EXPERIMENT 7
BALLISTIC PENDULUM

I. THEORY

The purpose of this experiment is to measure the velocity of a ball that is fired from a spring gun.

For many years, police laboratories used ballistic pendulums to measure the muzzle velocities of firearms. The ballistic pendulum consisted of a large block, suspended by cords. The bullet was fired horizontally into the block, and became embedded in it. The velocity of the bullet could then be calculated from the known masses of the bullet and block, and from the maximum height reached by the block after impact. Two fundamental principles of physics are used in the calculation: conservation of momentum and conservation of energy.

In this experiment, we employ a spring gun in order to minimize unfortunate incidents. A ball is fired horizontally into a pendulum and becomes embedded in it. The pendulum swings and is caught at the top of its swing by a toothed rack, which allows for the measurement of the vertical height the pendulum rises.

During the collision, momentum in the horizontal direction is conserved. The collision is completely inelastic and during the collision the kinetic energy lost is converted to thermal energy and sound. After the ball becomes embedded in the pendulum, mechanical energy is conserved as the pendulum swings to its highest point. Since the pendulum is an extended object, we will use the position of the center of mass of the system to determine the gravitational potential energy of the system.

For the kinetic energy and momentum of the system just after the impact, we will assume that the entire pendulum arm and the ball have the same horizontal velocity. Making this assumption means we are ignoring any horizontal force exerted on the arm by the axle.

The theory of projectile motion gives us a second method of measuring the velocity of the ball as fired from the spring gun. We will fire the ball horizontally from a table and measure the horizontal and vertical distances traveled by the ball. Using these distances and the standard value for the acceleration due to gravity, 9.80 m/s², we will calculate the initial velocity of the ball using the kinematics equations for constant acceleration. We may neglect the effects of air friction since the ball is dense and its velocity is small.

II. LABORATORY PROCEDURE

1. Record the mass of the pendulum arm, which is etched on the vertical portion of the arm. Note the horizontal line etched a short distance above the "catcher." This line marks the center of mass of the pendulum arm with the ball embedded in the "catcher". Also, record the number etched into the base of the apparatus.

2. With the pendulum hanging vertically, measure the height of the center of mass of the system above the table top. This is the height of the center of mass of the system above the table top just after the collision.

3. Place the ball on the rod of the spring gun. Cock the gun by pushing backward on the ball while holding the gun firmly in position. With the pendulum hanging at rest, fire the ball into the pendulum and record the tooth number at which the pendulum is caught. Perform this step five times. Repeat any shots in which the ball falls out of the pendulum. If the tooth number for any of the five shots is different from the other shots by more than 3, repeat the shot.

4. On your data sheet, calculate the average tooth number. Round this number to the nearest integer and place the pendulum on that tooth. Using the meter stick and sliding caliper jaw, measure the height of the center of mass of the ball-pendulum system above the tabletop. This height should be labeled in a way to distinguish it from the height measured in Step 2.

5. Using *the same* apparatus that you used in the previous steps, move it to the end of the laboratory bench. Move any of the center tables if necessary to have a clear path at least 3 meters straight ahead of the launcher. *Remember to unlock the wheels of the movable tables before attempting to push them.* To make the measurements that follow easier and more accurate, the apparatus should be placed at the corner of a table. Test the base of the apparatus with the level, in a direction parallel to the motion of the projectile. Make any necessary adjustments by placing pieces of paper under the feet of the apparatus.

6. Place a sheet of masonite on the floor with its center about 250 cm from the spring gun. Create a "back-stop" by holding another sheet of masonite close to vertical just behind the first sheet. Fire the ball onto the masonite, noting where it hits. Center the masonite over the impact point. Tape a piece of white paper over the center of the masonite. Tape a piece of carbon paper, inked side down, over the white paper. To protect the carbon paper, tape another piece of white paper over the carbon paper. Fire five shots onto the masonite sheet, taking care that neither the spring gun nor the masonite sheet moves during the process.

7. *Do not move the masonite sheet before completing this step or you will have to repeat the previous step.* Place the ball on the gun in the uncocked position. Remove the carbon paper and measure the horizontal distance from the center of the ball to the center of each of the impact marks on the paper. The distance may be measured in two or three parts.

8. While the apparatus still in place, with the ball in place, measure the vertical distance from the top of the masonite sheet to the bottom of the ball.

9. Using a triple beam balance, measure the mass of the ball.

III. CALCULATIONS

1. Calculate the height that the center of mass of the ball-pendulum system was raised when the ball was fired into the pendulum.

2. Using conservation of mechanical energy, calculate the velocity of the ball-pendulum system just after the impact. From this velocity, calculate the kinetic energy of the ball-pendulum system just after the impact.

3. Using conservation of momentum, calculate the velocity of the ball before the impact. From this velocity, calculate the kinetic energy of the ball just before the impact.

4. Calculate the amount of energy converted to thermal energy and sound during the collision. What percent of the ball's original kinetic energy was converted to thermal energy and sound? Explain why this large percentage does not affect the accuracy of the above calculations.

5. Using the equations for motion with a constant acceleration, calculate the time of flight of the ball during projectile motion. Use 9.80 m/s² for the acceleration due to gravity.

6. Calculate the average of the five horizontal distances traveled by the ball during projectile motion.

7. Using the equations for motion with a constant acceleration, calculate the initial velocity of the ball.

8. Calculate the percent difference between the two calculated values for the initial velocity of the ball.