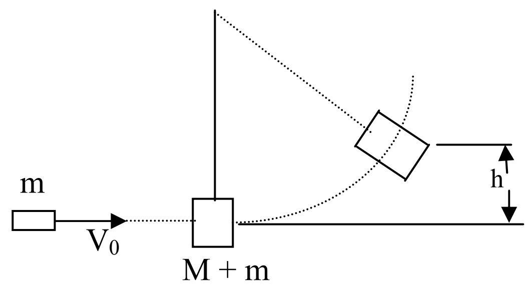
The Ballistic Pendulum

Purpose: To use the ballistic pendulum to determine the initial velocity of a projectile using conservation of momentum and conservation of energy.

Equipment: Ballistic pendulum, carbon paper, meter stick, clamp, box, triple beam balance, plumb.

Introduction: In this experiment a steel ball will be shot into the bob of a pendulum and the height, h, to which the pendulum bob moves, as shown in Figure 1, will determine the initial velocity, V, of the bob after it receives the moving ball.

Figure 1



If we equate the kinetic energy of the bob and ball at the bottom to the potential energy of the bob and ball at the height, h, that they are raised to, we get:

$$(K.E)_{bottom} = (P.E)_{top}$$

$$\frac{1}{2}(M + m)V^2 = (M + m)g.h$$

where M is the mass of the pendulum and m is the mass of the ball. Solving for V we get:

$$V = \sqrt{2gh} \qquad \ldots\ldots\ldots\ldots\ldots (1)$$

Using conservation of momentum we know the momentum before impact (collision) should be the same as the momentum after impact. Therefore:

$$P_i = P_f$$

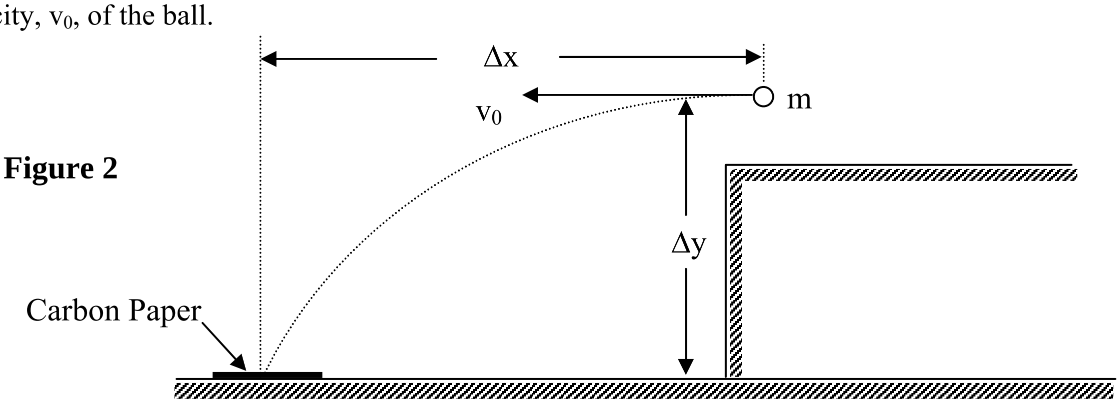
or

$$mv_0 = (M + m)V \quad \ldots\ldots\ldots\ldots\ldots (2)$$

where v_0 is the initial velocity of the ball before impact. By using equations (1) and (2) we can therefore find the initial velocity, v_0, of the ball.

We can also determine the initial velocity of the ball by shooting the ball as above but this time allowing the ball to miss the pendulum bob and travel horizontally under the influence of gravity. In this case we simply have a projectile problem where we can measure the distance traveled horizontally and vertically (see Figure 2) and then determine the initial velocity, v_0, of the ball.

Figure 2



Starting with equations:

$$\Delta x = v_{ox}t + \tfrac{1}{2}a_x t^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \; (3)$$

$$\Delta y = v_{oy}t + \tfrac{1}{2}a_y t^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \; (4)$$

You should be able to derive the initial velocity of the ball in the horizontal direction (assuming that Δx and Δy are known). Include this derivation in your lab report.

Procedure:

Part I Determination of Initial Velocity from Conservation of Energy

1. Set the apparatus near one edge of the table as shown in figure 2. Make sure that the base is accurately horizontal, as shown by a level. Clamp the frame to the table.
   To make the gun ready for shooting, rest the pendulum on the rack, put the ball in position on the end of the rod and, holding the base with one hand, pull back on the ball with the other until the collar on the rod engages the trigger. This compresses the spring a definite amount, and the ball is given the same initial velocity every time the gun is shot.
2. Release the pendulum from the rack and allow it to hang freely. When the pendulum is at rest, pull the trigger, thereby propelling the ball into the pendulum bob with a definite velocity. This causes the pendulum to swing from a vertical position to an inclined position with the pawl engaged in some particular tooth of the rack.
3. Shoot the ball into the cylinder about nine times, recording each point on the rack at which the pendulum comes to rest. This in general will not be exactly the same for all cases but may vary by several teeth of the rack. The mean of these observations gives the mean highest position of the pendulum. Raise the pendulum until its pawl is engaged in the tooth corresponding most closely to the mean value and measure h_1, the elevation above the surface of the base of the index point for the center of gravity. Next release the pendulum and allow it to hang in its lower most position and measure h_2. The difference between these two values gives h, the vertical distance through which the center of gravity of the system is raised after shooting the ball.
4. Carefully remove the pendulum from its support. Weigh and record the masses of the pendulum and of the ball. Replace the pendulum and carefully adjust the thumb screw.
5. From these data calculate the initial velocity v using equations (1) and (2).

Part II Determination of Initial Velocity from Measurements of Range and Fall

1. To obtain the data for this part of the experiment the pendulum is positioned up on the rack so that it will not interfere with the free flight of the ball. One observer should watch carefully to determine the point at which the ball strikes the floor. The measurements in this part of the experiment are made with reference to this point and the point of departure of the ball. Clamp the frame to the table, as it is important that the apparatus not be moved until the measurements have been completed. A piece of paper taped to the floor at the proper place and covered with carbon paper will help in the exact determination of the spot at which the ball strikes the floor.

Note: Use caution in shooting the gun.

2. Shoot the ball a number of times, noting each time the point at which it strikes the floor. Determine, relative to the edge of the paper, the average position of impact of the ball. Determine the distances Δx using this average position on the floor. From the the values of Δx and Δy calculate v_0 by the use of equations (3) and (4). Make careful sketches in your lab report that clearly show all of the distances involved.
3. Find the percentage difference between the values of v_0 determined by the two methods in parts I and II. Try to analyze, the probable errors of the two methods and estimate which one should give the more accurate result.

Note: Before leaving the apparatus, put the ball on its peg and be sure that the spring gun is released.