

Includes
Teacher's Notes
and
Typical
Experiment Results



Instruction Manual and Experiment Guide for the PASCO scientific Model ME-9215B

012-06379B

PHOTOGATE TIMER

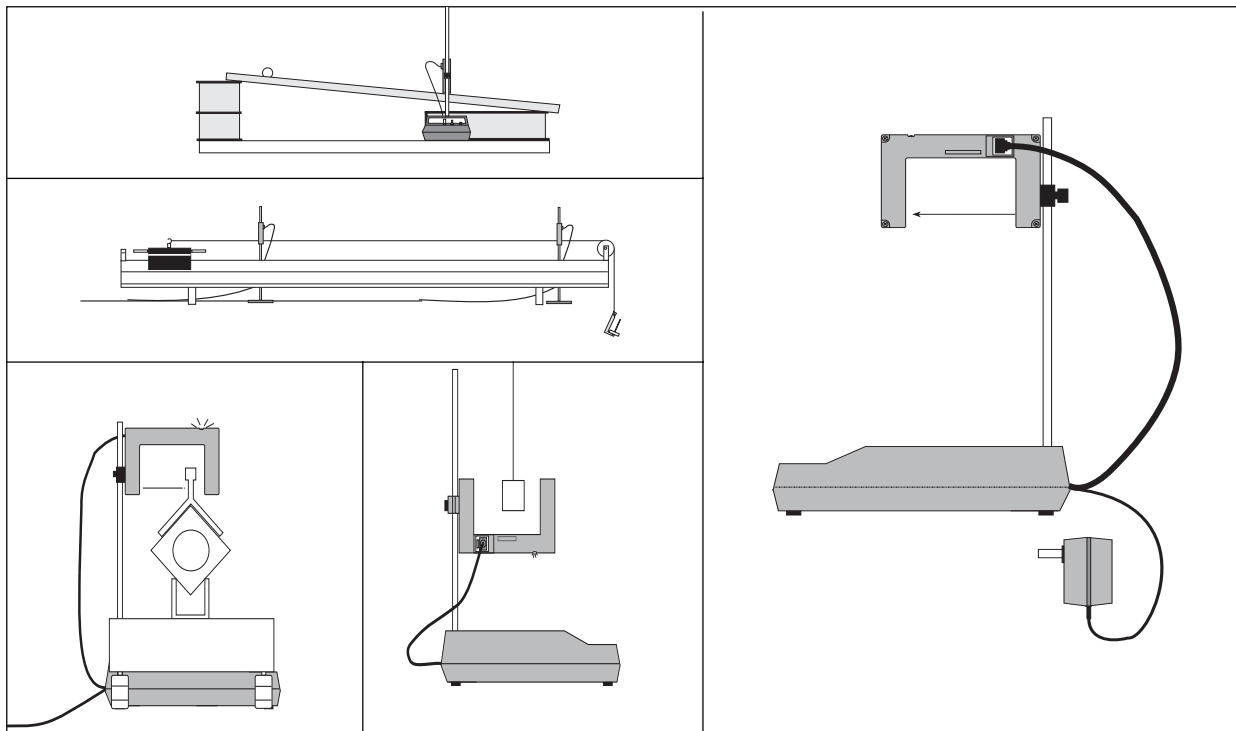


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Copyright, Warranty and Technical Support

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Introduction

The PASCO ME-9215B Photogate Timer is an accurate and versatile digital timer for the student laboratory.

The ME-9215B memory function makes it easy to time events that happen in rapid succession, such as an air track glider passing twice through the photogate, once before and then again after a collision.

The Photogate Timer uses PASCO's narrow-beam infrared photogate (see Figure 1) to provide the timing signals. An LED in one arm of the photogate emits a narrow infrared beam. As long as the beam strikes the detector in the opposite arm of the photogate, the signal to the timer indicates that the beam is unblocked. When an object blocks the beam so it doesn't strike the detector, the signal to the timer changes. The timer has several options for timing the photogate signals. The options include Gate, Pulse, and Pendulum modes, allowing you to measure the velocity of an object as it passes through the photogate or between two photogates, or to measure the period of a pendulum. There is also a START/STOP button that lets you use the timer as an electronic stopwatch.

An important addition to your Photogate Timer is the ME-9204B Accessory Photogate, which must be ordered separately. It plugs directly into the Photogate Timer and triggers the timer in the same manner as the built-in photogate. In Pulse Mode, the Accessory Photogate lets you measure the time it takes for an object to travel between two photogates. In Gate mode, it lets you measure the velocity of the object as it passes through the first photogate, and then again when it passes through the second photogate.

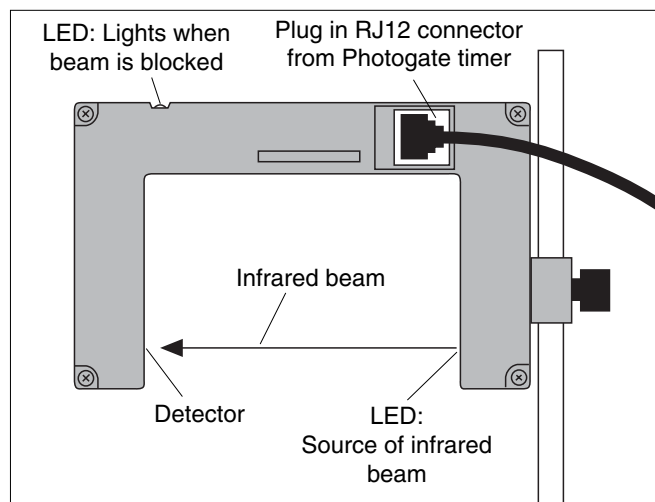


Figure 1: The PASCO Photogate Head

► NOTES:

- ① The Photogate Timer can be powered using the included 7.5 V adapter. It will also run on 4 C-size, 1.5 Volt batteries. Battery installation instructions are in the Appendix.
- ② Ten ready-to-use experiments are included in this manual, showing a variety of ways in which you can use your Photogate Timer. The equipment requirements vary for different experiments. For many of the experiments, you will need an air track (dynamics carts will also work). Many also require a ME-9204B Accessory Photogate in addition to the Photogate Timer. Check the equipment requirements listed at the beginning of each experiment.

Operation

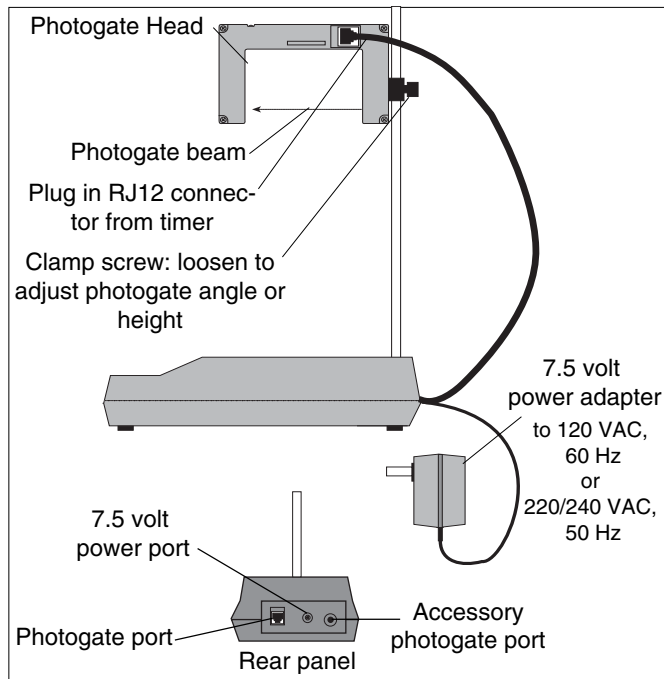


Figure 2: Setting Up the Photogate Timer

To Operate the Photogate Timer:

- ① Plug the RJ12 phone connector from the timer into the RJ12 phone jack on the Photogate Head.
- ② Plug the 7.5 volt power adapter into the small receptacle on the rear of the timer and into a standard 110 VAC, 60 Hz (or 220/240 VAC, 50 Hz) wall outlet.
- ③ Position the Photogate Head so the object to be timed will pass through the arms of the photogate, blocking the photogate beam. Loosen the clamp screw if you want to change the angle or height of the photogate, then tighten it securely.
- ④ If you are using a ME-9204B Accessory Photogate, plug the stereo phone plug of the Accessory Photogate into the large receptacle (see Figure 2) on the rear of the timer.
- ⑤ Slide the mode switch to the desired timing mode: Gate, Pulse, or Pendulum. Each of these modes is described below. Switch the MEMORY switch to OFF.
- ⑥ Press the RESET button to reset the timer to zero.
- ⑦ As a test, block the photogate beam with your hand to be sure that the timer starts counting when the beam is interrupted and stops at the appropriate time.
- ⑧ Press the RESET button again. You are ready to begin timing.

Timing Modes

Gate Mode: In Gate mode, timing begins when the beam is first blocked and continues until the beam is unblocked. Use this mode to measure the velocity of an object as it passes through the photogate. If an object of length L blocks the photogate for a time t , the average velocity of the object as it passed through the photogate was L/t .

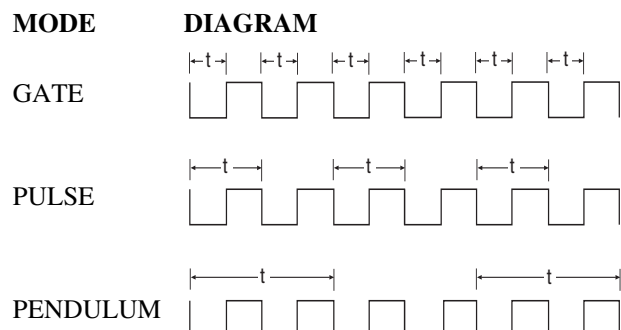
Pulse Mode: In Pulse mode, the timer measures the time between successive interruptions of the photogate. Timing begins when the beam is first blocked and continues until the beam is unblocked and then blocked again. With an Accessory Photogate plugged into the Photogate Timer, the timer will measure the time it takes for an object to move between the two photogates.

Pendulum Mode: In Pendulum mode, the timer measures the period of one complete oscillation. Timing begins as the pendulum first cuts through the beam. The timer ignores the next interruption, which corresponds to the pendulum swinging back in the opposite direction. Timing stops at the beginning of the third interruption, as the pendulum completes one full oscillation.

Manual Stopwatch: Use the START/STOP button in either Gate or Pulse mode. In Gate mode the timer starts when the START/STOP button is pressed. The timer stops when the button is released. In Pulse mode, the timer acts as a normal stopwatch. It starts timing when the START/STOP button is first pressed and continues until the button is pressed a second time.

TIMING DIAGRAMS

The following diagrams show the interval, t , that is measured in each timing mode. In each diagram, a low signal corresponds to the photogate being blocked (or the START/STOP button pressed). A high signal corresponds to the photogate being unblocked (and the START/STOP button unpressed).



TIMING SUGGESTION

Since the source and detector of the photogate have a finite width, the true length of the object may not be the same as the effective length seen by the photogate. This parallax error may be minimized by having the object pass as close to the detector side of the photogate as possible, with the line of travel perpendicular to the beam. To completely eliminate the parallax error in experimental data, determine the effective length of the object as follows:

- ① With the Timer in Gate mode, push the object through the photogate, along the path it will follow in the experiment.
- ② When the photogate is triggered (the LED on top of the photogate comes ON), measure the position of the object relative to an external reference point.
- ③ Continue pushing the object through the photogate. When the LED goes OFF, measure the position of the object relative to the same external reference point.
- ④ The difference between the first and second measurement is the effective length of the object. When measuring the speed of the object, divide this effective length by the time during which the object blocked the photogate.

Memory Feature

When two measurements must be made in rapid succession, such as measuring the pre- and post-collision velocities of an air track glider, use the memory function. It can be used in either the Gate or the Pulse mode.

To use the memory:

- ① Turn the MEMORY switch to ON.
- ② Press RESET.
- ③ Run the experiment.

When the first time (t_1) is measured, it will be immediately displayed. The second time (t_2) will be automatically measured by the timer, but it will not be shown on the display.

- ④ Record t_1 , then push the MEMORY switch to READ. The display will now show the TOTAL time, $t_1 + t_2$. Subtract t_1 from the displayed time to determine t_2 .

► **NOTE:** If additional photogate interruptions occur after the second time is measured, and before the MEMORY switch is flipped to READ, they too will be measured by the timer and included in the cumulative time.

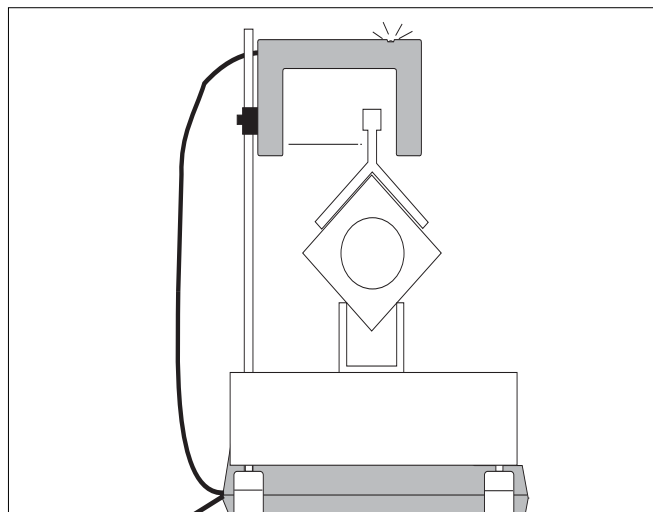


Figure 3: Timing an Air Track Glider

SPECIFICATIONS

Detector rise time: 200 ns max.

Fall Time: 200 ns max.

Parallax error: For an object passing through the photogate, within 1 cm of the detector, with a velocity of less than 10 m/s, the difference between the true and effective length of the object will be less than 1 millimeter.

Infrared source: Peak output at 880 nm; 10,000 hour life.

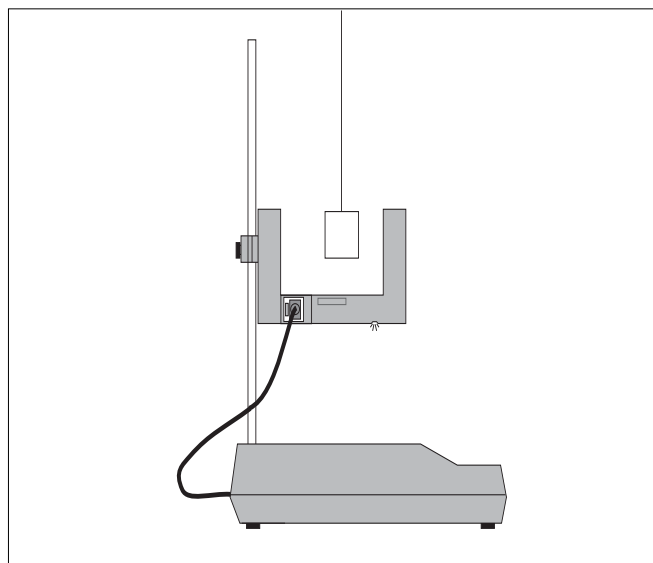


Figure 4: Photogate Timing a Pendulum

Accessories for the Photogate Timer

The following accessories are available to help extend the utility of your model ME-9215B Photogate Timer. All the accessories work equally well with either model. See the current PASCO catalog for more information.

ME-9204B Accessory Photogate

The stereo phone plug of the ME-9204B Accessory Photogate plugs into the phone jack on the rear of the Photogate Timer, giving you two identical photogates operating from a single timer. With the timer in Gate mode, you can measure the velocity of an object as it passes through one photogate, then again as it passes through the second photogate. With the timer in Pulse mode, you can measure the time it takes for an object to pass between the two photogates. (Many of the experiments in this manual are most easily performed using a Photogate Timer with an Accessory Photogate.)

ME-9207B Free Fall Adapter

For easy and accurate measurements of the acceleration of gravity, the ME-9207B Free Fall Adapter is hard to beat. The Free Fall Adapter plugs directly into the phone plug on the rear of the Photogate Timer. It comes with everything you need, including two steel balls (of different size and mass), a release mechanism, and a receptor pad. The release mechanism and the receptor pad automatically trigger the timer, so you get remarkably accurate measurements of the free fall time of the steel ball.

ME-9259A Laser Switch

This highly collimated photodetector is identical to a photogate, except that you use a laser (not included) as the light source. You can now time the motion of objects that are far too big to fit through a standard photogate. Measure the period of a bowling ball pendulum or the velocity of a car. The Laser Switch operates in all three timing modes (Gate, Pulse, and Pendulum).

10 Copy-Ready Experiments

The following 10 experiments are written in worksheet form. Feel free to photocopy them for use in your lab.

NOTE: In each experiment, the first paragraph is a list of equipment needed. Be sure to read this paragraph first, as the equipment needs vary from experiment to experiment.

This manual emphasizes the use of an air track, but the air track experiments can also be performed with dynamics carts. Many also require a ME-9204B Accessory Photogate in addition to a Photogate Timer. Collision experiments, such as experiments 6 and 7, require four times to be measured in rapid succession and are therefore most easily performed using two Photogate Timers.

Experiment 1: Instantaneous Versus Average Velocity

EQUIPMENT NEEDED:

- Photogate Timer with Accessory Photogate
- Air Track System with one glider.

Introduction

An *average velocity* can be a useful value. If you know you will average 50 miles per hour on a 200 mile trip, it's easy to determine how long the trip will take. On the other hand, the highway patrolman following you doesn't care about your average speed over 200 miles. He wants to know how fast you're driving at the instant his radar strikes your car, so he can determine whether or not to give you a ticket. He wants to know your *instantaneous velocity*. In this experiment you'll investigate the relationship between instantaneous and average velocities, and see how a series of average velocities can be used to deduce an instantaneous velocity.

Procedure

- ① Set up the air track as shown in Figure 1.1, elevating one end of the track with a 1-2 cm support.
- ② Choose a point x_1 near the center of the track. Measure the position of x_1 on the air track metric scale, and record this value in Table 1.1. If you are using an air track without a scale, use a meter stick to measure the distance of x_1 from the edge of the upper end of the track.
- ③ Choose a starting point x_0 for the glider, near the upper end of the track. With a pencil, carefully mark this spot on the air track so you can always start the glider from the same point.
- ④ Place the Photogate Timer and Accessory Photogate at points equidistant from x_1 , as shown in the figure. Record the distance between the photogates as D in Table 1.1.
- ⑤ Set the slide switch on the Photogate Timer to PULSE.
- ⑥ Press the RESET button.
- ⑦ Hold the glider steady at x_0 , then release it. Record time t_1 , the time displayed after the glider has passed through both photogates.
- ⑧ Repeat steps 6 and 7 at least four more times, recording the times as t_2 through t_5 .
- ⑨ Now repeat steps 4 through 9, decreasing D by approximately 10 centimeters.
- ⑩ Continue decreasing D in 10 centimeter increments. At each value of D , repeat steps 4 through 8.

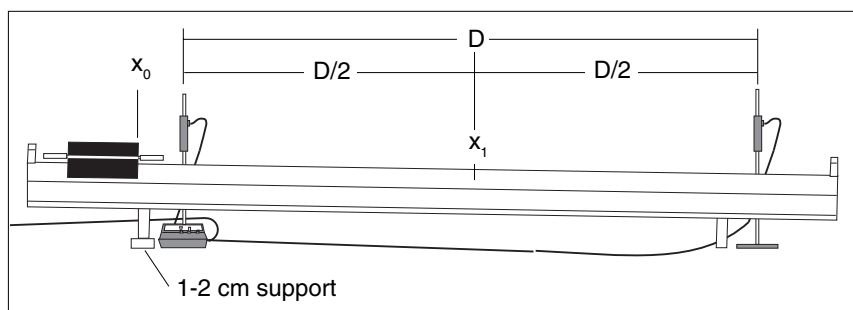


Figure 1.1: Setting Up the Equipment

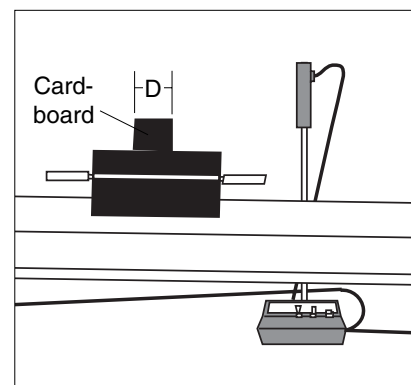


Figure 1.2: Measuring Velocity in Gate Mode

Optional

You can continue using smaller and smaller distances for **D** by changing your timing technique. Tape a piece of cardboard on top of the glider, as shown in Figure 1.2. Raise the photogate so it is the cardboard, not the body of the glider, that interrupts the photogate. Use just one photogate and place it at x_1 . Set the timer to GATE. Now **D** is the length of the cardboard. Measure **D** by passing the glider through the photogate and noting the difference in glider position between where the LED first comes on, and where it goes off again. Then start the glider from x_0 as before, and make several measurements of the time it takes for the glider to pass through the photogate. As before, record your times as t_1 through t_5 . Continue decreasing the value of **D**, by using successively smaller pieces of cardboard.

Data and Calculations

- ① For each value of **D**, calculate the average of t_1 through t_5 . Record this value as t_{avg} .
- ② Calculate $v_{avg} = D/t_{avg}$. This is the average velocity of the glider in going between the two photogates.
- ③ Plot a graph of v_{avg} versus **D** with **D** on the x-axis.

Table 1.1 Data and Calculations

$x_1 =$ _____

D	t_1	t_2	t_3	t_4	t_5	t_{avg}	v_{avg}

Questions

- ① Which of the average velocities that you measured do you think gives the closest approximation to the instantaneous velocity of the glider as it passed through point x_1 ?
- ② Can you extrapolate your collected data to determine an even closer approximation to the instantaneous velocity of the glider through point x_1 ? From your collected data, estimate the maximum error you expect in your estimated value.
- ③ In trying to determine an instantaneous velocity, what factors (timer accuracy, object being timed, type of motion) influence the accuracy of the measurement? Discuss how each factor influences the result.
- ④ Can you think of one or more ways to measure instantaneous velocity directly, or is an instantaneous velocity always a value that must be inferred from average velocity measurements?

Experiment 2: Kinematics on an Inclined Plane

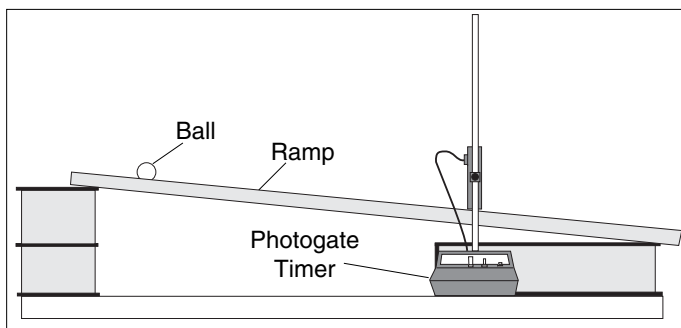
EQUIPMENT NEEDED:

- Photogate Timer
- Meter stick
- Ball and ramp, [A ball bearing (approximately 1.8 cm diameter) and a U-channel ramp (approximately 50 cm long with an inside width of approximately 1 cm) will work well, but the exact dimensions are not important].

Introduction

In this lab you will investigate how the velocity of an object varies as it undergoes a constant acceleration. The object is a ball rolling down an inclined ramp. Instead of the usual investigation of velocity as a function of time, you will measure its velocity as a function of the distance it has travelled from its starting point.

► **Note:** This experiment is just as easily performed with a glider on an inclined airtrack.)



Procedure

- ① Set up the apparatus as shown in Figure 2.1.
- ② Move the ball slowly through the photogate, using the meter stick as shown in Figure 2.2. Determine the point at which the ball first triggers the Photogate Timer—this is the point at which the LED on top of the photogate first turns ON—and mark it with a pencil on the side of the channel. Then determine the point at which the ball last triggers the timer, and mark this point also. Measure the distance between these marks and record this distance as Δd . Determine the mid-point of this interval, and mark it in pencil on the side of the channel.
- ③ Set the Photogate Timer to GATE mode and press the RESET button.
- ④ Move the ball to a point 5 cm along the track above your mid-point. Hold it at this position using a ruler or block of wood. Release the ball so that it moves along the ramp and through the photogate. Record the distance travelled (from the starting point to the midpoint) and the time (t_1) in Table 2.1.
- ⑤ Repeat the trial 3 times so you have a total of four measured times, then take the average of your measured times. Record your results in the table.
- ⑥ Move the ball to positions 10, 15, 20...40 cm from the midpoint, and repeat steps 3-5.

Fig-

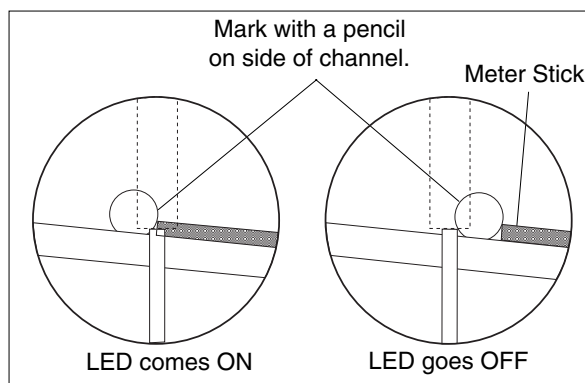


Figure 2.2: Measuring Δd

Data and Calculations

- ① For each distance from the midpoint of the photogate, calculate the final velocity of the ball by dividing Δd by your average time.
- ② Construct a velocity versus distance graph, with distance on the horizontal axis.

- ③ If the graph doesn't turn out to be a straight line (as it shouldn't), manipulate the data mathematically and replot it until you obtain a straight line graph. For example, try plotting distance as a function of \sqrt{v} , v^2 , $1/v$, etc. From your graph, what is the mathematical relationship between the velocity of an object on an inclined plane and the distance from its starting point that it has travelled along the plane?

Questions

Table 2.1 Data and Calculations

Distance inside photogate = _____
 Δd :

Distance Travelled	t_1	t_2	t_3	t_4	Average Time	Final Velocity

- ① The standard equations for motion with a constant acceleration (starting from rest) include: $x = 1/2 at^2$ and $v = at$. Eliminate t from these equations to determine the relationship between x and v . Using your result and your graph, can you determine the acceleration of the ball as it rolled down the plane?
- ② From your answer to question 1, write the equation of motion for the accelerating ball, giving its position as a function time. Why do you think equations of motion are most often expressed as a function of time instead of simply relating position to velocity and acceleration?

Experiment 3: Speed of a Projectile

EQUIPMENT NEEDED:

- | | |
|--|---------------|
| -Photogate Timer, with Accessory Photogate | -Meter stick |
| -Ball and ramp | -Carbon paper |
| -Plumb bob | |

Introduction

Projectile motion adds a new dimension, literally, to experiments in linear acceleration. Once a projectile is in motion, its acceleration is constant and in one direction only—down. But unless the projectile is fired straight up or down, it will have an initial velocity with a component perpendicular to the direction of acceleration. This component of its velocity, since it is perpendicular to the applied force of gravity, remains unchanged. Projectile motion is therefore a superposition of two relatively simple types of motion: constant acceleration in one direction, and constant velocity in an orthogonal direction.

In this experiment you will determine the initial velocity of a projectile directly, using the Photogate Timer, and compare that with a value calculated by examining the motion of the projectile.

Procedure

- ① Set up the apparatus as in figure 3.1, so the ball rolls down the ramp onto the table, then passes through the photogate, interrupting the beam.
- ② Tape a piece of paper to the table, under the Accessory Photogate. Use the ramp to push the ball slowly through the Accessory Photogate, as shown in Figure 3.2. Determine the point at which the ball first triggers the Photogate Timer—this is the first point at which the LED turns ON—and mark it on the paper. Then determine the point at which the ball last triggers the timer, and mark this point also. Measure the distance between these marks and record this distance as Δd . Replace the ramp as in Figure 3.1.
- ③ Use a plumb bob to determine the point directly below where the ball will leave the edge of the table after rolling down the ramp. Measure the distance from the floor to the top of the table at the point where the ball leaves the table and record this value as d_y .
- ④ To measure the position where the ball will strike the floor after rolling down the ramp, tape a piece of plain paper onto the floor with a piece of carbon paper on top. The impact of the ball will leave a clear mark for measuring purposes.

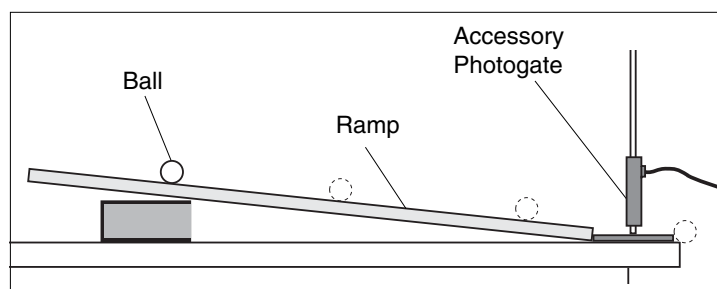


Figure 3.1: Equipment Setup

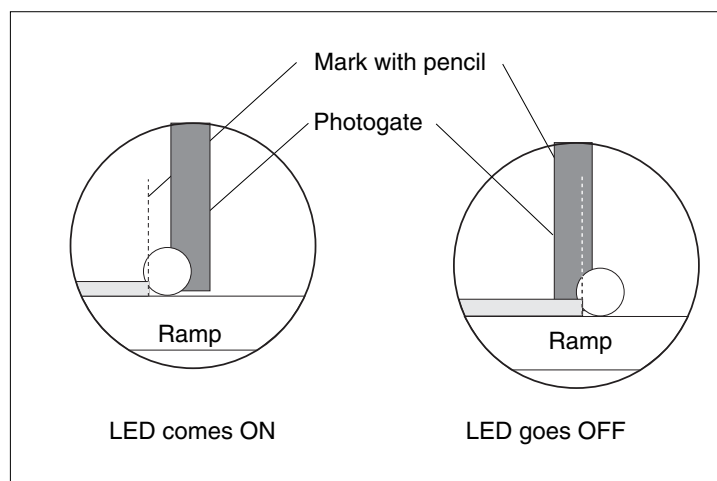


Figure 3.2: Measuring Δd

- ⑤ Set the Photogate Timer to GATE mode. Now move the ball to a starting point somewhere on the ramp. Mark this starting position with a pencil so you will be able to repeat the run, starting the ball each time from the same point. Hold the ball at this position using a ruler or block of wood. Press the RESET button. Release the ball so that it moves along the ramp and through the photogate. Record the time in Table 3.1.
- ⑥ Repeat the trial at least four more times with the same starting point, and record your times in the table.
- ⑦ Measure the distance from the point directly below the ramp to each of the landing spots of your ball. Record these distances in the data table.

Data and Calculations

- ① Take the average of your measured times and of your measured distances. Record these averages in the data table. Also record the average distance as d_x in the space provided to the right of the table.

Table 3.1

Data from Photogate Timer

Trial	Time	Distance
1		
2		
3		
4		
5		
Averages		
v_0 (avg)		

$\Delta d =$ _____

Vertical height, $d_y =$ _____

Average horizontal distance, $d_x =$ _____

Horizontal velocity, $v_0 =$ _____

Percentage difference = _____

- ② Divide Δd by your average time to determine v_0 , the velocity of the ball just before it left the table.
- ③ Now determine the horizontal velocity of the sphere using the equations for projectile motion and your measured values for d_x and d_y :

$$d_x = v_0 t; d_y = 1/2 at^2;$$

where a equals the acceleration caused by gravity (9.8 m/s^2 or 980 cm/s^2).

- ④ Compare your two values for v_0 . Report the two values and the percentage difference.

Optional

If you have time, choose a value for d_x and a value for d_y . For what value of v_0 will the ball travel the distance d_x as it falls the distance d_y ? Adjust the height and angle of the ramp and the starting point until you produce the predicted value of v_0 . Now run the experiment to see if your calculated values for d_x and d_y are correct.

Experiment 4: Newton's Second Law

EQUIPMENT NEEDED:

- Photogate timer with Accessory Photogate (or two Photogate Timers)
- Air Track System with one glider
- Pulley
- Universal Table Clamp
- Masses
- Pulley Mounting Clamp

Introduction

There's nothing obvious about the relationships governing the motions of objects. In fact, it took around 4,000 years of civilization and the genius of Isaac Newton to figure out the basic laws. Fortunately for the rest of us, hindsight is a powerful research tool. In this experiment you will experimentally determine Newton's second law by examining the motion of an air track glider under the influence of a constant force. The constant force will be supplied by the weight of a hanging mass that will be used to pull the glider. By varying the mass of the hanging weight and of the glider, and measuring the acceleration of the glider, you'll be able to determine Newton's second law.

Procedure

- ① Set up the air track as shown in Figure 4.1. Level the air track very carefully by adjusting the air track leveling feet. A glider should sit on the track without accelerating in either direction. There may be some small movement of the glider due to unequal air flow beneath the glider, but it should not accelerate steadily in either direction.

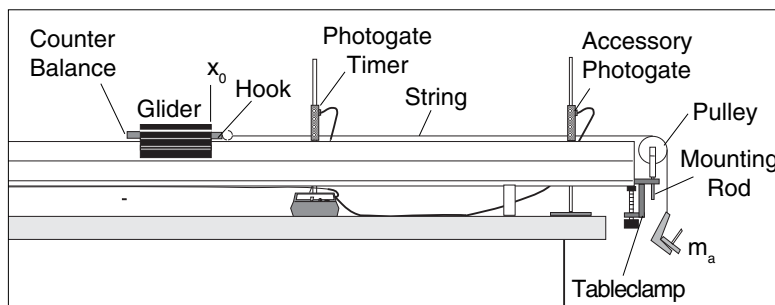


Figure 4.1: Equipment Setup

- ② Measure the effective length of the glider, and record your value as L in Table 4.1.
- ③ Mount the hook into the bottom hole of the cart. To counterbalance its weight, add a piece of similar weight on the opposite end as shown on Fig. 4.1.
- ④ Add 50-60 grams of mass to the glider using 10 or 20 gram masses. Be sure the masses are distributed symmetrically so the glider is balanced. Determine the total mass of your glider with the added masses and record the total as m in Table 4.1.
- ⑤ Place a mass of approximately 5-10 grams on the weight hanger. Record the total mass (hanger plus added mass) as m_a .
- ⑥ Set your Photogate Timer to GATE mode.
- ⑦ Choose a starting point x_0 for the glider, near the end of the track. Mark this point with a pencil so that you can always start the glider from this same point.
- ⑧ Press the RESET button.
- ⑨ Hold the glider steady at x_0 , then release it. Note t_1 , the time it took for the glider to pass through the first photogate, and t_2 , the time it took for the glider to pass through the second photogate. Repeat this measurement four times. Take the average of your measured t_1 's and t_2 's and record these averages as \bar{t}_1 and \bar{t}_2 in Table 4.1. panel
- ⑩ Set the Photogate Timer to PULSE mode.
- ⑪ Press the RESET button.

- ⑫ Again, start the glider from x_0 . This time measure and record t_3 , the time it takes the glider to pass between the photogates. Repeat this measurement four more times and record the average of these measurements as t_3 in Table 4.1.
- ⑬ Vary m_a , by moving masses from the glider to the hanger (thus keeping the total mass, $m + m_a$, constant.) Record m and m_a and repeat steps 5 through 11. Try at least four different values for m_a .
- ⑭ Now leave m_a constant at a previously used value. Vary m by adding or removing mass from the glider. Repeat steps 5-11. Try at least four different values for m .

Calculations

For each set of experimental conditions:

- ① Use the length of the glider and your average times to determine v_1 and v_2 , the average glider velocity as it passed through each photogate.
- ② Use the equation $a = (v_2 - v_1)/t_3$ to determine the average acceleration of the glider as it passed between the two photogates.
- ③ Determine F_a , the force applied to the glider by the hanging mass.
($F_a = m_a g$; $g = 9.8 \text{ m/s}^2 = 980 \text{ cm/s}^2$)

Analysis

- ① Draw a graph showing average acceleration as a function of applied force, F_a .
- ② Draw a second graph showing average acceleration as a function of the glider mass with M_a being held constant.
- ③ Examine your graphs carefully. Are they straight lines? Use your graphs to determine the relationship between applied force, mass, and average acceleration for the air track glider.
- ④ Discuss your results. In this experiment, you measured only the average acceleration of the glider between the two photogates. Do you have reason to believe that your results also hold true for the instantaneous acceleration? Explain. What further experiments might help extend your results to include instantaneous acceleration?

Table 4.1 Data and Calculations

Glider Length, $L =$ _____

m	m_a	t_1	t_2	t_3	v_1	v_2	a	F_a

Experiment 5: The Force of Gravity

EQUIPMENT NEEDED:

-Photogate timer with Accessory Photogate

-Air Track System with one glider.

Introduction

In this experiment, you will use Newton's Second Law ($F = ma$) to measure the force exerted on an object by the Earth's gravitational field. Ideally, you would simply measure the acceleration of a freely falling object, measure its mass, and compute the force. However, the acceleration of a freely falling object is difficult to measure accurately. Accuracy can be greatly increased by measuring the much smaller acceleration of an object as it slides down an inclined plane. Figure 5.1 shows a diagram of the experiment. The gravitational force F_g can be resolved into two components, one acting perpendicular and one acting parallel to the motion of the glider. Only the component acting along the direction of motion can accelerate the glider. The other component is balanced by the force from the air cushion of the track acting in the opposite direction. From the diagram, $F = F_g \sin \theta$, where F_g is the total gravitational force and F is the component that accelerates the glider. By measuring the acceleration of the glider, F can be determined and F_g can be calculated.

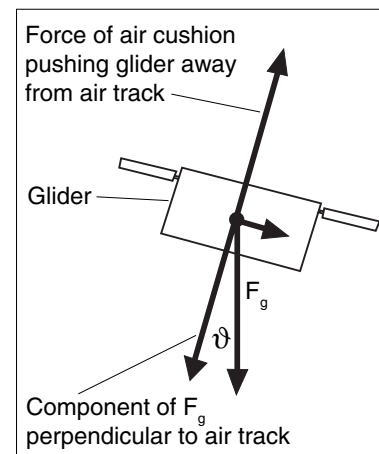


Figure 5.1: Forces Acting on the Glider

Procedure

- ① Set up the air track as shown in Figure 5.2. Remove the block and level the air track very carefully.
- ② Measure d , the distance between the air track support legs. Record this distance in the space on the following page.
- ③ Place a block of thickness h under the support leg of the track. Measure and record h on the following page. (For best results, measure h with calipers.)
- ④ Measure and record D , the distance the glider moves on the air track from where it triggers the first photogate, to where it triggers the second photogate. (Move the glider and watch the LED on top of the photogate. When the LED lights up, the photogate has been triggered.)
- ⑤ Measure and record L , the effective length of the glider. (Move the glider slowly through a photogate and measure the distance it travels from where the LED first lights up to where it just goes off.)
- ⑥ Measure and record m , the mass of the glider.
- ⑦ Set the Photogate Timer to GATE mode and press the RESET button.
- ⑧ Hold the glider steady near the top of the air track, then release it so it glides freely through the photogates. Record t_1 , the time during which the glider blocks the first photogate, and t_2 , the time during which it blocks the second photogate. Use the memory function to determine each time.
- ⑨ Repeat the measurement several times and record your data in Table 5.1. You needn't release the glider from the same point on the air track for each trial, but it must be gliding freely and smoothly (minimum wobble) as it passes through the photogates.

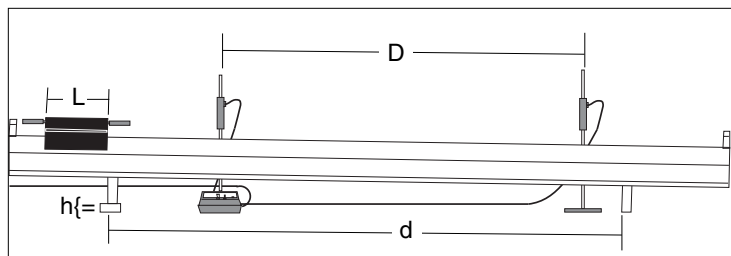


Figure 5.2: Equipment Setup

- ⑩ Change the mass of the glider by adding weights and repeat steps 6 through 8. Do this for at least five different masses, recording the mass (**m**) for each set of measurements. (If you have time, you may also want to try changing the height of the block used to tilt the track.)

Data and Calculations

d = _____ D = _____ θ = _____
 h = _____ L = _____

Table 5.1 Data and Calculations

m	t ₁	t ₂	v ₁	v ₂	a	a _{avg}	F _g

- ① Calculate θ , the angle of incline for the air track, using the equation $\theta = \tan^{-1}(h/d)$.
- ② For each set of time measurements, divide **L** by **t₁** and **t₂** to determine **v₁** and **v₂**, the velocities of the glider as it passed through the two photogates.
- ③ For each set of time measurements, calculate **a**, the acceleration of the glider, using the equation

$$v_2^2 - v_1^2 = 2a(x_2 - x_1) = 2aD.$$
- ④ For each value of mass that you used, take the average of your calculated accelerations to determine **a_{avg}**.
- ⑤ For each of your average accelerations, calculate the force acting on the glider along its line of motion (**F = ma_{avg}**).
- ⑥ For each measured value of **F**, use the equation **F = F_g sin θ** to determine **F_g**.
- ⑦ Construct a graph of **F_g** versus **m**, with **m** as the independent variable (x-axis).

Analysis

Does your graph show a linear relationship between **F_g** and **m**? Does the graph go through the origin? Is the gravitational force acting on the mass proportional to the mass? If so, the gravitational force can be expressed by the equation **F_g = mg**, where **g** is a constant. If this is the case, measure the slope of your graph to determine the value of **g**.

g = _____

Questions

- ① In this experiment, it was assumed that the acceleration of the glider was constant. Was this a reasonable assumption to make? How would you test this?
- ② The equation $v_2^2 - v_1^2 = 2a(x_2 - x_1)$ was used to calculate the acceleration. Under what conditions is this equation valid? Are those conditions met in this experiment? (You should be able to find a derivation for this equation in your textbook.)
- ③ Could you use the relationship **F_g = mg** to determine the force acting between the Earth and the Moon? Explain.

Experiment 6: Conservation of Momentum

EQUIPMENT NEEDED:

-Air track system with two gliders

-Two Photogate Timers.

Introduction

When objects collide, whether locomotives, shopping carts, or your foot and the sidewalk, the results can be complicated. Yet even in the most chaotic of collisions, as long as there are no external forces acting on the colliding objects, one principle always holds and provides an excellent tool for understanding the dynamics of the collision. That principle is called the conservation of momentum. For a two-object collision, momentum conservation is easily stated mathematically by the equation:

$$p_i = m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f} = p_f ;$$

where m_1 and m_2 are the masses of the two objects, v_{1i} and v_{2i} are the initial velocities of the objects (before the collision), v_{1f} and v_{2f} are the final velocities of the objects, and p_i and p_f are the combined momentums of the objects, before and after the collision. In this experiment, you will verify the conservation of momentum in a collision of two airtrack gliders.

Procedure

- ① Set up the air track and photogates as shown in Figure 6.1, using bumpers on the gliders to provide an elastic collision. Carefully level the track.

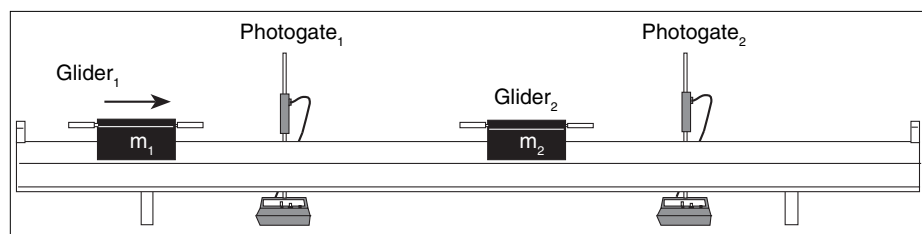


Figure 6.1: Equipment Setup

- ② Measure m_1 and m_2 , the masses of the two gliders to be used in the collision. Record your results in Table 6.1.
- ③ Measure and record L_1 and L_2 , the length of the gliders. (e.g., push glider $_1$ through photogate $_1$ and measure the distance it travels from where the LED comes on to where it goes off again.)
- ④ Set both Photogate Timers to GATE mode, and press the RESET buttons.
- ⑤ Place glider $_2$ at rest between the photogates. Give glider $_1$ a push toward it. Record four time measurements in Table 6.1 as follows:

t_{1i} = the time that glider $_1$ blocks photogate $_1$ before the collision.

t_{2i} = the time that glider $_2$ blocks photogate $_2$ before the collision.
(In this case, there is no t_{2i} since glider $_2$ begins at rest.)

t_{1f} = the time that glider $_1$ blocks photogate $_1$ after the collision.

t_{2f} = the time that glider $_2$ blocks photogate $_2$ after the collision.

➤ **IMPORTANT:** The collision must occur after glider $_1$ has passed completely through photogate $_1$ and, after the collision, the gliders must be fully separated before either glider interrupts a photogate.

➤ **NOTE:** Use the memory function to store the initial times while the final times are being measured. Immediately after the final times are recorded, the gliders must be stopped to prevent them from triggering the photogate again due to rebounds.

- ⑥ Repeat the experiment several times, varying the mass of one or both gliders and varying the initial velocity of glider₁.
- ⑦ Try collisions in which the initial velocity of glider₂ is not zero. You may need to practice a bit to coordinate the gliders so the collision takes place completely between the photogates.

Data and Calculations

- ① For each time that you measured, calculate the corresponding glider velocity.
(e.g., $v_{1i} = \pm L_1/t_{1i}$, where the velocity is positive when the glider moves to the right and negative when it moves to the left.
- ② Use your measured values to calculate p_i and p_f , the combined momentum of the gliders before and after the collision. Record your results in the table.

Questions

Table 6.1 Data and Calculations

$L_1 =$ _____ $L_2 =$ _____

m_1	m_2	t_{1i}	t_{2i}	t_{1f}	t_{2f}	v_{1i}	v_{2i}	v_{1f}	v_{2f}	p_i ($m_1 v_{1i} + m_2 v_{2i}$)	p_f ($m_1 v_{1f} + m_2 v_{2f}$)

- ① Was momentum conserved in each of your collisions? If not, try to explain any discrepancies.
- ② If a glider collides with the end of the air track and rebounds, it will have nearly the same momentum it had before it collided, but in the opposite direction. Is momentum conserved in such a collision? Explain.
- ③ Suppose the air track was tilted during the experiment. Would momentum be conserved in the collision? Why or why not?

Optional Equipment

Design and conduct an experiment to investigate conservation of momentum in an inelastic collision in which the two gliders, instead of bouncing off each other, stick together so that they move off with identical final velocities. If you are using a PASCO airtrack, replace the bumpers with the wax and needle. Otherwise, velcro fasteners can be used with most gliders.

Experiment 7: Conservation of Kinetic Energy

EQUIPMENT NEEDED:

-Two Photogate Timers

-Air Track System with two gliders.

Introduction

Momentum is always conserved in collisions that are isolated from external forces. Energy is also always conserved, but energy conservation is much harder to demonstrate since the energy can change forms: energy of motion (kinetic energy) may be changed into heat energy, gravitational potential energy, or even chemical potential energy. In the air track glider collisions you'll be investigating, the total energy before the collision is simply the kinetic energy of the gliders:

$$E_k = (1/2)mv_1^2 + (1/2)mv_2^2.$$

In this experiment you'll examine the kinetic energy before and after a collision to determine if kinetic energy is conserved in air track collisions.

Procedure

- ① Set up the air track and photogates as shown in Figure 7.1, using bumpers on the gliders to provide an elastic collision. Carefully level the track.

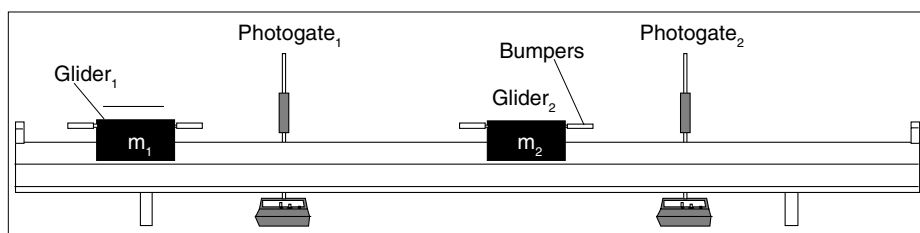


Figure 7.1: Equipment Setup

- ② Measure m_1 and m_2 , the masses of the two gliders to be used in the collision. Record your results in Table 7.1.
- ③ Measure and record L_1 and L_2 , the length of the gliders. (e.g., push glider $_1$ through photogate $_1$ and measure the distance it travels from where the LED comes on to where it goes off again.)
- ④ Set both Photogate Timers to GATE mode, and press the RESET buttons.
- ⑤ Place glider $_2$ at rest between the photogates. Give glider $_1$ a push toward it. Record four time measurements in Table 7.1 as follows:

t_{1i} = the time that glider $_1$ blocks photogate $_1$ before the collision.

t_{2i} = the time that glider $_2$ blocks photogate $_2$ before the collision.
(In this case, there is no t_{2i} since glider $_2$ begins at rest.)

t_{1f} = the time that glider $_1$ blocks photogate $_1$ after the collision.

t_{2f} = the time that glider $_2$ blocks photogate $_2$ after the collision.

► **IMPORTANT:** The collision must occur after glider $_1$ has passed completely through photogate $_1$ and, after the collision, the gliders must be fully separated before either glider interrupts a photogate.

► **NOTE:** Use the memory function to store the initial times while the final times are being measured. Immediately after the final times are recorded, the gliders must be stopped to prevent them from triggering the photogate again due to rebounds.

- ⑥ Repeat the experiment several times, varying the mass of one or both gliders and varying the initial velocity of glider₁.
- ⑦ Try collisions in which the initial velocity of glider₂ is not zero. You may need to practice a bit to coordinate the gliders so the collision takes place completely between the photogates.

Data and Calculations

- ① For each time that you measured, calculate the corresponding glider velocity (e.g., $v_1 = L_1/t_{1i}$).
- ② Use your measured values to calculate E_{ki} and E_{kf} , the combined kinetic energy of the gliders before and after the collision. Record your results in the table.

Table 7.1 Data and Calculations

$L_1 =$ _____ $L_2 =$ _____

m_1	m_2	t_{1i}	t_{2i}	t_{1f}	t_{2f}	v_{1i}	v_{2i}	v_{1f}	v_{2f}	E_{ki}	E_{kf}

Questions

- ① Was kinetic energy conserved in each of your collisions?
- ② If there were one or more collisions in which kinetic energy was not conserved, where did it go?

Optional Equipment

Design and conduct an experiment to investigate conservation of kinetic energy in an inelastic collision in which the two gliders, instead of bouncing off each other, stick together so that they move off with identical final velocities. If you are using a PASCO air track, replace the bumpers with the wax and needle. Otherwise, velcro fasteners can be used with most gliders.

Experiment 8: Conservation of Mechanical Energy

EQUIPMENT NEEDED:

- Photogate timer and Accessory Photogate
- air track system with one glider
- block of wood of known thickness (approximately 1-2 cm).

Introduction

Though conservation of energy is one of the most powerful laws of physics, it is not an easy principle to verify. If a boulder is rolling down a hill, for example, it is constantly converting gravitational potential energy into kinetic energy (linear and rotational), and into heat energy due to the friction between it and the hillside. It also loses energy as it strikes other objects along the way, imparting to them a certain portion of its kinetic energy. Measuring all these energy changes is no simple task.

This kind of difficulty exists throughout physics, and physicists meet this problem by creating simplified situations in which they can focus on a particular aspect of the problem. In this experiment you will examine the transformation of energy that occurs as an airtrack glider slides down an inclined track. Since there are no objects to interfere with the motion and there is minimal friction between the track and glider, the loss in gravitational potential energy as the glider slides down the track should be very nearly equal to the gain in kinetic energy. Stated mathematically:

$$\Delta E_k = \Delta(mgh) = mg\Delta h;$$

where E_k is the change in kinetic energy of the glider [$\Delta E_k = (1/2)mv_2^2 - (1/2)mv_1^2$] and $\Delta(mgh)$ is the change in its gravitational potential energy (m is the mass of the glider, g is the acceleration of gravity, and Δh is the change in the vertical position of the glider).

Procedure

- ① Level the airtrack as accurately as possible.
- ② Measure d , the distance between the air track support legs. Record this distance in Table 8.1.
- ③ Place a block of known thickness under the support leg of the track. For best accuracy, the thickness of the block should be measured with calipers. Record the thickness of the block as h in Table 8.1.
- ④ Setup the Photogate Timer and Accessory Photogate as shown in Figure 8.1.
- ⑤ Measure and record D , the distance the glider moves on the air track from where it first triggers the first photogate, to where it first triggers the second photogate. (You can tell when the photogates are triggered by watching the LED on top of each photogate. When the LED lights up, the photogate has been triggered.)
- ⑥ Measure and record L , the effective length of the glider. (The best technique is to move the glider slowly through one of the photogates and measure the distance it travels from where the LED first lights up to where it just goes off.)
- ⑦ Measure and record m , the mass of the glider.
- ⑧ Set the Photogate Timer to GATE mode and press the RESET button.
- ⑨ Hold the glider steady near the top of the air track, then release it so it glides freely through the

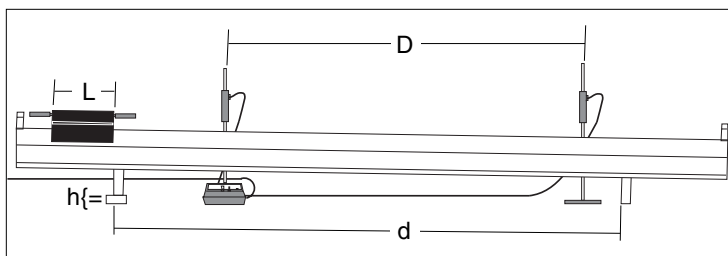


Table 8.1: Data and Calculations

photogates. Record t_1 , the time during which the glider blocks the first photogate, and t_2 , the time during which it blocks the second photogate. (If you have an ME-9215A Photogate Timer, the memory function will make it easier to measure the two times. If not, someone will need to watch the timer during the experiment and quickly record t_1 before the glider reaches the second photogate.)

- ⑩ Repeat the measurement several times and record your data in Table 8.1. You needn't release the glider from the same point on the air track for each trial, but it must be gliding freely and smoothly (minimum wobble) as it passes through the photogates.
- ⑪ Change the mass of the glider by adding weights and repeat steps 7 through 10. Do this for at least five different masses, recording the mass (m) for each set of measurements. (If you have time, you may also want to try changing the height of the block used to tilt the track or the distance between the photogates.)

Table 8.1 Data and Calculations

$d =$ _____ $h =$ _____
 $D =$ _____ $L =$ _____ $m =$ _____

m	θ	t_1	t_2	v_1	v_2	E_{k1}	E_{k2}	$\Delta(mgh)$

Data and Calculations

- ① Calculate θ , the angle of incline for the air track, using the equation $\theta = \arctan (h/d)$.
- For each set of time measurements:**
- ② Divide L by t_1 and t_2 to determine v_1 and v_2 , the velocity of the glider as it passed through each photogate.
 - ③ Use the equation $E_k = (1/2)mv^2$ to calculate the kinetic energy of the glider as it passed through each photogate.
 - ④ Calculate the change in kinetic energy, $\Delta E_k = E_{k2} - E_{k1}$.
 - ⑤ Calculate Δh , the distance through which the glider dropped in passing between the two photogates ($\Delta h = D \sin \theta$, where $\theta = \arctan h/d$).
 - ⑥ Compare the kinetic energy gained with the loss in gravitational potential energy. Was mechanical energy conserved in the motion of the glider?

Experiment 9: Elastic-Kinetic Energy

EQUIPMENT NEEDED:

- | | |
|---|---|
| <ul style="list-style-type: none"> -Photogate timer -Weight hanger with weights -Spring (with a low spring constant) | <ul style="list-style-type: none"> -Air Track with one glider -Flag (see Procedure 1 below) |
|---|---|

Introduction

It takes work to stretch or compress a spring. Suppose a spring has a natural (unstretched) length L_0 , and a spring constant k . If that spring is stretched or compressed to a new length, $L = L_0 \pm x$, the work required is given by the expression $1/2 kx^2$. If the energy stored in the spring is then used to accelerate an object, the kinetic energy of the object, $1/2 mv^2$, will be equivalent to the work that was originally stored in the spring. In this lab you will investigate this equivalency between the work stored in a stretched spring and the kinetic energy it can impart to an object.

Procedure

- ① Set up the equipment as shown in Figure 9.1, and level the track. As shown, attach a cardboard flag to your glider with masking tape. The flag can be from 1 to 5 cm wide. Make a platform for your spring, so it will be supported horizontally and will not sag. Attach the platform securely to the end of the air track. Connect the spring to the glider with a piece of thread so that the glider is about in the middle of the air track with the spring unstretched. Run another piece of thread from the glider over a pulley at the end of the track and attach it to a hanger.
- ② Hang masses on the hanger and determine how far the spring stretches. This is easily done using the metric scale on the side of the air track and using the glider to monitor the distance the spring has extended. Record the masses added and the position of the glider in Table 9.1. (The air flow should be on while gathering this data.) Then remove the hanger and thread.
- ③ Measure and record m , the mass of your glider and flag, in Table 9.2. Then pass the glider slowly through the photogate and note the position of the glider when the LED on the photogate first goes on and again when the LED goes off. The difference between these positions is Δd . Record Δd on the following page.
- ④ Position the glider so the spring exerts no force on the glider, but the thread does not sag. Record this glider position as x_1 . Position the photogate between the glider and the spring.
- ⑤ Pull the glider approximately 5 cm farther away from the spring. Measure the distance between this glider position and x_1 , and record this distance as the Spring Stretch in Table 9.2.
- ⑥ Set the Photogate Timer to GATE mode and press the RESET button.
- ⑦ Hold the glider steady as you turn the air flow on. Release the glider, but catch it before it crashes into the spring platform. Record the measured time as t_1 in Table 9.2.

Figure 9.1: Equipment Setup

- ③ Repeat steps 5-8 four more times. Record your times as t_2 through t_5 in Table 9.2. Determine the average of these five times and record this value as t_{avg} .
- ④ Repeat steps 5-9 for different distances of stretch of the spring up to 20 cm. Also try varying the mass of the glider by adding masses to it. Note the new masses in Table 9.2.

Data and Calculations

On another sheet of paper:

- ① Determine k , the spring constant of your spring. Construct a graph of the stretch of the spring versus the amount of force applied to it by the hanging weights. The slope of this graph, in newtons/meter, is equal to k .
- ② For each set of trials you performed for a given spring stretch and glider mass, divide Δd by your average time to determine the average velocity of the glider as it passed through the photogate. Calculate the final kinetic energy of the glider, $1/2 mv^2$.
- ③ Calculate the energy stored in the spring in each case, $1/2 kx^2$, where k is the spring constant, and x is the spring stretch.
- ④ For each trial, determine the percentage difference between the elastic potential energy stored in the spring and the final translational kinetic energy of the glider.

Table 9.1 Determining the Spring Constant

Added Mass	Glider Position	Applied Force	Spring Stretch

Table 9.2 Spring Stretch and Glider Velocities

$x_1 =$ _____ Flag width, Δd _____

Trial	m	Spring Stretch	t_1	t_2	t_3	t_4	t_5	t_{avg}

Experiment 10: Pendulum Motion

EQUIPMENT NEEDED:

- Photogate timer
- Meter stick.
- Pendulums of various masses and lengths (the pendulum bob should be no more than 3 cm in diameter)

Introduction

In this experiment, you will investigate two aspects of pendulum motion. First you will investigate the relationship between pendulum length, pendulum mass, and the period of oscillation. Then you will determine whether mechanical energy is conserved as the pendulum swings.

Procedure

Part 1: Period of Oscillation versus Mass and Length

- ① Measure the mass of the pendulum bob. Record this value as m in Table 10.1.
- ② Set up the pendulum and photogate as shown in Figure 10.1. For best results, the pendulum should be suspended from two points as shown. This helps keep the swing of the pendulum in the plane perpendicular to the photogate.
- ③ Measure and record L , the length of the pendulum. (If you are suspending the bob from two points, L is the distance from the center of mass of the bob to the point midway between the points of suspension.)
- ④ Set the Photogate Timer to GATE mode. Adjust the height of the photogate so the bob interrupts the photogate beam as it swings.
- ⑤ Switch the Timer to PENDULUM mode. Start the bob swinging, but keep the swings relatively small.
- ⑥ Press the RESET button on the Timer. Note the first time displayed. This is the period of the pendulum, the time for one complete oscillation. Repeat this measurement several times by pressing the RESET button and recording the first time measured. Take the average of these measured times to determine T , the period of the pendulum. Record T in Table 10.1.
- ⑦ Change the mass of the pendulum bob and repeat the measurement. Do this for several different mass values, keeping the length constant.
- ⑧ Using one of the masses you used from a previous measurement, change the string length and remeasure the period. Do this for at least 5 different string lengths.

Part 2: Conservation of Mechanical Energy

- ① Use a long string (at least one meter long), to suspend the pendulum between the photogate as shown on Fig 10.1. Make and attach a rigid protractor as shown on Fig 10.1. This protractor can be created by photocopying the angular readings of a compass onto a piece of white paper before attaching it to a rigid board by means of adhesive. This compass-board will be used to keep track of θ , the angle between the string and the vertical.
- ② Measure L , the length of the pendulum.

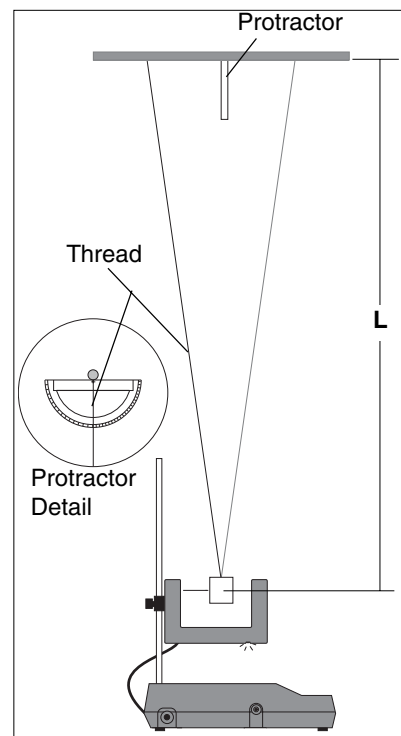


Figure 10.1: Equipment

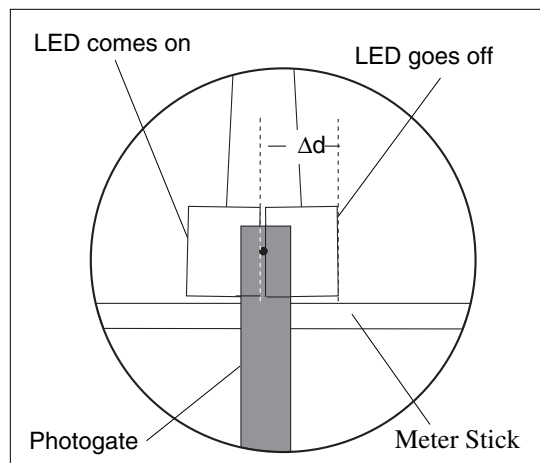


Figure 10.2: Measuring Δd

Questions

- ① Discuss your graphs of pendulum period versus mass and length. What relationship between mass and length produces a straight line graph?
- ② Did the period of your pendulum vary with the mass of the bob? Discuss why it did or did not.
- ③ Was mechanical energy conserved during a single swing of the pendulum?
- ④ No matter how high the initial height of the bob, the pendulum ultimately slows down and stops. Does this slowing down defy the principle of the conservation of energy? Explain.

Table 10.2

$L =$ _____ (m)

$\Delta d =$ _____ (m)

$m =$ _____ (Kg)

θ (deg)	t (S)	Δh (m)	ΔU (J)	E_k (J)

Teachers Guide

Exp. 1 - Instantaneous Versus Average Velocity

Notes - on Procedure, Experiment 1: Instantaneous vs Average Velocity

- ④ In order to accurately measure D , allow D to be the distance between the points where the glider first triggers the Photogate Timers.
- ⑦ If the Photogate Timer does not have a memory function, after the glider has passed through both photogates, prevent it from triggering the Photogate Timer again upon rebound.

Notes - on Analysis

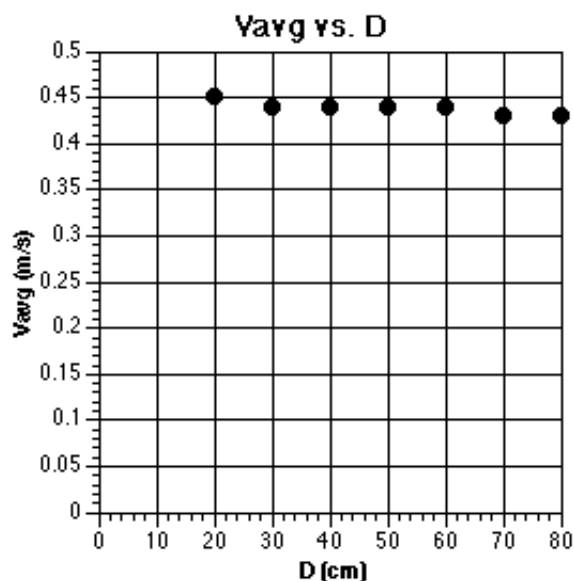
Here are the results for the measurement of average velocities with Photogate Timers positioned at seven different distances apart.

Table 1.1

$$X_1 = 100.0 \text{ cm}$$

D (cm)	t_1 (s)	t_2 (s)	t_3 (s)	t_4 (s)	t_5 (s)	t_{avg} (s)	V_{avg} (m/s)
80	1.85	1.85	1.85	1.86	1.86	1.85	0.43
70	1.61	1.61	1.61	1.61	1.62	1.61	0.43
60	1.37	1.38	1.38	1.37	1.38	1.38	0.44
50	1.13	1.14	1.14	1.13	1.14	1.14	0.44
40	0.90	0.90	0.91	0.90	0.90	0.90	0.44
30	0.68	0.68	0.68	0.68	0.68	0.68	0.44
20	0.45	0.45	0.45	0.45	0.45	0.45	0.45

Here is a plot of the average velocities of the glider being measured by Photogate Timers positioned at seven different distances apart.



Answers - to Questions

- ① The average velocity becomes a closer approximation to the instantaneous velocity when the distance between the photogates is reduced.
- ② Yes. The maximum error can be evaluated using the standard deviation or best fit methods.
- ③ Timer accuracy has the greatest impact on the accuracy of velocity measurements. The ability to measure small time intervals accurately will allow a better approximation of the instantaneous velocity. The object being timed and type of motion should not influence the accuracy of the measurements.
- ④ Instantaneous velocity is always inferred from an average velocity.

Exp. 2 - Kinematics on an Inclined Plane

Notes - on Procedure, Experiment 2: Kinematics on an Inclined Plane

- ④ If the ramp tends to wobble upon ball release, stabilize it by holding on to the upper end of the ramp.

Notes - on Analysis

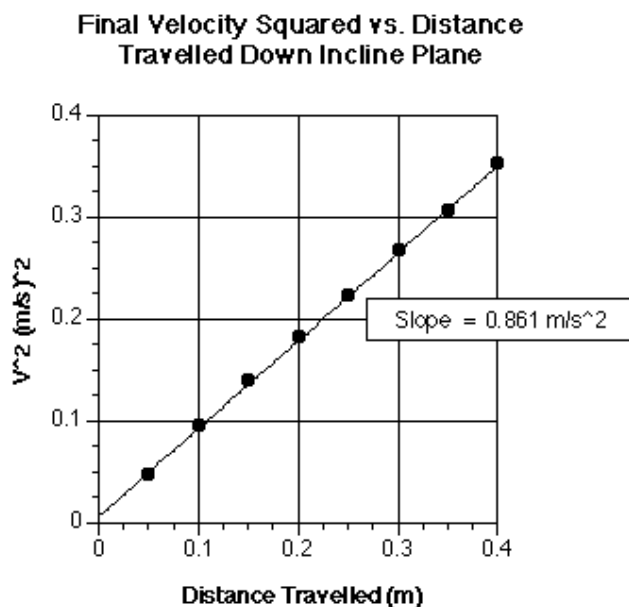
Here are the results for the measurement of the final velocities of the ball down the incline plane.

Table 2.1

$\Delta d = 1.6 \text{ cm}$

Distance Travelled (cm)	t1 (s)	t2 (s)	t3 (s)	t4 (s)	Average Time (s)	Final Velocity (m/s)
5	0.07	0.07	0.07	0.07	0.07	0.22
10	0.05	0.05	0.05	0.05	0.05	0.30
15	0.04	0.04	0.04	0.04	0.04	0.37
20	0.04	0.04	0.04	0.04	0.04	0.42
25	0.03	0.03	0.03	0.03	0.03	0.47
30	0.03	0.03	0.03	0.03	0.03	0.52
35	0.03	0.03	0.03	0.03	0.03	0.55
40	0.03	0.03	0.03	0.03	0.03	0.59

Here is a plot of describing the linear relationship between the squared of the final velocity and distance travelled by the ball down the incline plane.



The mathematical relationship being depicted by the plot is

$$v_f^2 - v_i^2 = 0.861 D$$

Answers - to Questions

- ① Yes. $a = 0.43 \text{ m/s}^2$
- ② $D = \frac{0.43 t^2}{2}$. This is because time can be accurately measured. This is not true for velocity and acceleration for complex motions.

Exp 3 - Speed of a Projectile

Notes - on Procedure

- ① Slide a horizontal plate against the ramp if needed to ensure that the ball is rolling on a nearly continuous surface. This is critical for the success of the ensuing experiments.

- ③ If the ramp tends to wobble upon ball release, stabilize it by holding on to the upper end of the ramp using a clamp.

Notes - on Analysis

Here are the results for the measurement of the final velocities of the ball down the incline plane.

Table 3.1

$$\Delta d \text{ (cm)} = 1.60$$

Trial	Time (s)	d _x (cm)	d _y (cm)
1	0.0161	40.7	73.3
2	0.0161	40.7	73.3
3	0.0161	40.7	73.3
4	0.0161	40.7	73.3
5	0.0161	40.7	73.3
Averages	0.0161	40.7	73.3
	v _o exp	0.99	m/s
	v _o theo	1.05	m/s
	% of Error	5.56	%

Exp 4 - Newton's Second Law

Notes - on Procedure

- ① ► **IMPORTANT:** Elevate the Air track setup if necessary to prevent the weight hanger from striking the ground before the glider clears the final photogate.

► **NOTE:** The placement of the final photogate can be easily obtained by allowing the glider to slide forward until the weight hanger nearly reaches the ground.

- ③ Mount the hook into the bottom hole of the glider. To counterbalance its weight, add an accessory with similar weight to the opposite end of the glider as shown.

The tables below list the results from two experimental conditions. The value of each parameter was the average derived after five trials.

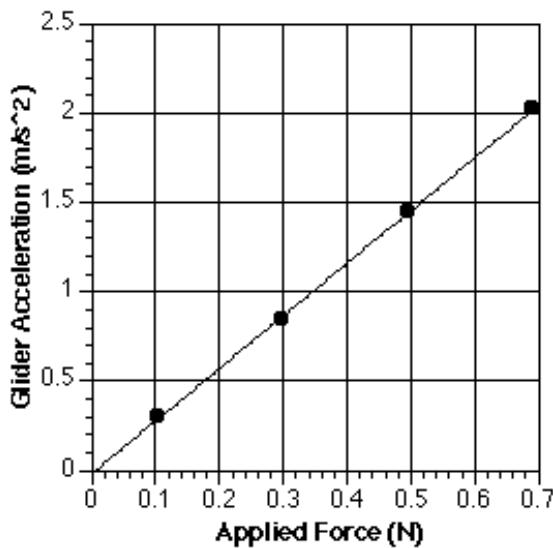
Table 4.1 Constant System Mass

M (g)	Ma (g)	t ₁ (s)	t ₁ +t ₂ (s)	t ₂ (s)	t ₃ (s)	v ₁ (m/s)	v ₂ (m/s)	a (m/s ²)	F _a (N)
260.5	10.3	0.31	0.48	0.17	1.19	0.41	0.76	0.30	0.10
240.48	30.32	0.20	0.30	0.10	0.68	0.65	1.22	0.84	0.30
220.47	50.33	0.14	0.21	0.07	0.54	0.93	1.70	1.45	0.49
200.47	70.33	0.11	0.18	0.06	0.44	1.10	1.99	2.02	0.69

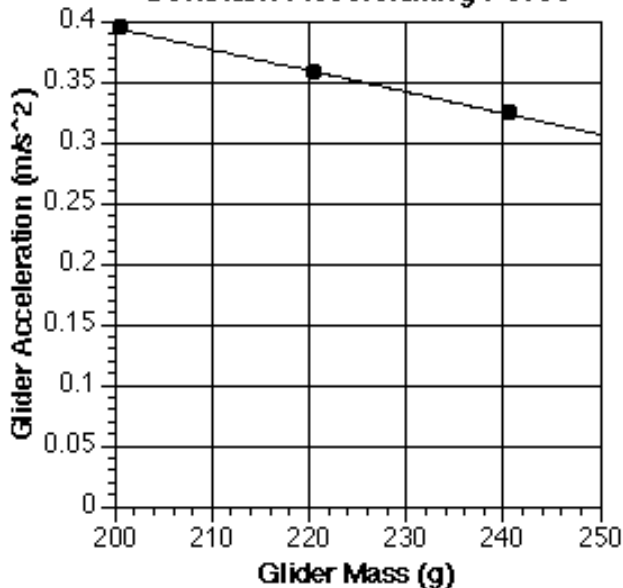
Table 4.2 Constant Accelerating Force

M (g)	M _a (g)	t ₁ (s)	t ₁ +t ₂ (s)	t ₂ (s)	t ₃ (s)	v ₁ (m/s)	v ₂ (m/s)	a (m/s ²)	Fa (N)
240.48	10.3	0.30	0.46	0.16	1.15	0.42	0.79	0.32	0.10
220.48	10.3	0.29	0.44	0.15	1.11	0.43	0.83	0.36	0.10
200.48	10.3	0.28	0.42	0.14	1.06	0.46	0.88	0.39	0.10

Glider Acceleration vs. Applied Force



Acceleration vs. Mass of Glider with Constant Accelerating Force



Notes - on Analysis

- ③ yes. The acceleration of the glider is linearly proportional to the applied force. The acceleration of the glider is inversely proportional to the glider mass.
- ④ The relationship among applied force, mass and acceleration seemed to obey Newton's Second Law of Motion $F = ma$. Yes. Instantaneous acceleration is defined as change of velocity per unit of time. As the incremental time period or the length of the object being measured becomes sufficiently small, the acceleration being measured will become a better approximation of the instantaneous acceleration. One way to include instantaneous acceleration in the experiment is to reduce the distance between the photogates.

Exp 5 - The Force of Gravity

Notes - on Procedure

- ④ In order to maintain a constant D throughout the experiment, It is recommended that the Photogate Timers be held down to their respective locations by means of tape.

The tables below list the results from two experimental conditions. The value of each parameter was the average derived after numerous trials.

Table 5.1

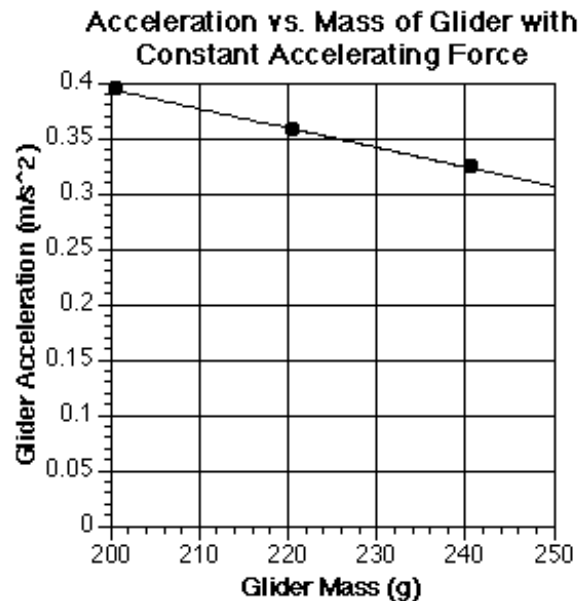
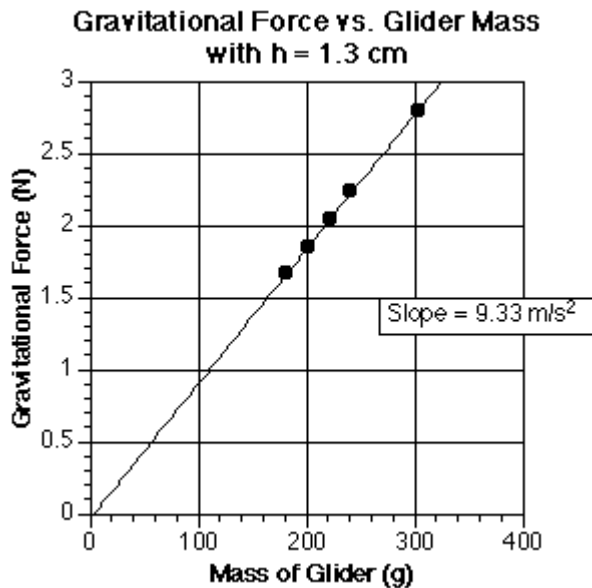
d (cm) = 100 D (cm) = 80 h (cm) = 1.3 L (cm) = 12.6 $\theta = 0.013$ rad

m (g)	t ₁ (s)	t ₁ +t ₂ (s)	t ₂ (s)	v ₁ (m/s)	v ₂ (m/s)	a _{avg} (m/s ²)	F _g (N)
180.2	0.35	0.57	0.22	0.36	0.57	0.12	1.66
200.2	0.35	0.57	0.22	0.36	0.57	0.12	1.84
220.2	0.35	0.57	0.22	0.36	0.57	0.12	2.03
240.3	0.35	0.57	0.22	0.36	0.57	0.12	2.23

Table 5.2

d (cm) = 100 D (cm) = 80 h (cm) = 2.6 L (cm) = 12.6 $\theta = 0.026$ rad

m (g)	t ¹ (s)	t ₁ +t ₂ (s)	t ₂ (s)	v ₁ (m/s)	v ₂ (m/s)	a _{avg} (m/s ²)	F _g (N)
180.2	0.25	0.40	0.16	0.51	0.80	0.24	1.67
220.2	0.25	0.41	0.16	0.51	0.80	0.24	2.00
261.6	0.25	0.41	0.16	0.51	0.80	0.24	2.43



Notes - on Analysis

- ① Yes. Yes. Yes. $g \approx 9.33$ m/s² in both cases. This value is approximately 5% below the established value of 9.80 m/s². These results however seemed to reaffirm

that gravitational acceleration is for all practicality constant for different masses and altitudes near the earth's surface. Try repeat the experiments for higher values of h.

Notes - on Questions

- ① Yes. This assumption can be tested by setting the photogates at a fixed distance apart but moving them along the air track to measure and compare the average accelerations along the line of motion.
- ② This equation is valid if and only if the acceleration is truly constant. Yes.

- ③ No. The gravitational force by the earth on the moon and vice versa is described by

$$F = \frac{Gm_1m_2}{R^2},$$

where:

G = universal gravitational constant

m_1 = Mass of Earth

m_2 = Mass of Moon

R = Distance between the centers of gravity of the two bodies

Exp 6 - Conservation of Momentum**Notes - on Procedure**

- ⑦ In order to ensure that the gliders are as close to travelling at constant velocities as possible prior to collision, the distance between the photogates should be reduced. Also, the gliders should be pushed to collide with the ends of air track so that the rebounded gliders will have near constant velocities prior to triggering the photogates.

The tables below list the results from two experimental conditions. Table 6.1 presents the results of elastic collision with one glider being initially stationary. Table 6.2 presents the results of elastic collision with both gliders moving initially.

Table 6.1 Glider 2 is initially Stationary $L_1 = 12.6 \text{ cm}$ $L_2 = 12.8 \text{ cm}$

Distance Between Photogates = 79.8cm

m_1 (g)	m_2 (g)	t_{1i} (s)	t_{2i} (s)	t_{1f} (s)	t_{2f} (s)	v_{1i} (m/s)	v_{2i} (m/s)	v_{1f} (m/s)	v_{2f} (m/s)	P_i (kg*m/s)	P_f (kg*m/s)	% Error (%)
180.2	201.3	0.275	N/A	3.81	0.318	0.46	0	-0.03	0.40	0.08	0.08	9.08
180.2	201.3	0.33	N/A	4.267	0.381	0.38	0	-0.03	0.34	0.07	0.06	9.44
180.2	201.3	0.242	N/A	3.369	0.278	0.52	0	-0.04	0.46	0.09	0.09	8.40
180.2	201.3	0.295	N/A	3.43	0.341	0.43	0	-0.04	0.38	0.08	0.07	10.43
180.2	201.3	0.239	N/A	3.635	0.274	0.53	0	-0.03	0.47	0.10	0.09	7.59
180.2	261.5	0.492	N/A	3.956	0.637	0.26	0	-0.03	0.20	0.05	0.05	-1.43
180.2	261.5	0.38	N/A	2.597	0.481	0.33	0	-0.05	0.27	0.06	0.06	-1.83
180.2	261.5	0.243	N/A	1.513	0.309	0.52	0	-0.08	0.41	0.09	0.09	0.13
180.2	261.5	0.202	N/A	1.164	0.256	0.62	0	-0.11	0.50	0.11	0.11	1.03
180.2	261.5	0.274	N/A	1.625	0.35	0.46	0	-0.08	0.37	0.08	0.08	1.45
180.2	302.2	0.4	N/A	1.747	0.562	0.31	0	-0.07	0.23	0.06	0.06	1.64
180.2	302.2	0.31	N/A	1.317	0.436	0.41	0	-0.10	0.29	0.07	0.07	2.41
180.2	302.2	0.262	N/A	1.119	0.366	0.48	0	-0.11	0.35	0.09	0.09	1.46
180.2	302.2	0.246	N/A	1.053	0.342	0.51	0	-0.12	0.37	0.09	0.09	0.82
180.2	402.5	0.3	N/A	0.834	0.51	0.42	0	-0.15	0.25	0.08	0.07	2.50
180.2	402.5	0.15	N/A	0.421	0.259	0.84	0	-0.30	0.49	0.15	0.14	4.22
180.2	402.5	0.219	N/A	0.602	0.368	0.58	0	-0.21	0.35	0.10	0.10	1.34
180.2	402.5	0.214	N/A	0.596	0.363	0.59	0	-0.21	0.35	0.11	0.10	2.14
180.2	402.5	0.171	N/A	0.473	0.287	0.74	0	-0.27	0.45	0.13	0.13	0.96

Table 6.2 Both Gliders have Initial Velociies $L_1 = 12.6$ cm $L_2 = 12.8$ cm

Distance Between Photogates = 60cm

m_1 (g)	m_2 (g)	t_{1i} (s)	t_{2i} (s)	t_{1f} (s)	t_{2f} (s)	v_{1i} (m/s)	v_{2i} (m/s)	v_{1f} (m/s)	v_{2f} (m/s)	P_i (kg*m/s)	P_f (kg*m/s)	% Error
180.2	261.3	0.362	0.422	0.312	0.589	0.35	-0.303	-0.40	0.22	-0.02	-0.02	3.31
180.2	261.3	0.353	0.427	0.313	0.568	0.36	-0.300	-0.40	0.23	-0.01	-0.01	2.51
180.2	261.3	0.49	0.468	0.356	0.848	0.26	-0.274	-0.35	0.15	-0.03	-0.02	3.15
180.2	261.3	0.461	0.574	0.42	0.726	0.27	-0.223	-0.30	0.18	-0.01	-0.01	11.38
180.2	261.3	0.486	0.593	0.435	0.778	0.26	-0.216	-0.29	0.16	-0.01	-0.01	4.93

 $L_1 = 12.8$ cm $L_2 = 12.6$ cm

Distance Between Photogates = 60cm

m_1 (g)	m_2 (g)	t_{1i} (s)	t_{2i} (s)	t_{1f} (s)	t_{2f} (s)	v_{1i} (m/s)	v_{2i} (m/s)	v_{1f} (m/s)	v_{2f} (m/s)	P_i (kg*m/s)	P_f (kg*m/s)	% Error
261.3	180.2	0.349	0.285	0.475	0.265	0.37	-0.442	-0.27	0.48	0.02	0.02	5.57
261.3	180.2	0.442	0.354	0.583	0.332	0.29	-0.356	-0.22	0.38	0.01	0.01	4.44
261.3	180.2	0.491	0.451	0.769	0.372	0.26	-0.279	-0.17	0.34	0.02	0.02	1.31
261.3	180.2	0.4	0.327	0.542	0.302	0.32	-0.385	-0.24	0.42	0.01	0.01	4.99
261.3	180.2	0.346	0.298	0.503	0.264	0.37	-0.423	-0.25	0.48	0.02	0.02	4.70

Notes - on Questions

- ① No. In most cases, there is slight loss of momentum due to existence of slightly inelastic collisions. Secondly, as the gliders collide, the linear motion of the gliders may be changed to include vibrations that introduced additional loss of momentum due to friction or drag.
- ② Yes. This the definition for the conservation of momentum.
- ③ No. In this case momentum is added or lost due to the influenced of gravitational acceleration.

General Notes

Generally the amount of momentum loss in the collisions for this experiment ranged from 1% to 11%. Momentum loss is contributed by equipment setup and the inability to maintain a constant velocity throughout the experiment. It however also points out the fact that momentum is always loss not gained. The increased in momentum in one or two cases is due to additional influences such as gravitational introduced by unlevelled airtrack .

Exp 7 - Conservation of Kinetic Energy

Notes - on Procedure

- ⑦ In order to ensure that the gliders are as close to travelling at constant velocities as possible prior to collision, the distance between the photogates should be reduced. Also, the gliders should be pushed to collide with the ends of air track so that the rebounded gliders will have near constant velocities prior to triggering the photogates.

The tables below list the results from two experientnal conditions. Table 7.1 presents the results of elastic collision with one glider being initially stationary. Table 7.2 presents the results of elastic collision with both gliders moving intially.

Table 7.1 Glider 2 is Initially Stationary

 $L_1 = 12.6 \text{ cm}$
 $L_2 = 12.8 \text{ cm}$
 $\text{Distance Between Photogates} = 79.8 \text{ cm}$

m_1 (g)	m_2 (g)	t_{1i} (s)	t_{2i} (s)	t_{1f} (s)	t_{2f} (s)	v_{1i} (m/s)	v_{2i} (m/s)	v_{1f} (m/s)	v_{2f} (m/s)	E_{ki} (J)	E_{kf} (J)	% Error (%)
180.2	201.3	0.275	N/A	3.81	0.318	0.46	0	-0.03	0.40	0.02	0.02	13.26
180.2	201.3	0.33	N/A	4.267	0.381	0.38	0	-0.03	0.34	0.01	0.01	12.92
180.2	201.3	0.242	N/A	3.369	0.278	0.52	0	-0.04	0.46	0.02	0.02	12.12
180.2	201.3	0.295	N/A	3.43	0.341	0.43	0	-0.04	0.38	0.02	0.01	12.98
180.2	201.3	0.239	N/A	3.635	0.274	0.53	0	-0.03	0.47	0.03	0.02	11.85
180.2	261.5	0.492	N/A	3.956	0.637	0.26	0	-0.03	0.20	0.01	0.01	9.11
180.2	261.5	0.38	N/A	2.597	0.481	0.33	0	-0.05	0.27	0.01	0.01	4.39
180.2	261.5	0.243	N/A	1.513	0.309	0.52	0	-0.08	0.41	0.02	0.02	4.80
180.2	261.5	0.202	N/A	1.164	0.256	0.62	0	-0.11	0.50	0.04	0.03	3.74
180.2	261.5	0.274	N/A	1.625	0.35	0.46	0	-0.08	0.37	0.02	0.02	5.37
180.2	302.2	0.4	N/A	1.747	0.562	0.31	0	-0.07	0.23	0.01	0.01	7.08
180.2	302.2	0.31	N/A	1.317	0.436	0.41	0	-0.10	0.29	0.01	0.01	6.97
180.2	302.2	0.262	N/A	1.119	0.366	0.48	0	-0.11	0.35	0.02	0.02	5.83
180.2	302.2	0.377	N/A	1.408	0.474	0.33	0	-0.09	0.27	0.01	0.01	-16.65
180.2	302.2	0.246	N/A	1.053	0.342	0.51	0	-0.12	0.37	0.02	0.02	5.00
180.2	402.5	0.3	N/A	0.834	0.51	0.42	0	-0.15	0.25	0.02	0.01	7.30
180.2	402.5	0.15	N/A	0.421	0.259	0.84	0	-0.30	0.49	0.06	0.06	9.99
180.2	402.5	0.219	N/A	0.602	0.368	0.58	0	-0.21	0.35	0.03	0.03	5.13
180.2	402.5	0.214	N/A	0.596	0.363	0.59	0	-0.21	0.35	0.03	0.03	6.99
180.2	402.5	0.171	N/A	0.473	0.287	0.74	0	-0.27	0.45	0.05	0.05	5.10

Table 7.2 Both Gliders have Initial Velocities

$L_1 = 12.6$ cm $L_2 = 12.8$ cm Distance Between Photogates = 60cm

m_1 (g)	m_2 (g)	t_{1i} (s)	t_{2i} (s)	t_{1f} (s)	t_{2f} (s)	v_{1i} (m/s)	v_{2i} (m/s)	v_{1f} (m/s)	v_{2f} (m/s)	P_i (kg*m/s)	P_f (kg*m/s)	% Error
180.2	261.3	0.362	0.422	0.312	0.589	0.35	-0.30332	-0.40	0.22	0.02	0.02	9.03
180.2	261.3	0.353	0.427	0.313	0.568	0.36	-0.29977	-0.40	0.23	0.02	0.02	8.54
180.2	261.3	0.49	0.468	0.356	0.848	0.26	-0.27350	-0.35	0.15	0.02	0.01	9.33
180.2	261.3	0.461	0.574	0.42	0.726	0.27	-0.22300	-0.30	0.18	0.01	0.01	7.99
180.2	261.3	0.486	0.593	0.435	0.778	0.26	-0.21585	-0.29	0.16	0.01	0.01	8.63

$L_1 = 12.8$ cm $L_2 = 12.6$ cm Distance Between Photogates = 60cm

m_1 (g)	m_2 (g)	t_{1i} (s)	t_{2i} (s)	t_{1f} (s)	t_{2f} (s)	v_{1i} (m/s)	v_{2i} (m/s)	v_{1f} (m/s)	v_{2f} (m/s)	P_i (kg*m/s)	P_f (kg*m/s)	% Error
261.3	180.2	0.349	0.285	0.475	0.265	0.37	-0.44211	-0.27	0.48	0.04	0.03	15.14
261.3	180.2	0.442	0.354	0.583	0.332	0.29	-0.35593	-0.22	0.38	0.02	0.02	13.84
261.3	180.2	0.491	0.451	0.769	0.372	0.26	-0.27938	-0.17	0.34	0.02	0.01	12.29
261.3	180.2	0.4	0.327	0.542	0.302	0.32	-0.38532	-0.24	0.42	0.03	0.02	14.15
261.3	180.2	0.346	0.298	0.503	0.264	0.37	-0.42282	-0.25	0.48	0.03	0.03	14.72

Notes - on Questions

- ① Yes.
- ② In most cases, there was a slight loss of kinetic energy due to existence of slightly inelastic collisions.

sions. Secondly, as the gliders collided, the linear motion of the gliders might be changed to include vibrations thus converting simple kinetic energy to include vibrational energy not accounted for. Some of the kinetic energy was converted into heat due to friction.

Exp 8 - Conservation of Mechanical Energy**Notes - on Analysis**

The tables below list the typical results for the experiment performed at two different incline angles.

Table 8.1

$d = 100$ cm $h = 1.3$ cm
 $D = 80$ cm $L = 12.6$ cm $\theta = 0.013$ rad

m (g)	t_1 (s)	t_2 (s)	v_1 (m/s)	v_2 (m/s)	E_{k1} (J)	E_{k2} (J)	$E_{k2} - E_{k1}$ (J)	$\Delta(mgh)$ (J)	% Error
180.2	0.35	0.22	0.36	0.57	0.01	0.03	0.02	0.02	5.82
200.2	0.35	0.22	0.36	0.57	0.01	0.03	0.02	0.02	6.31
220.2	0.35	0.22	0.36	0.57	0.01	0.04	0.02	0.02	5.75
240.3	0.35	0.22	0.36	0.57	0.02	0.04	0.02	0.02	5.39
301.8	0.35	0.22	0.36	0.57	0.02	0.05	0.03	0.03	5.53

Table 8.2

$d = 100 \text{ cm}$ $h = 2.6 \text{ cm}$
 $D = 80 \text{ cm}$ $L = 12.6 \text{ cm}$ $\theta = 0.026 \text{ rad}$

m (g)	t₁ (s)	t₂ (s)	v₁ (m/s)	v₂ (m/s)	E_{k1} (J)	E_{k2} (J)	E_{k2}-E_{k1} (J)	Δ(mgh) (J)	% Error (%)
180.2	0.25	0.16	0.51	0.80	0.02	0.06	0.03	0.04	5.67
220.2	0.25	0.16	0.51	0.80	0.03	0.07	0.04	0.04	7.32
261.6	0.25	0.16	0.51	0.80	0.03	0.08	0.05	0.05	5.16

⑥ Yes. The experimental data indicated that potential energy was consistently transformed into kinetic energy. There was however a loss of 5% to 7% in energy. This

is attributed to experimental error as well measurement as loss of energy due to friction between gliders and air track.

Exp 9 - Elastic-Kinetic Energy

Notes - on Analysis

The results of the each portion of the experiment is presented to the right.

Figure 9.1 Spring Constant

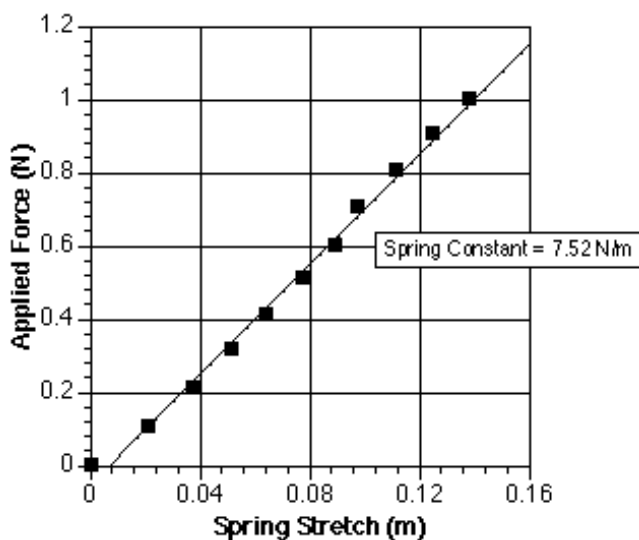


Table 9.2 Potential Energy vs. Kinetic Energy of Spring Mass System

$X_1 = 104.2 \text{ cm}$ $K = 7.52 \text{ N/m}$ Flag Width = 3.8 cm

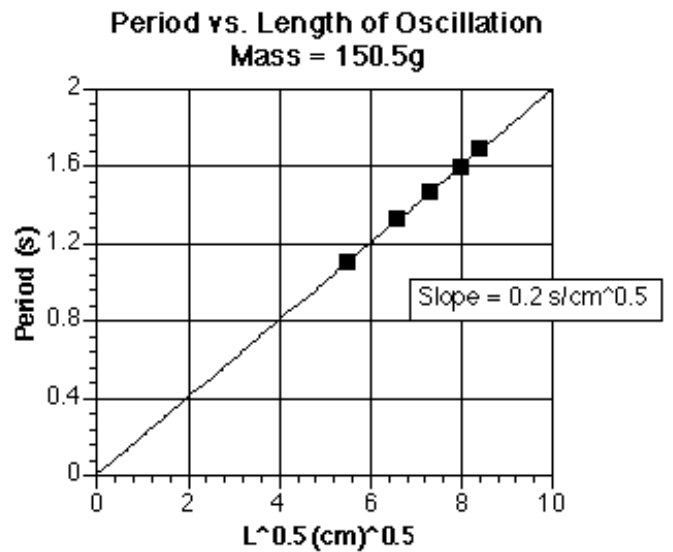
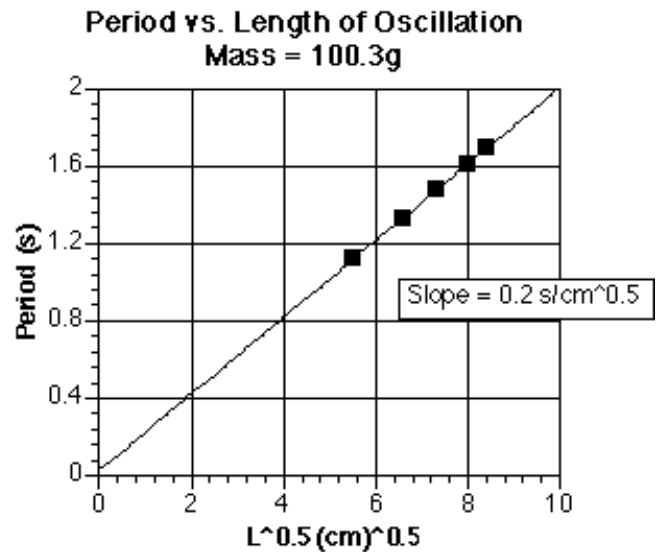
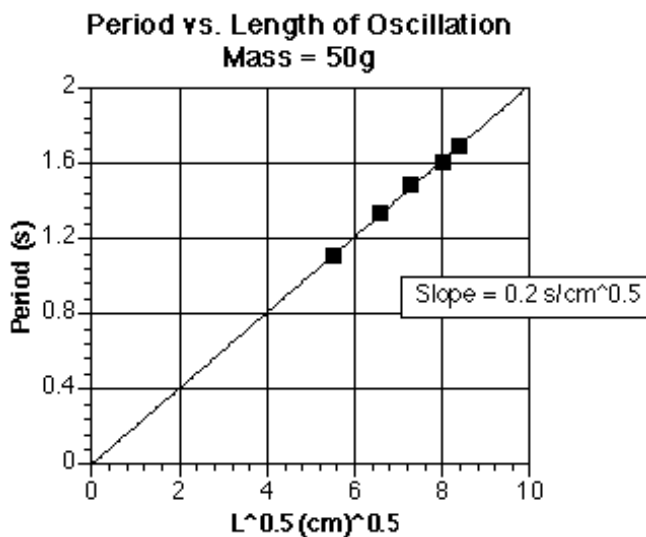
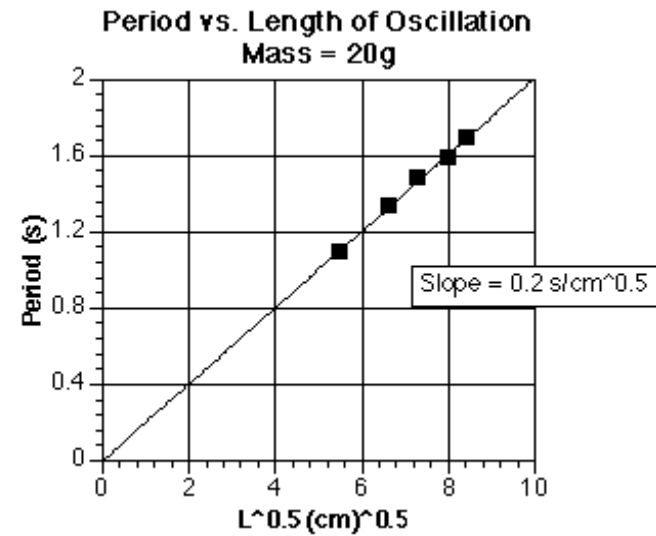
m (g)	Spring Stretch (cm)	t_{avg} (s)	v_{avg} (m/s)	K.E. (J)	P.E. (J)	% Error (%)
211.5	5	0.13	0.29	0.01	0.01	4.6
211.5	10	0.06	0.60	0.04	0.04	0.0
211.5	15	0.04	0.88	0.08	0.08	3.3
211.5	20	0.03	1.18	0.15	0.15	1.9
231.5	5	0.13	0.29	0.01	0.01	-3.7
231.5	10	0.07	0.57	0.04	0.04	0.0
231.5	15	0.04	0.86	0.09	0.08	0.0
231.5	20	0.03	1.13	0.15	0.15	1.9

Exp 10- Pendulum Motion

Notes - on Analysis

Part 1: Period of Oscillation versus Mass and Length

The graphs below present the relationship between period and length of oscillation for four different masses.



Part 2: Conservation of Mechanical Energy

The table below present the results for the conservation of energy with the pendulum dropped at varying heights.

$L = 100 \text{ cm}$	$\Delta d = 2 \text{ cm}$		$\text{Mass} = 175.2 \text{ g}$			
θ (deg)	Δh (cm)	t (s)	Δu (J)	E_k (J)	% of diff. (%)	
15	3.41	0.00	0.06	0.07	-11.97	
20	6.03	0.00	0.10	0.11	-3.50	
25	9.37	0.00	0.16	0.16	0.00	
30	13.40	0.00	0.23	0.21	6.96	
35	18.08	0.00	0.31	0.30	2.55	

After repeated trials, these are the best results that can be obtained by means of a Photogate Timer. The accuracy of the experiment increases with an increase in the precision of measurements of angles and lengths. To get even better accuracy, you may consider using the Computer Photogate Timing System.

Notes - Questions

- ① From the graphs, there exist a linear relationship between period and the squared root of the length of oscillation. This relationship remained unchanged despite changes in mass of pendulum.
- ② No. For small oscillation, period of oscillation is independent of mass.
- ③ Yes.
- ④ No. During the repeated cycles of conversion of energy from purely potential to kinetic energy, frictional and gravitational forces continued to act on the pendulum to convert some of the energy to other forms.

Maintenance

Battery Replacement

The batteries probably need replacing when:

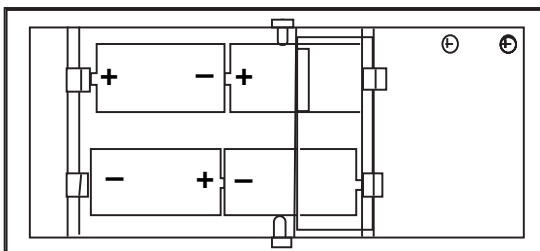
- ① The timer counts when there is no object interrupting the beam,
- ② The LCD display loses contrast, or
- ③ The LCD display appears sluggish when switching from one number to another,

To Replace the Batteries:

- ① Remove the two screws on the bottom of the timer and lift out the bottom panel.
- ② Remove the thumb screw which holds the battery retainer plate, then lift out the retainer plate and the batteries.
- ③ Replace with four new “C” size, 1.5 VDC batteries. Be sure the polarity is as shown on inside of the case.
- ④ Replace the battery retainer plate and the bottom panel.

► **CAUTION:** Do not store the timer with the batteries installed. The batteries may leak and damage the timer electronics.

Inside the Timer with the bottom panel removed.



Insert 4 "C" size batteries with the polarity as shown.

Figure 5: Battery Replacement

