Physics 221 - Experiment 8

Conservation of Energy and Linear Momentum

Fig. 8-1 Ballistic Pendulum

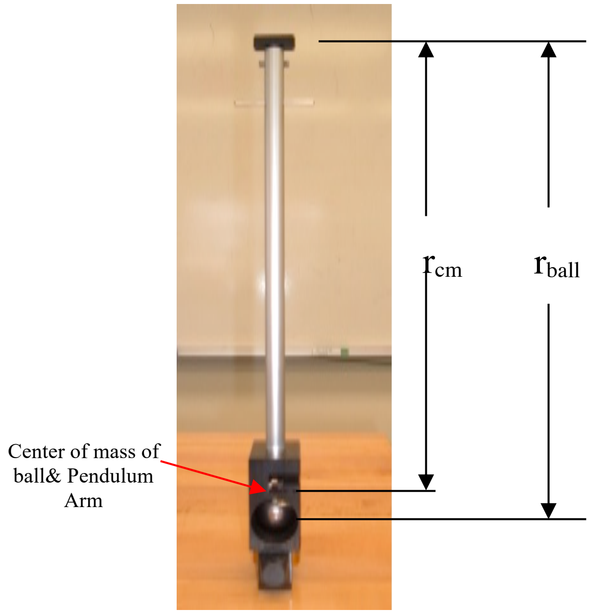

Fig 8-2 Radii of rotation for r_{cm} & r_{ball}

Equipment

Ballistic Pendulum
30-cm Ruler
Triple Beam Balance
C-clamp
Safety glasses

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Advance Reading

Openstax University Physics- Vol 1
Chapter 8, sections 8-1, 8-2 & 8-3 (Example 8.7) and Chapter 9, sections, 9-1, 9-3 & 9-4 (pages 424 & 424). Note the difference between elastic and inelastic collisions and the concept of mechanical energy.

Objective
To determine the speed of the ball as it leaves the ballistic pendulum using conservation of linear momentum and conservation of energy considerations.

Theory
In this experiment an inelastic collision will occur between the ball and the ballistic pendulum arm. The momentum of the system before and after the collision must be the same (i.e., as always, momentum [both linear and angular] is conserved). *The pendulum arm and ball are assumed to be point masses.* We can then write

$$m_b v_b + M_{pa} v_{pa} = m_b v_b' + M_{pa} v_{pa}' \qquad \text{(Eq. 8-1)}$$

In this case, m_b is the mass of the ball and M_{pa} is the mass of the pendulum arm. Before the collision, the ball has a velocity of v_b and the pendulum arm has a velocity of v_{pa}.

The collision is perfectly inelastic, with the ball being caught by the pendulum arm, so that the velocities on the right-hand side of Eq. 5-1 are equal. Label this velocity V_{pab}. The mass of the pendulum-ball system is $m_b + M_{pa}$. The result of this is:

$$m_b v_b = (m_b + M_{pa}) V_{pab} \qquad \text{(Eq. 8-2)}$$

Mechanical energy is not conserved during an inelastic collision, but just after the collision (*again the pendulum arm and ball are assumed to be point masses)* the pendulum-ball system has kinetic energy (KE = $1/2mv^2$).

We assume this kinetic energy is conserved and transformed into gravitational potential energy (PE = mgh) as the pendulum arm swings up. In mathematical form $KE_i = PE_f$, or:

$$\tfrac{1}{2}(m_b + M_{pa})V_{pab}^2 = (m_b + M_{pa})g\Delta h \qquad \text{(Eq. 8-3)}$$

By measuring the rise of the center of mass of the system, Δh, the initial velocity of the ball can be determined. The center of mass of the pendulum arm is indicated on fig. 8-2. This is the reference point for initial and final height.

When the ball is fired, it causes the arm to rise and the angle is indicated. Use this angle and the radius of the center of mass, r_{cm}, to calculate Δh.

PROCEDURE

1. Measure and record the mass of the ball, m_b. Mass of ball is 65.8g. Carefully remove the arm from the ballistic pendulum. Measure and record the mass of the pendulum arm, M_{pa}. Mass of pendulum arm is 249.9g.

2. Measure the distance from the axis of rotation to the center of mass of pendulum and ball, r_{cm}. See Fig. 8-2. Next, measure the distance from the axis of rotation to the center of mass of the ball, r_{ball}. See Fig. 8-2. Use figure 8.2 and measure the r_{cm} & r_{ball} on the figure using a ruler. Multiply both measured values by scale factor of 4.8 *(for instance if you measured 5 cm, you would then multiply by 4.8 to get r_{cm}= 24.0 cm).*

3. Reattach the arm on the ballistic pendulum.

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Before firing:

Do not aim at people or computers!

4. Place the ball on the firing mechanism. Cock the firing mechanism to the 3rd detent position. Fire the ball into the pendulum arm catcher. See You Tube video below to see apparatus in action. https://youtu.be/XfWtlHMJkdo

5. Measure and record the new angle; calculate Δh. See photo below on page 4 for measured angle.

   See example 8.7 of Openstax text Vol 1 page 373 for help on how to find Δh. Please note that r_{cm} is equal to L in example.

6. Calculate the velocity of the ball, v_b first using Eq. 8-3 to find V_{pab} and then Eq. 8-3.

   Note that Eq-8-3 can be simplified by dividing both sides by ($m_b + M_{PA}$).

Questions

1. For 3rd detent only.

- Calculate the mechanical energy of the system *just before the collision*. This is (initial) kinetic energy of ball.

- Calculate the mechanical energy of the system *just after the collision*. This is potential energy of ball-arm system.

- What percent of the initial mechanical energy remains after the collision? What happened to the "lost" mechanical energy?

2. Assume that the ballistic pendulum was not held firmly to the table when it was fired. What effect would this have on the velocity of the ball? Explain.

3. It was assumed that the pendulum arm system was a point mass. This is not true. Rather than conservation of linear momentum, *conservation of angular momentum should be used,* and equation 8-2 can be written as

$$L_{initial} = L_{final} = m_b v_b r_{ball} = I_{pab}\omega_{pab}$$

where I_{pab} is the moment of inertia of pendulum arm and ball system, v_b is the velocity of the ball and r_{ball} is the distance

from the center of mass of the ball to the axis of rotation. See step 2.

Since $\omega_{pab} = \frac{V_{pab}}{r_{cm}}$, the equation above can be written as

$$m_b v_b r_{ball} = I_{pab}\frac{V_{pab}}{r_{cm}} . \qquad \text{Eq 8-4}$$

Equation 8-3 now becomes

$$\tfrac{1}{2}(I_{pab})\omega_{pab}^2 = (m_b + M_{pa})g\Delta h .$$

Again, since $\omega_{pab} = \frac{V_{pab}}{r_{cm}}$, the equation above can be written as

$$\tfrac{1}{2}(I_{pab})\frac{V_{pab}^2}{r_{cm}^2} = (m_b + M_{PA})g\Delta h \qquad \text{Eq 8-5}$$

Using I_{pab}=0.025 kg-m^2, your measured values for masses, r_{ball} from figure 8-2 (& scale factor), r_{cm} and Eqs- 8-4 (first to get V_{pab}) & 8-5 above, calculate the velocity of the ball, v_b.

Was the assumption of the system being point sources a reasonable assumption? Show all work.

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