Experiment 8
Conservation of Energy and Linear Momentum

Advanced Reading
(Serway) 7-3, 7-4, 8-1 thru 8-5, 9-1 thru 9-4

Equipment

- Beck’s ballistic pendulum
- height gauge
- 30 cm ruler
- Dial-o-gram balance
- Vernier caliper

Objective

The objective of this experiment is to measure the speed of a ball as it leaves the ballistic pendulum and to compare this value to that predicted by the conservation of momentum and energy.

Theory

There are two types of collisions—elastic and inelastic. In an elastic collision, the total kinetic energy is conserved (i.e., constant), and in an inelastic collision total kinetic energy is not conserved (typically decreasing). In a perfectly inelastic collision, the initial bodies permanently stick together to form a single final body.

In this experiment an inelastic collision occurs between a brass ball and the arm of a ballistic pendulum (Fig. 8-1). The momentum of the system before and after a collision must be the same (momentum is conserved):

\[ m v_i + M V_i = m v_f + M V_f \]

(1)

where \( m \) is the mass of the ball and \( M \) is the mass of the pendulum arm. Before the collision, the ball has velocity \( v \) and the pendulum has zero velocity. Because the ball is caught by the pendulum arm, the collision is perfectly inelastic. Thus, the velocities on the right-hand side of equation (1) have the same value which we will call \( V \), and the mass of the pendulum-ball system is \( m + M \). The result is

\[ m v = (m + M) V. \]  

(2)

Mechanical energy is not conserved during the collision. Immediately after the collision the pendulum has kinetic energy which is converted into gravitational potential energy as the pendulum arm swings upwards. This energy is conserved:

\[ 1/2 (m + M) V^2 = (m + M) g \Delta h. \]  

(3)

where \( \Delta h \) is the rise of the center of mass of the system (Fig. 10-2). By measuring \( \Delta h \) the initial velocity of the ball can be determined with the use of Eqs. (2) and (3).

Fig. 8-2 Initial and final positions of center of mass of pendulum arm and ball.


**Procedure**

1. Select the same apparatus that was used in Experiment 4. Measure the mass of the ball with the Dial-o-Gram balance. Record this mass.

2. Carefully remove the arm from the ballistic pendulum and weigh it on the Dial-o-gram balance. Record this mass. (Include the mass of the nut.) Securely reattach the arm on the ballistic pendulum.

3. There is a line drawn on the arm at the center of mass. Place the pointer of the height gauge on this line and measure the height above the table top. Record this height.

4. Place the ball on the firing mechanism. Cock the firing mechanism to the *first* detent position and fire the ball into the pendulum arm catcher while holding the ballistic pendulum firmly to the table. (Be sure that the catcher has a rubber band in order to activate the catching mechanism.)

5. Measure the height rise $\Delta h$ using the height gauge. From this information, calculate the ball’s initial velocity. Perform three trials. Compare the average value to the value obtained in Experiment four (Projectile Motion).

6. Repeat the parts 1-5 with the ball cocked to the *third* detent position.

**Questions/Conclusions**

1. Calculate the energy of the system before and after the collision for both the first and the third detent positions. What percentage of the initial energy remains after each collision? What happened to this energy?

2. What effect would not holding the ballistic pendulum firmly to the table have on the velocity of the ball? Explain.

3. Calculate the percent difference between the velocity of the ball for the first detent position in this experiment with the value found in Experiment 4 (Projectile Motion).

4. What effect does the friction due to the rack of notches have on the determined value of the initial velocity? Explain.

5. Determine the spring constant of the ballistic pendulum. The energy relationship for the potential energy of the spring and the kinetic energy of the ball of the ballistic pendulum is

   \[
   \frac{1}{2}k\left((\Delta x_{\text{meas}} + 0.0580)^2 - (0.0580)^2\right) = \frac{1}{2}(m_{\text{ball}} + 0.1255)v^2
   \]

   where $\Delta x_{\text{meas}}$ is the measured compression of the spring, $k$ is the spring constant and $m_{\text{ball}}$ is the mass of the ball. All units are SI.