

Ballistic Pendulum

ME-6830

Introduction

The Ballistic Pendulum is used to determine the muzzle velocity of a ball shot into the pendulum by the Projectile Launcher. The only additional equipment required is a C-clamp for mounting the base of the apparatus to a table or other sturdy horizontal surface.

Two small holes at the bottom of the upright allow you to mount the Projectile Launcher facing the Ballistic Pendulum so that the ball is fired into the pendulum. The sensitive spring-loaded barb-type catch on the Ballistic Pendulum will catch balls with a large range of speeds. The catcher holds a ball in line with the pendulum rod, increasing the accuracy of measurements. All moving parts of the pendulum may be removed so that the mass and center of mass can be measured accurately. Additionally, the pendulum can be reversed so that elastic collisions and inelastic collisions can be compared. The pendulum includes masses that can be removed, allowing you to use the pendulum with lightweight balls over a wide range of speeds. Leave the masses on the pendulum when you use heavyweight balls.

 **NOTE:** For more detailed information about using the Projectile Launcher, see the product manual for the launcher.

Equipment

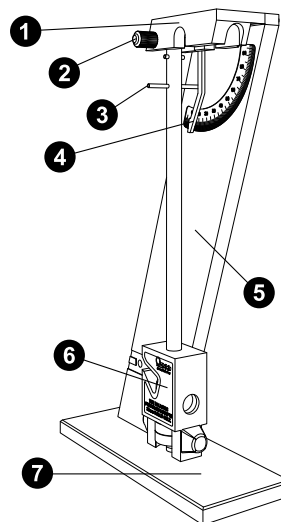
Equipment included:

- Ballistic Pendulum without Launcher (ME-6831), including hex key, launcher mounting thumbscrews, and 2× steel balls
- Projectile Launcher (ME-6800), including ramrod, launcher base, and 3× plastic balls

Required equipment:

- Large C-Clamp (SE-7285) or similar clamp

Features



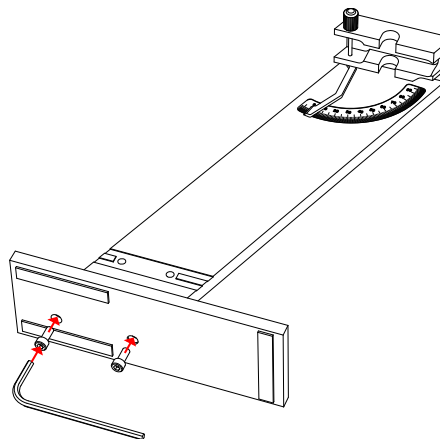
- ❶ Yoke
- ❷ Axle
- ❸ Long pin
- ❹ Angle indicator
- ❺ Vertical upright
- ❻ Pendulum
- ❼ Base

Assembly

The Ballistic Pendulum and Projectile Launcher arrive in custom-made packages, and some assembly is required. The sections below will walk you through the process of assembling the base and attaching the pendulum and Projectile Launcher.

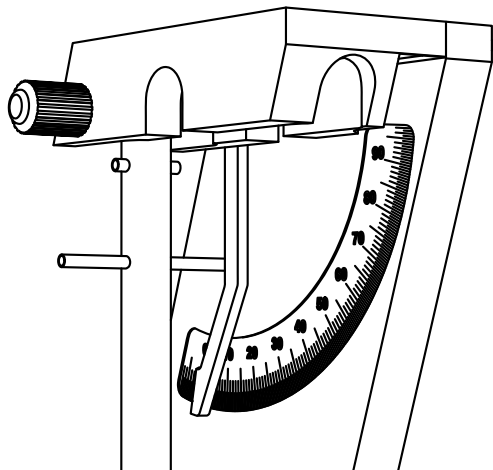
Assemble the base

Use the hex key and the two socket head screws to attach the base to the upright, as shown below. The screws are coated with a strong adhesive that activates when they are screwed into place.



Mount the Ballistic Pendulum

To attach the Ballistic Pendulum to the upright, start by unscrewing the axle from the yoke. The Ballistic Pendulum has a hinge at the top of the rod with a hole through it. Line up the hole in the hinge with the axle hole in the yoke, then screw the axle back into place. Note that the long pin that extends from either side of the Ballistic Pendulum rod should be behind the angle indicator, as shown below.

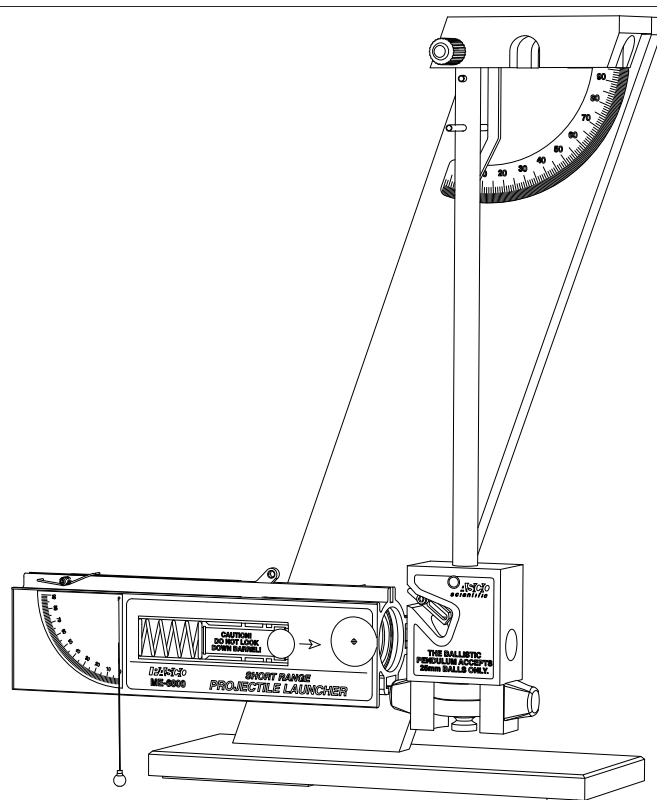


Mount the Projectile Launcher

1. Attach the included trigger string to the hole in the trigger, such as by looping the string through the hole and tying the ends together.
2. Firmly clamp the base of the Ballistic Pendulum to a sturdy table or other horizontal surface.
3. Detach the Projectile Launcher from its own base if you have not already done so. Remove its thumbscrews.
4. Align the Projectile Launcher with the holes near the bottom of the base. Make sure that the Launcher is aligned with the "front" side of the base so that it is aligned with the pendulum, and that the Launcher is oriented upright so that the numbers on the protractor are readable.
5. Insert the launcher mounting thumbscrews included with the Ballistic Pendulum into the holes, then tighten to secure the Projectile Launcher in place on the base. Make sure the washers remain on the thumbscrews.

 **NOTE:** Do NOT use the thumbscrews included with the Projectile Launcher to mount the launcher on the base, as they are a different length from the launcher mounting thumbscrews and will not properly secure the device.

The full assembly with the Projectile Launcher mounted on the Ballistic Pendulum is shown at the top of the next column.



General usage

About the equipment

Keep the following information in mind as you set up and use the Ballistic Pendulum and Projectile Launcher:

- To minimize variation in data, securely clamp the base to a sturdy table. Any wobble in the table will negatively affect the data.
- Angles reached by the swinging Ballistic Pendulum should be repeatable to within 0.5°.
- Overall error in the measurement of ball velocity should not exceed 2.5% (if using the exact method) or 10% (if using the approximate method). For more information, see **Ballistic pendulum theory**.
- Adjustable leveling feet are not needed for good results. Small deviations from the horizontal will not cause any significant error.

Loading a ball

The Launcher features three range settings, which control how much force is used when launching the projectile. These settings are labeled SHORT RANGE, MEDIUM RANGE, and LONG RANGE on the launcher. The current position of the piston can be determined by examining the range-setting slots along the barrel and observing which marker the yellow indicator tape is aligned with. For more information on range settings, see the Projectile Launcher manual.

 **CAUTION:** Never look down the front of the barrel of the Projectile Launcher, as it may be loaded. Safety glasses are provided with the apparatus and should *always* be worn when in a room where the Projectile Launcher is being used.

To load a ball in the Projectile Launcher:

1. Rotate the pendulum until the rod is horizontal and catches in the component clip on the underside of the yoke, or simply hold the pendulum out of the way for the following steps.
2. Place a ball into the muzzle of the Launcher.

 **NOTE:** Always ensure a ball is in the barrel before you cock the piston. Using the ramrod without a ball in place may damage the piston.

3. While looking through the range-setting slots on the top of the Launcher, push the ball down the barrel using the included ramrod until the trigger catches the edge of the piston at the desired range setting. The trigger will "click" into place, and the yellow indicator tape will be visible through the appropriate range-setting slot.
4. Remove the ramrod from the barrel, then gently return the pendulum to its resting position.

Shooting the ball

Before shooting the ball, make sure there are no people or breakable objects in the way. To shoot the ball, pull straight up on the string attached to the trigger. When the ball strikes the pendulum, the pendulum will swing upwards by some angle, which is measured by the position of the angle indicator after the collision. To remove the ball, press the protruding tab on the metal catch and allow the ball to roll out.

 **TIP:** For best results, repeat the shot after setting the angle indicator to two degrees less than the angle reached on the first shot. This will nearly eliminate the friction against the pendulum caused by the angle indicator, since the pendulum will only move the angle indicator for a short distance.

Maintenance and storage

The Ballistic Pendulum and Projectile Launcher do not require any special maintenance. In particular, do *not* oil the Projectile Launcher, as this will likely negatively affect its performance.

Ballistic pendulum theory

Overview

The ballistic pendulum is a classic method of determining the velocity of a projectile, as well as a good demonstration of many basic physics principles. The ball is fired into the pendulum, which then swings upward a measured amount. From the height reached by the pendulum, you can calculate the gravitational potential energy it gains. This gravitational potential energy is equal to the kinetic energy of the pendulum just after the collision with the ball.

You cannot equate the kinetic energy of the pendulum after the collision with the ball's kinetic energy before the collision, since the collision is inelastic and kinetic energy is converted to thermal energy in inelastic collisions. However, *momentum* is conserved in all forms of collisions, so you know that the momentum of the ball before the collision is equal to the momentum of the pendulum and ball system after the collision. Once you know the momentum of the ball and the ball's mass, you can calculate the ball's initial velocity.

There are two methods of calculating the velocity of the ball. The first method, called the "approximate method", does not take rotational inertia into account in its calculations. Instead, it assumes that the pendulum and the ball together act as a point mass located at their combined center of mass. This method is somewhat quicker and easier, but its results are not as accurate.

The second method, called the "exact method", uses the actual rotational inertia of the pendulum in the calculations. The equations of this method are slightly more complicated, and it requires more data in order to find the moment of inertia of the pendulum. However, the results of this method are generally more accurate.

Approximate method

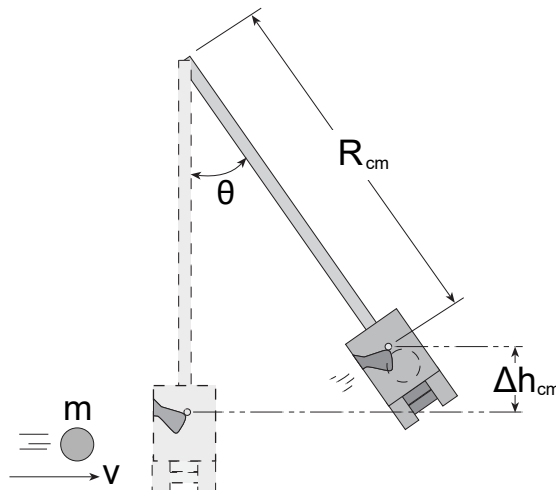
After the collision with the ball, the potential energy of the pendulum at the top of its swing is given by:

$$\Delta PE = Mg\Delta h_{cm}$$

where M is the combined mass of the pendulum and ball, g is the acceleration due to gravity, and Δh_{cm} is the change in height of the pendulum and ball system's center of mass. The change in height is equivalent to:

$$\Delta h_{cm} = R_{cm}(1 - \cos\theta)$$

where R_{cm} is the distance from the pivot point to the center of mass of the pendulum/ball system and θ is the maximum angle reached by the pendulum. (See below.)



Substituting this into the potential energy equation, we get:

$$\Delta PE = MgR_{cm}(1 - \cos\theta)$$

This potential energy is equal to the kinetic energy immediately after the collision, which is given by:

$$KE = \frac{1}{2}M(v_p)^2$$

where v_p is the speed of the pendulum just after the collision. The momentum of the pendulum and ball P_p just after the collision is given by the equation:

$$P_p = Mv_p$$

Solving this equation for v_p and substituting this into the kinetic energy equation gives:

$$KE = \frac{(P_p)^2}{2M}$$

Solving this equation for the momentum of the pendulum, we find that:

$$P_p = \sqrt{2M(KE)}$$

Conservation of momentum tells us that P_p is equal to the momentum of the ball just before the collision. This momentum, P_b , is given by:

$$P_b = mv_b$$

Setting the two momentum equations equal to each other and replacing KE with our known potential energy, we find that:

$$mv_b = \sqrt{2M^2 g R_{cm}(1 - \cos\theta)}$$

Solving this for the ball's velocity and simplifying, we obtain our equation for the initial velocity of the ball:

$$v_b = \frac{M}{m} \sqrt{2gR_{cm}(1 - \cos\theta)}$$

Exact method

The potential energy is found in the same way as in the approximate method, resulting in the equation:

$$\Delta PE = MgR_{cm}(1 - \cos\theta)$$

For the kinetic energy, this method uses the equation for *angular* kinetic energy instead of the equation for linear kinetic energy. The angular kinetic energy is given by:

$$KE = \frac{1}{2} I \omega^2$$

where I is the moment of inertia of the pendulum/ball combination and ω is the angular velocity immediately after the collision. The angular momentum of the ball at this time is given by $L_p = I\omega$; solving this equation for ω and substituting it into the angular kinetic energy equation, we find that:

$$KE = \frac{L_p^2}{2I}$$

Solving for the angular momentum, this equation becomes:

$$L_p = \sqrt{2I(KE)}$$

This angular momentum is equal to the angular momentum of the ball immediately before the collision, as measured from the pendulum pivot point. In mathematical terms:

$$L_p = mR_b^2 \omega_b = mR_b v_b$$

where v_b is the velocity of the ball before the collision and R_b is the distance from the pendulum pivot to the ball. (Note that R_b is usually **not** equal to R_{cm} , which is the distance from the pivot point to the center of mass for the pendulum and ball system.)

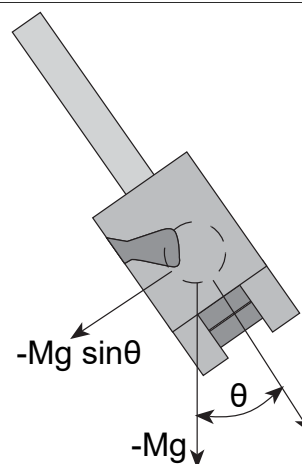
Setting these two angular momenta equal to each other, plugging in the kinetic energy equation, and solving for velocity, we find that:

$$v_b = \frac{1}{mR_b} \sqrt{2IMgR_{cm}(1 - \cos\theta)}$$

From here, you will need a way to calculate I . To do this, start with the rotational equivalent of Newton's Second Law:

$$\tau = I\alpha$$

where τ is torque and α is angular acceleration. The force on the center of mass of the pendulum is Mg , and the component of force directed along the pendulum's path of movement is $F = -Mg \sin\theta$.



Since torque is given by $\tau = Fd$, where d is the distance from the axis of rotation to the point where torque is applied, this means that the torque on the pendulum is equivalent to:

$$I\alpha = -R_{cm}Mg \sin\theta$$

In situations where the angle θ is small, $\sin\theta$ is approximately equal to θ ; substituting this in place of θ and solving for α , the previous equation becomes:

$$\alpha = -\frac{MgR_{cm}}{I} \theta$$

This angular equation is in the same form as the equation for linear simple harmonic motion, which is given by:

$$\alpha = -\frac{k}{m} x = -\omega^2 x$$

If you compare the linear and angular equations, you can see that the pendulum exhibits simple harmonic motion. The square of the angular frequency for this motion is given by:

$$\omega^2 = \frac{MgR_{cm}}{I}$$

Solving for I , we obtain our desired result:

$$I = \frac{MgR_{cm}}{\omega^2} = \frac{MgR_{cm}T^2}{4\pi^2}$$

where T is the period of the pendulum.

NOTE: We used a small-angle approximation for I , but I does not depend on θ . Therefore, you must measure the period T using small angle oscillations, but once you have calculated I with that period, you may use that same value of I during other parts of the experiment regardless of the amplitude reached.

Experiment 1: Projectile Velocity - Approximate Method

Required equipment

- Ballistic Pendulum and Projectile Launcher
- Steel ball
- C-clamp
- Mass balance
- String

Purpose

The muzzle velocity of the Projectile Launcher is determined by launching the ball into the ballistic pendulum and observing the angle to which the pendulum swings. As derived in the main manual, the equation for the velocity of the ball is approximately:

$$v_b = \frac{M}{m} \sqrt{2gR_{cm}(1 - \cos\theta)}$$

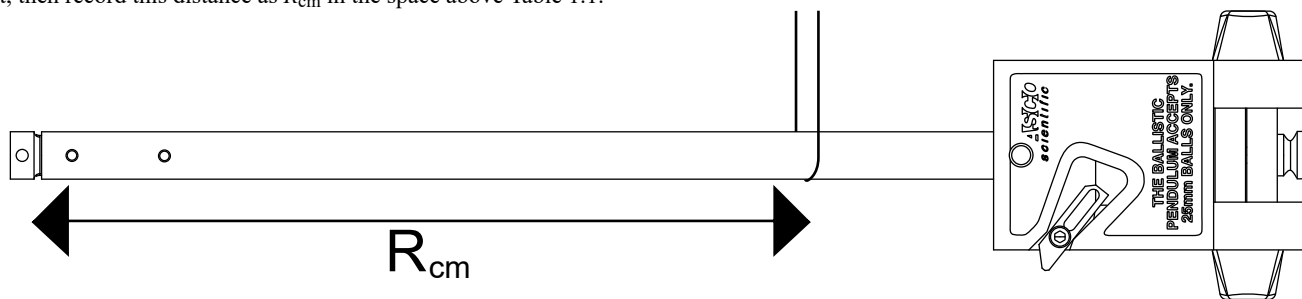
where M is the mass of the pendulum and ball combined, m is the mass of the ball, g is the acceleration due to gravity, R_{cm} is the distance from the pivot point to the center of mass, and θ is the angle reached by the pendulum after the collision.

Setup

1. Mount the Projectile Launcher on the Ballistic Pendulum. Make sure that the pendulum can hang vertically without touching the launcher.
2. Clamp the Ballistic Pendulum base to a sturdy table. Make sure that the clamp does not interfere with the pendulum swing.

Procedure

1. Latch the pendulum at 90° so that it is temporarily out of the way, then load the Projectile Launcher with the steel ball. Allow the pendulum to hang freely and move the angle indicator to zero degrees.
2. Fire the launcher and record the angle reached. If you want to perform the experiment with a lower or higher angle, add to or remove mass from the pendulum, then repeat the test measurement. Repeat this process until you are satisfied with the mass of the pendulum.
3. Once you have chosen the mass to use for your experiments, unscrew and remove the axle, then remove the pendulum from the upright. Use a mass balance to find the mass of the pendulum and ball *together*. Record this value as M in the space above Table 1.1.
4. Measure the mass of the ball alone. Record this value as m in the space above Table 1.1.
5. Tie a loop in a piece of string, then hang the pendulum horizontally from the loop, as shown below. With the ball latched in position in the ball catcher, adjust the position of the pendulum in the loop until the pendulum balances. Measure the distance from the pivot point to this balance point, then record this distance as R_{cm} in the space above Table 1.1.



NOTE: It may be easier to balance the pendulum on the edge of a ruler or similar object.

6. Reattach the pendulum to the upright, making sure that it is facing the correct direction and that the angle indicator is in front of the long pin of the pendulum.
7. Load the launcher, then set the angle indicator to an angle one or two degrees *less* than the angle reached in Step 2. This will mostly eliminate friction between the pendulum and the angle indicator, since the pendulum will only move the angle indicator for a short distance.
8. Fire the launcher and record the angle reached by the pendulum in Table 1.1. Repeat this step several times, each time setting the angle indicator to an angle one or two degrees *less* than the previous angle reached by the pendulum.

Data

$M =$ _____ ; $m =$ _____ ; $R_{cm} =$ _____

Table 1.1

Item	Value
θ_1	
θ_2	
θ_3	
θ_4	
θ_5	
Average θ	
Muzzle velocity	

Calculations

1. Find the average angle reached by the pendulum. Record this value in Table 1.1.
2. Using the average angle, calculate the muzzle velocity of the ball fired from the Projectile Launcher. Record this value in Table 1.1.

Questions

1. Is there another way to measure the muzzle velocity that you could use to check your results? If so, try using this method and compare your two answers.
2. What sources of error are there in this experiment? How much do these errors affect your results?
3. If kinetic energy were conserved in the collision between the ball and the pendulum, the calculations would be greatly simplified. (See **Ballistic pendulum theory** in the main manual.) What percentage of the kinetic energy is lost in the collision between the ball and the pendulum? Would it be valid to assume that kinetic energy was conserved in the collision?
4. How does the angle reached by the pendulum change if the ball is *not* caught by the ball catcher? You may test this by turning the pendulum around so the ball strikes the back of the ball catcher. Is more energy or less energy transferred to the pendulum?

Experiment 2: Projectile Velocity - Exact Method

Required equipment

- Ballistic Pendulum and Projectile Launcher
- Steel ball
- Ruler or meter stick
- C-clamp
- Mass balance
- String
- Stopwatch
- Plumb bob
- Carbon paper, white paper, and tape

Purpose

The muzzle velocity of the Projectile Launcher is determined by launching the ball into the ballistic pendulum and observing the angle to which the pendulum swings.

As derived earlier in the manual, the equation for the velocity of the ball is approximately:

$$v_b = \frac{1}{mR_b} \sqrt{2IMgR_{cm}(1 - \cos\theta)}$$

where M is the mass of the pendulum and ball combined, m is the mass of the ball, g is the acceleration due to gravity, R_{cm} is the distance of the pivot point to the center of mass, R_b is the distance from the pivot point to the ball, θ is the angle reached by the pendulum, and I is the moment of inertia of the pendulum with the ball in the catcher.

The value of I can be found by measuring the period T of small oscillations of the pendulum/ball combination and using the equation:

$$I = \frac{MgR_{cm}T^2}{4\pi^2}$$

Setup

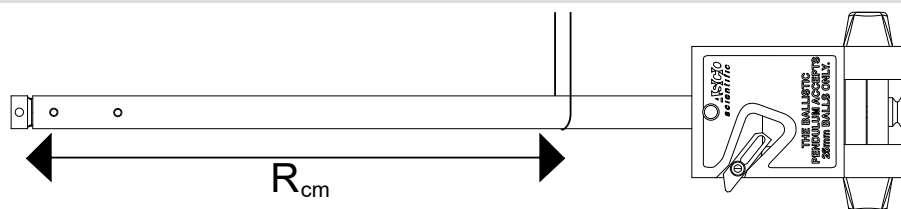
1. Mount the Projectile Launcher on the Ballistic Pendulum. Make sure the pendulum can hang vertically without touching the launcher.
2. Clamp the Ballistic Pendulum base to a sturdy table. Make sure that the clamp does not interfere with the pendulum swing.

Procedure

1. Latch the pendulum at 90° so it is temporarily out of the way, then load the Projectile Launcher with the steel ball. Allow the pendulum to hang freely and move the angle indicator to zero degrees.
2. Fire the launcher and record the angle reached. If you want to perform the experiment with a lower or higher angle, add to or remove mass from the pendulum, then repeat the test measurement. Repeat this process until you are satisfied with the mass of the pendulum.
3. Once you have chosen the mass to use for your experiments, unscrew and remove the axle, then remove the pendulum from the upright. Use a mass balance to find the mass of the pendulum and ball *together*. Record this value as M in the space above Table 2.1.
4. Measure the mass of the ball alone. Record this value as m in the space above Table 2.1.
5. Tie a loop in a piece of string, then hang the pendulum horizontally from the loop, as shown below. With the ball latched in position in the ball catcher, adjust the position of the pendulum in the loop until the pendulum balances. Measure the distance from the pivot point to this balance point, then record this distance as R_{cm} in the space above Table 2.1.



NOTE: It may be easier to balance the pendulum on the edge of a ruler or similar object.



- Measure the distance between the pivot point and the center of the ball. Record this distance as R_b in the space above Table 2.1.
- Reattach the pendulum, then remove the Launcher so that the pendulum can swing freely.
- With the ball still in the catcher, give the pendulum an initial displacement of 5° or less. Using the stopwatch, time how long it takes to go through ten complete oscillations. Divide this time by the number of oscillations and record the result as T in the space above Table 2.1.
- Calculate the value of I and record it in the space above Table 2.1.
- Reattach the Launcher, then remove the ball from the catcher and load it into the Launcher. Set the angle indicator to an angle one or two degrees *less* than the angle reached in Step 2. This will mostly eliminate friction between the pendulum and the angle indicator, since the pendulum will only move the angle indicator for a short distance.
- Fire the Launcher and record the angle reached by the pendulum in Table 2.1. Repeat this step several times, each time setting the angle indicator to an angle one or two degrees *less* than the angle reached by the pendulum in the previous trial.

Data

$M =$
 $m =$
 $R_{cm} =$

$R_b =$
 $T =$
 $I =$

Table 2.1	
Item	Value
θ_1	
θ_2	
θ_3	
θ_4	
θ_5	
Average θ	
Muzzle velocity	

Calculations

- Find the average angle reached by the pendulum and record this value in Table 2.1 above.
- Using the average angle, calculate the muzzle velocity of the ball fired from the Projectile Launcher. Record this value in Table 2.1.

Verify the projectile velocity

- Make sure that the apparatus is oriented towards a large open space, then latch the pendulum at 90° so that the Projectile Launcher can fire a ball onto the floor.
- Load a ball into the Projectile Launcher's barrel, then fire the Launcher and observe where the ball hits the floor. At this position, tape a piece of white paper to the floor, then tape a piece of carbon paper on top of the white paper with the carbon side down.
- Fire ten additional shots from the Projectile Launcher. As each ball strikes the carbon paper on the floor, it will leave a mark on the white paper.
- Measure the vertical distance from the floor to the bottom of the ball as it leaves the barrel. (The position of ball as it leaves the Projectile Launcher is indicated by the "Launch Position of Ball" marker on the side of the barrel.) Record this distance as y_0 in Table 2.2.
- Use a plumb bob to find the point on the floor that is directly beneath the release point on the barrel (indicated by the crosshairs on the "Launch Position of Ball" label). Measure the horizontal distance between this point and the near edge of the piece of white paper. Record this distance as x_0 in Table 2.2.
- Carefully remove the carbon paper. Measure the distance from the leading edge of the white paper to each of the ten dots, then take the average of these ten distances to obtain the average distance x_{av} . Record this value in Table 2.2.
- Calculate the total horizontal distance x by adding the distances x_0 and x_{av} . Record this value in Table 2.2.
- Calculate the time of flight t of the ball using the equation:

$$t = \sqrt{\frac{2y}{g}}$$

Record this value in Table 2.2.

9. Calculate the initial velocity v_0 using the equation:

$$v_0 = \frac{x}{t}$$

Record this value in Table 2.2.

10. Compare your value of v_0 to the muzzle velocity you obtained in the Calculations section. These values should be extremely similar. If there are significant differences between the two, check your experimental setup for sources of error.

Table 2.2

Quantity	Value
y	
x_0	
x_{av}	
x	
t	
v_0	

Questions

1. What sources of error are there in this experiment? How much do these errors affect your results?
2. If kinetic energy were conserved in the collision between the ball and the pendulum, the calculations would be greatly simplified. (See **Ballistic pendulum theory** in the main manual.) What percentage of the kinetic energy is lost in the collision between the ball and the pendulum? Would it be valid to assume that kinetic energy was conserved in the collision?
3. Does increasing the mass of the pendulum increase or decrease the efficiency of the energy transfer in the collision? Test your hypothesis.
4. The "Projectile Velocity - Approximate Method" experiment uses the approximate equation for velocity:

$$v_b = \frac{M}{m} \sqrt{2gR_{cm}(1 - \cos\theta)}$$

What is the value of velocity when you use this equation? Is there a significant difference between these two calculated values? What factors would increase the difference between these two results? How would you build a ballistic pendulum so that the approximate method gave more accurate results?

Teacher's guide

Experiment 1: Projectile Velocity - Approximate Method

Calculations:

The following is a set of sample data collected with one mass removed from the pendulum and the Projectile Launcher set to the medium range setting. Your specific values will vary depending on your range settings and the weights attached to the pendulum.

$$M = 0.2629 \text{ kg}; m = 0.0657 \text{ kg}$$

$$R_{cm} = 0.278 \text{ m}$$

Item	Value
θ_1	35°
θ_2	35.5°
θ_3	35.25°
θ_4	35°
θ_5	35.5°
Average θ	35.25°
Muzzle velocity	4.00 m/s

Questions:

1. Student answers will vary.
2. The greatest source of error in this experiment is the assumptions used to derive our equations. This experiment relies on the assumption that the masses involved are point masses, which simplifies the involved mathematics but is not accurate to our physical setup. Depending on your collected data and precise setup, the value of velocity obtained by this method may differ from the actual value by up to 8%.
3. Using our calculations for the ball's initial kinetic energy and the ball and pendulum's final gravitational potential energy, we find that approximately 75% of the ball's initial kinetic energy is lost by the time the pendulum reaches the top of its arc. As such, kinetic energy was *not* conserved in the collision.
4. If the ball is not caught by the ball catcher, the collision will be elastic and the pendulum will rise to a higher angle than in the inelastic collision of the main experiment. This indicates that more energy is transferred to the pendulum than in the inelastic collision.

Experiment 2: Projectile Velocity - Exact Method

Calculations:

The following is a set of sample data collected with one mass removed from the pendulum and the Projectile Launcher set to the medium range setting. Your specific values will vary depending on your range settings and the weights attached to the pendulum.

$$M = 0.2629 \text{ kg}; m = 0.0657 \text{ kg}$$

$$R_{cm} = 0.278 \text{ m}; R_b = 0.30 \text{ m}$$

$$T = 1.098 \text{ s}; I = 0.0219 \text{ kgm}^2/\text{s}$$

Item	Value
θ_1	35°
θ_2	35.25°
θ_3	35.25°
θ_4	35.5°
θ_5	35°
Average θ	35.2°
Muzzle velocity	3.84 m/s

Questions:

1. Common sources of error in this experiment include friction between the pendulum and the yoke, air resistance, and imprecise measurements of the period T .
2. Comparing the final gravitational potential energy and the initial kinetic energy, we find that approximately 73% of the ball's initial kinetic energy is lost by the time the pendulum reaches the top of its arc. As such, kinetic energy was *not* conserved in the collision.
3. Precise student answers will vary. However, in general, students should find that increasing the mass of the pendulum makes the energy transfer less efficient.
4. Using our data from this experiment with the equation from Experiment 1, we obtain a velocity of 3.99 m/s. This value differs from the one we calculated in this experiment by approximately 3.9%. The difference between these results would increase as weight is removed from the ball catcher, making it harder to approximate the pendulum as a point mass. Student answers about a new ballistic pendulum will vary, but may include such changes as concentrating the mass closer to the ball catcher so that the pendulum functions more like a swinging point mass.

Technical support

Need more help? Our knowledgeable and friendly Technical Support staff is ready to answer your questions or walk you through any issues.

- 🌐 Web [pasco.com/support](https://www.pasco.com/support)
- 💬 Chat [pasco.com](https://www.pasco.com)
- ✉ Email support@pasco.com
- 📞 Phone 1-800-772-8700 x1004 (USA)
+1 916 462 8384 (outside USA)

Limited warranty

For a description of the product warranty, see the Warranty and Returns page at www.pasco.com/legal.

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