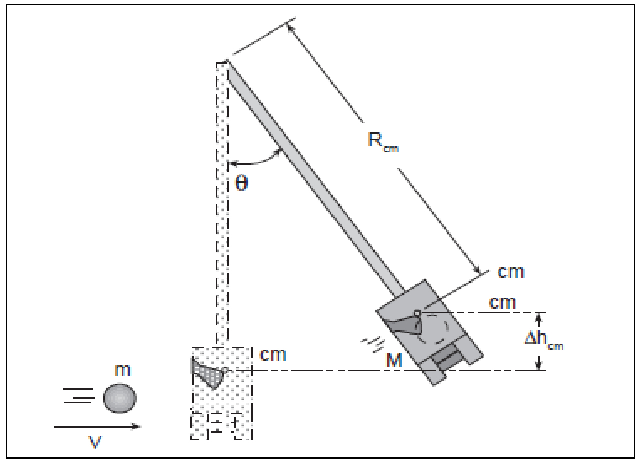
Ballistic Pendulum

Equipment Needed	Qty
ballistic pendulum	1
ruler	1
balance	1
DataStudio	1
Photogate mounting bracket	1
photogate	1



This exercise illustrates the concepts of **conservation of energy** and **conservation of momentum**, and uses a type of device (the **ballistic pendulum**) originally invented for determining the speed of a bullet.

In our version, a steel ball is shot from a spring-powered projectile launcher and lodges itself in a motionless pendulum (figure). The pendulum and ball swing up due to the ball's momentum, and the height Δh_{CM} to which they swing is used to determine the ball's speed prior to striking the pendulum.

Because of the conservation of momentum, the ball's momentum prior to striking the pendulum is equal to the momentum of the ball and pendulum after contact.

$$p_1 = p_2$$

$$mv_1 = (m + M)v_2 \qquad (1)$$

p_1 momentum of ball before contact
p_2 momentum of ball/pendulum after contact
m mass of ball
v_1 speed of ball before contact
M mass of pendulum
v_2 speed of ball/pendulum after contact

In this way, the speed of the ball prior to contact (v_1) can be determined from the speed of the ball/pendulum after contact (v_2). Moreover, v_2 can be determined from Δh_{CM}, the height increase of the ball/pendulum. So then, v_1 can be determined from Δh_{CM}.

The conservation of energy is used to relate v_2 and Δh_{CM} . The kinetic energy of the moving pendulum/ball is converted to potential energy as their center of mass rises. So then, their speed after contact is related to the height to which they rise by:

$$KE_2 = PE_3$$

$$^1/_2\,(m + M)v_v^2 = (m + M)g\Delta h_{CM}$$

$$v_2 = \sqrt{2g\Delta h_{CM}} \tag{2}$$

KE_2 Kinetic energy of ball and pendulum after contact

PE_3 Potential energy of ball and pendulum at peak of swing.

Δh_{CM} Distance that ball/pendulum center of mass rises

In our setup, Δh_{CM} is determined from θ, the angle of the pendulum at maximum swing (figure). Some trigonometry shows that

$$\Delta h_{CM} = R_{CM}(1 - cos\theta) \tag{3}$$

Where R_{CM} measures from the pendulum pivot to the center of mass. When measuring this be sure the ball is in the pendulum and find the pendulum's balance point using the aluminum fulcrum.

Procedure:

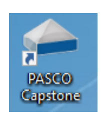
The following steps can be used to determine v_1 from θ (as always, remember to use SI units for all quantities).

1. Measure and record the following: R_{CM} = ________ m = ________ M = ________
2. Fire the apparatus 10 times, recording θ each time and find their average. θ_{avg} = ________
3. Use equation 3 to calculate Δh_{CM} from the average θ. Δh_{CM} = ________
4. Use equation 2 to calculate v_2 from Δh_{CM}. v_2 = ________
5. Use equation 1 to calculate v_1 from v_2. v_1 = ________

The speed of the ball will also be measured more directly (for comparison with your result above) using an infrared photogate sensor. The projectile launcher must be removed from its mount and reattached higher up on the vertical aluminum column, as in the figure below. Attach the photogate mounting bracket as in the figure.

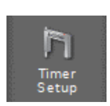
Setup for Measuring Ball Speed

1. Plug the photogate into port 3 of "DIGITAL INPUTS" on the 850 interface box.
2. Double click the PASCO Capstone icon to start the software.



3. Click on the "Hardware Setup" icon.

4. You should see an image of the 850 box. Click on the port 3 plug in "Digital Inputs."
5. Choose "Photogate."
6. Click again on "Hardware Setup" to dismiss it.
7. Click on the "Timer Setup" icon.



8. Since we'll use the Pre-Configured Timer, click "Next."
9. Since we'll use a Photogate on Ch 3, click "Next."
10. Click the "Select a Timer" dropdown menu and choose "One Photogate (Single Flag)."
11. In the next step, just the Speed box should be checked. Click "Next."
12. Set the Flag Width to 0.0254 m. Click "Next." This value is one inch, the diameter of the ball.
13. Click "Finish."

14. The “Record” button should now be red, indicating that the photogate can collect data.
15. Click again on the Timer Setup icon to dismiss it.

16. Double click the “Digits” icon (on the right-hand side of the screen). This will produce a digital readout for measuring the speed of the ball through the photogate.

17. Click on <Select Measurements> and choose “Speed.”
18. With the photogate mounted on the ballistic pendulum using the Photogate Mounting Bracket, you can now measure the gun’s muzzle velocity.
19. When the experiment is finished, you can kill the Capstone window. When you’re asked whether to save changes, click “Discard.”

Questions

1. Find the percent difference between the v_1 that you determined using the ballistic pendulum and the v_m that you found using the photogate. $\% \, diff =$ _______
2. Determine KE_1, the ball’s kinetic energy prior to contact with the pendulum, as well as KE_2, the kinetic energy of the ball/pendulum after contact. $KE_1 =$ _______ $KE_2 =$ _______
3. The KE_2 (of the ball/pendulum) should be smaller than KE_1 (of the ball prior contact). What percentage of KE_1 is KE_2? _______
4. Since energy is a conserved quantity, all the energy in the system prior to contact still remains after contact. What form does the missing energy take after contact? ____________________
5. How many Joules of energy is this? $Q =$ _______
6. The impact of the ball causes the pendulum to exert a forward impulse on the pivot on which it swings. Thus not all of the ball’s momentum is in the ball/pendulum after contact, a fact that we have not taken into consideration in our calculations. As a result of this oversight, is our estimate of the ball’s velocity too high or too low? ____________________
7. It turns out that $KE_2/KE_1 = m/(m+M)$. If we had used a plastic ball instead of a steel ball, would this fraction be greater or smaller? ____________________