Lab 12

Ballistic Pendulum

Experimental Objectives

- To verify that the equations of conservation of momentum and conservation of mechanical energy give the same results as the equations of two-dimensional motion by comparing the initial velocity of the ballistic projectile from two different sets of experimental measurements:
  - the range and vertical height measurements of the projectile motion, and
  - through the use of the ballistic pendulum.

Introduction

Conservation laws will again play a significant part in this ballistic pendulum experiment. A ballistic pendulum is a devise which has a cavity in the pendulum bob, and a small ball will be fired into and captured in this cavity. When this happens, the initially stationary pendulum will swing about the pendulum's point of support. During this collision between the ball and the pendulum, the momentum of the total system should be conserved from the instant just prior, to the instant just after the collision. Physicist's hold true a general conservation law for momentum which applies in all interactions of two or more objects where there are no other outside forces acting on the system. For collisions on the earth, the force of gravity is an outside force but momentum is still considered to be conserved if the time of the interaction is small.

The collision in this experiment is called a totally inelastic collision because after the collision the two objects are held together, they move together with a single velocity, and the kinetic energy of the system is not conserved during the collision. Using the general conservation of momentum law for the collision described an equation can be written for the initial velocity of the ball in terms of the velocity of the system at the instant after the collision and the individual masses of the ball and the pendulum. After the collision the pendulum and ball will swing and at the highest point in the swing they will be caught. The KE of the system at the instant after the collision is converted totally to PE at the highest point in the swing. The velocity of the system at the instant after the collision can then be determined using the law of conservation of energy. Then with these two conservation laws, the initial velocity of the ball can be determined.

The initial velocity of the ball can also be determined by firing the ball horizontally off the edge of the table and analyzing the 2-dimensional projectile motion of the ball moving under the influence of the gravitational force. This analysis involves separating the motion into its component directions, using the standard kinematic equations of motion and an appropriate set of measurements.

For these two very different techniques calculate the same initial velocity of the projectile. An analysis and comparison of the two methods will help to illustrate the interconnections between these physics topics.

12.1 Pre-Lab Considerations

- Draw before and after pictures for a totally inelastic collision between two masses, m_1 and M_2. Assume that M_2 is initially stationary, and that m_1 is initially moving horizontally with a velocity of v.
- For this collision, write out the conservation of momentum equation. Solve for the shared velocity of the pair after the collision.
- After the collision, the pendulum and ball will swing. The KE of the pair at the instant after the collision will be converted to PE as it swings. Write out a conservation of energy equation for this process, in terms of the mass of the pendulum and ball, the change in height of the system and the velocity of the system at the instant after the collision.
- Combine these two conservation laws to derive an expression for the initial velocity of the ball (before the collision) to the final height of the ball and pendulum system.
- Draw a picture of the ball's path when fired horizontally off of a table. Draw the ball in its initial position (at the moment it begins its free fall), and in its final position (at the moment just before it hits the floor). Make the ball larger than its scale size so that it size can be easily seen in your picture. On the picture label the height and the range of the projectile. Think about whether the measurements should be taken from the top, bottom or the middle of the ball. What part of the ball will hit the floor? Think about this for both the horizontal and the vertical measurements.
- For this projectile motion, use the kinematic equations of motion to derive an equation for the initial velocity of the ball in terms of the height and range measurements.

12.2 Procedure

12.2.1 Projectile Motion

- Set-up the ballistic spring gun so that it will fire the projectile ball horizontally off the edge of the table. Use a bubble level or the ball itself to make sure that the gun is level. Move the pendulum out of the way. Clamp the apparatus to the table, and use cardboard pads. The initial velocity of the projectile can be changed by adjusting the spring tension.
- Tape a piece of paper to the floor where the ball will land, then tape a sheet of carbon paper at this spot.
- Be careful not to hit anything or anybody with the ballistic projectile! Use larger pads or boxes to protect the tables and the walls.
- Repeat the experiment for a sufficient number of trials (15-20), and calculate a standard deviation of the range.
- Calculate the initial velocity (and uncertainty) of the projectile after taking the appropriate measurements.

12.2.2 The Ballistic Pendulum

The ballistic pendulum apparatus consists of three parts: 1) a ballistic spring-loaded gun for the firing of the projectile, 2) a hollow pendulum bob suspended by a light rod for catching the fired projectile, and 3) an angled platform for catching the pendulum bob at the highest position of the bob's swing.

- When removing the ball from the pendulum, be sure to push up on the spring catch in the pendulum so as to not to damage the pendulum.
- The pointer on the side of the pendulum indicates the position of the center of mass of the system.

- Do not try to take the apparatus apart, the instructor will give you the mass of the pendulum.
- Clamp the base to the table, so that there is no relative motion of the base.
- Fire the ball into the pendulum bob and mark the final notch position of the pendulum.
- Repeat the experiment with a sufficient number of trials (15) so that a standard deviation of the notch positions can be obtained.
- Measure the change in height of the pendulum's pointer from its initial position to the average notch position. Calculate the uncertainty in this distance.
- Calculate the initial velocity (and uncertainty) of the projectile ball.

12.3 Analysis

Quantitatively compare the two methods. Calculate a percent difference between the two methods. Calculate the uncertainties for the velocity in both methods (propagation of error), and also write these in a % form. Which method is more precise? Decide whether this experiment has random or systematic errors. Discuss and show your experimental evidence.

12.4 Questions

1. Under what conditions are the laws of momentum and energy conserved in this experiment? State why. Why is the mechanical energy not conserved during the collision? Conclude whether the collision between the steel ball and the pendulum bob is elastic or inelastic.

2. During the collision, what percent of the kinetic energy of the ball was transferred to the combination of the pendulum and ball? If energy is lost, where does it go?

3. If this gun was aimed and fired vertically from the table top, would the ball hit the ceiling? Assume a vertical height of 1.5 meters. Show all of your work.

4. What effect does the force of gravity have on the horizontal velocity of the projectile?

5. Does the air resistance on the ball have a significant effect on the results of this experiment?