THE BALLISTIC PENDULUM AND COLLISIONS IN TWO DIMENSIONS

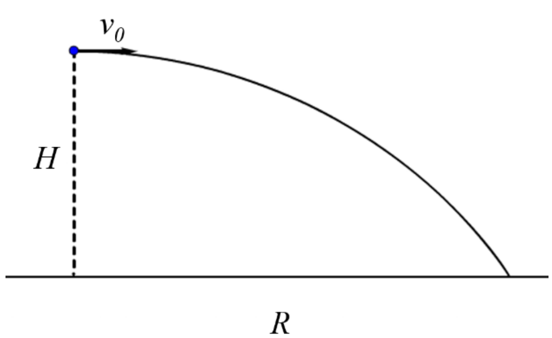
OBJECT: To compare the values of the initial velocity of a projectile as found by two different methods. The first method for determining the initial velocity of the projectile is from using kinematic equations as was done in a previous lab. The second method is by using a perfectly inelastic collision of the projectile into a ballistic pendulum, and then using the concepts of conservation of momentum and energy to determine the initial velocity of the projectile.

APPARATUS: Ballistic pendulum, sheets of plain paper and carbon paper, meter stick, protractor, laboratory balance, tape, and plumb line.

INTRODUCTION: The principle of conservation of linear momentum can be difficult to measure using elastic or inelastic collisions in a real lab setting because there must be no net external forces on a system for linear momentum to be conserved. To avoid this problem, we will consider the *perfectly inelastic* collision of two objects where most forces are *internal* to the system.

THEORY:

Method 1:
The velocity of a horizontal projectile can be found by measuring the range R, and height from which the projectile falls, as you have done in a previous lab. This method is the first one you will use to find the initial velocity of the projectile, and a diagram and summary of the relevant equations is shown below.



$$H = \frac{1}{2}gt^2, \text{ so } t = \sqrt{\frac{2H}{g}}$$

$$\text{then } v_0 = \frac{R}{t}$$

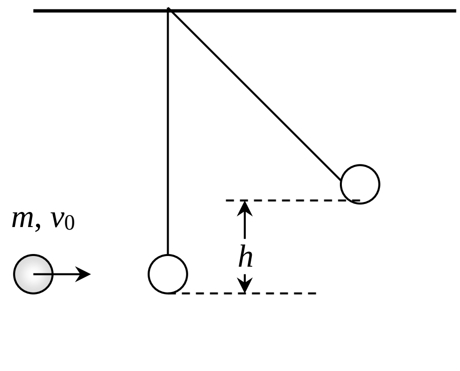
Method 2:
The velocity of a horizontal projectile can also be measured using a ballistic pendulum. In a ballistic pendulum, a projectile with mass *m* is fired with initial velocity v_0 into a stationary pendulum bob of mass *M*, and sticks to the bob as a perfectly inelastic collision. Linear momentum is conserved in the collision, and so after the collision the pendulum and projectile will have a combined velocity v_1, according to the expression:

$$mv_0 = (m+M)v_1 \ .$$

With the combined velocity v_1, the projectile and bob will swing upward against the force of gravity, during which mechanical energy is conserved. A catch is designed to hold the combined pendulum bob and projectile at its highest position when all of the kinetic energy of the combined bob and projectile has been converted to gravitational potential energy by raising the center of mass of the system a height h. By measuring the vertical displacement h of the center of mass of the bob and projectile, the initial velocity of the pendulum and projectile v_1 can be determined by:

$$\frac{1}{2}(m+M)v_1^2 = (m+M)gh \text{, so } v_1 = \sqrt{2gh} \text{ .}$$

Then by using conservation of momentum, the initial velocity v_0 of the projectile before the collision can be calculated. A photo and diagram of the system is shown below.



PROCEDURE:

1. In this part of the experiment, the initial velocity of the projectile is obtained from measurements of the range (R) and height (H). The apparatus should be set near one edge of a leveled table and the pendulum is not used. It should be swung up onto the rack so that it does not interfere with the flight of the ball.
2. The gun is prepared for firing by pressing the ball at the end of the spring-loaded assembly to compress the spring until the trigger is engaged. The ball is fired horizontally so that it strikes a target placed on the floor. By firing the ball and finding where it strikes the floor, approximate range is determined. Then a sheet of white paper is placed on the floor so that the ball will hit it near its center and it is covered with carbon paper. Weights should be placed on the corners of the paper to keep it from moving around. In this way, a record is obtained for the exact spot where the ball strikes the floor. Complete *five* trials.
3. Find the range R of each trial. This is the horizontal distance from the point of projection to the point of contact with the floor. A plumb line or meter stick is used to locate the point on the floor directly below the ball where it leaves the gun.
4. Measure the height H through which the ball falls during its projectile motion.
5. For the <u>second method</u>, get the gun ready for firing. Release the pendulum from the rack and allow it to hang freely. When the pendulum is at rest, pull the trigger, thereby firing the ball into the pendulum bob. This will cause the pendulum with the ball inside it to swing upward where it should stay at its highest point. Record this change in height (h). Remove the ball from the pendulum while holding up the spring catch. Be gentle.

6. Repeat procedure *five* times, recording the highest position of the pendulum each time.
7. Find the mass of the ball by using a triple beam balance. In most cases the weight of the pendulum is inscribed on the back of the apparatus. If it is not, consult with your instructor.

Mass of the ball (*m*) ____________ **kg**

Mass of the pendulum (*M*) ____________ **kg**

<u>Method 1</u>

Trial	*H* (m)	*R* (m)	v_0 (m/s)
1			
2			
3			
4			
5			
Average:			

<u>Method 2</u>

Trial	*h* (m)	v_1 (m/s)	v_0 (m/s)
1			
2			
3			
4			
5			
Average:			

Calculate the % difference in v_0 determined by method I and method II:

Do you think the projectile method or ballistic pendulum method is more accurate, and why?

Questions:

1. Using the data of your experiment, calculate the kinetic energy K_0 of the ball just before impact with the pendulum. Use the more *precise* of the two methods for your calculations.

2. Calculate the kinetic energy K_f of the pendulum bob and ball just after impact using the common velocity v_1 and their masses ($m+M$).

3. (a) Using the results of Question 1 and 2, calculate what fraction K_f/K_0 of energy is remaining in the system after the perfectly inelastic collision.

   (b) What became of the lost kinetic energy?

4. (a) Compute the ratio of the mass of the ball to the total mass of the bob and the ball: $\frac{m}{m+M}$.

   (b) How does this ratio compare with the fraction of energy K_f/K_0?

5. A bullet weighing 15 grams is fired horizontally into a block of wood weighing 3.0 kg and suspended like a ballistic pendulum. The bullet sticks in the block and the impact causes it to swing so that its center of gravity rises 15 cm. Find the velocity of the bullet just before the impact.

6. A 5-g bullet traveling horizontally with velocity of magnitude 400 m/s is fired into a wooden block of mass 1.00 kg initially at rest on a level surface. The bullet passes through the block and emerges with a reduced speed of 120 m/s. The block slides a distance of 0.25 m along the surface from its initial position. What is the coefficient of kinetic friction between the block and the surface?