Ballistic Pendulum

Equipment

- Safety Glasses (not necessarily chemical goggles)
- Calculator, Computer
- Ballistic Pendulum Apparatus (Stand, Launcher, Pendulum, Ball)
- Ruler

Objectives

To determine the initial velocity of a projectile through proper application of the principles of conservation of momentum and energy.

Introduction

The ballistic pendulum is a classic method of determining the velocity of a projectile. It is also a good demonstration of many of the basic principles of physics. The ball is fired into the ballistic pendulum, which then swings up a measured amount. From the height reached by the pendulum, you can calculate its gravitational potential energy. The gravitational potential energy is equal to the kinetic energy of the pendulum at the bottom of the swing, just after the collision with the ball. You cannot equate the kinetic energy of the pendulum after the collision with the kinetic energy of the ball before the swing since the collision between ball and pendulum is inelastic, and kinetic energy is not conversed in inelastic collisions. Momentum is conserved in all forms of collisions, so you know that the momentum of the ball before the collision is equal to the momentum of the pendulum after the collision. Once you know the momentum of the ball and the ball's mass, you can determine the initial velocity.

Momentum

As discussed in the Collisions lab, the momentum of an object depends on its mass and velocity, and the units of momentum are kg·m/s. Remember: As a vector, momentum in a direction can be positive or negative!

Definition: $$\vec{p}_i = m\vec{v}_i \qquad (1)$$

In a collision, the total momentum of the two objects is conserved.

$$\begin{gathered}\vec{p}_i = \vec{p}_f \\ m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}\end{gathered} \qquad (2)$$

Kinetic and Potential Energy

Again, as discussed in Lab 11, the kinetic energy of an object is a positive, scalar (not vector) quantity that also depends on its mass and velocity. Energy is important because it can be transformed back into different kinds of energy. The units of energy are joules ($1\ \text{J} = 1\ \text{kg} \cdot \text{m}^2/s^2$).

Definition: $$\text{KE} = \frac{1}{2}mv^2 \quad (3)$$

Potential energy is another form of energy. For some forces (called conservative forces), there is a corresponding potential energy. For gravity, the potential energy is:

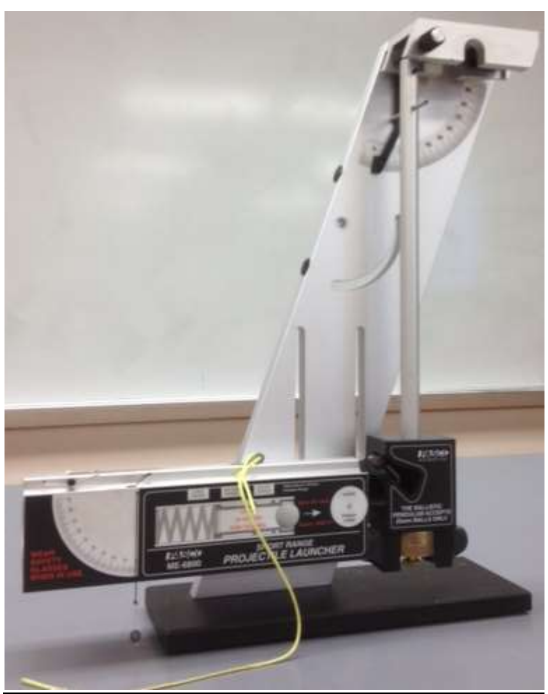
Definition: $$\text{PE}_g = mgy \quad (4)$$

When only conservative forces do work, conservation of energy applies. This means the total of the kinetic and potential energies must be constant. An important example is when the initial potential energy is initially zero (because $y_i = 0$) and the final kinetic energy is zero (because $v_f = 0$).

$$\begin{gathered} \text{KE}_i + \text{PE}_{gi} = \text{KE}_f + \text{PE}_{gf} \\ \frac{1}{2}mV_i^2 = mg\Delta y \end{gathered} \quad (5)$$

Experimental Setup

You should be wearing eye protection for the entire duration of the lab. The ballistic pendulum should already be set up.



1. Set the mass of the pendulum as desired. In the picture, there are two extra masses attached to the bottom of the pendulum.
2. Latch the pendulum at the top so it is out of the way. Set the spring to the desired launch strength, and load the launcher. Then lower the pendulum. Use the same launch strength every time, or the ball velocity will keep changing.

3. Set the angle indicator to 0°.
4. Firmly hold the base of the apparatus against the table. Fire the pendulum and record the maximum angle.
5. Repeat the angle measurement for 5 trials.

Once your trials are complete:

6. Measure the mass of the ball and record this as m_{ball}.
7. Measure the mass of the pendulum and record this as M_{pendulum}.
8. Find the center of gravity of the pendulum arm *with the ball in it*. To do this, find the center of mass by balancing it on a pencil, edge of a table, or on the launcher ramrod. Record the distance from the pivot point to the center of mass as R.

Change an experimental parameter.

9. Repeat the experiment for 3 different sets of conditions: no extra masses on the bottom, one extra mass, and two extra masses. Use the same launcher setting every time, and you can expect the initial ball velocities to come out the same.

Data Analysis

1. Average the angles for your trials.
2. Calculate the change in height of the center of mass of the pendulum:

Hint:
$$\Delta h = R(1 - \cos\theta) \tag{6}$$

3. Use the law of conservation of energy to calculate the velocity of the pendulum (with the ball inside) just after the collision. (Equation 5 above.)
4. Use the law of conservation of momentum to calculate the velocity of the ball just before the collision. (Equation 2 above. Note that $v_{2i} = 0$, and $v_{1f} = v_{2f}$ are both the result of the previous step.)
5. Find the average and standard deviation of the three calculations of the initial velocity. Since the same launcher and projectile was used, the initial velocity should be consistent. Was it?

Condition		No added mass	One added mass	Two added masses
Angle (degrees)	Trial 1			
	Trial 2			
	Trial 3			
	Trial 4			
	Trial 5			
	Average			
m_{ball} (kg)				
M_{pendulum} (kg)				
Radius of the Pendulum (m)				
Elevation, Δh (m)				
Velocity of the Pendulum (m/s)				
Initial Velocity of the Ball (m/s)				
Initial Velocity Average (m/s):				
Initial Velocity Standard Dev (m/s):				

Table 1: Measured and Calculated value for the experiment. The ascent of the pendulum is calculated by …., velocity of the pendulum is calculated by …, and initial velocity of the ball is calculated by…

Requirements for Ballistic Pendulum Report (also consult the Rubric on Blackboard):

Save your data (Excel file) on the Blackboard Group File Exchange.

- If the lab is **submitted the same day** the lab is performed, simply add a header and good caption to the Excel file and submit that. The caption should briefly make a conclusion based on the initial velocity values.
- If the lab is **not submitted the same day**, a Data Report must be submitted. The abstract must be included and contain:
  - How the data was collected and how it was analyzed for Table 1.
  - Explain the trigonometry that allowed you to solve for Δh.
  - Explain the physical principles at work regarding energy that helped you derive the velocity of the pendulum.
  - Explain the physical principles at work regarding momentum that helped you derive the equation to solve for the initial velocity.
  - The **data section** must include Table 1, labeled and Captioned.