

Experiment 8: Ballistic Pendulum

I. About the Experiment

This experiment combines several physical concepts in order to determine the velocity of a rapidly moving object. By using a ballistic pendulum apparatus the kinetic energy of the object is determined. From the kinetic energy the initial velocity can be determined. As a check on our results for the ballistic pendulum the velocity of the object is also determined by measuring the trajectory of the object in free-flight.

II. The Experimental Set-up

A. Ballistic Pendulum

Consider the ballistic pendulum apparatus depicted below. The projectile of mass m moves with velocity v on a collision course with the stationary pendulum. We know that the projectile has kinetic energy equal to $\frac{1}{2}mv^2$. The projectile is captured by the pendulum of mass M in an inelastic collision (kinetic energy is lost in the collision). The pendulum then swings upward and the system is raised to a final height h . The change in potential energy of the system is given by

$$\Delta(\text{P.E.}) = (m + M)(h - h_0)g \quad \text{Eqn. 1}$$

If the projectile-pendulum collision were totally elastic with no energy lost to the apparatus, we would simply set the change in potential energy equal to the initial kinetic energy of the projectile and solve for the velocity v . There is, however, a considerable kinetic energy loss in the collision so we must take a different approach to the problem.

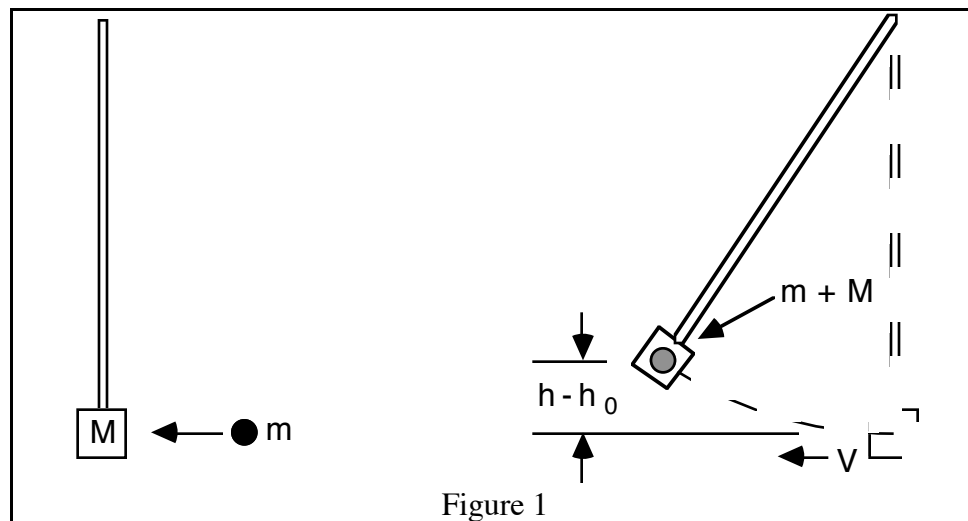


Figure 1

If we designate \vec{V} to be the velocity of the combined projectile-pendulum system immediately after the collision occurs then the momentum of the combined system at this instance in time is $(m + M)\vec{V}$. From conservation of momentum we can write:

$$m\vec{v} = (m + M)\vec{V} \quad \text{Eqn. 2}$$

A detailed discussion of the theoretical validity of equation 2 is given in Chapter 8. Experiment 8, which is described in Chapter 8 tests experimentally the validity of equation 2.

For one dimensional motion equation 2 can be written as

$$mv = (m + M)V \quad \text{Eqn. 3}$$

The kinetic energy of the projectile-pendulum system immediately after the collision is $\frac{1}{2}(m + M)V^2$. This kinetic energy is converted to gravitational potential energy. Thus using Equation 1 we have

$$\frac{1}{2}(m + M)V^2 = (m + M)(h - h_0)g. \quad \text{Eqn. 4}$$

Solving Equation 3 for V which is then substituted into Equation 4 leads to

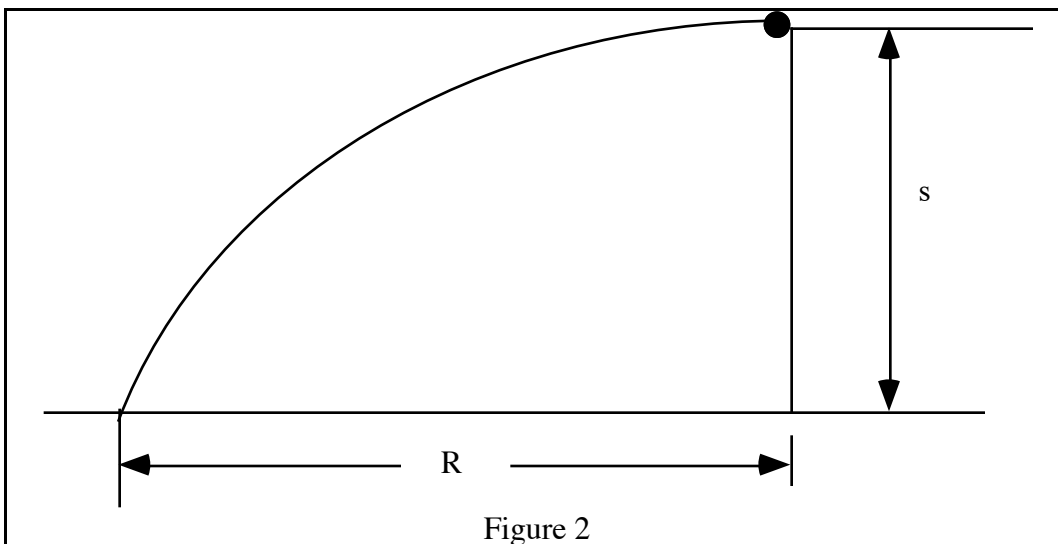
$$v = \frac{m + M}{m} \sqrt{2g(h - h_0)}. \quad \text{Eqn. 5}$$

Thus we can determine the initial velocity of the projectile by measuring its mass and the rise in height of the pendulum after the collision.

B. Free Flight

Refer to Figure 2. If a projectile is initially moving with speed v in a **horizontal** direction and travels a horizontal distance R in its time of flight, then we can determine its **horizontal** velocity from the relation

$$v = \frac{R}{t} \text{ where } t \text{ is the time it takes to fall the distance } s$$



Since the initial velocity in the vertical direction is zero, we can calculate the time of fall from the relation $s = \frac{1}{2} at^2$ where s is the vertical distance through which the bodies fall and a is the acceleration due to gravity, $a = g = 9.8 \text{ m/sec}$. This leads to

$$v = R\sqrt{\frac{g}{2s}} \quad \text{Eqn. 6}$$

Thus we can determine the initial velocity of the projectile by measuring its height of fall and its distance of horizontal travel.

III. Procedures

A. Ballistic pendulum experiment

1. Measure the mass of the projectile ball.
2. With the pendulum in position to capture the ball, fire the ball into the pendulum five or six times and record the height, h , to which the pendulum is raised as measured from the base of the apparatus to the center of mass of the pendulum-projectile combination. The center of mass of the pendulum-projectile combination is indicated by a pointer mounted on the side of the pendulum.
3. Measure the height of the pointer from the base of the apparatus when the pendulum is in its initial rest position h_0 .

B. Free-Flight Experiment

1. Check to see that you have sufficient open space in front of the set-up so as not to endanger other persons in the lab.
2. To load the projectile "gun", place the projectile ball on the end of the gun and press hard until the trigger engages the spring and the gun is "cocked". **Note** - once you have begun the experiment do not change the setting of the knurled knob at the back of the "gun"; this will change the spring tension in the gun and alter your results.
3. With the pendulum raised out of the path of the ball and all nearby persons alerted, fire the gun to gauge the distance at which the ball will strike the floor. Now, with the gun unloaded, center the cardboard target box at the point of impact of the ball.
4. Place a sheet of paper (you may wish to tape it to the bottom of the box) in the target box. Then place a sheet of carbon paper over the paper, carbon side down. Next place a pair of lead weights at two corners inside the target box to prevent the target from moving when the ball strikes it.
5. Fire the gun onto the target five or six times into the target box in order to measure the horizontal distance R which the ball travels from the muzzle of the gun to the target. After this is done make sure the gun is unloaded and then make the measurements.. You may find it helpful to use a plumb-bob suspended from the edge of the lab bench to determine the starting point for measuring the distance to the target. = _____
6. Measure the height of the muzzle of the gun from the floor, s = _____

IV. Calculations and Analysis

Be sure to include all your data and **calculations** in an Excel spread sheet.

1. From the data of section A calculate the average value of h (\bar{h}). Then use Equation 5 with $\bar{h} - h_0$ for $h - h_0$ to calculate the initial velocity of the projectile ball.
2. From the data of section B calculate the average value of R (\bar{R}). Then use Equation 6 with R replaced by \bar{R} to determine the initial velocity of the projectile ball.
3. What is the unbiased percent difference between the two results for the initial velocity? Which method do you think is most accurate? **Why?**
4. Calculate the percentage of the original kinetic energy of the ball ($\frac{1}{2}mv^2$) that is lost in the collision of the ball with the pendulum. Where does the energy go and how is it transferred?

V. Questions:

1. This question is from the Colorado State driver's license exam: A car at 30 miles per hour skids 40 feet with locked brakes. How far will the car skid with locked brakes at 90 miles per hour? (Hint: think about Kinetic Energy)
2. Suppose that you and two friends are discussing the design of a roller coaster. One friend says that each summit must be lower than the previous one. Your other friend says this is nonsense, for as long as the first one is the highest it doesn't matter what height the others are. What do you say?
3. When a jet plane lands on the deck of a carrier, is this an elastic or an inelastic "collision?" In this "collision" the before is just before landing and the after is after the plane has come to a stop.
4. In the measurement of v by the free-flight method, what would be the effect on the measurements if
 - a) the floor were not truly horizontal?
 - b) the base of the apparatus were not truly horizontal?