Exp 1: Ballistic Pendulum

EQUIPMENT NEEDED

– Projectile Launcher (ME-6800)
– Projectile Catcher Accessory (ME-6815)
[Velcro must be assembled (See Figure 3)]
– Base and Support Rod (ME-9355)
– table clamp

-meter stick
-white paper
-carbon paper
-mass balance

Optional: Photogates and Photogate Bracket

Purpose

The muzzle velocity of the Projectile Launcher can be determined by shooting the ball into a ballistic pendulum and then measuring the height reached by the pendulum.

Theory

A ball is launched horizontally and embeds in the bob of a pendulum. The pendulum then swings up to a particular height, h. (See Figure 1.1.)

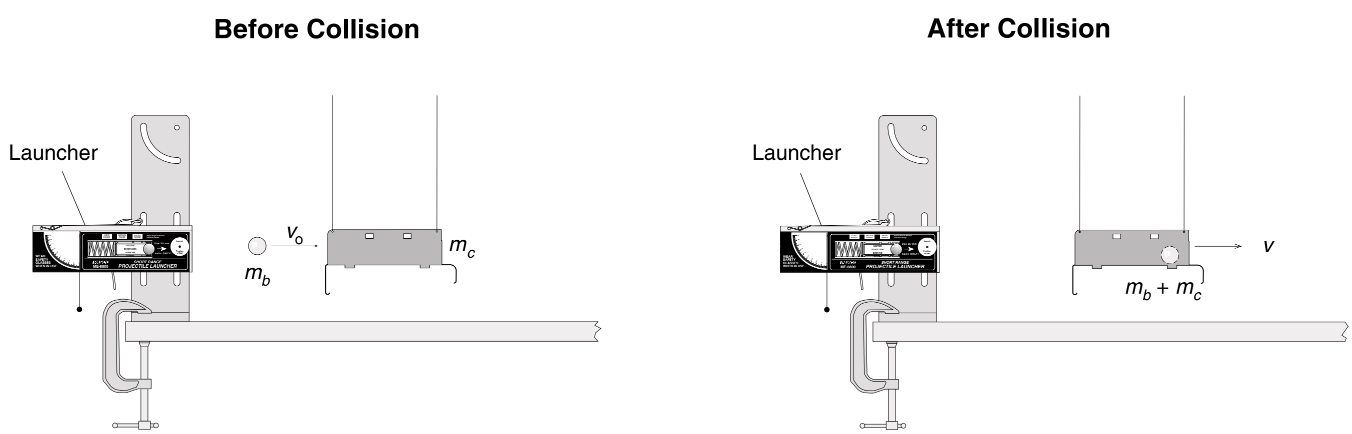

Figure 1.1: Conservation of Momentum

Momentum is conserved during the collision, but kinetic energy is not. The momentum after the collision is equal to the momentum before the collision:

$$(1) \quad m_b v_o = (m_b + m_c)v$$

where m_b is the mass of the ball, v_o is the muzzle velocity of the ball, m_c is the mass of the catcher, and v is the velocity of the catcher (and ball) after the collision.

The kinetic energy of the catcher (and ball) after the collision is converted completely to potential energy at the top of the swing:

$$(2) \quad \frac{1}{2}(m_b + m_c)v^2 = (m_b + m_c)gh$$

To find the muzzle velocity of the ball, we begin with the potential energy of the pendulum at the top of its swing and work backwards from there. From our equation for energy conservation (2):

(3) $v = \sqrt{2gh}$

Substitute (3) into the equation for momentum conservation (1):

$$m_b v_o = (m_b + m_c)\sqrt{2gh}$$
$$v_o = \left(\frac{m_b + m_c}{m_b}\right)\sqrt{2gh}$$

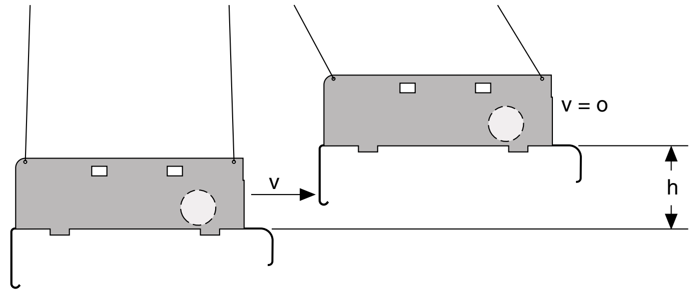

Figure 1.2: Conservation of Energy

For comparison, the initial speed (muzzle velocity) of the ball is determined by shooting the ball horizontally off the table onto the floor and measuring the vertical and horizontal distances through which the ball travels.

For a ball shot horizontally off a table with an initial speed, v_0, the horizontal distance ("x") traveled by the ball is given by $x = v_0 t$, where t is the time the ball is in the air. Air friction is assumed to be negligible.

The vertical distance the ball drops in time t is given by $y = \frac{1}{2}gt^2$.

The initial velocity of the ball can be determined by measuring *x* and *y*. The time of flight of the ball can be found using

$$t = \sqrt{\frac{2y}{g}}$$

and then the muzzle velocity can be found using $v_o = \frac{x}{t}$.

Part I: Determining the Initial Velocity of the Ball

Set Up

1. Clamp the Projectile Launcher to a sturdy table (near one end of the table).
2. Adjust the angle of the Projectile Launcher to zero degrees so the ball will be shot off horizontally, away from the table onto the floor.

Procedure

1. Put the steel ball into the Projectile Launcher and cock it to the long range position. Fire one shot to locate where the ball hits the floor. At this position, tape a piece of white paper to the floor. Place a piece of carbon paper (carbon-side down) on top of this paper and tape it down. When the ball hits the floor, it will leave a mark on the white paper.
2. Fire about ten shots.

3. Measure the vertical distance from the bottom of the ball as it leaves the barrel (this position is marked on the side of the barrel) to the floor. Record this distance in Table 1.1.
4. Use a plumb bob to find the point on the floor that is directly beneath the release point on the barrel. Measure the horizontal distance along the floor from the release point to each of the ten dots. Record in Table 1.1.
5. Find the average of the ten distances and record in Table 1.1.
6. Using the vertical distance and the average horizontal distance, calculate the time of flight and the initial velocity of the ball.

   Record in Table 1.1 and Table 1.4.

Table 1.1: Determining the Initial Velocity

Vertical distance = ______________.

Initial velocity = _______________. ______________

steel plastic

	Steel	Plastic
Trial Number	Distance	
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Average		
Total Distance		

Alternate Method: Determining the Muzzle Velocity with Photogates

1. Attach the Photogate Bracket to the launcher and attach two Photogates to the bracket. Plug the Photogates into a computer or other timer.
2. Put the ball into the Projectile Launcher and cock it to the long range position.
3. Run the timing program and set it to measure the time between the ball blocking the two Photogates.
4. Shoot the ball three times and take the average of these times. Record in Table 1.2.
5. Use a distance of 10 cm (between the Photogates) to calculate the initial speed. Record the initial speed in Table 1.2 and Table 1.4.

Table 1.2: Initial Speed Using Photogates

Trial Number	Time
1	
2	
3	
Average Time	
Initial Speed	

Part II: Ballistic Pendulum

Set Up

1. Find the masses of the balls and catcher. Record in Table 1.3.
2. Suspend the ball catcher as a pendulum, as explained in the general instructions.
3. With the Projectile Launcher mounted as in Figure 1.1, clamp the suspended ball catcher directly in front of the muzzle.
4. Attach a thread to the ball catcher and string it through the Velcro assembly (see the general instructions) on the base of the Launcher.

Procedure

1. Load the Launcher (set to long range) with the ball. Fire a test shot to see how far out the thread is pulled. Pull a few centimeters of the thread back through the Velcro, leaving the rest of the thread slack between the Launcher and the catcher. When the ball is shot into the pendulum again, the thread will become taut just before the catcher reaches its maximum height. This reduces the effect of friction on the thread.
2. Fire the ball into the pendulum five times. After each trial, pull the pendulum back until the thread is taut and measure the height above the level of the muzzle to which the pendulum swung. Record in Table 1.3.

Analysis

1. Calculate the average of the heights in Table 1.3. Record the result in Table 1.4. Using the average height, calculate the velocity immediately after the collision and record it in Table 1.4.
2. Using the velocity calculated in the previous step and the masses, calculate the muzzle velocity of the ball and record in Table 1.4.
3. Calculate the percent difference between the muzzle velocities found in Parts 1 and 2. Record in Table 1.4.

Table 1.3: Ballistic Pendulum Data

Steel Ball

Mass of Ball = _____________.

Mass of Catcher = __________.

Height

Table 1.4: Results

Average Height	
Velocity, v	
Calculated Muzzle Velocity, v_o	
Muzzle Velocity (Part 1)	
% Difference	

Questions

1. What percentage of the kinetic energy is lost in the collision? Use the masses and velocities to calculate this percentage:

$$\%Lost = \frac{KE_{before} - KE_{after}}{KE_{before}} \; x \; 100\%$$

2. How does the height to which the pendulum swings change if the ball is bounced off the rubber bumper on the front of the catcher instead of being caught?

   Try it, but be sure to move the catcher farther away from the Launcher so the steel ball won't rebound into the Launcher and damage the Launcher.

Analysis

1. Calculate the average of the heights in Table 1.5. Record the result in Table 1.6. Using the average height, calculate the velocity immediately after the collision and record it in Table 1.6.
2. Using the velocity calculated in the previous step and the masses, calculate the muzzle velocity of the ball and record in Table 1.6.
3. Calculate the percent difference between the muzzle velocities found in Parts 1 and 2. Record in Table 1.6.

Table 1.5: Ballistic Pendulum Data

Plastic Ball

Mass of Ball = _____________.

Mass of Catcher = __________.

Height

Table 1.6: Results

Average Height	
Velocity, v	
Calculated Muzzle Velocity, v_o	
Muzzle Velocity (Part 1)	
% Difference	

Questions

1. What percentage of the kinetic energy is lost in the collision? Use the masses and velocities to calculate this percentage:

$$\%Lost = \frac{KE_{before} - KE_{after}}{KE_{before}} \ x \ 100\%$$

2. ~~How does the height to which the pendulum swings change if the ball is bounced off the rubber bumper on the front of the catcher instead of being caught?~~

   ~~Try it, but be sure to move the catcher farther away from the Launcher so the steel ball won't rebound into the Launcher and damage the Launcher.~~