part of the experiment?

2. What are the random errors in this part of the experiment?

3. Can you think of another method for determining the velocity of the ball? (hint: refer to the projectile motion lab)

Once we have the velocity of the ball, we are ready to proceed to the second half of the experiment. Remove the photogate and turn off the software before proceeding.

1. Measure the mass (include the two brass masses at the bottom of the pendulum when doing this) and the length of the pendulum. Return the pendulum to the device such that the ball will be captured by the ball when it leaves the end of the plunger. Measure the mass of the ball.

Mass of the ball = m_b = _____ g Mass of the pendulum = m_p = _____ g

2. Load the ball into the launcher.
3. Making sure that the path is clear, fire the ball into the pendulum. Measure the angle to which the pendulum swings. Use this angle to determine the height to which the pendulum and the ball went. Record this data.

	Run 1	Run 2	Run 3	Run 4	Run 5	Avg.
Angle θ_f						
Height h_f						

4. Repeat this procedure 4 more times.

A. What is the initial momentum of the system made up of the moving mass and the pendulum?

B. What is the initial mechanical energy of the system made up of the moving mass and the pendulum?

C. What is the final mechanical energy of the system made up of the mass and the pendulum?

D. Calculate the efficiency of the energy transfer and compare this to the theoretical value.

$$\text{Efficiency}_{exp} = \frac{2(m_b + m_p)gh_f}{m_b v_{bi}^2} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \qquad \text{Efficiency}_{theory} = \frac{m_b}{m_b + m_p} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

Percent error = ________________

E. What are the systematic errors in this experiment?

F. Do your systematic errors account for your percent difference? Why or why not?