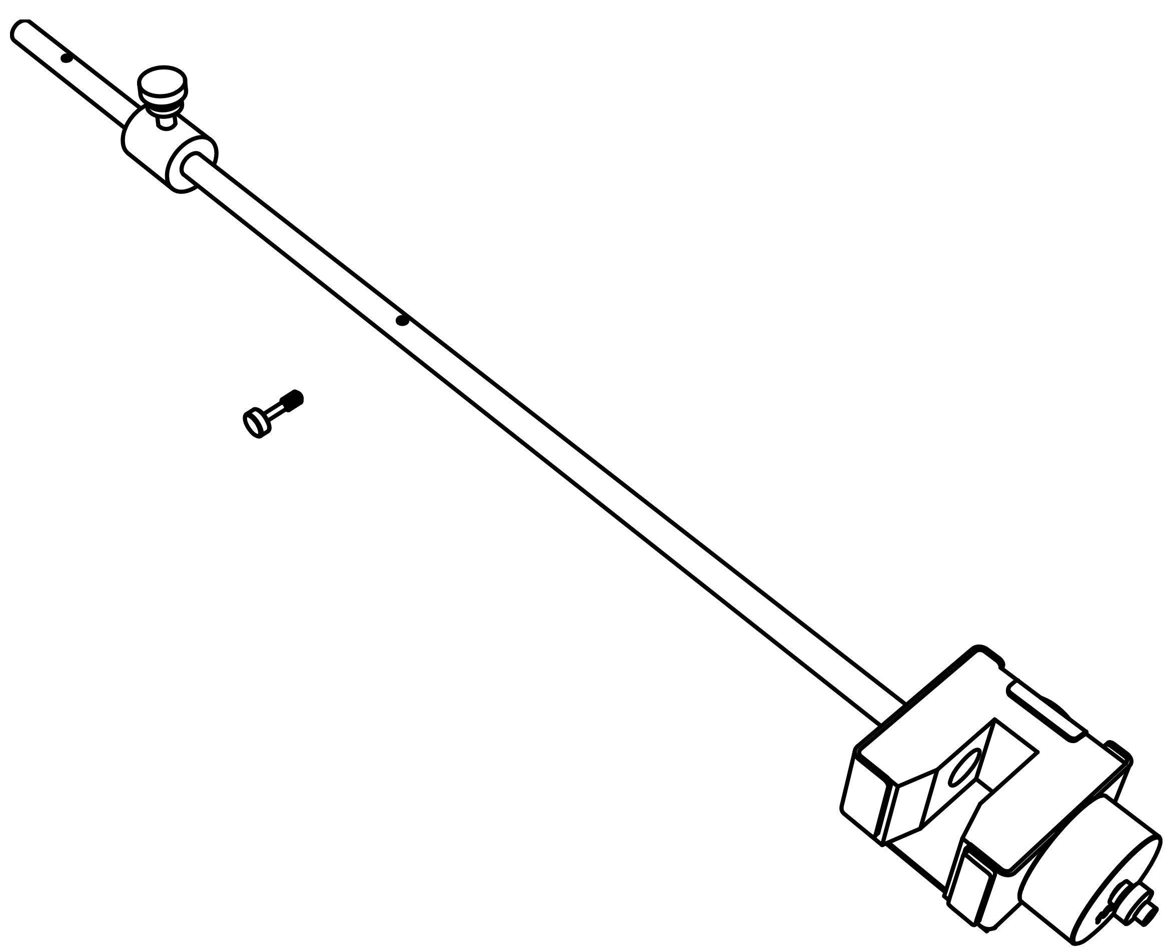
Instruction Manual with
Experiment Guide
012-09851B

Mini Launcher Ballistic Pendulum

ME-6829



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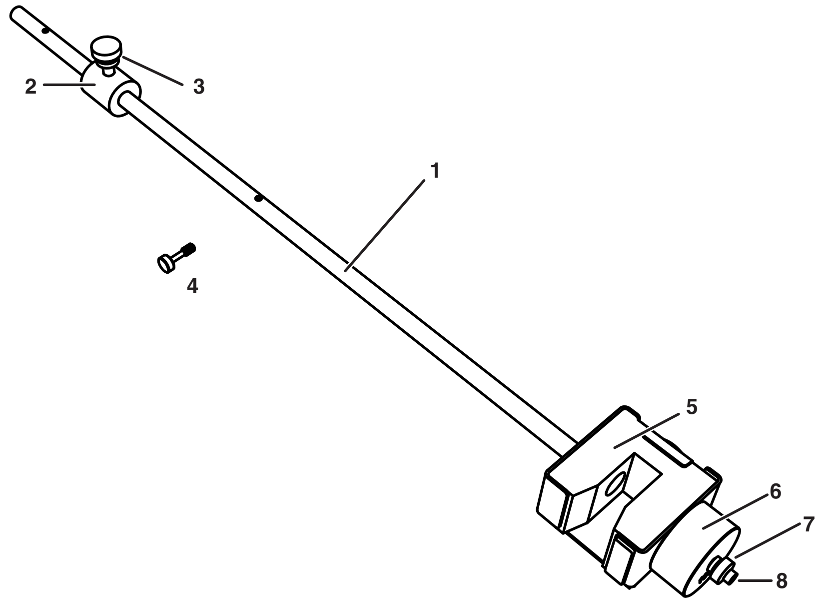

Included Equipment	Part Number
1. Catcher and pendulum rod	ME-6829
2. Sliding counterweight	648-09595
3. Counterweight set screw	613-047
4. Pendulum attachment screw	613-076
5. Replaceable foam insert	648-09400
6. Ballast mass	648-06511
7. Ballast lock nut	614-029
8. Ballast fastening screw	611-043

Required Equipment	Part Number
Mini Launcher[1] (includes projectile)	ME-6825A
PASPORT Rotary Motion Sensor with three-step pulley[2]	PS-2120
Table Clamp	ME-9472, *or similar*
90 cm mounting rod	ME-8738, *or similar*

Optional Equipment[3]	
Photogates (qty. 2)	ME-9498A, *or similar*
Digital Adapter[2]	PS-2159
Photogate Mounting Bracket	ME-6821
Super Pulley with Clamp	ME-9448A
Hanging mass	ME-9348, *or similar*

[1]The new-style mounting bracket included with model ME-6825A is required. If you have an older mini launcher (model ME-6825), upgrade it with a model ME-6836 bracket.

[2]Sensor requires a PASPORT interface and PASCO data collection software.

[3]For measuring launch velocity and rotational inertial. See Experiment 3.

Introduction

Use the Mini Launcher Ballistic Pendulum in combination with a Mini Launcher and Rotary Motion Sensor (RMS) to measure the velocity of a steel ball. The Mini Launcher shoots the ball into the Mini Launcher Ballistic Pendulum. The RMS measures the resulting angular displacement and velocity of the pendulum. The pendulum can be configured to catch the ball or allow the ball to bounce off. Two pivot locations and removable masses allow it to approximate a simple pendulum or a physical pendulum.

This manual includes set-up instructions and experiment instructions ranging from a simple (Experiment 1) to more advanced (Experiment 3).

Equipment Set-up

Assemble the Apparatus

1. Set up the mini launcher, bracket, table clamp, mounting rod, and RMS as shown in Figure 1. The exact position of the RMS is not important yet. Note that the side of the RMS *without* the model number on the label is facing you. (If the RMS is mounted the other way, it will measure negative displacement.)

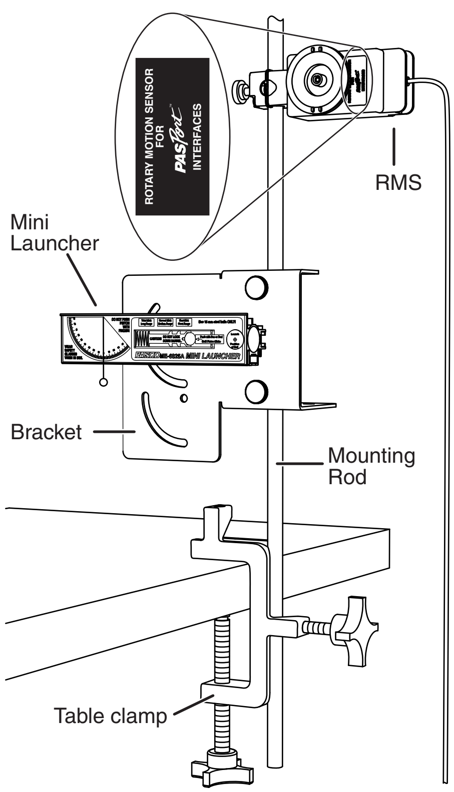

Figure 1: Launcher and RMS mounted on rod

2. Slide the three-step pulley onto the RMS shaft with the largest pulley out as shown in Figure 2.

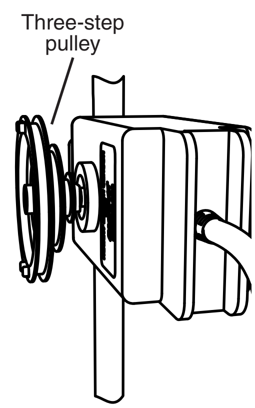

Figure 2: Three-step pulley on RMS

3. Select one of the holes on the pendulum rod: either the center hole or the end hole. If you will be using the end hole, remove the counterweight. Also select a side of the pendulum: either the catcher or the bumper. Thread the attachment screw into the hole as shown in Figure 3. Screw it all the way in so it is loosely captured.

4. Thread the screw into the end of the RMS shaft. Align the pendulum rod with the tabs on the pulley as shown in Figure 4. Tighten the screw.

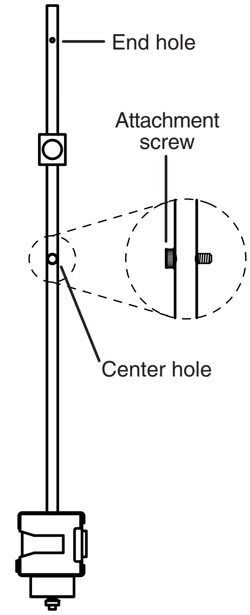

Figure 3: Attachment screw loosely captured in center hole

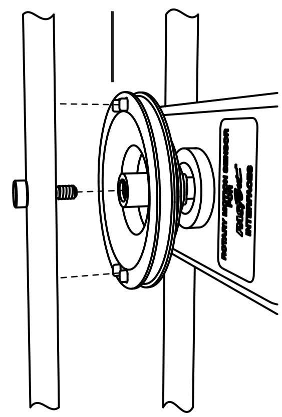

Figure 4: Attaching pendulum to RMS

5. Adjust the position of the RMS so the pendulum is aligned with the launcher as shown in Figure 5.

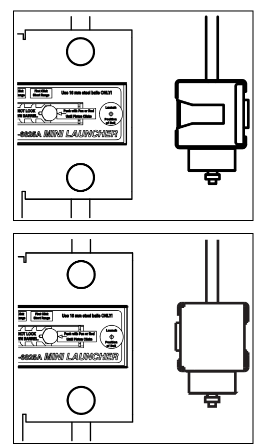

Figure 5: Pendulum aligned with launcher, catcher side (top) and bumper side (bottom)

Load the Launcher

1. Swing the pendulum out of the way as shown in Figure 6.

2. Place the projectile (included with the launcher) in the end of the barrel.

3. Use the pushrod included with the launcher to push the ball down the barrel until the trigger catches in the first, second, or third position (for a slow, medium, or fast launch).

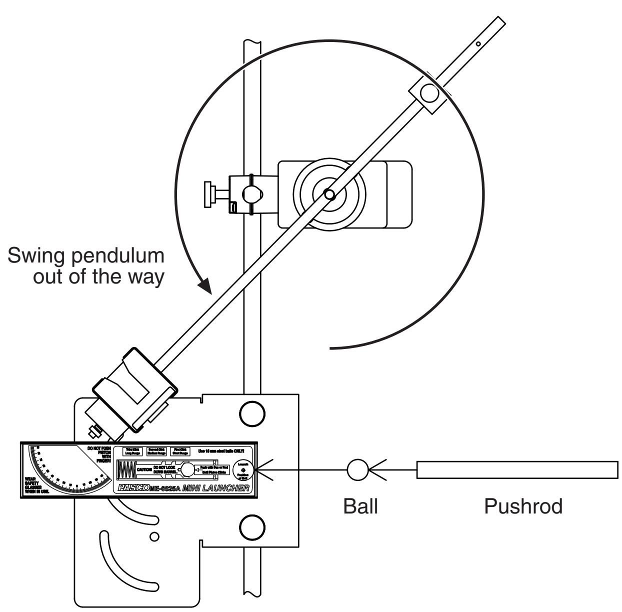

Figure 6: Loading the launcher

4. Return pendulum to its normal hanging position.

Prepare the Sensor

1. Connect the RMS to a PASPORT interface. If you will be using a computer, connect the interface to it and start the data collection software.

2. Set the sampling rate of the RMS to 40 Hz.

3. Prepare a graph to show angular position versus time.

For detailed instructions, refer to the documentation that came with your interface or the data collection software on-line help.

Test Fire

1. Start data recording.

2. Pull the trigger of the launcher.

3. Stop data collection.

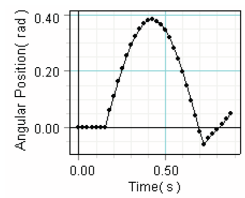

Figure 7: Typical data

Figure 7 shows typical data for an inelastic collision. If your data shows negative angular displacement, disassemble the RMS from the mounting rod and pendulum and remount it with the pendulum attached to the other end of the RMS shaft.

Foam Insert Replacement

With age and repeated use, the foam catcher insert may lose elasticity. If the catcher does not reliably hold the ball, remove the foam insert and replace it with a new one. (Contact PASCO Teacher Support for replacement part 648-09400.)

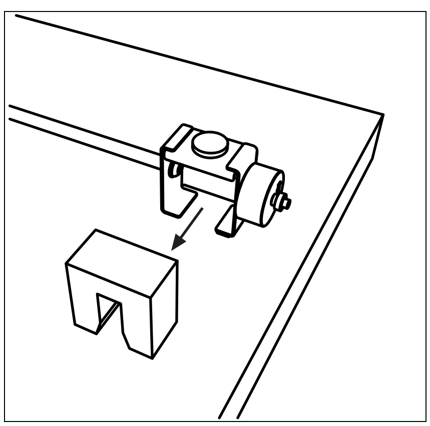
Figure 8: Removable foam insert

Experiment 1: Inelastic Collisions

Experiment Set-up

Set up the equipment and software as described on pages 4–6 with the pendulum rod attached to the RMS at the center hole and the catcher side of the pendulum facing the launcher. Place the counterweight on the pendulum rod midway between the RMS shaft and the top end of the rod. Attach the ballast mass to the bottom of the catcher.

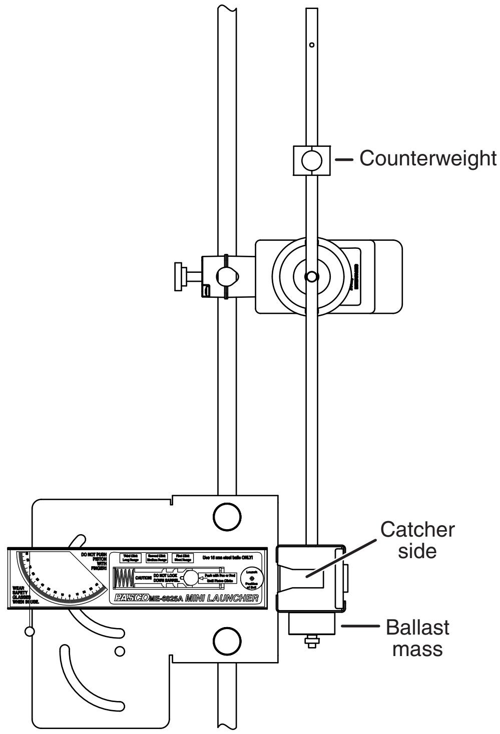

Figure 1.1: Set-up for Part A

Part A: Completely Inelastic Collision (Ball Catch)

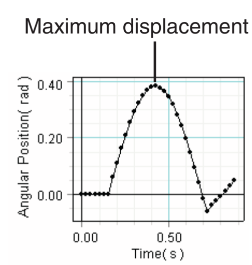

Figure 1.2: Typical data

1. Load the launcher and push the ball in to the first (slowest) position.
2. Start data collection.
3. Pull the trigger to launch the ball so it is caught by the pendulum.
4. After the pendulum has swung out and back, stop collection.
5. Record the maximum angular displacement of the pendulum here. ___________

Part B: Partially Inelastic Collision (Ball Bounce)

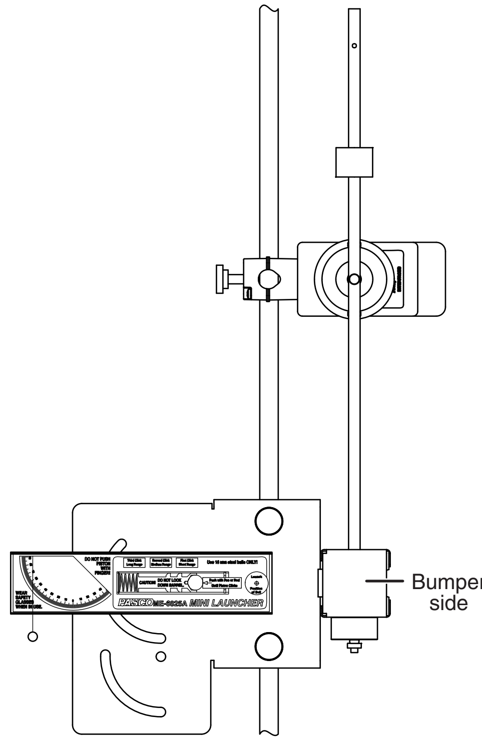

Figure 1.3: Set-up for Part B

1. Remove the pendulum from the RMS. Reattach the pendulum with the bumper facing the launcher. There should be a gap of a few centimeters between the end of the launcher and the bumper.

2. **Predict** what will happen. Will the maximum angular displacement in this part be *greater* or *less than* in the maximum displacement in Part A? _____________

3. Guess the maximum angle that the pendulum will swing to. Record your prediction here. ______________

4. Start data collection.

5. Pull the trigger to launch the ball so it hits the pendulum and bounces off.

6. After the pendulum swung out and back, stop collection.

7. Record the maximum angular displacement of the pendulum here. ___________

Analysis

1. Was the maximum angular displacement in Part B greater or less than in Part A? ______________

2. Was your prediction in Part B step 2 correct? ______________

3. Create a graph of angular velocity versus time showing the data from parts A and B. Which type of collision (completely inelastic or partially inelastic) resulted in the greater maximum velocity? ______________

4. Explain qualitatively how maximum velocity is related to maximum angular displacement.

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Experiment 2: Ballistic Pendulum

Theory

The ballistic pendulum has historically been used to measure the launch velocity of a high speed projectile. In this experiment, a projectile launcher fires a steel ball (of mass m_{ball}) at a launch velocity, V_0. The ball is caught by a pendulum of mass m_{pend}. As the momentum of the ball is transferred to the catcher-ball system, the pendulum swings freely upwards, raising the center of mass of the system by a distance h.

The pendulum rod is hollow to keep its mass low, and most of the mass is concentrated at the end so that the entire system approximates a simple pendulum. During the collision of the ball with the catcher, the total momentum of the system is conserved. Thus the momentum of the ball just before the collision is equal to the momentum of the ball-catcher system immediately after the collision:

(eq. 2.1)
$$m_{ball}V_0 = MV$$

where V is the speed of the catcher-ball system just after the collision, and

(eq. 2.2)
$$M = m_{ball} + m_{pend}$$

During the collision, some of the ball's initial kinetic energy is converted into thermal energy. But *after* the collision, as the pendulum swings freely upwards, we can assume that energy is conserved and that all of the kinetic energy of the catcher-ball system is converted into the increase in gravitational potential energy.

(eq. 2.3)
$$\frac{1}{2}MV^2 = Mgh$$

where g =9.81 m/s^2, and the distance h is the vertical rise of the center of mass of the pendulum-ball system.

Combining equations 2.1 through 2.3 (eliminating V) yields

(eq. 2.4)
$$V_0 = \left(1 + \frac{m_{pend}}{m_{ball}}\right)\sqrt{2gh}$$

Experiment Set-up

1. Attach the ballast mass to the bottom of the catcher.

2. Set up the equipment and software as described on pages 4–6 with the pendulum rod attached to the RMS at the end hole and the catcher side of the pendulum facing the launcher. Do not put the sliding counterweight on the pendulum rod.

Procedure

Record Data

1. Load the launcher and push the ball in to the third (fastest) position.

2. Start data collection.

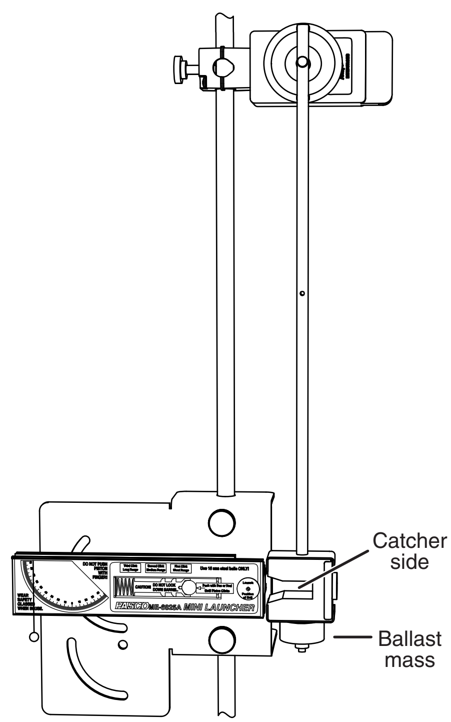


Figure 2.1: Set-up

3. Launch the ball so that it is caught in pendulum.

4. After the pendulum has swung out and back, stop data collection.

5. Note the maximum angular displacement measured by the RMS. Record it in Table 2.1.

6. Repeat steps 1 through 5 several times.

7. Calculate the average maximum displacement, θ_{max}.

Table 2.1: Maximum Angular Displacement

Trial	Angle
Trial 1	
Trial 2	
Trial 3	
Trial 4	
Trial 5	
Trial 6	
Avg:	θ_{max}=

Find the Mass and Center of Mass

1. Fire the ball one more time (without recording data). Stop the pendulum near the top of its swing so it does not swing back and hit the launcher (this will prevent the ball from falling out or shifting).

2. Remove the pendulum from the RMS.

3. Remove the screw from the pendulum shaft.

4. With the ball still in the catcher, place the pendulum at the edge of a table with the pendulum shaft perpendicular to the edge and the counterweight hanging over the edge. Push the pendulum out until it just barely balances on the edge of the table. The balance point is the center of mass. (See Figure 2.1.)

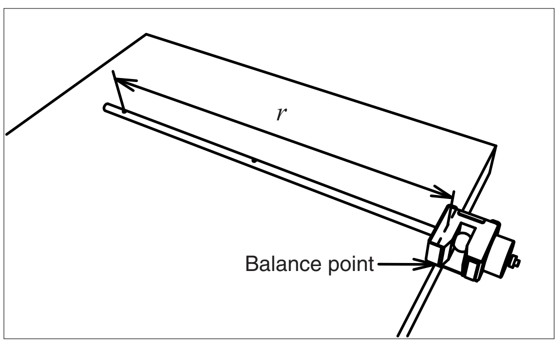


Figure 2.1: Pendulum-ball system balanced on table edge

5. Measure the distance, r, from the center of rotation (where the pendulum was attached to the RMS) to the center of mass. r = ______________________.

6. Remove ball from the catcher.

7. Measure the mass of the pendulum (without the ball). m_{pend} = ________________

8. Measure the mass of the ball. m_{ball} = ______________________

Analysis

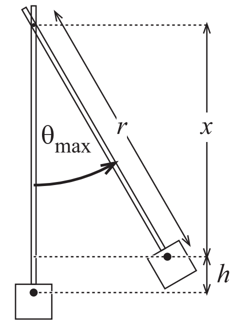
1. Use your value of θ_{max}, the distance r, and Equation 2.5 to calculate the maximum height (h) that the center of mass rises as the pendulum swings up (see Figure 2.2).

(eq. 2.5) $$h = r(1 - \cos(\theta_{max}))$$

h = ______________________

2. Use your value of h and Equation 2.4 to calculate the launch velocity of the ball.

V_0 = ______________________



$x = r\cos(\theta_{max})$

$r = x + h$

Figure 2.2: Calculating h

Question

The theory for this experiment ignores the rotational inertia of the pendulum. Because the pendulum is not really a simple pendulum (a point mass on a massless rod), a systematic error is introduced. Does this simplistic analysis tend to give a launch velocity that is too high or too low? (See Experiment 3 for a more exact treatment.)

Further Study

Use two photogates to measure the launch velocity of the ball. Compare this value to the value you found using the ballistic pendulum.

Experiment 3: Conservation of Momentum and Energy

Background

In this experiment you will analyze the angular collision between a ball and a physical pendulum. You will compare the rotational momentum of the ball before the collision to the rotational momentum of the pendulum-ball system after the collision. Both rotational momenta are measured about the pendulum's pivot point.

You will also compare the kinetic energy of the ball before the collision, the kinetic energy of the pendulum-ball system just after the collision, and the maximum potential energy of the system after the collision.

The data-taking phase of this experiment has three parts. In Part 1 you will use photogates to measure the launch velocity of the ball. In Part 2 you will measure the maximum rotational velocity and angular displacement of the pendulum after the collision. In Part 3 you will measure the rotational inertia of the pendulum-ball system.

Part 1: Measure Launch Velocity

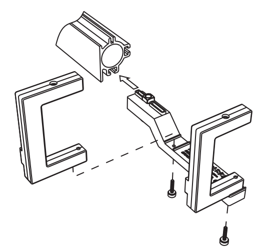


Figure 3.1: Launcher with photogates

Set up the launcher with two photogates and a photogate bracket (see Figure 3.1). Measure the launch velocity (v_{launch}) of the ball on the fastest setting. Do several trials and use the average value.

If you will be doing the Advanced Study part of this experiment, also measure the launch velocity for the medium and slow settings.

Part 2: Record Ballistic Pendulum Data

Set-up

1. Set up the equipment and software as described on pages 4 through 6 with the pendulum rod attached to the RMS at the center hole and the catcher side of the pendulum facing the launcher. Do *not* attach the ballast mass to the bottom of the catcher.

2. Slide the counterweight onto the pendulum rod above the RMS attachment point. Adjust the position of the counterweight so the pendulum is perfectly balanced *without the ball*. If you release the pendulum in the horizontal position, it should not move. (See Figure 3.2.)

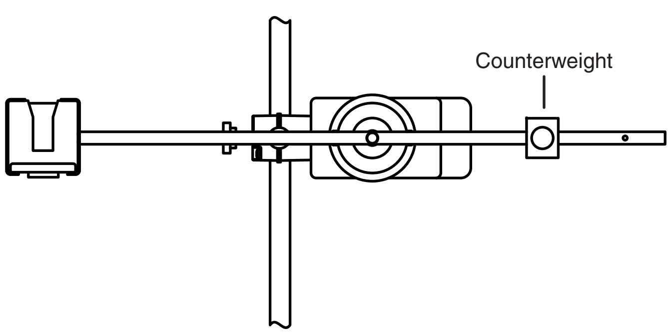


Figure 3.2: Pendulum balanced horizontally

3. Prepare a graphs to display angular velocity versus time and position versus time.

Procedure

1. Load the launcher and push the ball in to the third (fastest) position.

2. Move the pendulum into the vertical position. If it does not stay that way by itself, hold it very lightly with one finger.

3. Start data collection.

4. Launch the ball so that it is caught by pendulum.

5. After the pendulum has swung out and back, stop data collection.

6. Note the maximum angular displacement measured by the RMS. Record it in Table 3.1

7. Record the initial angular velocity (just after the collision) in Table 3.1. Because this velocity occurs close to the collision, the RMS cannot measure it accurately. Instead, note the maximum *negative* velocity that occurs when the pendulum swings back toward the launcher (record it as a positive value). Though this might be slightly smaller than the actual initial velocity (due to friction), it is a more reliable measurement.

8. Repeat steps 1 through 7 several times.

9. Calculate the average maximum displacement (θ_{max}) and the average initial velocity (ω_0).

Table 3.1: Angular Displacement and Velocity

Trial	Maximum Angle	Initial Angular Velocity
Trial 1		
Trial 2		
Trial 3		
Trial 4		
Trial 5		
Trial 6		
Average:	θ_{max}=	ω_0=

10. Measure the mass of the ball. m_{ball} = ____________________

11. Fire the ball into the catcher one more time (without recording data). Stop the pendulum near the top of its swing so it does not swing back and hit the launcher (this will prevent the ball from falling out or shifting).

12. Measure the distance, ℓ, from the center of rotation (where the pendulum attaches to the RMS) to the center of ball. ℓ = ____________________

Part 3: Determine Rotational Inertia of Pendulum-ball System

Set-up

1. Remove the RMS from the mounting rod. (Leave the pendulum attached to the RMS and leave the ball in the catcher.)

2. Clamp the RMS on the mounting rod so that the pendulum can rotate in a horizontal plane (see Figure 3.3).

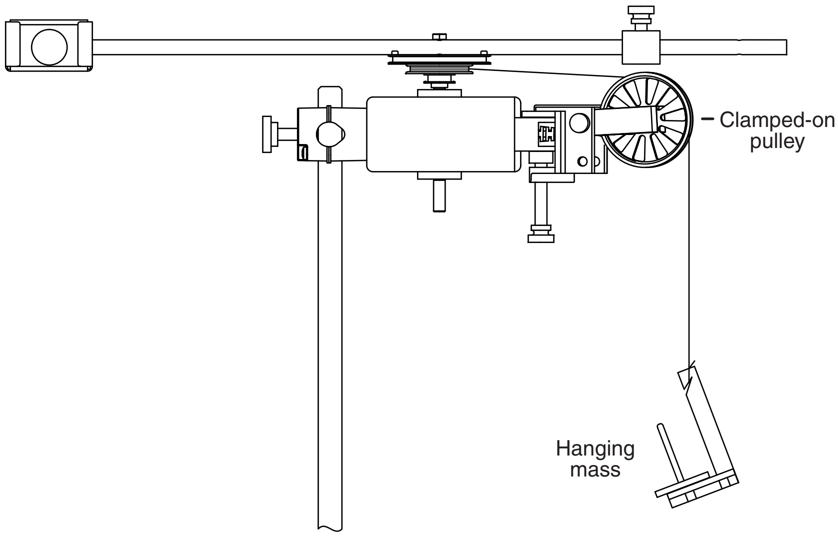


Figure 3.3: Setup for determining rotational inertia

3. Clamp a pulley to the RMS and set up a string and hanging mass (approximately 20 g to 30 g) as shown in Figure 3.3. Wind the string a few times around the middle step of the three-step pulley. Adjust the angle and height of the clamped-on pulley so that the string will unwind and run over the pulley with as little friction as possible.

Procedure

1. Start data collection.

2. Release the hanging mass.

3. After the string has unwound from the three-step pulley, stop data collection.

4. Determine the angular acceleration of the pendulum (α) from the slope of the angular velocity versus time graph. α = ____________________

5. Measure the radius of the middle step of the three-step pulley. R_{pulley} = ____________________

6. Measure the mass of the hanging mass. m = ____________________

7. Calculate the acceleration (a) of the hanging mass.

$$a = \alpha R_{pulley}$$

8. Calculate the tension in the string (F_T). Since the hanging mass is accelerating, the string tension is not the weight of the mass. Writing Newton's 2nd Equation for the free-body diagram in Figure 3.4 yields:

$$ma = mg - F_T$$

where $g = 9.8\ \text{m/s}^2$.

F_T = ____________________

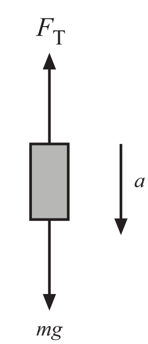


Figure 3.4: Free-body diagram of hanging mass

9. Calculate the torque (τ) applied to the pulley by the string.

$$\tau = R_{pulley} F_T$$

10. Calculate the rotation inertia (I) of the pendulum-ball system using the rotational form of Newton's 2nd Law:

$$\tau = I\alpha$$

I = ____________________

Analysis

1. Calculate the initial angular momentum of the ball (L_{launch}) just *before* the collision. The angular momentum is calculated about the pendulum pivot.

$$L_{launch} = m_{ball} \ell V_{launch}$$

2. Calculate the angular momentum of the ball-pendulum system (L_0) immediately after the collision.

$$L_0 = I\omega_0$$

3. Calculate the kinetic energy of the ball (K_{launch}) before the collision.

$$K_{launch} = \frac{1}{2} m_{ball} v_0^2$$

4. Calculate the kinetic energy of the ball-pendulum system (K_0) immediately after the collision.

$$K_0 = \frac{1}{2} I\omega_0^2$$

5. Use the maximum angular displacement of the pendulum (θ_{max}) to calculate the change in height (h_{max}) of the ball. Refer to Figure 3.5.

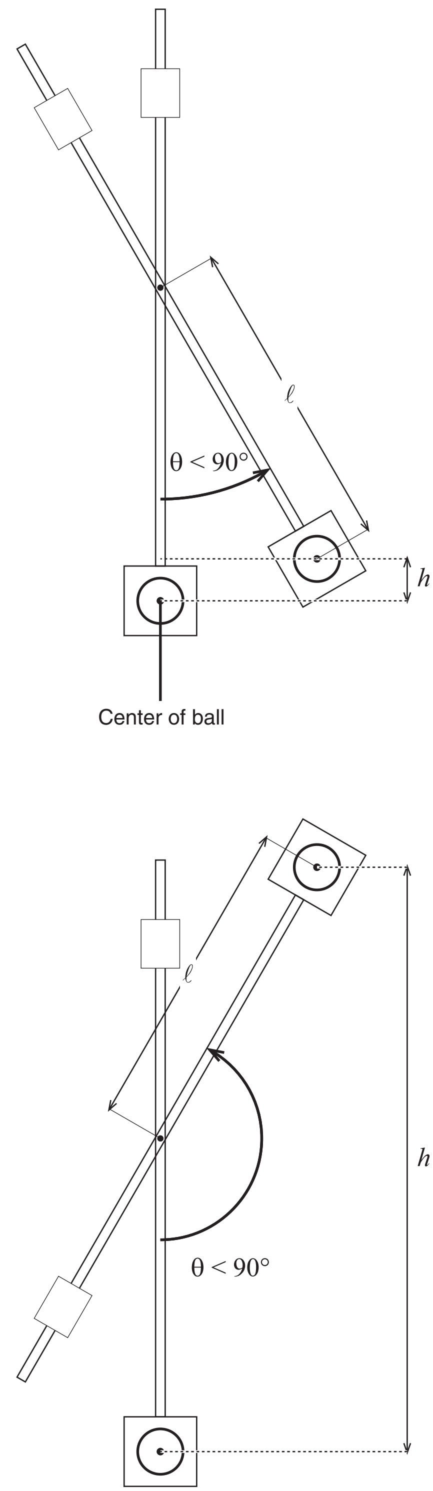


Figure 3.5: Calculating h

6. Calculate the gain in potential energy of the ball (ΔU_{ball}).

$$\Delta U_{ball} = m_{ball}\, g\, h_{max}$$

Questions

1. Why did you calculate the ball's rotational momentum rather than the linear momentum? Why did you calculate the rotational momentum around the pendulum pivot rather than the center of the ball?

2. Compare the rotational momentum of the ball before the collision to the rotational momentum of the pendulum-ball system just after the collision. Was momentum conserved?

3. Compare the kinetic energy of the ball before the collision to the kinetic energy of the pendulum-ball system just after the collision. Was energy conserved in the collision?

4. What was the gain in potential energy of the pendulum (not including the ball)? What was the purpose of the counterweight?

5. Compare the kinetic energy of the pendulum-ball system just after the collision to the gain in potential energy of the ball. Was energy conserved as the pendulum swung after the collision?

Further Study

I. Different Launch Speeds

Repeat the experiment for the slow and medium launch speeds. How does changing the launch speed affect how well momentum is conserved?

Look at the ratio of initial kinetic energy (of just the ball) to the kinetic energy of the pendulum-ball system (just after the collision). How does the launch speed of the ball affect this ratio?

II. Different Center of Mass

Repeat the experiment without the counterweight. This time, you will need to find the center of mass of the pendulum-ball system (see Experiment 2). Measure the distance (r) from the axis of the RMS to the center of mass. When you calculate the potential energy gain of the system, the height (h) is the change in height of the center of mass of the system, not the ball.

III. Elastic Collision

Examine the difference between catching the ball (completely inelastic collision) and allowing the ball to hit the bumper on the back of the catcher:

1. Place the counter-weight on the lower half of the pendulum rod between the middle hole and the catcher. Fasten the pendulum to the RMS using the middle hole with the bumper side towards the launcher. There should be a gap of a few centimeters between the end of the launcher and the bumper.

2. Launch the ball at its slowest speed. What happens to the ball when it hits the rubber bumper on the catcher? Adjust the position of the counter weight so that the ball drops *straight down* after the collision. If the counterweight is positioned too low, the ball bounces backwards. If the counterweight is too high, the ball still has some forward velocity. You want the horizontal velocity of the ball to be zero after the collision.

3. Perform the experiment as before and measure the maximum displacement (θ_{max}) and initial angular velocity (ω_0) of the pendulum.

4. Measure the rotational inertia of the pendulum *without* the ball.

   Find the pendulum's center of mass (without the ball). Measure the distance r from the axis of the RMS to the center of mass.

5. Perform the analysis for energy and momentum as before. What is the kinetic energy of the ball immediately after the collision? Why?

When you calculate the gain in potential energy, remember that h is the change in height of the center of mass of the pendulum, not including the ball.

Is this a perfectly elastic collision? What is the percentage of the kinetic energy lost (converted to thermal energy) during the collision?

6. Turn the pendulum around and repeat the experiment for catching the ball. (Do not change the position of the counterweight.) Note that both the rotational inertia and the center of mass (and thus the distance r) will change due to the ball being in the catcher.

7. For the two cases (ball hitting the bumper and ball being caught), compare the angular velocity of the pendulum just after the collision. Compare the maximum angular displacement for the two cases. Which type of collision causes the greater angular displacement? Why?

IV. Alternative Determination of Rotational Inertia

In the procedure above, you found the rotational inertia of the pendulum by applying a known torque and measuring the resulting angular acceleration. An alternate method is to measure the period of oscillation.

For a physical pendulum of rotational inertia I and mass M, the theoretical period (for low-amplitude oscillations) is given by

$$T = 2\pi\sqrt{\frac{I}{Mgr}}$$

where r is the distance from the axis of rotation to the center of mass of the pendulum.

Measure the period of the pendulum (with a low amplitude) and calculate its rotational inertia. Compare this to the answer you got by applying a known torque.

Technical Support

For assistance with any PASCO product, contact PASCO at:

Address: PASCO scientific
10101 Foothills Blvd.
Roseville, CA 95747-7100

Phone: 916-462-8384 (worldwide)
877-373-0300 (U.S.)

Web: www.pasco.com

Email: support@pasco.com

Limited Warranty
For a description of the product warranty, see the PASCO catalog.

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