The Ballistic Pendulum

Introduction:

By this time, you have probably become familiar with the concepts of **work**, **energy**, and **potential energy**, in the lecture part of the course. In this lab, we will be studying the transfer of **kinetic energy** to potential energy. For an object with velocity, v, the kinetic energy *(K.E.)* is defined by the following equation:

$$K.E. = \frac{1}{2} mv^2 \tag{1}$$

The MKS unit for energy is the Joule. One Joule is equal to one kilogram•meter^2/second^2. You will notice that this unit is similar to that for the force but with the length unit squared. The work done on an object by a force **F** displaced an amount **x**, is defined as:

$$W = \mathbf{F} \bullet \mathbf{x} \tag{2}$$

or

$$W = Fx$$

if the force and the displacement are in the same direction.

The potential energy describes the amount of work necessary to move a certain mass from one point to another in a force field. The difference in the potentials between the starting point and the ending point is the amount of work or energy necessary to move the mass. For the gravitational force, mg, the potential energy is simply:

$$P.E. = mgh \tag{3}$$

where h is the difference in height from the initial position to the final position.

In the case of the ballistic pendulum, a projectile is launched from a spring loaded gun and is trapped in the base of a pendulum. From conservation of momentum, we can calculate the velocity which the pendulum will move after trapping the ball. We use the equation for a totally inelastic collision to determine this:

$$m_b v_0 = (m_b + m_p)\, v_1 \tag{4}$$

where m_b and m_p are the masses of the ball, or projectile, and the pendulum, respectively.

After the pendulum traps the projectile ball, it will move with a velocity v_1. At the maximum swing height, the velocity of the pendulum is zero and all of the kinetic energy has been converted to gravitational potential energy. Using the principle of conservation of energy, we can relate the maximum swing height h to the velocity, v_1 as follows:

$$\frac{1}{2}(m_b + m_p) \quad v_1^2 = (m_b + m_p)\, gh \tag{5}$$

$$v_1 = \sqrt{2gh} \tag{6}$$

Combining equations (4) and (6), we can solve for the initial velocity of the launcher.

$$v_0 = ((m_b + m_p) / m_b)\sqrt{2gh} \tag{7}$$

This equation shows that by measuring the masses of the pendulum, the ball, and the height of the pendulum swing, that the muzzle velocity of the launcher can be computed. The height difference is measured by measuring the height from the table of the center of mass marked on the pendulum both before and after the collision. The difference between these is the height h.

Procedure:

Part One

1. Make sure the apparatus is level and clamped securely to the table. Use the leveling screws and the bubble level on the apparatus base to level properly.
2. Use one of the Allen wrenches provided to unscrew the pendulum. Carefully remove the screw that holds the pendulum in place. A spacer on the opposite side of the pendulum will fall when the screw is removed. *Make sure that this spacer is replaced when the unit is reassembled.*
3. Measure the mass of the pendulum and the ball on the three-beam balance.
4. Measure the distance between the base and the center of mass of the pendulum (labeled on the pendulum shaft). Make sure the pendulum is hanging vertically. Record this as $h_{initial}$.
5. Place the metal ball on the front of the gun shaft and cock the gun until the shaft is locked in position.
6. Press back the trigger to fire the ball.
7. After the pendulum comes to rest, measure the vertical distance between the base of

the apparatus and the center of mass. Record this measurement as h_{final} . The value of h is the difference between the two height measurements.

8. Repeat steps 5-7 several times and compute the average value of h.
9. Compute the muzzle velocity, v_0, using equation 7.

Part Two

10. Now, you will measure the muzzle velocity by another method. Remove the pendulum trap from the path of the ball. Place your pendulum on the edge of a table and make sure the path it clear in front of it (that there are no people, chairs, et cetera).
11. Measure the height of the pendulum gun from the floor. Record this as h. (Be careful not to confuse the h from part one with the h from part two.) Load and fire the gun, again making sure that the path of the ball of clear of obstacles. Mark the place where the ball lands and measure the range (R) that the ball travels. Use the equation from the collisions and momentum lab relating g, R, h, and v to compute the muzzle velocity from the range and the height.

Part Three

12. Reduce the gun spring tension by unscrewing the tension adjustment screw. Repeat steps 5-7. Compute v_0. How much does the muzzle velocity change with the decreased spring tension?

Conclusions:

1. Discuss your results for this experiment.
2. Draw a simple picture of the apparatus and label the different forces at work in this experiment. Carefully examine the apparatus to determine this.
3. Why did we use the equation for momentum conservation for the collision and energy conservation for the pendulum height?
4. Compare your two values for the muzzle velocity. Which one is greater? Why?

Error Analysis:

Did your data fluctuate very much? What could be the primary sources of error in this experiment? What role does friction play?

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Name:________________________Station:____Section: _________

Abstract:

Data:

Part One

m_b = _________ m_p = ________

$h_{initial}$	h_{final}	h

h_{ave} =

v_0 = ____________

Part Two

R = _____________ h = _____________

v_0 = ____________

Part Three

With reduced spring tension:

v_0 = ____________

Calculations:

Conclusions:

Error Analysis: