1 Introduction

This lab simulation explores the concept of conservation of energy by way of a ballistic pendulum and a projectile.

1.1 Tools

This lab requires the use of the Google Chrome browser. Make certain it is installed on your computer. Navigate to `http://physics.bu.edu/~duffy/HTML5/ballistic_pendulum.html` to use the simulation. Intall the following Google Chrome extensions: *Measure-it* and *Web Paint*. They can be found at:
`https://chrome.google.com/webstore/detail/measure-it/jocbgkoackihphodedlefohapackjmna?hl=en`
`https://chrome.google.com/webstore/detail/web-paint/emeokgokialpjadjaoeiplmnkjoaegng?hl=en`.

1.2 Relevant Equations

Kinetic energy:

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

Gravitational potential energy:

$$U = mgh \tag{2}$$

Total energy:

$$E_{Total} = K + U = \frac{1}{2}mv^2 + mgh \tag{3}$$

The velocity of the bullet-pendulum system immediately after the collision is:

$$v = v_b(\frac{m_b}{m_b + M}) \tag{4}$$

Where m_b and v_b are the mass and initial velocity of the bullet, and M is the mass of the ball hanging at the end of the pendulum.

The kinetic energy of the bullet-pendulum system immediately after the collision is:

$$K = \frac{1}{2}(m_b + M)(\frac{m_b}{m_b + M})^2 v_b^2 = \frac{1}{2}\frac{m_b^2 v_b^2}{(m_b + M)} \tag{5}$$

2 Procedure

Note: This simulation moves fast. For this reason, we'll take data using successive presses of the "step" button.
Another note: For the purposes of this lab, assume that the initial gravitational potential of the pendulum is 0.

2.1 Part I: Initial Measurements

1. Press the *Reset* button to make certain the pendulum is completely vertical. Set the *Pendulum Length* to be 2 m. Then open *Web Paint* and make a horizontal line at the center of the ball (*note*: clicking on the "cursor" icon in *Web Paint* gives you back control of the cursor). Using these marks, use *Measure-it* to measure *in pixels* (1) the length of the string and (2) the distance from the top of the string to the center of the ball. At this moment we do not know whether the *Pendulum Length* setting is the length of the string or the distance from the top of the string to the center of the ball. You will determine which length is correct in this lab. Assume for now that the *Pendulum Length* is the distance from the top of the string to the center of the ball. Then you will now have calibrated the length of the pendulum: your pendulum length in pixels = 2 m (*note*: this is a conversion factor).

2.2 Part II: Varying Mass

1. Set the mass of the target to be 800 g.
2. Set the bullet speed to be 100 m/s.
3. Set the pendulum length to 2 m.
4. Set the mass of the bullet to be 10 g.
5. Using these initial conditions and using Eq. (5) and Eq. (2), calculate the height the pendulum will reach after being hit with the bullet.
6. Using the step button, move the simulation forward until the pendulum's ball reaches its maximum height (the deviation angle from the vertical is maximized).
7. Using *Web Paint* draw a horizontal line through the center of the ball.
8. Using *Measure-it* measure the height the center of the ball rises.
9. Repeat steps 5-8 using bullets having a mass of 15, 20, 25, and 30 grams.

2.3 Part III: Varying the Velocity

1. Set the mass of the pendulum to 800 g.
2. Set the mass of the bullet to 30 g.
3. Set the pendulum length to 2 m.
4. Set the velocity of the projectile to 60 m/s.
5. Perform steps 5-8 in the above section.
6. Repeat steps 5-8 in the above section with initial velocities of 70, 80, 90, and 100 m/s.

3 Data Analysis

1. Consider the experimental errors above. Each initial condition (mass, length of pendulum, etc) were set on a computer and thus have an uncertainty of 0. However, there is still uncertainty in the experiment. Describe where it comes from and estimate it.

2. For each point of data above (10 total), calculate the percent error between the calculated value of the height and the measured value.

3. For the last data point (where the bullet's mass and speed are 30 g and 100 m/s, respectively), calculate the height assuming that the *Pendulum Length* is the length of the string. Using a percent error calculation, determine whether the *Pendulum Length* is the "length of the string" or the "length of the string plus the radius of the ball".

4. Write a short paragraph (minimum two sentences) describing the quality of the data you took, motivated by your percent errors.

5. Using your data, make a plot of the mass of the bullet vs. final height.

6. Using your data, make a plot of the bullet's initial velocity vs. final height.

7. For your data where you varied the velocity, calculate the thermal energy generated in the collisions.

8. Make a plot of "thermal energy" versus velocity.

4 Questions

1. Derive Eq (4) using conservation of momentum assuming the collision is very brief.

2. Did changing the mass of the projectile effect the final height of the pendulum more than, less than, or the same as changing it's initial velocity? Explain why.

3. Imagine you did the same experiment with a certain mass m, initial velocity v, and found a final height of h. If you then doubled the mass, what would happen to the final height? If you instead doubled the initial velocity, what would happen to the final height?

4. Does the thermal energy generated increase linearly or quadratically with the velocity of the bullet?