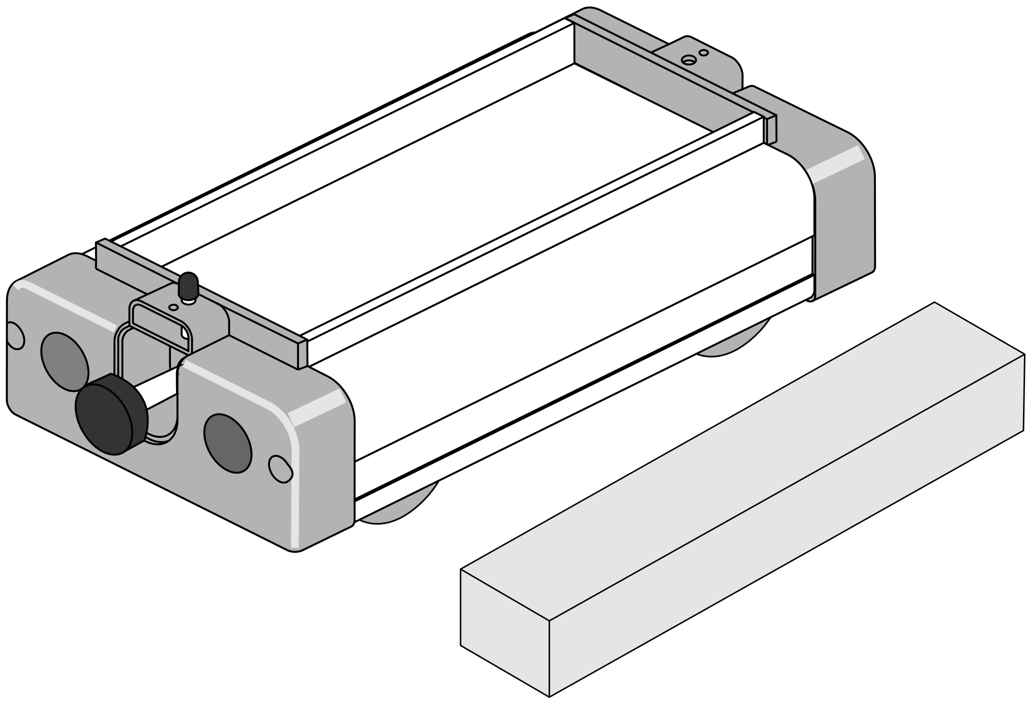
Instruction Manual and Experiment Guide for the PASCO scientific Model ME-9430

012-04840D
4/94

Dynamics Cart with Mass



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Credits

This manual authored by: Scott K. Perry

This manual edited by: Dave Griffith

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③ Make certain that the packing material cannot shift in the box or become compressed, allowing the instrument come in contact with the packing carton.

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Introduction

The PASCO Model ME-9430 Dynamics Cart with Mass performs high quality motion experiments through its low-friction design.

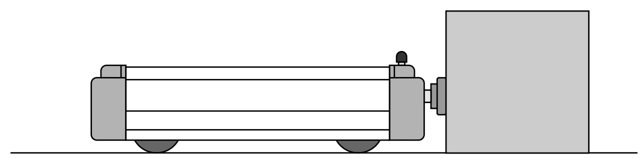
The PASCO Dynamics Cart has several excellent features:

- Extremely low friction ball-bearing design provides smooth motion.
- Built-in spring plunger, activated by a convenient trigger (button) located on the front end cap, with three positions of launching amplitude enables the cart to be launched without using additional apparatus.
- Unique suspension system allows the wheels to collapse inside the body of the cart to prevent damage to the internal components of the cart caused by being dropped or other misuse (such as the cart being used as a roller skate).
- Rugged construction on the cart-body and end-caps prevents damage to the cart and the environment during high-impact situations.
- Convenient holes located at the top of the end cap on each end of the Dynamics Cart facilitate the use of string, springs, etc..
- Hook and loop fasteners on the front of each Dynamics Cart enable the user to perform inelastic collision experiments without using additional apparatus.
- The mass of the Dynamics Cart is approximately 500g. The additional mass also has an approximate mass of 500g.

  ➤ **NOTE:** For best results, measure the mass of the cart and mass bar with an accurate balance or scale.
- Other features include: rounded corners on molded plastic end caps for durability, a tray on top of the cart for application of additional mass and the ability of the carts to be stacked.

While performing experiments you may find that you get better results by making the surface over which the cart rolls more uniform and clean. One way that this can be achieved is by taping a long piece of butcher paper to the surface on which the cart rolls.

The spring plunger of the Dynamics Cart has three cocking positions. Determine the one that gives you a range that fits your situation best, taking into account the limitations of space. Most experiments require a range of at least 2 meters or more. To cock the spring plunger, push the plunger in, and then push the plunger upward slightly to allow one of the notches on the plunger bar to “catch” on the edge of the small metal bar at the top of the hole.



Practice launching the Dynamics Cart by placing the cart on the floor with its cocked plunger against a wall or a secured brick.

➦ **NOTE:**

① Before performing experiments with the Dynamics Cart and Mass they should be calibrated to insure accurate results from your experiments. It is suggested to perform Experiment #2 before Experiment #5 and #4 before #6.

② To insure that you do not give the cart an initial velocity, other than that supplied by the spring plunger, release the trigger by tapping it with a rod or stick using a flat edge.

③ Rolling distance can be shortened by adding more mass to the cart.

④ For even less friction use 1/4 inch plate glass as surface for the dynamics cart.

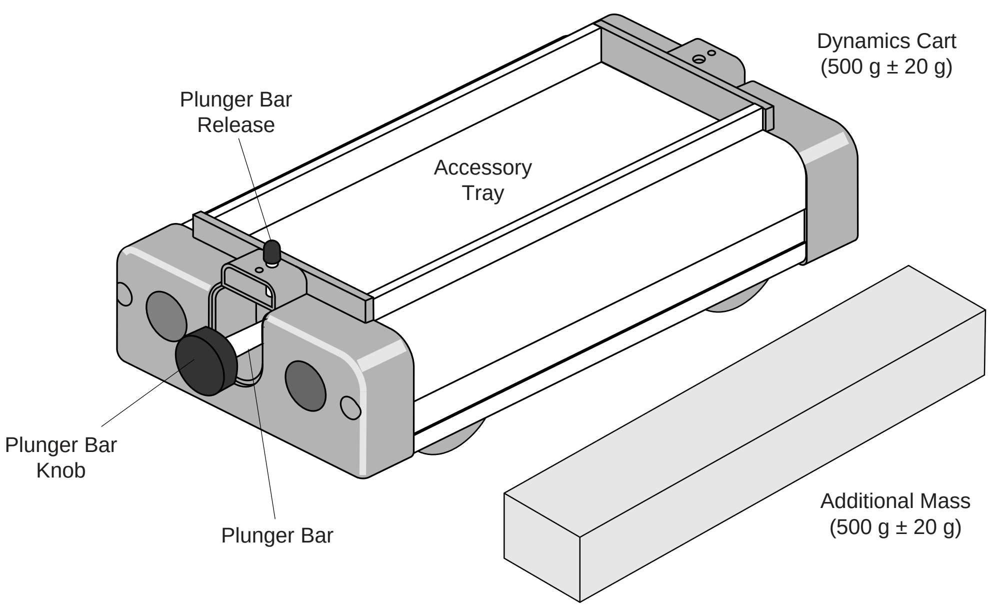
Equipment

The ME-9430 Dynamics Cart with Mass includes the following:

- (1) Dynamics Cart
- (1) 500g Mass
- Instruction Manual/Experiments Guide.

Additional Equipment Required

- A spool of thread
- Masses such as Slotted Mass Set (SE-8704)
- A pulley and clamp such as Super Pulley with Clamp (ME-9448) or Super Pulley (ME-9450) used with Model ME-9376A Universal Table Clamp and Model SA-9242 Pulley Mounting Rod
- Metric Ruler such as Metric Measuring Tape (SE-8712) and 30cm/12in. Ruler (SE-8731)
- Stopwatch such as Digital Stopwatch (SE-8702)
- Mass balance such as Triple-Beam Balance (SE-8723)
- A Friction Block that can fit in the cart's accessory tray (such as PASCO part number 003-04708)



Experiment 1: Kinematics (Average vs. Instantaneous Velocities)

EQUIPMENT NEEDED:

– Dynamics Cart (ME-9430)

– Metric tape (SE-8712)

– Stopwatch (SE-8702)

Figure1.1

Purpose

In this lab, the Dynamics Cart will be used to investigate one dimensional accelerated motion. The cart will be launched over the floor using the built-in spring plunger. The cart will “decelerate” over the floor under the combined action of rolling friction and floor slope. You will be able to establish whether or not the acceleration of the cart is constant. This will be done by initially assuming a constant acceleration and then by examining the results to see if they are consistent with this assumption.

Theory

The cart will be allowed to roll to a stop. The distance covered **D** and the total elapsed time **T** from launch to stop will be measured and recorded. The average velocity over this interval is given by:

$$v_{av} = \frac{D}{T} \qquad \text{EQN–1}$$

If the acceleration of the cart is constant as it rolls to a stop over the floor, then the initial instantaneous velocity of the cart at the final moment of launch is given by:

$$v_0 = 2v_{av} = \frac{2D}{T} \qquad \text{EQN–2}$$

And the value of the acceleration would be given by:

$$a = \frac{v}{t} = \frac{0 - v_0}{T} = -\frac{2D}{T^2} \qquad \text{EQN–3}$$

If the acceleration and $\mathbf{v_0}$ are known, then the time $\mathbf{t_1}$ required to cover the distance **d** to some intermediate point (i.e. short of the final stopping point!) can be calculated by applying the quadratic formula to:

$$d = v_0 t_1 + 1/2 a t_1^2 \qquad \text{EQN–4}$$

Calculated values of $\mathbf{t_1}$ will be compared with directly measured values. The extent to which the calculated values agree with the directly measured values is an indication of the constancy of the acceleration of the cart.

Note your theoretical values in Table 1.1.

Procedure

① Once you have roughly determined the range of the cart, clearly mark a distance **d** that is about half way out from the start. Measure this distance and record it at the top of Table 1.1.

② Using a stopwatch with a lap timer and metric tape, it is possible to determine $\mathbf{t_1}$, **T** and **D** for each launch. Practice this step a few times before you start recording data.

> ➡**NOTE:** In order to eliminate reaction time errors, it is very important to have the person who launches the cart also be the timer!

③ Launch the cart and record the data described in the previous step for six trials. To cock the spring plunger, push the plunger in, and then push the plunger upward slightly to allow one of the notches on the plunger bar to "catch" on the edge of the small metal bar at the top of the hole. (Don't count the trials in which the timer feels that a distraction interfered with the measurement.) Record your best trials in Table 1.1.

④ Using the equations described in the theory section and the data recorded in the table, then do the calculations needed to complete the table.

Data Analysis

d = _______cm

Trial	Experiment					Theory	% Diff.
	t_1 (sec)	T (sec)	D (cm)	v_o (cm/s)	a (cm/s^2)	t_1 (sec)	
1							
2							
3							
4							
5							
6							

Table 1.1

Questions

① Is there a systematic difference between the experimental and calculated values of $\mathbf{t_1}$? If so, suggest possible factors that would account for this difference.

② Can you think of a simple follow-up experiment that would allow you to determine how much the cart's "deceleration" was affected by floor slope?

Experiment 2: Coefficient of Friction

EQUIPMENT NEEDED:

– Dynamics Cart (ME-9430)

– Metric tape (SE-8712)

– Stopwatch (SE-8702)

Purpose

In this lab, the Dynamics Cart will be launched over the floor using the on-board spring launcher. The cart will "decelerate" over the floor under the combined action of rolling friction and the average floor slope. In order to determine both the coefficient of rolling friction $\boldsymbol{\mu_r}$ and θ, the small angle at which the floor is inclined, two separate experiments must be done. (Recall that to determine the value of two unknowns you must have two equations.)

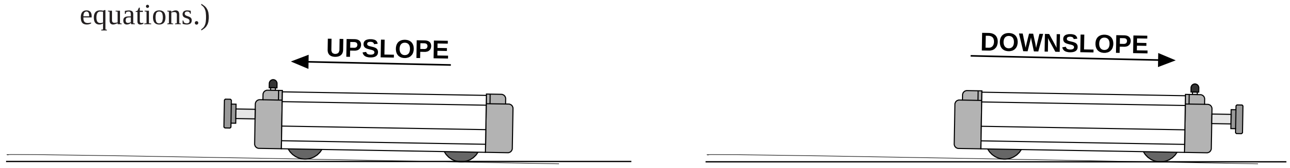


Figure 2.1

Theory

The cart will be launched several times in one direction and then it will be launched several times along the same course but in the opposite direction. For example, if the first few runs are toward the east then the next few runs will be toward the west. See Figure 2.1. In the direction which is slightly down-slope the acceleration of the cart is given by:

$$\mathbf{a_1 = + g\sin\theta - \mu_r g} \qquad \textbf{EQN-1 (since } \cos\theta \quad \textbf{1)}$$

And the acceleration in the direction that is slightly up-slope will be:

$$\mathbf{a_2 = - g\sin\theta - \mu_r g} \qquad \textbf{EQN-2}$$

Numerical values for these accelerations can be determined by measuring both the distance **d** that the cart rolls before stopping and the corresponding time **t**. Given these values the acceleration can be determined from:

$$\mathbf{a = \frac{2d}{t^2}} \qquad \textbf{EQN-3}$$

Having obtained numerical values for $\mathbf{a_1}$ and $\mathbf{a_2}$, **EQN-1** and **EQN-2** can be solved simultaneously for $\boldsymbol{\mu_r}$ and θ.

Procedure

① Place the cart in its starting position and then launch it. To cock the spring plunger, push the plunger in, and then push the plunger upward slightly to allow one of the notches on the plunger bar to "catch" on the edge of the small metal bar at the top of the hole. Using a stopwatch and metric tape, determine the range **d** and the total time spent rolling **t**. Record these in Table 2.1.

② Repeat step ① six times for each direction and enter your results in Table 2.1.

③ Using **EQN-3**, compute the accelerations corresponding to your data and an average acceleration for each of the two directions.

④ Using the results of step ③ determine μ_r, and θ by solving for the two unknowns algebraically.

Trial	First Direction		
	d (cm)	t (sec)	a ($\frac{cm}{s^2}$)
1			
2			
3			
4			
5			
6			

Trial	Second Direction		
	d (cm)	t (sec)	a ($\frac{cm}{s^2}$)
1			
2			
3			
4			
5			
6			

Table 2.1

Average Acceleration = __________ $\frac{cm}{s^2}$

Average Acceleration = __________ $\frac{cm}{s^2}$

Data Analysis

Coefficient of rolling friction = ________________ Floor Angle = ________________

Questions

① Can you think of another way to determine the acceleration of the cart? If you have time try it!

② How large is the effect of floor slope compared to that of rolling friction?

Experiment 3: Newton's Second Law (Predicting Accelerations)

EQUIPMENT NEEDED:

– Dynamics Cart (ME-9430)
– Pulley and pulley clamp (ME-9448)
– Mass set (SE-8704)
– Stopwatch (SE-8702)
– String
– Paper clips
– Block (to act as bumper)
– Balance (SE-8723 or equiv.)

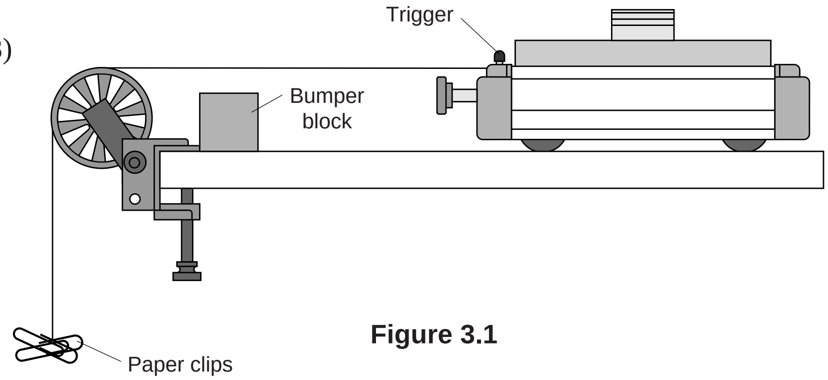


Figure 3.1

Purpose

In this lab, a small mass **m** will be connected to the Dynamics Cart by a string as shown in Figure 3.1. The string will pass over a pulley at the table's edge so that as the mass falls the cart will be accelerated over the table's surface. As long as the string is not too elastic and there is no slack in it, both the falling mass and the dynamics cart will have the same acceleration. The resulting acceleration of this system will be determined experimentally and this value will be compared to the acceleration predicted by Newton's Second Law.

Theory

The cart will be released from rest and allowed to accelerate over a distance **d**. Using a stopwatch, you will determine how long it takes, on average, for the cart to move through the distance **d**. An experimental value for the cart's acceleration **a** can be determined from:

$$d = \frac{1}{2}at^2 \quad \text{which leads to:} \quad a = \frac{2d}{t^2} \quad \text{(Experimental Value)}$$

Assuming that the tabletop is truly horizontal (i.e. level), Newton's Second Law (**F = ma**) predicts that the acceleration of this system will be:

$$a = \frac{F_{net}}{M_{TOTAL}} \quad \text{or} \quad a = \left(\frac{m}{M_{TOTAL}}\right) g \quad \text{(Theoretical Value)}$$

Procedure

① Set up the pulley, cart, and a bumper of some sort to prevent the cart from hitting the pulley at the end of its run. Add the following masses to the bed of the cart: 10 g, 50 g, 500 g and two 20 gram masses.

② Carefully level the table until the cart has no particular tendency to drift or accelerate in either direction along its run.

③ Put a loop in one end of the string and place this loop over the spring-release trigger on the Dynamics Cart. Drape the string over the pulley. Adjust the pulley so the string is level.

④ Adjust the length of the string so that the longest arrangement of masses that you intend to use will not hit the floor before the cart has reached the end of its run. Put a loop in this end of the string.

➦ **NOTE:** The cart's acceleration falls to zero when the falling mass hits the floor.

⑤ Hang enough paper clips onto the dangling loop in the string until the cart will just continue to move without apparent acceleration when barely nudged. This small added mass will compensate for friction in the system and will be ignored in the following calculations. The paper clips will remain attached to the loop throughout the experiment!

⑥ Move a 10 gram mass from the bed of the cart to the hanging loop and pull the cart back to a clearly marked starting point. Determine the distance **d** that the cart will move from the starting point to the bumper block and record this distance at the top of Table 3.1.

➦**NOTE:** The total mass of the system will remain constant throughout the experiment.

⑦ Practice releasing the cart being careful not to give it any push or pull as you do so. The best way to do this is to press your finger into the table in front of the cart thereby blocking its movement. Quickly pull your finger away in the direction that the cart wants to move. At the instant you pull your finger away, start your stopwatch. Stop your stopwatch at the instant the cart arrives at the bumper. To eliminate reaction time errors it is best that the person who releases the cart also does the timing!

⑧ Determine the average time for the cart to move through the distance **d** having been released from rest. Record the average of the four time trials in which you have the most confidence in Table 3.1.. Repeat for all of the masses given in the data table.

⑨ Excluding the pulley, determine the total mass of your system, $\mathbf{M_{Total}}$ (cart, added masses, string) and record at the top of Table 3.1. (It will be close to 1100 grams, but you might want to check it on a balance.)

⑩ Fill-in the table using your data and the equations given in the Theory section.

Data Analysis

d = __________ cm M_{TOTAL} = __________ grams

Trial	m (grams)	Average time (sec.)	a_{exp} $\frac{cm}{s^2}$	a_{Th} $\frac{cm}{s^2}$	% Diff.
1	10				
2	20				
3	30				
4	40				
5	50				
6	60				
7	70				
8	80				

Table 3.1

Questions

① Can you think of any systematic errors that would effect your results? Explain how each would skew your results.

Notes:

Experiment 4: Cart Calibration (Measuring the Spring Constant)

EQUIPMENT NEEDED:

– Dynamics Cart (ME-9430)
– Mass set (SE-8704)
– Pan for holding masses
– Balance (SE-8723 or equiv.)
– 500g mass
– Stopwatch (SE-8702)
– 15cm/6 in ruler (SE-8730)

Purpose

The Dynamics Cart has a spring plunger which can be used to produce relatively elastic collisions but can also be used to provide a reproducible launch velocity.

Theory

For this and following experiments, it will be necessary to find the spring constant **k** of the cart's spring plunger. As compressional forces **F** are applied to the spring the spring will compress a distance **x** which is measured with respect to its uncompressed equilibrium position. If **F** is plotted versus **x** on graph paper, the spring constant is given by the slope of the graph as:

$$k = \Delta F / \Delta x \qquad \text{EQN-1}$$

Once **k** is known it is possible to predict the launch velocity v_o by using conservation of energy since the elastic potential energy stored in the spring is converted into kinetic energy at the time of launch. The launch velocity can be found from:

$$\frac{1}{2} m v_0^2 = \frac{1}{2} k x_0^2 \qquad \text{EQN-2}$$

which leads to:

$$v_o = x_o \sqrt{\frac{k}{m}} \qquad \text{EQN-3}$$

This predicted launch velocity can be checked experimentally by measuring the total rolling distance **d** on a horizontal surface and the corresponding time **t** for given launch conditions. This leads to:

$$v_o = 2\,\frac{d}{t} \qquad \text{EQN-4}$$

Where it is assumed that the acceleration of the cart is constant so that the initial velocity of the cart at the moment of launch is twice the average velocity of the cart over its whole run.

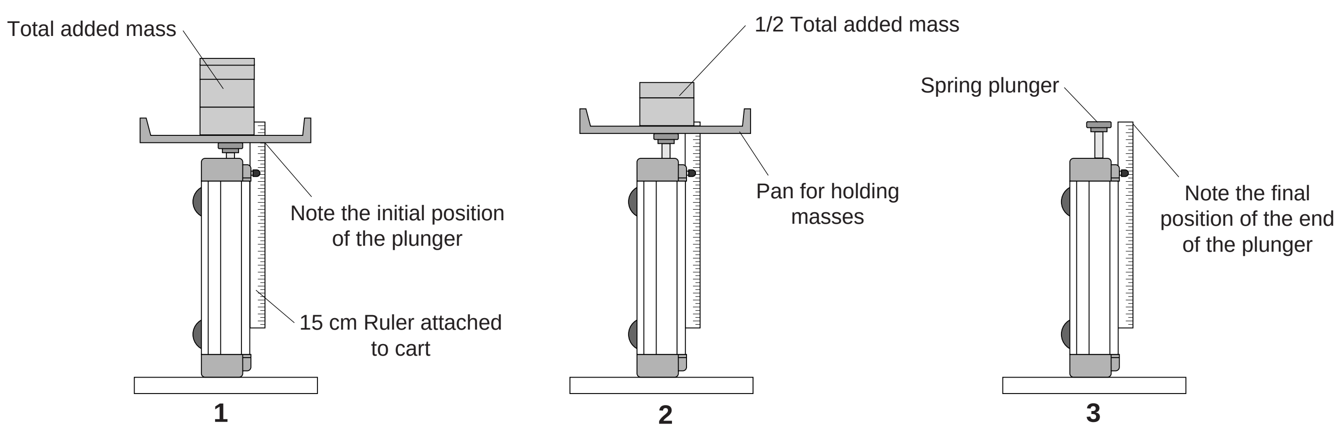


Figure 4.1

Procedure

① Stand the Dynamics cart on its end so that the spring plunger is aimed up as shown in Figure 4.1. Using masking tape or rubber bands fix a ruler to the cart and adjust it so that the 0 cm mark on the ruler lines up with the upper surface of the plunger. Take care to avoid parallax errors!

② Carefully add enough mass to the top of the plunger so that it is nearly fully depressed. Record this mass and the corresponding compression **x** (initial position) of the spring in Table 4.1.

③ Remove approximately one quarter of the mass used in step 2 and record the new mass and **x** values in Table 4.1.

④ Repeat step ③ until no mass remains on the plunger.

⑤ Plot a graph of **F versus x** using your data and determine the slope of the best line through your data points. This slope is the spring constant for your cart. Show your slope calculations on the graph and record **k** below.

⑥ Determine the mass of the cart using a mass balance and record this value below.

⑦ Using **EQN-3** and your values for **m**, $\mathbf{x_o}$ (i.e. the compression of the cocked spring) and **k**, predict the launch velocity of your cart and record this below.

⑧ Cock the spring plunger to the value of $\mathbf{x_o}$ that you have chosen then place the cart in it's starting position and launch it. Using a stopwatch and a meter stick, determine the average range **d** and the average total time spent rolling **t**. Record these below.

> ➦ **NOTE:** To avoid reaction time errors, the person who launches the cart should also time the cart's motion.

⑨ Using **EQN-4**, determine the observed value of $\mathbf{v_o}$ and compare it with the predicted value.

Data and Analysis

Mass of cart = _________ kg

k = ________ $\frac{N}{m}$ **x_o = ________ m**

Predicted value of launch velocity v_o = __________ $\frac{m}{s}$

Average d = _________ m **Average t = __________ sec**

Observed value of the launch velocity v_o = __________ $\frac{m}{s}$

% Difference between observed and expected values of v_o = __________

Trial	m (kg)	F (= mg) (newtons)	x (meters)
1			
2			
3			
4			
5			
6			
7			
8			

Table 4.1

Notes:

Experiment 5: Rackets, Bats and "Sweet Spots"

EQUIPMENT NEEDED:

– Dynamics Cart (ME-9430)
– Mass set (SE-8704)
– Metric tape (SE-8712)
– Meter stick or a long rod
– Long horizontal table or board (3/4” x 1’ x 8’)

Purpose

When a batter or tennis player strikes a ball a portion of the rotational kinetic energy of the bat or racket is transferred to the ball. In a somewhat oversimplified picture, the motion of the bat or racket can be thought of as a simple rotation about a pivot which is located near its end and close to the batter’s wrists. The portion of the bat’s original kinetic energy that is transferred to the ball depends on the distance **y** between the point of impact and the pivot point. The position on the bat corresponding to the maximum energy transfer is called a “sweet-spot”. We will call this maximum energy sweet-spot **SS1**.

➦ **NOTE:** For simplicity it is assumed that the collisions are perfectly elastic

Theory

As any batter can tell you; if you hit the ball at a certain point on the bat, there will be no shock, or impulse, transferred to your hands! This “sweet-spot” is generally located at a different position than **SS1** and is called the “percussion point”. We will call this zero-impulse sweet-spot **SS2**. For a given “bat” and pivot the position of **SS2** can be found from:

$$y_{SS2} = \frac{I}{m y_{cm}} \qquad \textbf{EQN-1}$$

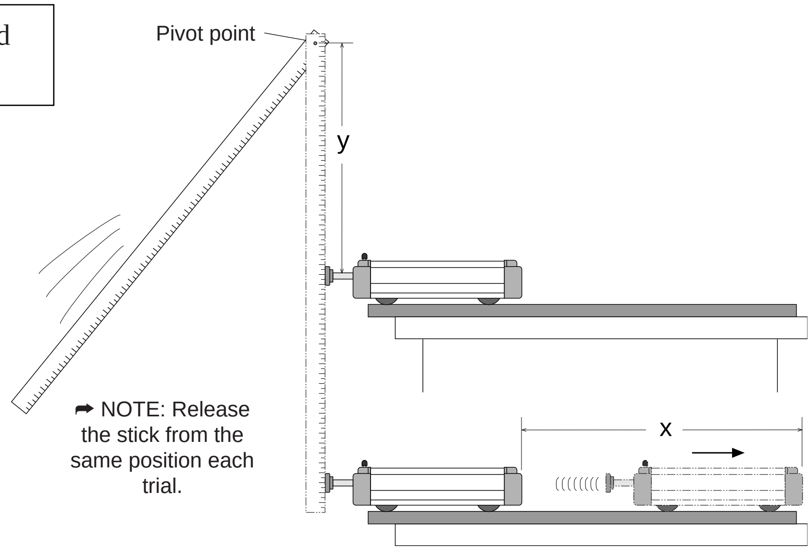


Figure 5.1

where **I** is the rotational inertial of the bat for the corresponding pivot, **m** is the total mass of the bat, and $\mathbf{y_{cm}}$ is the distance from the pivot to the center of mass of the bat. (e.g. If a uniform rod of length **L** is pivoted about an end-point, **SS2** is located at 0.67L from the pivot.)

The positions of both **SS1** and **SS2** can be found theoretically, or by using the Sweet-Spot computer program (see page 18 for details). The position of **SS2** can be found experimentally using the PASCO Force Transducer or, roughly, by actually hitting a ball at a variety of positions on the bat and noting where the least shock to your wrists occurs. In this experiment, a method for determining the location of **SS1** is described.

Using a meter stick or rod as a bat (see Figure 5.1), the Dynamics Cart can play the role of a ball. By observing how far the cart rolls after impact, the relative, or even absolute energy transfer can be determined for various values of **y**. In this manner **SS1** can be found.

If you have already done the experiment to determine the coefficient of rolling friction for your cart for the same surface that you will be using in this experiment, you can determine the kinetic energy of the cart at the moment after impact since:

$$\frac{1}{2}mv^2 = \mu mgx \qquad \textbf{EQN-2}$$

Procedure

① Set up the system as shown in Figure 5.1. Position the cart so that its plunger hangs over the edge of the table several centimeters.

> ➦ **NOTE:** You will need a long, horizontal table, or board for this experiment. A 3/4 inch by 1 foot by 8 foot plywood board is recommended.

② Arrange to have a stop of some sort to insure that you always use the same pull-back angle for the hanging meter-stick.

③ Pull the meter-stick or rod back to the pull-back angle that you have chosen and release it, allowing it to strike the cart plunger. Record the corresponding values of **y** and **x** in Table 5.1.

④ Repeat step ③ four times for each value of **y**, changing it from roughly 10 to 90 cm in 10 cm increments.

⑤ Compute the average value of **x** for each value of **y**.

⑥ By interpolation, determine the location of **SS1** from your data and record it below Table 5.1.

⑦ Using **EQN-1** compute the location of **SS2** and record it below Table 5.1.

⑧ If time permits, repeat the above after either re-positioning the pivot (i.e. “choking up”) or adding 100 grams or so at some point on the stick

> ➦ **NOTE:** this would add a little realism to the experiment since neither a bat nor a tennis racket is uniform!

Data and Analysis

Trial	y (cm)	x (cm)	Average x (cm)	Optional μmgx (joules)
1	10	_____ _____ _____ _____		
2	20	_____ _____ _____ _____		
3	30	_____ _____ _____ _____		
4	40	_____ _____ _____ _____		
5	50	_____ _____ _____ _____		
6	60	_____ _____ _____ _____		
7	70	_____ _____ _____ _____		
8	80	_____ _____ _____ _____		

Table 5.1

y-position of SS1 = _________ cm & y-position of SS2 = _________ cm

Questions

① Is it possible to construct a “Super-bat” for which both **SS1** and **SS2** coincide? If so, what changes would have to occur to the uniform rod to bring **SS1** and **SS2** closer together? (You might use the Sweet-Spot computer program to help you answer this!)

② What assumptions have we made in analyzing this system? How do they effect our results?

"Sweet Spot" Computer Program

The following is a listing of the "Sweet Spot" computer program written by Scott K. Perry of American River College, Sacramento, CA., using Quickbasic 4.5.

```
REM Program: SWEET SPOTS and PERCUSSION POINTS (Fixed Pivot)
REM (Version: 15DEC91)
CLS
LOCATE 1, 1
INPUT "What pullback angle will you be using for this experiment (deg.)"; theta
INPUT "What is the mass of your meter-stick 'bat' (kg); Ms

g = 9.8:  Mc = .5:  L = 1:  theta = theta / 57.3
COLOR 15

Begin:
CLS
LOCATE 1, 1

INPUT "How far from the center-of-mass is the pivot located (m)"; S
INPUT "How large is the load mass (kg)"; m
IF m = 0 GOTO Skip
INPUT " How far is the load mass from the pivot (m)"; y

Skip:

I = (1 / 12) * Ms * L ^ 2 + Ms * S ^ 2 + m * y ^ 2
PE = (Ms * S + m * y) * (1 – COS(theta)) * g

Wo = SQR(2 * PE / I)

h = (1 + 2 * (y / L) * (m / Ms)) * (1 – COS(theta)) * L / 2
PRINT: PRINT
COLOR 14
PRINT "Y-Impact (m)";  TAB(16);  "Cart-Speed (m/s)";  TAB(35);  "Omega (rad/sec)";  TAB(54);  "Impulse at Pivot (N*sec)"
COLOR 15
PRINT

FOR k = 1 TO 9

r = k / 10
a = Mc / 2 + (Mc * r) ^ 2 / (2 * I)
b = –Mc * Wo * r
c = –PE + (1 / 2) * I * Wo ^ 2

v = (–b + SQR(b ^ 2 – 4 * a * c)) / (2 * a)
w = (I * Wo – Mc * r * v) / I
DeltaP = Mc * v + Ms * w * L / 2 – Ms * Wo * L / 2
v = INT(1000 * v + .5) / 1000
w = INT(1000 * w + .5) / 1000

DeltaP = INT(100 * DeltaP + .5) / 100

PRINT TAB(5);  r;  TAB(20);  v;  TAB(39);  w;  TAB(60);  DeltaP
NEXT

PRINT: PRINT
INPUT "Would you like to input different values "; a$
IF a$ < > "N" and a$ < > "n" GOTO Begin
END
```

Experiment 6: Sliding Friction and Conservation of Energy

EQUIPMENT NEEDED:

– Dynamics Cart (ME-9430)
– Metric tape (SE-8731)
– Long board that can be used as a ramp
– Protractor
– Stopwatch (SE-8702)
– Brick or block of wood
– Friction block (003-04708)

Purpose

In this lab, the Dynamics Cart will be launched down a ramp, as shown in Figure 6.1, while riding on a friction block. The initial elastic potential energy and gravitational potential energy of the cart are converted to thermal energy as the cart slides to a stop. The thermal energy generated on the surfaces is the same as the work done against sliding friction.

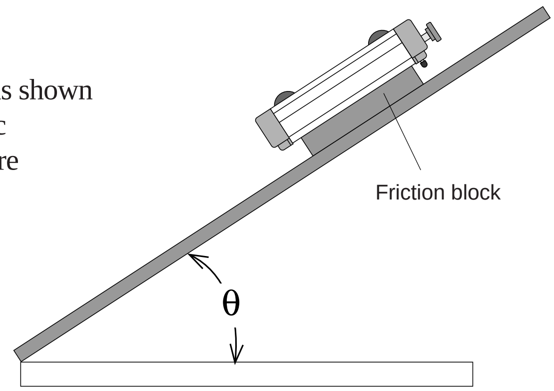


Figure 6.1

Theory

Using the principle of conservation of energy, we can equate the initial energy of the system with the final (i.e. thermal) energy of the system. This leads to:

$$\mathbf{1/2kx^2 + mgDsin\theta = \mu_k mgDcos\theta} \qquad \textbf{EQN-1}$$

(elastic P.E.) + (Gravitational P.E.) = (work done against friction)

where **k** is the spring constant of the plunger (from Experiment 4), **x** is the distance that the plunger is pushed in, **m** is the mass of the cart plus the friction block, **D** is the distance that the block slides after the cart's plunger is released, θ is the angle of the ramp to the horizontal, and $\boldsymbol{\mu_k}$ is the coefficient of kinetic or "sliding" friction.

In this experiment you will use the principle of the conservation of energy to predict **D** given certain measurements you will make and the value of k determined in Experiment 4. First you will need to determine the coefficient of kinetic or "sliding" friction for the friction block.

Determining $\boldsymbol{\mu_k}$: If the angle of the ramp is high enough, the friction block will slide down the ramp with uniform acceleration due to a net force on the block. The net force on the block is the difference between the component of the gravitational force (mgsinø) that is parallel to the surface of the ramp and the friction force ($-\mu_k$mgcosø) that retards the motion . The angle ø is the angle of the ramp when the block slides down the ramp with uniform acceleration. The acceleration down the ramp is given by:

$$\mathbf{a = mgsin\text{ø} - \mu_k mgcos\text{ø}} \qquad \textbf{EQN-2}$$

The average acceleration down the ramp is given by:

$$\mathbf{a = 2d/t^2} \qquad \textbf{EQN-3}$$

where **d** is the total distance the block slides and **t** is the time required to slide through that distance. If the acceleration is uniform, **EQN-2** equals **EQN-3**. You can use the measured values of the angle ø (the angle of uniform acceleration), the distance **d**, and the time **t** to calculate the kinetic coefficient of friction $\boldsymbol{\mu_k}$.

Procedure

> ➧ **NOTE:** To get consistent results in this experiment, you must insure that the ramp you will be using is both straight and clean. Wipe the surface of the ramp and the friction block with a rag.

Determining coefficient of kinetic or "sliding" friction:

① Place the cart with the friction block on the ramp. Set up the ramp at a relatively low angle (one that does not cause the friction block to begin sliding down the ramp by itself).

② Increase the angle of the ramp until the block will begin to slide down the ramp on its own, but only after you "release" it by slapping the table (or tapping the ramp very lightly). Now increase the angle of the ramp by a few more degrees so that the block will slide down the ramp with a uniform acceleration when you release it with a "slap" or tap. The angle of the ramp must be low enough so that the block does not begin to slide on its own - only when you release it. Measure the angle of the ramp with the protractor and record it as the angle of uniform acceleration (ø) in the data table.

③ Release the block from the grasp of static friction as described in the previous step and measure the time of the cart's descent down the ramp. Record this time as t in data table 6.1. Measure the distance **d** that the block slides down the ramp and record this in data table 6.1. Repeat the measurements four times. Use **EQN-3** to compute the accelerations of the block and enter the values in data table 6.1. Determine the average value of acceleration and enter it below data table 6.1.

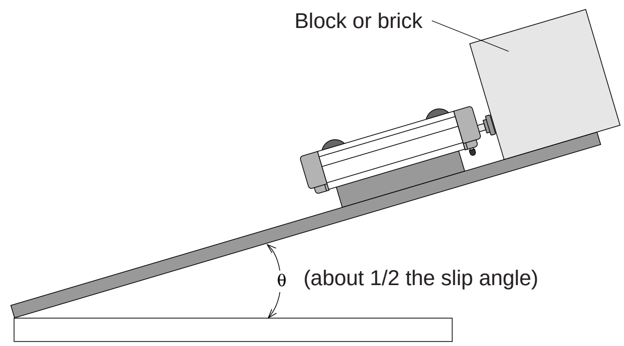


Figure 6.2

④ Use **EQN-2** to calculate the coefficient of kinetic or "sliding" friction. Enter it below the data table.

Prediction of D and Measurement of D:

⑤ Now reduce the angle of the ramp slightly until the block will just barely slide down the ramp with a uniform speed when you release it with a slap or tap. Measure this "slip" angle. Reduce the angle of the ramp to about one half of the "slip" angle. Measure this new angle and record its value in data table 6.2 as θ. Secure a brick or block at the upper end of the ramp as shown in figure 6.2.

⑥ It is time to make a prediction – Using **EQN-1** and the information that you have recorded, predict **D**, the distance that the cart will slide down the ramp after being launched. Assume that the plunger on the cart is fully cocked at the position of maximum spring compression. Record your prediction at the top of Table 6.2.

⑦ After double checking your work in the previous step, launch the cart down the ramp by placing it on the ramp with its cocked plunger against the secured brick. Then tap the spring-release trigger with a rod or stick using a flat edge.

> ➡ **NOTE:** This will help to insure that you do not give the cart an initial velocity other than that supplied by the spring plunger.

⑧ For six trials, measure the distance **D** that the cart slides and record these in Table 6.2.

> ➡ **NOTE:** Sometimes the cart will twist a bit as it descends so use the midpoint of the back edge of your cart as a reference point for measuring **D**.

⑨ Compare your results with your prediction. Compute the percent difference between these two values and enter it below Table 6.2.

Data and Analysis

ø = _________ Spring constant, k = _________ (from Experiment 4)

Trial	t (sec)	d (cm)	a ($\frac{cm}{s^2}$)
1			
2			
3			
4			

Table 6.1

average acceleration = _________ $\frac{cm}{s^2}$ coefficient of sliding friction = _________

θ = _________ **Predicted value of D = _________ cm**

Trial	D (cm)
1	
2	
3	
4	
5	
6	

Table 6.2

Average of measured value of D = _________ cm Percent of difference = _________%

Questions

① In analyzing this system, has the energy been fully accounted for? Discuss.

② How do your results agree with your prediction? Discuss.

③ What if you launched the cart up the same ramp? How far up would it go?

Notes:

Appendix

➧ WARNING!

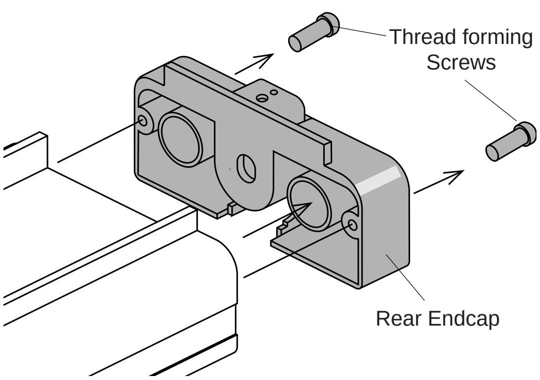
If the baseplate is removed, the axle assemblies may fly out, because they are held in place by compressed springs.

Removal of the plate is a two person operation: One person needs to push down on the wheels while the other slides out the base plate.

Replacing the Wheel-Axles Assemblies

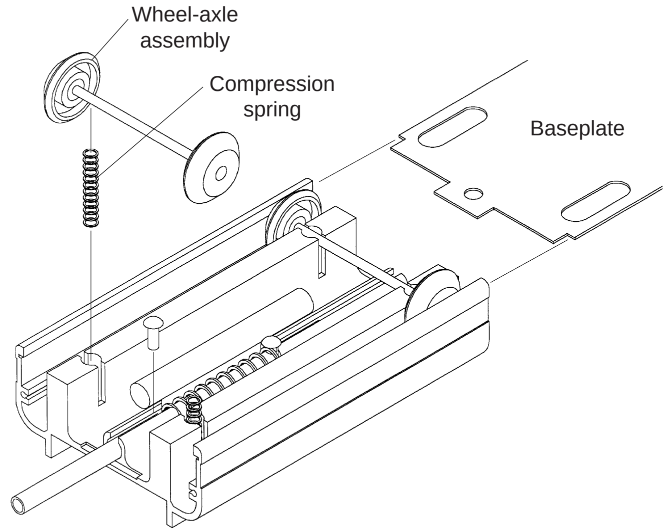
① Detach the end cap at the rear of the cart by removing the two screws from the rear end cap as shown.

➡ **NOTE:** The screws that secure the end caps to either end of the Dynamics Cart are thread forming screws and may require substantial force to remove and reinstall. A #1 Phillips point screw driver is required.



② Push the wheels into the recessed area and slide the base plate over the wheels.

③ Replace wheel-axle assembly and springs in reverse order.

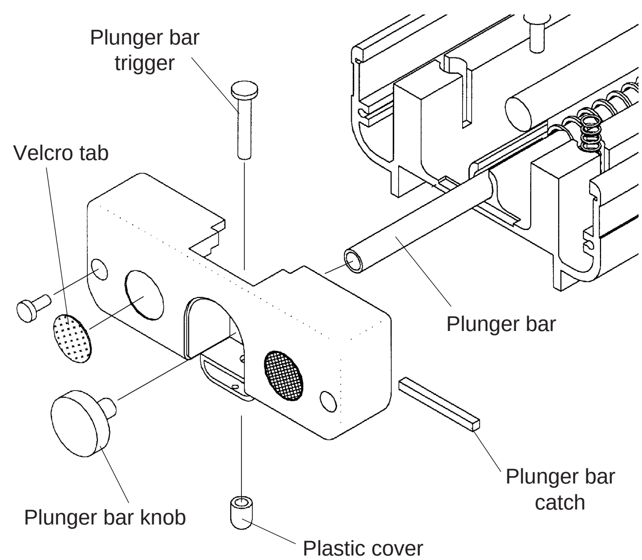


④ Slide baseplate back into position.

⑤ Replace the rear end cap with the two screws.

Replacing the Front End-Cap Attachments

- Screw the plunger bar knob finger-tight onto the plunger bar.
- Peel off velcro tab and replace with new tab.
- The plastic cover may get pulled off the plunger bar catch. Replace with new cover.
- If the plunger bar becomes defective please contact PASCO scientific for technical support.



Replacement Parts

Description	Part No.	Qty
Wheel-axle assembly		2
Wheel	648-04638	2 ea
Wheel Bearing	642-024	2 ea
Shaft	616-079	1 ea
End cap, modified	648-04699	2
For rear end cap assembly add:		
End cap plug	648-04694	1
Plunger bar	648-04653	1
Plunger bar knob assembly		
Screw (10-32x1/4 socket cap)	610-179	1
Knob	620-033	1
Plunger bar catch cover	699-04658	1
Compression spring (plunger bar)	632-035	1
Suspension spring	632-034	4
Base plate	648-04651	1
Velcro tab, 1/2 inch, Loop	616-074	1
Velcro tab, 1/2 inch, Hook	616-075	1
500 g Mass	648-04636	1

Technical Support

Feed-Back

If you have any comments about this product or this manual please let us know. If you have any suggestions on alternate experiments or find a problem in the manual please tell us. PASCO appreciates any customer feed-back. Your input helps us evaluate and improve our product.

To Reach PASCO

For Technical Support call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

Contacting Technical Support

Before you call the PASCO Technical Support staff it would be helpful to prepare the following information:

- If your problem is computer/software related, note:

  Title and Revision Date of software.

  Type of Computer (Make, Model, Speed).

  Type of external Cables/Peripherals.

- If your problem is with the PASCO apparatus, note:

  Title and Model number (usually listed on the label).

  Approximate age of apparatus.

  A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.)

  If possible, have the apparatus within reach when calling. This makes descriptions of individual parts much easier.

- If your problem relates to the instruction manual, note:

  Part number and Revision (listed by month and year on the front cover).

  Have the manual at hand to discuss your questions.

012-04966B
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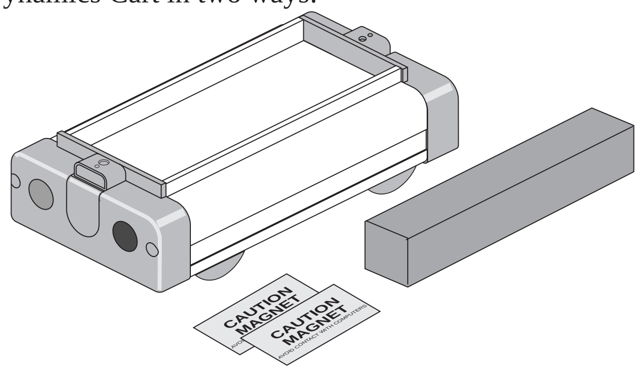
Instruction Sheet for the PASCO Model ME-9454

COLLISION CART

Introduction

The PASCO Model ME-9454 Collision Cart is designed specifically for collision experiments in conjunction with any of the PASCO Dynamics Cart and Dynamics Track systems. It differs from the ME-9430 Dynamics Cart in two ways:



① The Collision Cart has no spring plunger.

② It has magnets and Velcro® pads installed on both ends of the cart.

Otherwise the Collision Cart performs in the same manner as the Dynamics Cart:

- Its mass is approximately 500 g.
- An additional mass of approximately 500 g, which fits into the mass tray on top of the cart, is included.

> ➤ **NOTE:** For best results, measure the mass of the cart and additional mass with an accurate balance or scale.

- The Collision Cart has holes in each end-cap for attaching string or springs.

The advantages of the Collision Cart are:

- The cart comes supplied with Velcro ® pads attached, so a Collision Cart will stick to a Dynamics Cart during an inelastic collision.

> ➤ **NOTE:** The end of the ME-9430 Dynamics Cart used in the inelastic collision must not have magnets installed, or the two carts will not stick together due to the repulsive properties of the magnet assemblies.

- The cart has magnets installed, so the Collision cart will bounce off any other cart's magnetic bumpers in an elastic collision with very little frictional loss.

> ➤ **NOTE:** If you install magnets in the end of the ME-9430 Dynamics Cart, the magnets must be installed in the same orientation of polarity as the magnets in the ME-9454 Collision Cart, or they will attract rather than repel during collisions.

- The Collision Cart can be used against the plunger end of the Dynamics Cart to perform explosions.
- Multiple inelastic and elastic collisions may be performed using three or more carts.

Additional Equipment Required

- Dynamics Cart Track Accessory Set (ME-9435A 1.2 Meter Track or ME-9458 2.2 Meter Track)

Additional Equipment Recommended

See the current PASCO catalog for additional equipment available.

> ➤ **NOTE:** Experiments using the Collision Cart are described in the Instruction Manual/Experiment Guide for the ME-9458 and ME-9435A Dynamics Cart Track Accessory Sets.

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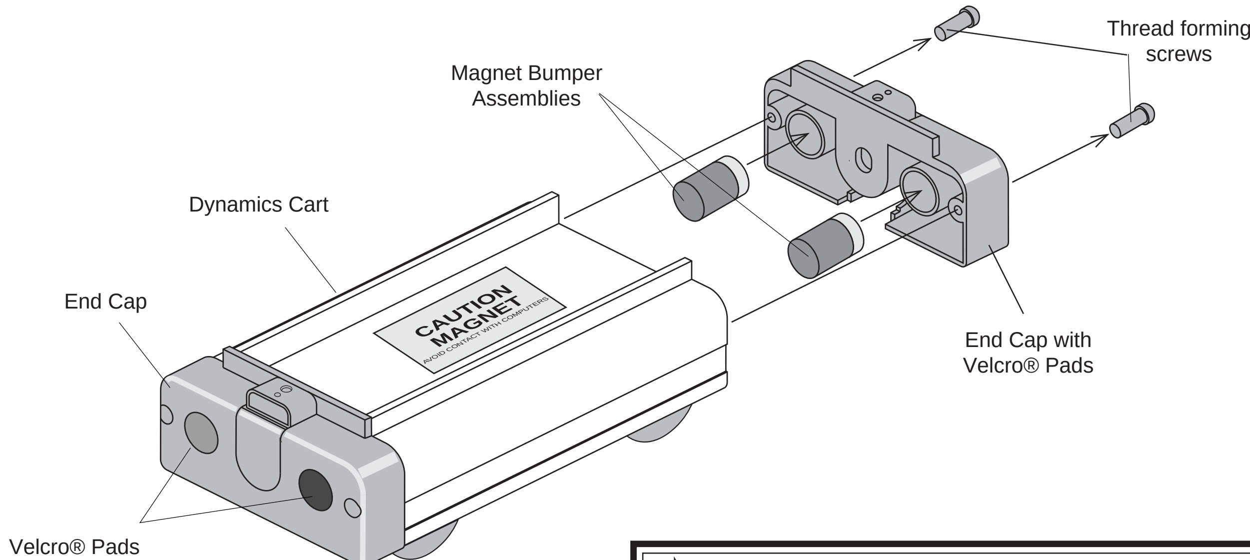


Removing the Magnet Bumpers

① Detach each end cap by removing the two screws from the rear of the end cap as shown.

➧ **Note:** The screws that secure the end caps to each end of the Dynamics Cart are thread forming screws and may require substantial force to remove and reinstall. A #1 Phillips point screw driver is required.

② Remove the two magnet bumper assemblies from the cavities on the inside of the end cap as shown.

➧ **Note:** When reinstalling the magnet assemblies, slide them magnet first into the end cap cavities.

③ Replace the rear end cap with the two screws.

Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

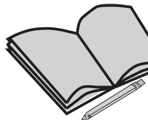
➧ **CAUTION!**

Each magnet assembly consists of a foam pad attached to a neodymium magnet. ***The neodymium magnets are extremely strong.*** Though only the north end of the magnet is exposed they can still be a hazard. ***When opposite poles are brought close to each other they will accelerate rapidly and can pinch fingers or be easily chipped. They can also erase computer disks and distort computer monitors and television sets.*** We recommend that you identify your Collision Cart with the "CAUTION MAGNET" labels provided

Replacement Parts

Description	Part No	Qty
Wheel-Axle Assembly		
Wheel	648-04864	4
Wheel Bearing	642-024	4
Axle	648-04962	2
End Cap modified	648-04969	2
End Cap Plug	648-04694	2
Suspension Spring	632-034	4
Base Plate	648-04651	1
1/2" Velcro® Loop	616-074	2
1/2" Velcro® Hook	616-075	2
Magnet Bumper Assembly		
Magnet	634-022	4
Foam Retainer	648-04702	4
500 g Mass	648-0636	1
Caution Magnet Label	646-04445	2

Includes Teacher's Notes and Typical Experiment Results



Instruction Manual and Experiment Guide for the PASCO scientific Model ME-9458 and ME-9452

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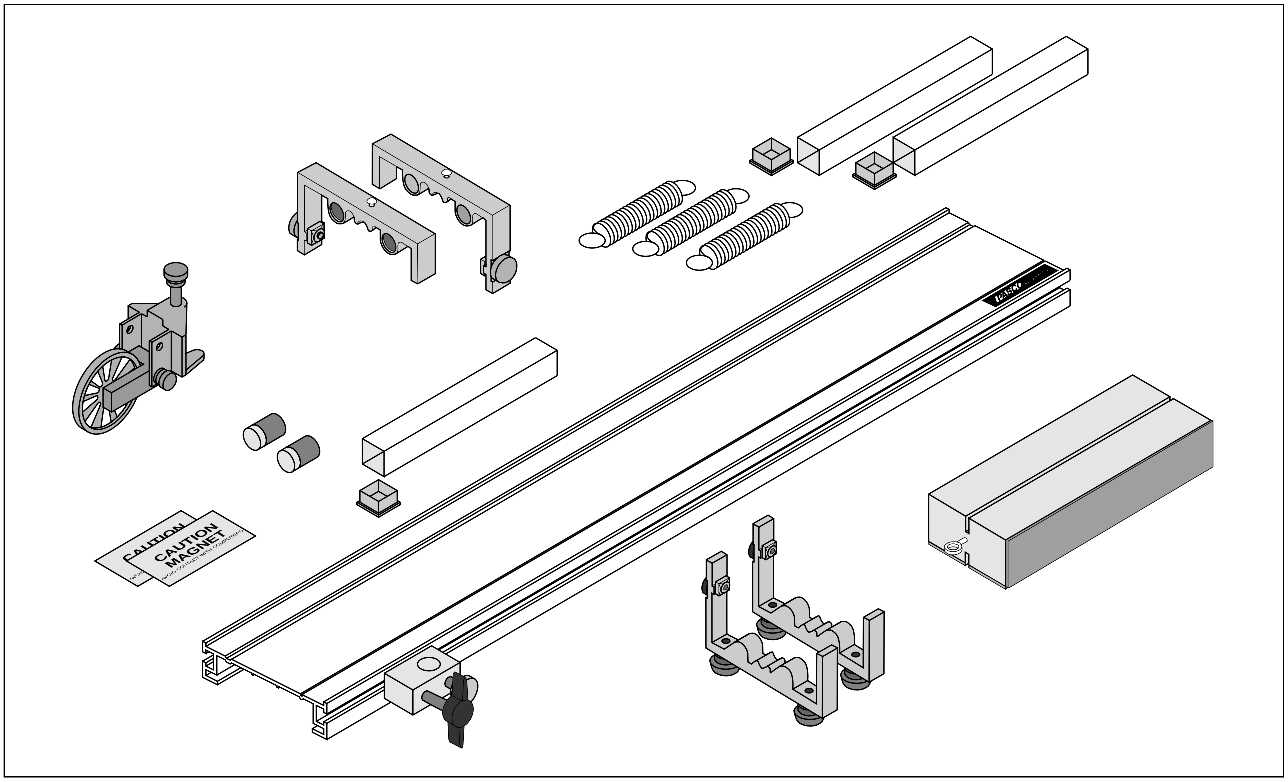
6/94

Dynamics Cart Accessory Track Set (2.2m version)



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Credits

This manual authored by: Ann & John Hanks

Teacher’s guide written by: Eric Ayars

Equipment Return

Should this product have to be returned to PASCO scientific, for whatever reason, notify PASCO scientific by letter or phone BEFORE returning the product. Upon notification, the return authorization and shipping instructions will be promptly issued.

➤ **NOTE:** NO EQUIPMENT WILL BE ACCEPTED FOR RETURN WITHOUT AN AUTHORIZATION.

When returning equipment for repair, the units must be packed properly. Carriers will not accept responsibility for damage caused by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

① The carton must be strong enough for the item shipped.

② Make certain there is at least two inches of packing material between any point on the apparatus and the inside walls of the carton.

③ Make certain that the packing material can not shift in the box, or become compressed, thus letting the instrument come in contact with the edge of the box.

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Introduction

The PASCO Model ME-9458 Dynamics Cart Accessory Track Set enables the user to perform a wide variety of experiments when used with the Dynamics Cart (ME-9430) and the Collision Cart (ME-9454). The Track ensures easy setup and accurate alignment with the lowest possible friction, and it accomodates most linear motion experiments.

Features include:

- Adjustable leveling feet.
- Low friction wheel slots keep the carts aligned even after a collision.
- Mounted to a standard lab rod, the track adjusts to any angle for inclined plane experiments.
- Durable construction with Adjustable End Stops protects the cart.

Equipment

The ME-9458 Dynamics Cart Accessory Track Set includes the following:

- Dynamics Cart Track:

  2.2 m (7.5') extruded aluminum track with alignment grooves in top surface, two leveling feet and two adjustable End Stops.

> ➤ **NOTE:** The End Stop has a round head screw on the top to allow easy attachment of springs, string, etc.

- Force Table Clamp with Super Pulley.
- (3) Springs for simple harmonic motion with storage tubes.

> ➤ **NOTE:** A small piece of double sided tape is attached to the ends of each storage tube so the tubes may be permanently attached to the underside of the Dynamics Cart Track.

- Friction Block
- Magnet Bumper Kit (includes 2 magnets) with storage tube.
- Pivot Clamp [for use with the Base and Support Rod (ME-9355)].
- (2) Labels: "CAUTION! MAGNET".

The ME-9452 Introductory Dynamics System (2.2 m version) includes all the components of the ME-9458 plus the following:

- Dynamics Cart with Mass (ME-9340)
- Collision Cart (ME-9454)

The ME-9459 Introductory Dynamics Demonstration System includes all the components of the ME-9458 plus the following:

- Dynamics Cart with Mass (ME-9340)
- (2) Collision Carts (ME-9454)
- Additional Spring

The ME-9453 Dynamics Track Set (2.2 m) includes the following:

- 2.2m Track
- (2) Leveling Feet (ME-9470)
- (2) Adjustable End Stops (ME-9469)

Additional Equipment Required for ME-9458

- Dynamics Cart with Mass (ME-9430)

Specific experiment requirements:

– Thread

– Mass Set

– Super Pulley with Clamp

– Base and Support Rod

– Metric Ruler

– Stopwatch

– Mass balance

– Wooden or metal block

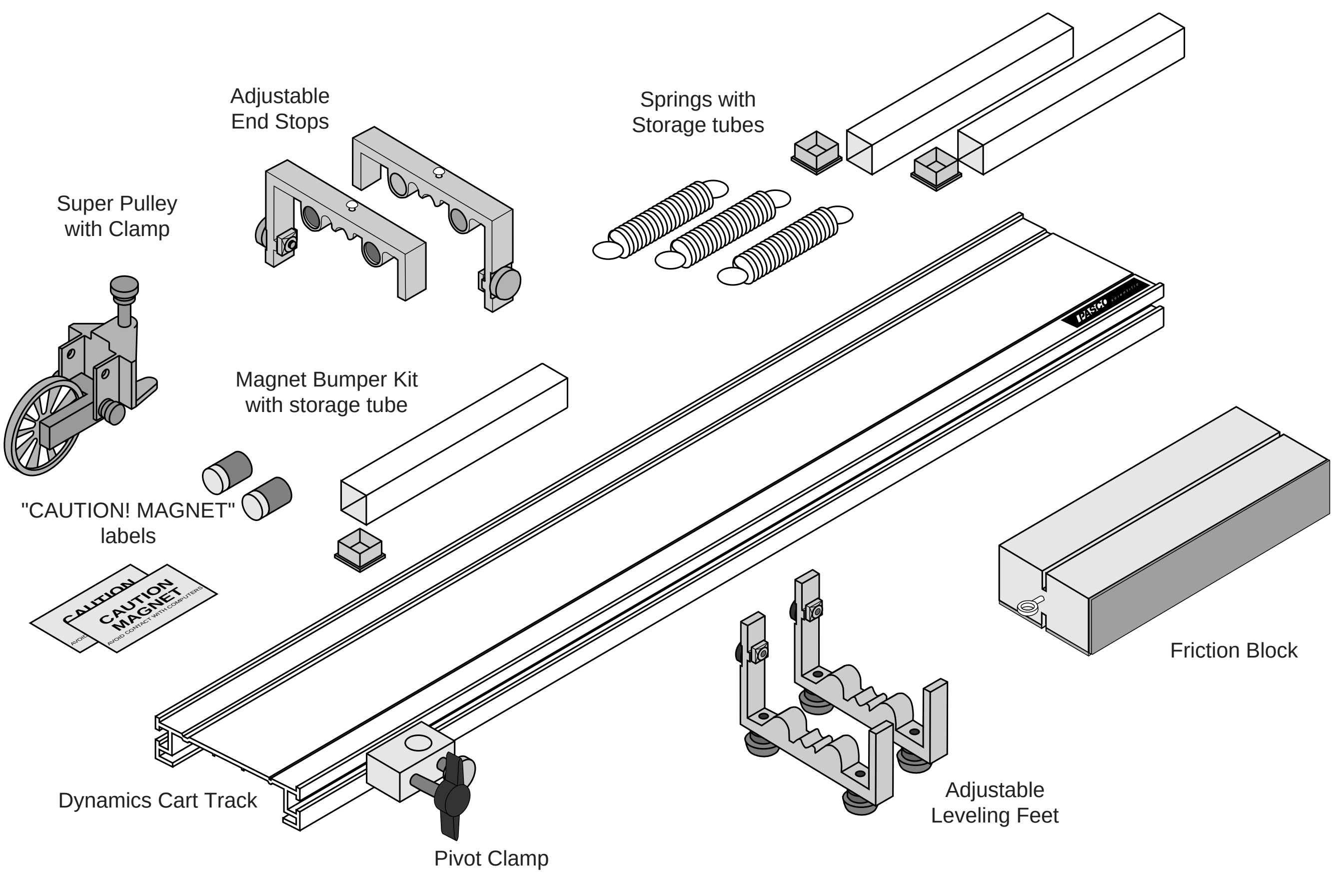
– Graph paper

Additional Equipment Recommended

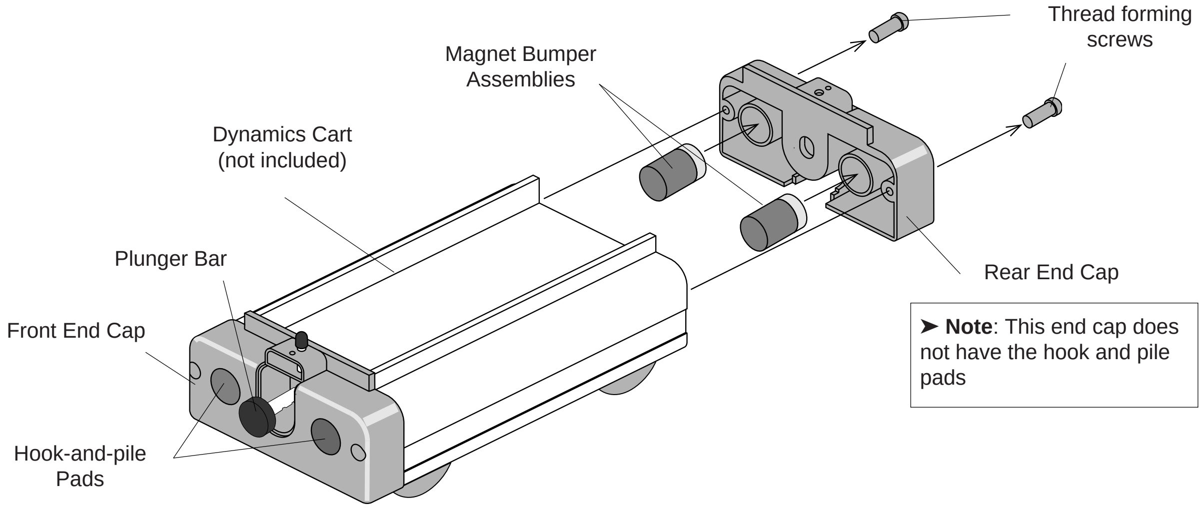
- Photogate Accessory Kit with Software, (Apple) (ME-9436) or (IBM PC) (ME-9437)

or

- Software Accessory Kit, (Apple) (ME-9438) or (IBM PC) (ME-9439).



Assembly



Installing the Magnet Bumpers

> ➤ **NOTE:** The ME-9454 Collision Cart comes with 2 sets of magnetic bumpers already installed. The ME-9430 Dynamics Cart comes without any magnetic bumpers.

① Detach the end cap at the rear of the cart by removing the two screws from the rear end cap as shown.

> ➤ **NOTE:** The screws that secure the end caps to either end of the Dynamics Cart are thread forming screws and may require substantial force to remove and reinstall. A #1 Phillips point screw driver is required.

② Insert the two magnet bumper assemblies, magnet end first, into the cavities on the inside of the end cap as shown.

> ➤ **CAUTION!**
>
> Each magnet assembly consists of a foam pad attached to a neodymium magnet. ***The neodymium magnets are extremely strong.*** Though only the south end of the magnet is exposed they can still be a hazard. When opposite poles are brought close to each other they will accelerate rapidly and can pinch fingers or be easily chipped. They can also erase computer disks and distort computer monitors and television sets.

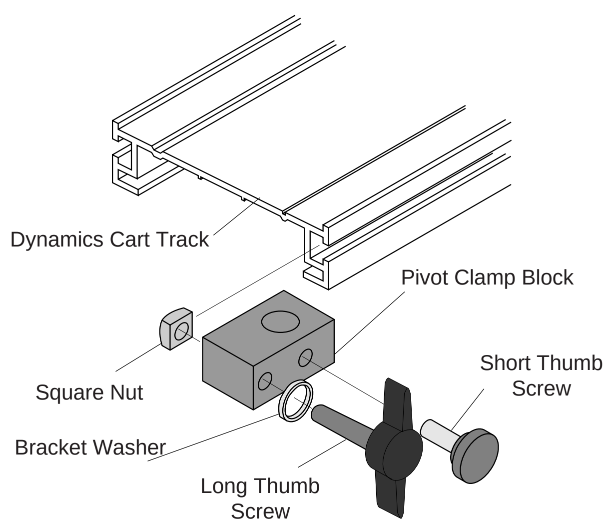
③ Replace the rear end cap with the two screws.

Installing the Pivot Clamp

① Remove Pivot Clamp Assembly from underneath the Dynamics Cart Track.

② Insert long thumb screw through the hole in the Pivot Clamp Block and thread ½ to ¾ turn into the hex nut.

> ➤ **NOTE:** Observe the orientation of the Pivot Clamp Block. Also note that the flat side of the square nut must face the outside of the Dynamics Cart Track as shown.



③ Align the square nut within the groove on the desired side of the Dynamics Cart Track. Locate and adjust Pivot Clamp to desired position and tighten thumb screw to secure.

Installing the Leveling Feet

The leveling feet serve 3 purposes: to level the track, to reduce any twist in the track, and to reduce any bow in the track. Assembly is as follows:

① Thread a locking nut onto each of the four long screws as shown in Figure 1.

② Thread two of the long screws in top the two holes in the bottom of each aluminum leveling foot. The heads of these screws form the feet which will rest on the table when the track is in use.

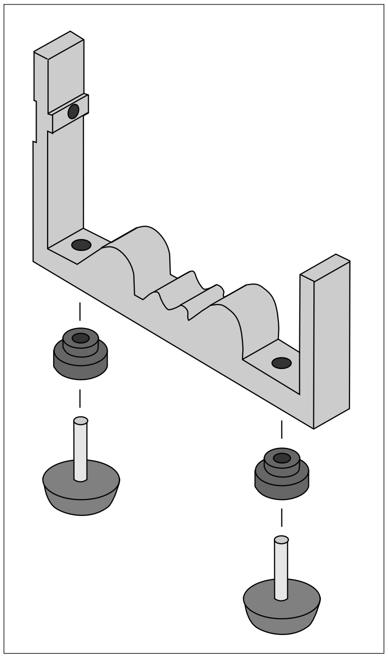


Fig. 1 - Attaching Feet

③ Place the washer on the short screw and insert the short screw through the hole in the side of the aluminum leveling foot as shown in Figure 2. Screw the square nut onto the end of the short screw just far enough to keep the short screw from falling out.

④ Align the square nut within the groove on the desired side of the Dynamics Cart Track. Slide the leveling foot down the track to the desired position. To minimize the bow in the track, it is best to place a leveling foot about 1/4 of the track length from each end of the track (see Figure 3).

⑤ To level the track, place a cart on the track to see which way it rolls. Then loosen the lock nuts and screw the leveling screws up or down to change the height of one end of the track until the cart when placed at rest will stay at rest. When the track is level, tighten the lock nuts against the aluminum foot.

⑥ It is also possible to take some twist out of the track by adjusting the leveling screws on one side of the track.

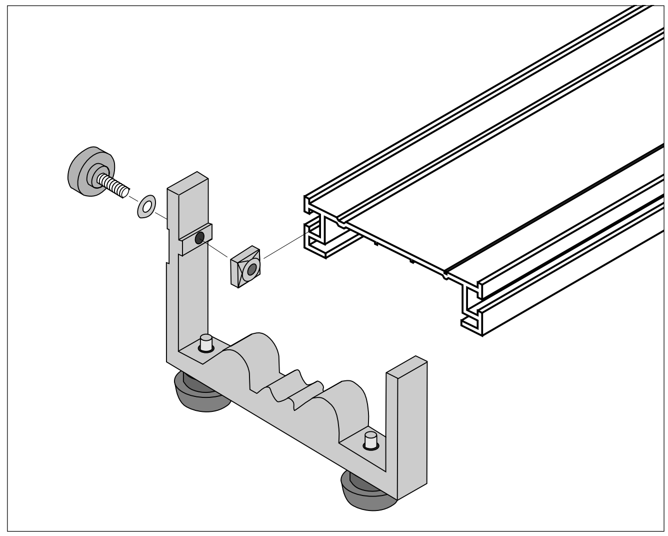


Fig. 2 - Attaching Leveling Bracket to Track

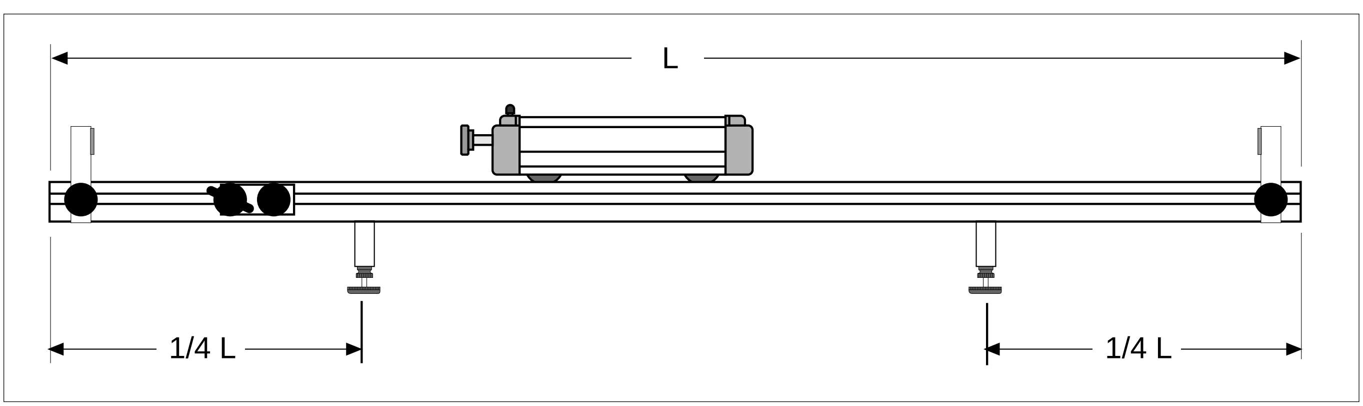


Fig. 3 - Optimum Position of Leveling Feet

Installing the Adjustable End Stop

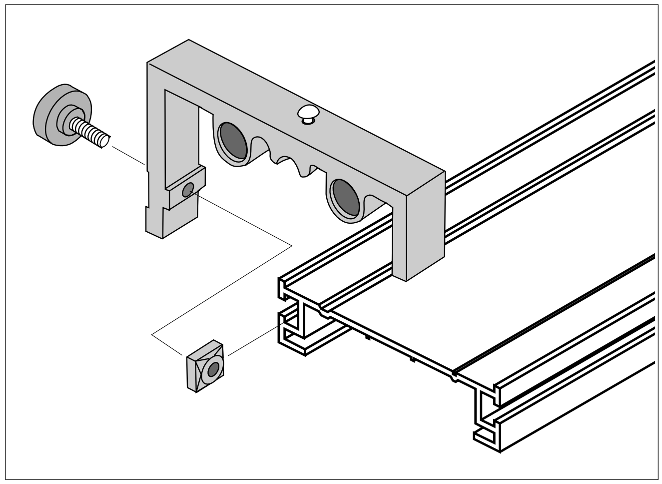
The Adjustable End Stop can be used at any point on the track as a bumper. Either the plunger bar on the cart or the cart's magnetic bumper can be used to rebound off the End Stop because the End Stop contains magnets. The cart can also be stopped against the End Stop when the velcro end of the cart hits the velcro side of the End Stop. This is useful when it is desired to keep the cart from rebounding. There is also a post on top of the End Stop to allow a string or spring to be attached. Assembly is as follows:

① The Adjustable End Stop Assembly consists of the end stop with two magnets installed, a black plastic thumb screw, and a square nut.

② It is best to install the End Stops in the groove opposite to the side being used for the leveling feet so the End Stops can slide past the leveling feet without interference.

③ Align the square nut within the groove on the desired side of the Dynamics Cart Track as shown. Locate and adjust the End Stop to the desired position and tighten the thumb screw to secure.

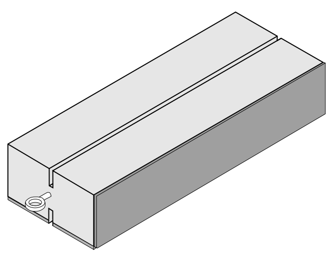
④ When storing the End Stop when it is not on the track, remember that it has two strong magnets in it. Keep the End Stop away from computers.



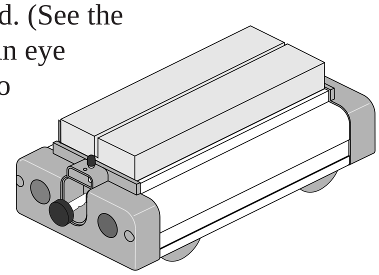
Attaching Adjustable End Stop to Track

Using the Friction Block

The Friction Block is a wood rectangle that fits neatly on top of the Dynamics Cart (ME-9430).

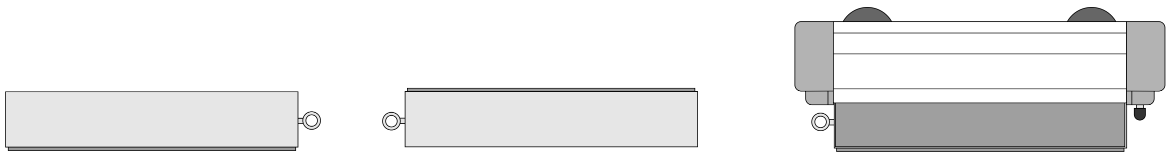


The top and bottom surfaces of the Friction Block have a slot which allows a “picket fence” to be inserted. (See the PASCO catalog.) An eye screw is provided so that you may easily attach a string to the block.



In experiments that use the Friction Block you will investigate some of the properties of sliding friction - the force that resists the sliding motion of two objects when they are already in motion.

The exposed wood on the top and one side of the block produce minimal friction. Felt pads attached to the bottom surface and the other side provide more friction. Mass can be placed on the top surface of the Friction Block as shown.



Replacement Parts (ME-9458)

Description	Part No.
Magnet Bumper Kit Assembly (4per)	003-05027
Super Pulley with Clamp (1ea)	ME-9448A
Friction Block (1ea)	003-04708
Label, Magnet Caution (1ea)	646-04445
Spring (3ea)	632-04978
Pivot Clamp Assembly:	003-05019
Pivot clamp (1ea)	648-04654
Long thumb screw (1ea)	610-183 & 620-047
Short thumb screw (1ea)	610-181 & 620-067
Washer	615-184
Square nut (1ea)	614-054
Adjustable End Stop (2ea)	ME-9469
Leveling Feet (2ea)	ME-9470

Experiment 1: Conservation of Momentum in Explosions

EQUIPMENT NEEDED:

– Dynamic Cart with Mass (ME-9430)
– Collision Cart (ME-9454)
– Dynamics Cart Track
– Meter stick
– Mass balance

Purpose

The purpose of this experiment is to demonstrate conservation of momentum for two carts pushing away from each other.

Theory

When two carts push away from each other and no net force exists, the total momentum of both carts is conserved. Because the system is initially at rest, the final momentum of the two carts must be equal in magnitude and opposite in direction so the resulting total momentum of the system is still zero.

$$p = m_1\vec{v}_1 - m_2\vec{v}_2 = 0$$

Therefore, the ratio of the final speeds of the carts is equal to the ratio of the masses of the carts.

$$\frac{v_1}{v_2} = \frac{m_2}{m_2}$$

To simplify this experiment, the starting point for the carts at rest is chosen so that the two carts will reach the end of the track simultaneously. The speed, which is the distance divided by the time, can be determined by measuring the distance traveled since the time traveled by each cart is the same.

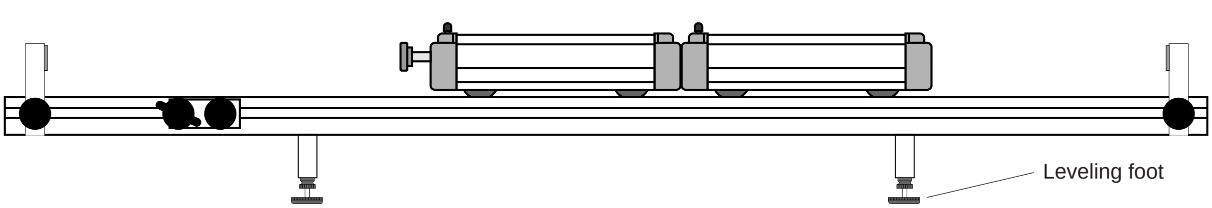
$$\frac{v_1}{v_2} = \frac{\frac{\Delta x_1}{\Delta t}}{\frac{\Delta x_2}{\Delta t}} = \frac{\Delta x_1}{\Delta x_2}$$

Thus the ratio of the distances is equal to the ratio of the masses:

$$\frac{\Delta x_1}{\Delta x_2} = \frac{m_2}{m_1}$$

Procedure

① Level the track by setting a cart on the track to see which way it rolls. Adjust the leveling feet to raise or lower the ends until a cart placed at rest on the track will not move.



② For each of the following cases, place the two carts against each other with the plunger of the Dynamics Cart pushed completely in and latched in its maximum position (see Figure 1.1).

③ Push the plunger release button with a short stick and watch the two carts move to the ends of the track. Experiment with different starting positions until the two carts reach their respective ends of the track at the same time. Then weigh the two carts and record the masses and the starting position in Table 1.1.

CASE 1: CARTS OF EQUAL MASS (Use two carts without any additional mass bars)

CASE 2: CARTS OF UNEQUAL MASS (Put one mass bar in one cart, none in the other)

CASE 3: CARTS OF UNEQUAL MASS (Put two mass bars in one cart, none in the other)

CASE 4: CARTS OF UNEQUAL MASS (Put two mass bars in one cart, one mass bar in the other)

Table 1.1

Mass 1	Mass 2	Position	x_1	x_2	x_1 / x_2	m_2/m_1

Data Analysis

① For each of the cases, calculate the distances traveled from the starting position to the end of the track. Record the result in Table 1.1.

② Calculate the ratio of the distances traveled and record in the table.

③ Calculate the ratio of the masses and record in the table.

Questions

① Does the ratio of the distances equal the ratio of the masses in each of the cases? In other words, is momentum conserved?

② When carts of unequal masses push away from each other, which cart has more momentum?

③ When the carts of unequal masses push away from each other, which cart has more kinetic energy?

④ Is the starting position dependent on which cart has its plunger cocked? Why?

Experiment 2: Conservation of Momentum in Collisions

EQUIPMENT NEEDED:

– Dynamics Cart with Mass (ME-9430)
– Collision Cart (ME-9454)
– (2) Bumper magnet set (installed)
– Dynamics Cart Track
– Paper

Purpose

The purpose of this experiment is to qualitatively explore conservation of momentum for elastic and inelastic collisions.

Theory

When two carts collide with each other, the total momentum $\vec{p} = m\vec{v}$ of both carts is conserved regardless of the type of collision. An elastic collision is one in which the two carts bounce off each other with no loss of kinetic energy. In this experiment, magnetic bumpers are used to minimize the energy losses due to friction during the collision. In reality, this "elastic" collision is slightly inelastic. A completely inelastic collision is one in which the two carts hit and stick to each other. In this experiment, this is accomplished with the hook-and-pile tabs on the end caps of the carts.

Procedure

① Level the track by setting a cart on the track to see which way it rolls. Adjust the leveling feet at the end of the track to raise or lower that end until a cart placed at rest on the track will not move.

② Draw two diagrams (one for before the collision and one for after the collision) for each of the following cases. In each diagram, show a velocity vector for each cart with a length that approximately represents the relative speed of the cart.

Part I: Elastic Collisions

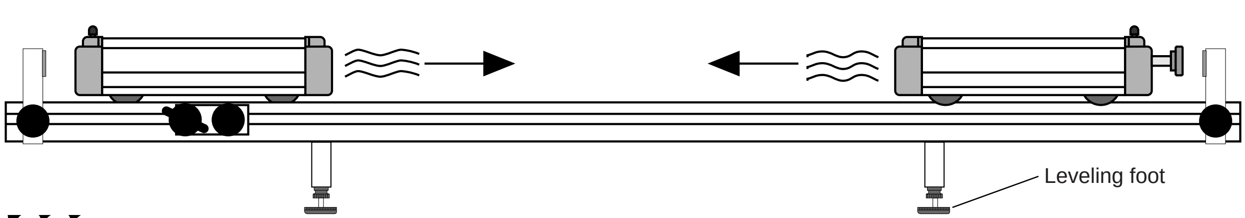
A. Carts with Equal Mass

Orient the two carts so their magnetic bumpers are toward each other.

Case 1: Place one cart at rest in the middle of the track. Give the other cart an initial velocity toward the cart at rest.

Case 2: Start the carts with one at each end of the track. Give each cart approximately the same velocity toward each other.

Case 3: Start both carts at one end of the track. Give the first cart a slow velocity and the second cart a faster velocity so that the second cart catches the first cart.



B. Carts with Unequal Mass

Put two mass bars in one of the carts so that the mass of one cart is approximately three times the mass (3M) of the other cart (1M).

Case 1: Place the 3M cart at rest in the middle of the track. Give the other cart an initial velocity toward the cart at rest.

Case 2: Place the 1M cart at rest in the middle of the track. Give the 3M cart an initial velocity toward the cart at rest.

Case 3: Start the carts with one at each end of the track. Give each cart approximately the same velocity toward each other.

Case 4: Start both carts at one end of the track. Give the first cart a slow velocity and the second cart a faster velocity so that the second cart catches the first cart. Do this for both cases: with the 1M cart first and then for the 3M cart first.

Part II: Completely Inelastic Collisions:

③ Orient the two carts so their hook-and-pile ends are toward each other. Make sure the plunger bar is pushed in completely so it won't interfere with the collision.

④ Repeat the same procedures listed in **Part I** for carts with equal mass **and** carts with unequal mass.

Questions

① When two carts having the same mass and the same speed collide and stick together, they stop. What happened to each cart's momentum? Is momentum conserved?

② When two carts having the same mass and the same speed collide and bounce off of each other elastically, what is the final total momentum of the carts?

Experiment 3: Simple Harmonic Oscillator

EQUIPMENT NEEDED:

– Dynamics Cart with Mass (ME-9430)
– (2) Springs
– Mass hanger and mass set (ME-9348)
– String
– Graph paper
– Dynamics Cart Track
– Super Pulley with clamp
– Stopwatch
– Mass balance (SE-8723)

Purpose

The purpose is to measure the period of oscillation of a spring and mass system and compare it to the theoretical value.

Theory

For a mass attached to a spring, the theoretical period of oscillation is given by

$$T = 2\pi\sqrt{\frac{m}{k}}$$

where **T** is the time for one complete back-and-forth motion, **m** is the mass that is oscillating, and **k** is the spring constant.

According to Hooke's Law, the force exerted by the spring is proportional to the distance the spring is compressed or stretched, **F = kx**, where **k** is the proportionality constant. Thus the spring constant can be experimentally determined by applying different forces to stretch the spring different distances. Then the force is plotted versus distance and the slope of the resulting straight line is equal to **k**.

Procedure

Measurements to Find the Theoretical Period

① Use the balance to find the mass of the cart. Record this value at the top of Table 3.1.

② Level the track by setting the cart on the track to see which way it rolls. Adjust the leveling feet at the ends of the track to raise or lower the ends until the cart placed at rest on the track will not move. Put the pulley with the table clamp at one end of the track.

③ Set the cart on the track and attach a spring to each end of the cart by inserting the end of the spring in the hole provided in the cart. Then attach the other ends of the springs to the endstops (See Figure 3.1).

④ Attach a string to the end of the cart and hang a mass hanger over the pulley as shown.

⑤ Record the equilibrium position in Table 3.1.

⑥ Add mass to the mass hanger and record the new position. Repeat this for a total of 5 different masses, being careful not to over-stretch the springs. Because both springs are acting on the mass, this method will give the effective spring constant for both springs.

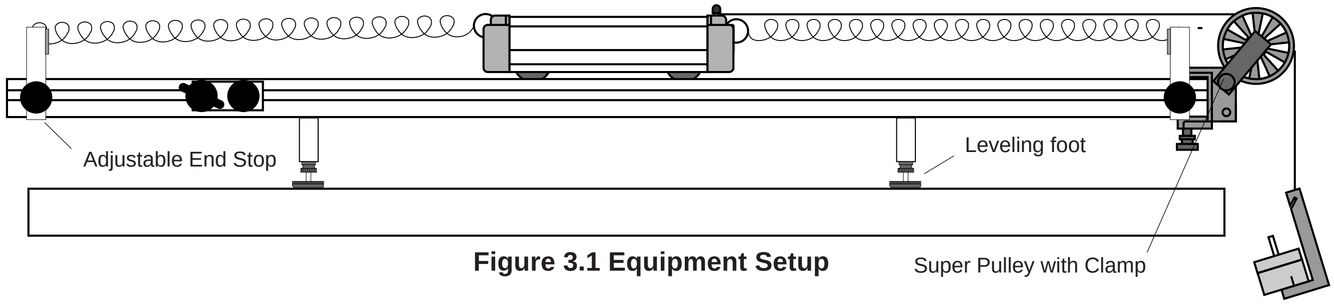


Figure 3.1 Equipment Setup

Data and Analysis

Table 3.1

Mass of cart =____________ Equilibrium position =____________

Added Mass	Position	Displacement from Equilibrium	Force (mg)

Measuring the Experimental Period

⑦ Displace the cart from equilibrium a specific distance and let it go. Time 5 oscillations and record the time in Table 3.2.

⑧ Repeat this measurement at least 5 times, using the same initial displacement (amplitude).

⑨ Add a 500 g mass to the cart. Measure the time for 5 oscillations 5 times and record this data in Table 3.2.

Calculations

Theoretical Period

① Using the data in Table 3.1, plot force versus displacement. Draw the best-fit straight line through the data points and determine the slope of the line. The slope is equal to the effective spring constant, **k**.

k = _______________

② Using the mass of the cart and the spring constant, calculate the period using the theoretical formula. Also calculate the theoretical period for the cart with the 500 g mass in it.

(cart alone) T = _________________

(cart with mass) T = _________________

Experimental Period

① Using the data in Table 3.2, calculate the average time for 5 oscillations with and without the 500 g mass in the cart.

② Calculate the period by dividing these times by 5 and record the periods in Table 3.2.

Table 3.2

Trial	Time for 5 Oscillations	Period
1		Without additional mass= ______
2		
3		
4		
5		
Average		
1		With additional mass= ______
2		
3		
4		
5		
Average		

Comparison

Calculate the percent difference between the measured and theoretical values:

(cart alone) % diff = ________________

(cart with mass) % diff = ________________

Questions

① Does the period of oscillation increase or decrease as the mass is increased? Does a more massive cart oscillate faster or slower?

② If the initial displacement from equilibrium (amplitude) is changed, does the period of oscillation change? Try it.

Notes:

Experiment 4: Oscillations on an Incline

EQUIPMENT NEEDED:

– Dynamics Cart with Mass (ME-9430)
– Spring
– Base and Support rod (ME-9355)
– Mass balance
– Dynamics Cart Track with End stop and Pivot clamp
– Mass hanger and mass set (ME-934 8)
– Stopwatch

Purpose

The purpose is to measure the period of oscillation of a spring and mass system on an incline at different angles and compare it to the theoretical value.

Theory

For a mass attached to a spring, the theoretical period of oscillation is given by

$$T = 2\pi\sqrt{\frac{m}{k}}$$

where **T** is the time for one complete back-and-forth motion, **m** is the mass that is oscillating, and **k** is the spring constant.

According to Hooke's Law, the force exerted by the spring is proportional to the distance the spring is compressed or stretched, **F = kx**, where **k** is the proportionality constant. The spring constant can be experimentally determined by applying different forces to stretch the spring different distances. When the force is plotted versus distance, the slope of the resulting straight line is equal to **k**.

Procedure

Measurements to Find the Theoretical Period

① Use the balance to find the mass of the cart. Record this value at the top of Table 4.1.

② Set the cart on the track and attach a spring to one end of the cart by inserting the end of the spring in the hole provided in the cart. Then attach the other end of the spring to the end of the track (See Figure 4.1).

③ Incline the track by raising the end of the track that has the spring attached. As the end of the track is raised the spring will stretch. Keep the angle of inclination of the track small enough so the spring is not stretched more than half the length of the track. Measure this angle and record it at the top of Table 4.1.

④ Record the equilibrium position in Table 4.1.

⑤ Add mass to the cart and record the new position. Repeat this for a total of 5 different masses, being careful not to over-stretch the spring.

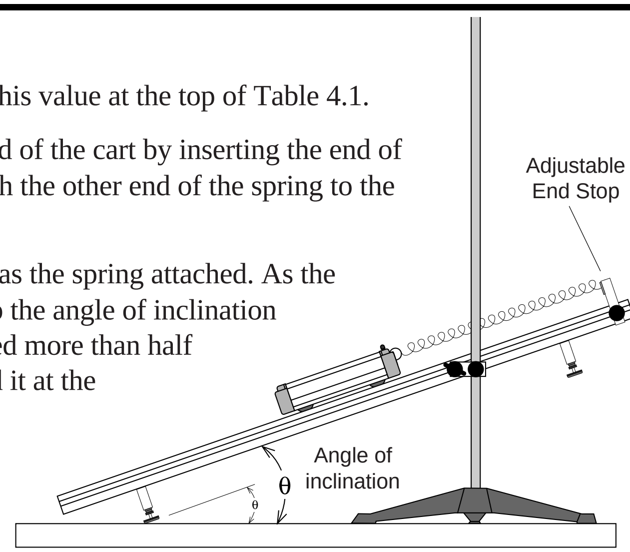


Figure 4.1 Equipment Setup

Table 4.1

Mass of Cart = _______________

Equilibrium position = _______________

Angle of Incline = _______________

Added Mass	Position	Displacement from Equilibrium	Force (mg sinθ)

Measuring the Experimental Period

⑥ Displace the cart from equilibrium a specific distance and let it go. Time 3 oscillations and record the time in Table 4.2.

⑦ Repeat this measurement at least 5 times, using the same initial displacement (amplitude).

⑧ Change the angle of the incline and repeat Steps 6 and 7.

Calculations

Theoretical Period

① Using the data in Table 4.1, calculate the force caused by the additional mass in the cart: $F = mg \sin\theta$, where θ is the angle of incline. Plot force versus displacement. Draw the best-fit straight line through the data points and determine the slope of the line. The slope is equal to the effective spring constant, k.

k = _______________

② Using the mass of the cart and the spring constant, calculate the period using the theoretical formula.

T = _______________

Table 4.2

Time for 3 oscillations

Angle	Trial 1	2	3	4	5	Avg	Period

Experimental Period

③ Using the data in Table 4.2, calculate the average time for 3 oscillations.

④ Calculate the period by dividing these times by 3 and record the periods in Table 4.2.

Questions

① Does the period vary as the angle is changed?

② How do the experimental values compare with the theoretical values?

③ Does the equilibrium position change as the angle is changed?

④ What would be the period if the angle was 90 degrees?

Notes:

Experiment 5: Springs in Series and Parallel

EQUIPMENT NEEDED:

– Dynamics Cart with Mass (ME-9430)
– Dynamics Cart Track with End stop
– (2) Springs
– Base and Support rod (ME-9355)
– Mass balance
– Stopwatch

Purpose

The purpose is to measure the period of oscillation of springs in series and parallel and compare it to the period of oscillation of one spring.

Theory

For a mass attached to a spring, the theoretical period of oscillation is given by

$$T = 2\pi\sqrt{\frac{m}{k}}$$

where **T** is the time for one complete back-and-forth motion, **m** is the mass that is oscillating, and **k** is the spring constant. If the period of oscillation is measured, the spring constant can be determined:

$$k = \frac{4\pi^2 m}{T^2}$$

When two springs are combined in series or in parallel, the spring constants add in different ways. One possible way to add two spring constants is $k_{effective} = k + k = 2k$. Another way is

$$k_{effective} = \frac{1}{k} + \frac{1}{k} = \frac{2}{k}$$

which means that

$$k_{effective} = \frac{1}{2}k$$

Procedure

Measuring k For a Single Spring

① Use the balance to find the mass of the cart. Record this value at the top of Table 5.1.

② Set the cart on the track and attach a spring to one end of the cart by inserting the end of the spring in the hole provided in the cart. Then attach the other end of the spring to the end of the track (See Figure 5.1).

➤ **NOTE:** Remove the leveling feet for this experiment.

③ Incline the track by raising the end of the track that has the spring attached. As the end of the track is raised the spring will stretch. Keep the angle of inclination of the track small enough so the spring is not stretched more than half the length of the track.

④ Displace the cart from equilibrium a specific distance and let it go. Time 2 oscillations and record the time in Table 5.1. Repeat this measurement at least 5 times, using the same initial displacement (amplitude).

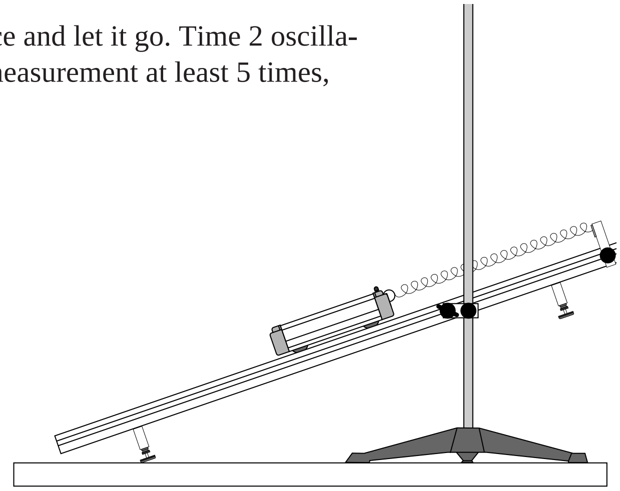


Figure 5.1 Equipment Setup

Measuring the Effective k For Pairs of Springs

⑤ Add a second spring in series as shown in Figure 5.2 and repeat Step ④.

⑥ Put the two springs in parallel as shown in Figure 5.3 and repeat Step ④.

⑦ Arrange the springs as shown in Figure 5.4 and repeat Step ④.

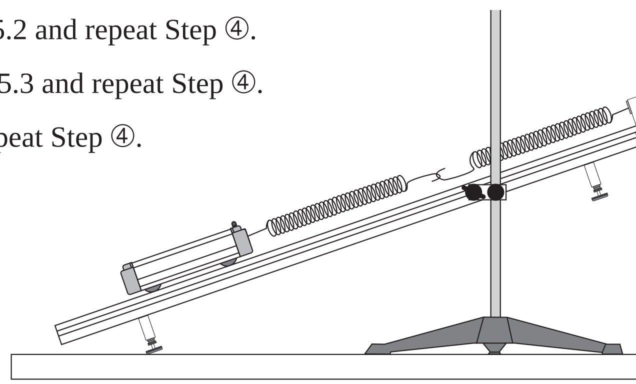


Figure 5.2 Springs in Series

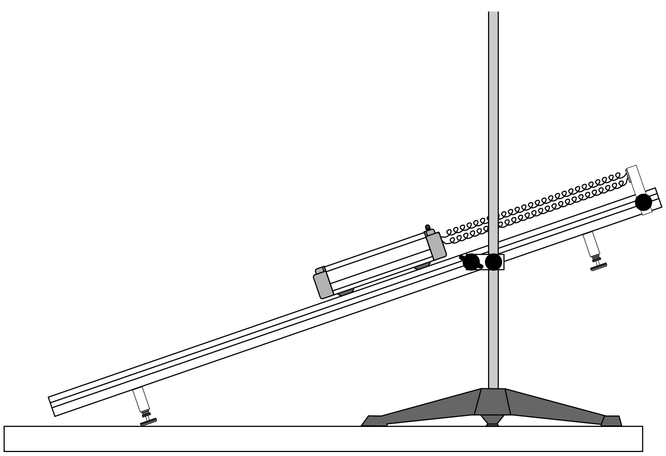


Figure 5.3 Springs in Parallel

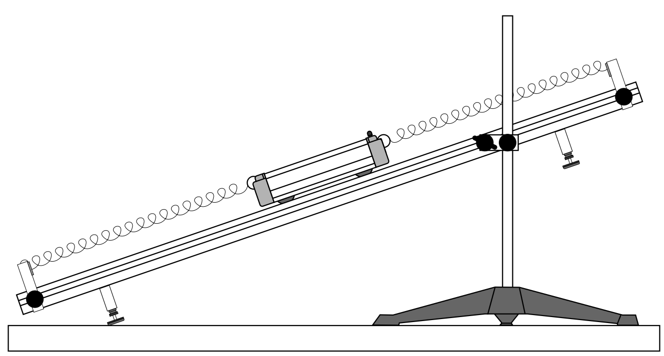


Figure 5.4 Final Spring Arrangement

Calculations

① Using the data in Table 5.1, calculate the average time for 2 oscillations.

② Calculate the period by dividing these times by 2 and record the periods in Table 5.1.

③ Using the periods and the mass of the cart, calculate the effective spring constants.

Table 5.1

Mass of Cart = _______________

Time for 2 oscillations

Springs	Trial 1	2	3	4	5	Avg	Period	k
One								
Series								
Parallel								
At Ends								

Questions

① Is $k_{effective} = 2k$ for springs in series or parallel?

② Is $k_{effective} = \frac{1}{2}k$ for springs in series or parallel?

③ Is the last spring arrangement series or parallel?

Experiment 6: Newton's Second Law

EQUIPMENT NEEDED:

– Dynamics Cart with Mass (ME-9430)
– Dynamics Cart Track
– Stopwatch

Purpose

The purpose is to show how the acceleration of an object is dependent on force and mass.

Procedure

① Level the track by setting the cart on the track to see which way it rolls. Adjust the leveling feet to raise or lower the ends until the cart placed at rest on the track will not move.

② To perform each of the following trials, cock the spring plunger on the cart and place the cart at rest at the end of the track with the plunger against the end stop. Then release the plunger by pressing the button on the cart with a ruler. Observe the resulting acceleration. This will be a qualitative measurement.

VARY THE FORCE: Perform the first trial with the spring plunger cocked to the first possible position (the least compression) and then do two more trials increasing the force applied to the cart by increasing the compression of the spring plunger.

VARY THE MASS: For these trials, always cock the spring plunger to the maximum. Observe the relative accelerations of the cart alone and the cart with one mass bar in it. If additional masses are available, use them to increase the mass for additional trials.

Data Analysis

① Does the acceleration increase or decrease as the force is increased?

② Does the acceleration increase or decrease as the mass is increased?

Question

From the results of this experiment, can you deduce the equation that relates acceleration to mass and force?

Experiment 7: Newton's Second Law II

EQUIPMENT NEEDED:

– Dynamics Cart (ME-9430)
– Super Pulley with Clamp
– String
– Stopwatch
– Mass balance
– Dynamics Cart Track
– Base and Support rod (ME-9355)
– Mass hanger and mass set
– Wooden or metal stopping block (See Procedure Step ③)

Purpose

The purpose is to verify Newton's Second Law, **F = ma**.

Theory

According to Newton's Second Law, **F = ma**. **F** is the net force acting on the object of mass **m** and **a** is the resulting acceleration of the object.

For a cart of mass $\mathbf{m_1}$ on a horizontal track with a string attached over a pulley to a mass $\mathbf{m_2}$ (see Figure 7.1), the net force **F** on the entire system (cart and hanging mass) is the weight of hanging mass, $\mathbf{F = m_2 g}$, assuming that friction is negligible.

According to Newton's Second Law, this net force should be equal to **ma**, where **m** is the total mass that is being accelerated, which in this case is $\mathbf{m_1 + m_2}$. This experiment will check to see if $\mathbf{m_1 g}$ is equal to $\mathbf{(m_1 + m_2)a}$ when friction is ignored.

To obtain the acceleration, the cart will be started from rest and the time (**t**) it takes for it to travel a certain distance (**d**) will be measured. Then since **d** = (½)at², the acceleration can be calculated using

$$a = \frac{2d}{t^2} \qquad \text{(assuming a = constant)}$$

Procedure

① Level the track by setting the cart on the track to see which way it rolls. Adjust the leveling feet to raise or lower the ends until the cart placed at rest on the track will not move.

② Use the balance to find the mass of the cart and record in Table 7.1.

③ Attach the pulley to the end of the track as shown in Figure 7.1. Place the dynamics cart on the track and attach a string to the hole in the end of the cart and tie a mass hanger on the other end of the string. The string must be just long enough so the cart hits the stopping block before the mass hanger reaches the floor.

④ Pull the cart back until the mass hanger reaches the pulley. Record this position at the top of Table 7.1. This will be the release position for all the trials. Make a test run to determine how much mass is required on the mass hanger so that

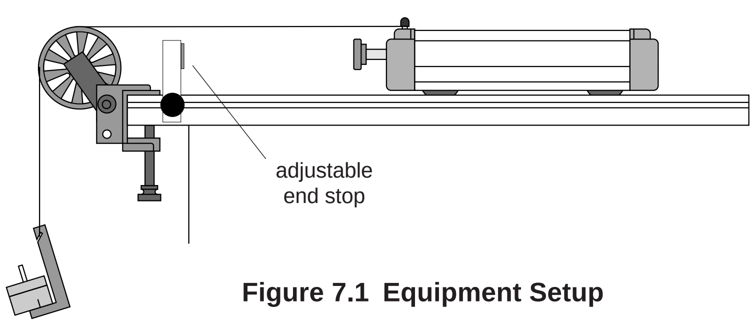


Figure 7.1 Equipment Setup

the cart takes about 2 seconds to complete the run. Because of reaction time, too short of a total time will cause too much error. However, if the cart moves too slowly, friction causes too much error. Record the hanging mass in Table 7.1.

⑤ Place the cart against the adjustable end stop on the pulley end of the track and record the final position of the cart in Table 7.1.

⑥ Measure the time at least 5 times and record these values in Table 7.1.

Table 7.1

Time

Cart Mass	Hanging Mass	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average Time

Initial release Position = ___________________

Final Position = ___________________

Total distance (d) = _________________

⑦ Increase the mass of the cart and repeat the procedure.

Data Analysis

① Calculate the average times and record in Table 7.1.

② Calculate the total distance traveled by taking the difference between the initial and final positions of the cart as given in Table 7.1.

③ Calculate the accelerations and record in Table 7.2.

④ For each case, calculate the total mass multiplied by the acceleration and record in Table 7.2.

⑤ For each case, calculate the net force acting on the system and record in Table 7.2.

⑥ Calculate the percent difference between $\mathbf{F_{NET}}$ and $\mathbf{(m_1+m_2)a}$ and record in Table 7.2.

Table 7.2

Cart Mass	Acceleration	$(m_1+m_2)a$	$F_{NET} = m_2g$	% Diff

Questions

① Did the results of this experiment verify that **F = ma**?

② Considering frictional forces, which force would you expect to be greater: the hanging weight or the resulting total mass times acceleration? Did the results of this experiment consistently show that one was larger than the other?

③ Why is the mass in **F = ma** not just equal to the mass of the cart?

④ When calculating the force on the cart using mass times gravity, why isn't the mass of cart included?

Experiment 8: Acceleration Down an Incline

EQUIPMENT NEEDED:

– Dynamics Cart with Mass (ME-9430)
– Base and Support rod (ME-9355)
– Stopwatch
– Dynamics Cart Track
– Meter stick
– Graph paper

Purpose

The purpose is to study how the acceleration of an object down an incline depends on the angle of the incline and to obtain the acceleration due to gravity.

Theory

A cart on an incline will roll down the incline as it is pulled by gravity. The acceleration due to gravity is straight down as shown in Figure 8.1. The component of gravity which is parallel to the inclined surface is **g sin**θ, so this is the net acceleration of the cart, neglecting friction.

To measure the acceleration, the cart will be started from rest and the time (**t**) it takes for it to travel a certain distance (**d**) will be measured. Then since **d** = (½)at², the acceleration can be calculated using

$$a = \frac{2d}{t^2}$$

Then a plot of acceleration versus sinθ should give a straight line with a slope equal to the acceleration due to gravity, **g**.

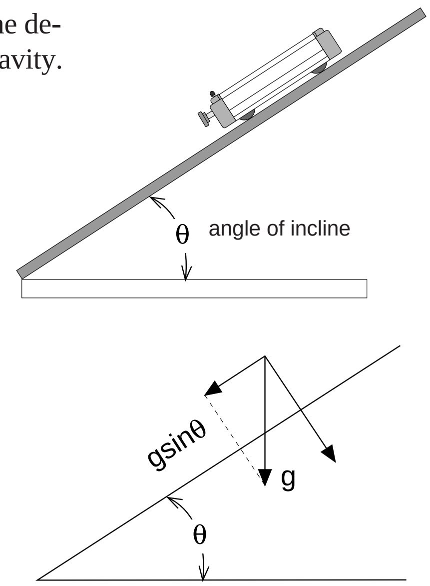


Figure 8.1

Procedure

① Set up the track as shown in Figure 8.2, raising the end of the track without an end stop about 10 cm.

② Set the cart on the track against the end stop and record this final position of the cart at the top of Table 8.1.

③ Pull the cart up to the top of the track and record the initial position where the cart will be released from rest.

④ Release the cart from rest and use the stopwatch to time how long it takes the cart to hit the end stop. The person who releases the cart should also operate the stopwatch. Repeat this measurement 10 times (with different people doing the timing). Record all the values in Table 8.1.

⑤ Lower the end of the track by 1 cm and measure the time 10 times.

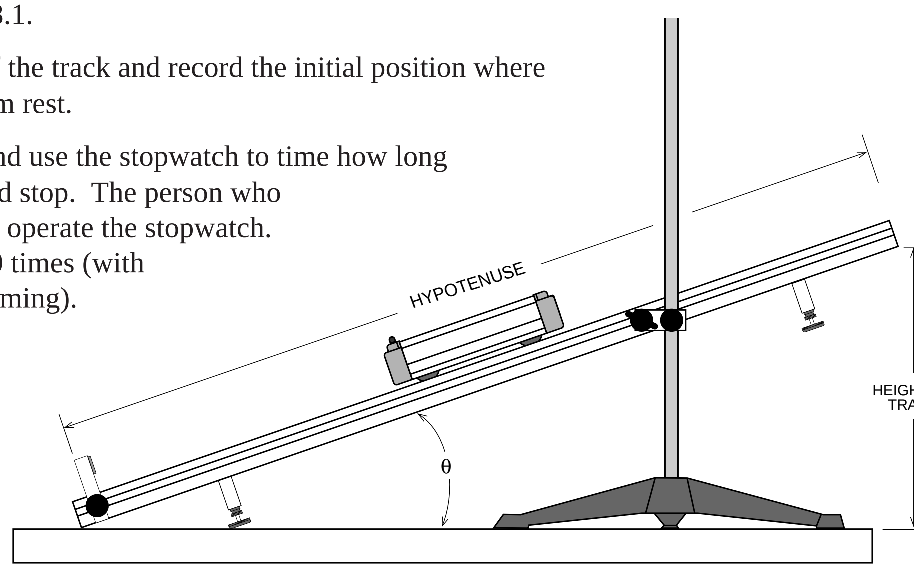


Figure 8.2 Equipment Setup

⑥ Repeat the experiment for a total of 7 angles, lowering the track in increments of 1 cm for each new angle.

Table 8.1

Data Analysis

Height of Track

Time	10 cm	9 cm	8 cm	7 cm	6 cm	15 cm	4 cm
Trial 1							
Trial 2							
Trial 3							
Trial 4							
Trial 5							
Trial 6							
Trial 7							
Trial 8							
Trial 9							
Trial 10							
Average							

Initial Position of Cart = _______________

Final Position of Cart = _______________

Total distance (d) = _______________

① Calculate the average time for each angle.

② Calculate the total distance traveled by taking the difference between the initial and final positions of the cart as given at the top of Table 8.1.

③ Calculate the accelerations using the distance and times and record in Table 8.2.

④ Measure the hypotenuse of the triangle formed by the track and use this to calculate sinθ for each of the heights.

Table 8.2

Height	Acceleration	sin θ

Hypotenuse = ________________

⑤ Plot acceleration versus **sin**θ. Draw the best-fit straight line and calculate its slope. (This slope should equal **g**.) Calculate the percent difference between the slope and **g**.

slope = ______________________

% difference = _______________

Questions

① Does your reaction time cause a greater percentage error for higher or lower angles?

② If the mass of the cart is doubled, how are the results affected? Try it.

Notes:

Experiment 9: Conservation of Energy

EQUIPMENT NEEDED:

– Dynamics Cart with Mass (ME-9430)
– Super Pulley with Clamp
– Base and Support rod (ME-9355)
– String
– Mass balance
– Dynamics Cart Track
– Meter stick
– Mass hanger and mass set (several kilograms)
– Graph paper

Purpose

The purpose is to examine spring potential energy and gravitational potential energy and to show how energy is conserved.

Theory

The potential energy of a spring compressed a distance **x** from equilibrium is given by **PE = (½)kx**^{2}, where **k** is the spring constant. According to Hooke's Law, the force exerted by the spring is proportional to the distance the spring is compressed or stretched, **F = kx**, where **k** is the proportionality constant. Thus the spring constant can be experimentally determined by applying different forces to stretch or compress the spring different distances. When the force is plotted versus distance, the slope of the resulting straight line is equal to **k**.

The gravitational potential energy gained by a cart as it climbs an incline is given by **potential energy = mgh**, where **m** is the mass of the cart, **g** is the acceleration due to gravity, and **h** is the vertical height the cart is raised. In terms of the distance, **d**, along the incline, the height is given by **h = d sin**θ.

If energy is conserved, the potential energy in the compressed spring will be completely converted into gravitational potential energy.

Procedure

① Level the track by setting the cart on the track to see which way it rolls. Adjust the leveling feet to raise or lower the ends until the cart placed at rest on the track will not move.

② Use the balance to find the mass of the cart. Record this value in Table 9.2.

Determining the Spring Constant

③ Set the cart on the track with the spring plunger against the stopping block as shown in Figure 9.1. Attach a string to the cart and attach the other end to a mass hanger, passing the string over the pulley.

④ Record the cart's position in Table 9.1.

⑤ Add mass to the mass hanger and record the new position. Repeat this for a total of 5 different masses.

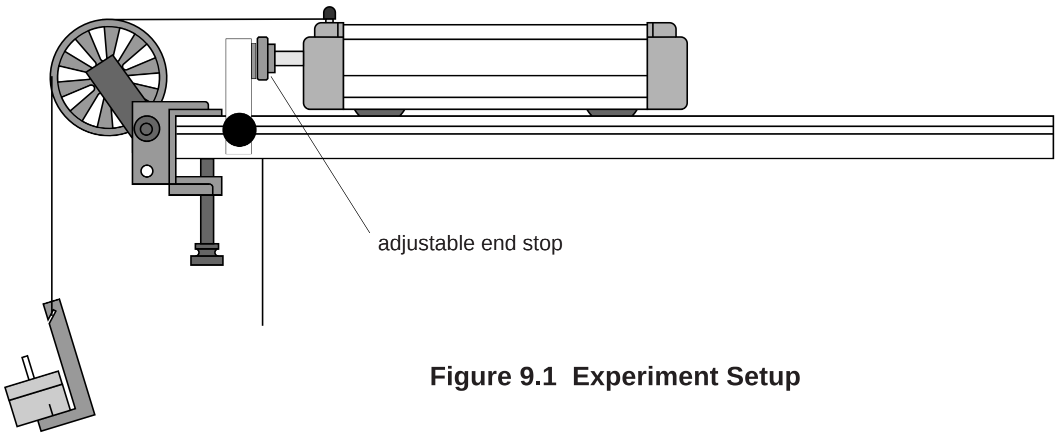


Figure 9.1 Experiment Setup

Table 9.1

Added Mass	Position	Displacement from Equilibrium	Force (mg)

Potential Energy

⑥ Remove the leveling feet.

⑦ Remove the string from the cart and cock the spring plunger to its maximum compression position. Place the cart against the end stop. Measure the distance the spring plunger is compressed and record this value in Table 9.2.

⑧ Incline the track and measure its height and hypotenuse (see Figure 9.2) to determine the angle of the track.

$$\text{angle} = \arcsin\left(\frac{\text{height}}{\text{hypotenuse}}\right)$$

Record the angle in Table 9.2.

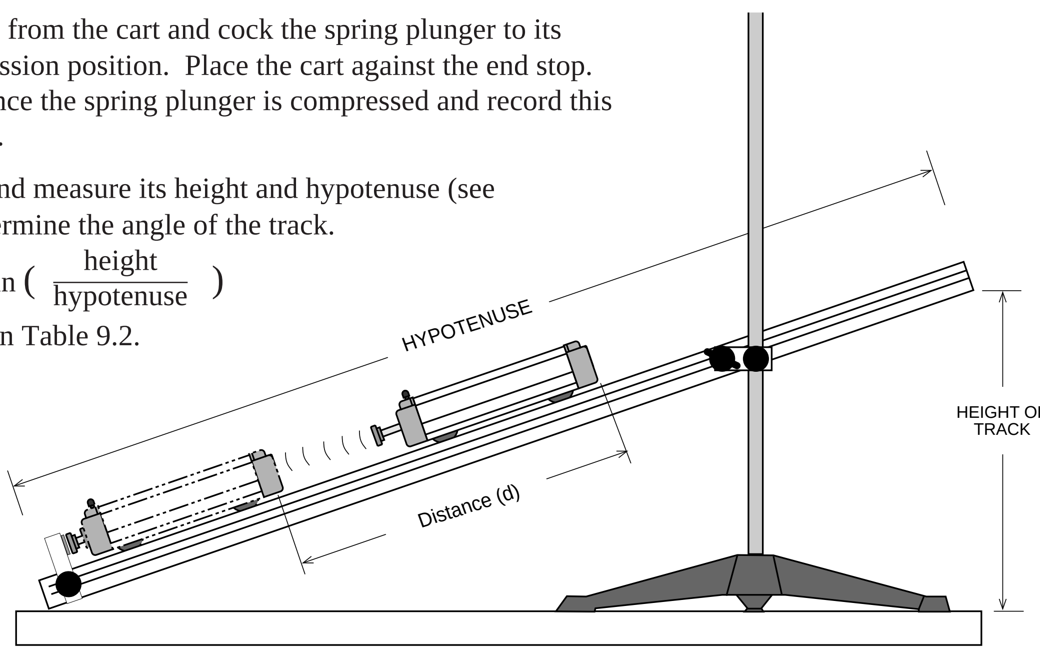


Figure 9.2

⑨ Record the initial position of the cart in Table 9.2.

⑩ Release the plunger by tapping it with a stick and record the distance the cart goes up the track. Repeat this five times. Record the maximum distance the cart went in Table 9.2.

⑪ Change the angle of inclination and repeat the measurements.

⑫ Add mass to the cart and repeat the measurements.

Table 9.2

Distance traveled by the cart (d)

Angle	Mass	Trial 1	2	3	4	5	Max	$h = d \sin\theta$

Distance spring is compressed (x) = _______________

Initial position of cart = ____________________

Data Analysis

① Using the data in Table 9.1, plot force versus displacement. Draw the best-fit straight line through the data points and determine the slope of the line. The slope is equal to the effective spring constant, k.

k = _______________

② Calculate the spring potential energy and record in Table 9.3.

③ Calculate the gravitational potential energy for each case and record in Table 9.3.

④ Calculate the percent difference between the spring potential energy and the gravitational potential energy.

Table 9.3

Angle/Mass	Spring PE ($\frac{1}{2}kx^2$)	Gravitational PE (mgh)	% Difference

Questions

① Which of the potential energies was larger? Where did this “lost” energy go?

② When the mass of the cart was doubled, why did the gravitational potential energy remain about the same?

Notes:

Additional Experiment Suggestions

Experiment 11: Conservation of Center of Mass

Set up the track in the configuration shown in Figure 1.1 in Experiment #1 but instead of putting the track directly on the table, place it on the additional mass bar so that the bar acts as a fulcrum. Position the bar so the carts and track are balanced. First use two carts of equal mass. Press the cocked plunger and watch the carts move to the ends of the track. Since the center of mass of the system does not move, the track will remain balanced.

Then repeat this procedure using carts of unequal mass.

Experiment 12: Oscillation Modes of Two Carts and Three Springs

Place two carts of equal mass on the track. Attach a spring between the two carts and connect each cart to their respective ends of the track with springs. Pull the carts away from each other and release and observe the mode of oscillation. Then displace both carts in the same direction initially and observe.

Add a mass bar to one cart and repeat.

Experiment 13: Newton's Second Law III

Repeat **Experiment 7** with the track inclined so the pulley is on the high end and the cart accelerates up the incline.

Experiment 14: Damped Motion

Incline the track with the end stop at the bottom. Release the cart from a measured distance up the inclined track. The spring plunger should be unlocked and directed toward the bottom of the incline so the cart will rebound. On each rebound, when the cart reaches its peak, record the time and position. A plot of amplitude versus time can be made.

Experiment 15: Rocket Cart with Balloon

Attach an untied inflated balloon to the cart with the neck of the balloon directed out the back of the cart. Let the air propel the cart.

Experiment 16: Oscillation Modes of Three Carts and Four Springs

(For the ME-9459 system)

Place three carts of equal mass on the track. Attach a spring between the carts and connect the end carts to their respective ends of the track with springs.

Displace the two end carts away from the middle cart and release and observe the mode of oscillation.

Displace the two carts on the left away from the cart on the right and release and observe the mode of oscillation.

Displace the middle cart and release and observe the mode of oscillation.

Experiment 17: Multiple Elastic Collisions

(For the ME-9459 system)

Use two Collision Carts and one Dynamics Cart. Try this experiment with carts of the same mass and then with carts of different masses. Set the three carts on the track with the Dynamics Cart on the right end with its magnetic bumper oriented toward the Collision Carts. Push the left Collision Cart into the middle cart, which in turn will collide with the right cart. Note the resulting final velocities of each cart.

Experiment 18: Multiple Inelastic Collisions

(For the ME-9459 system)

Use two Collision Carts and one Dynamics Cart with its magnets removed. Alternatively, two Dynamics Carts and one Collision Cart may be used. Try this experiment with carts of the same

mass and then with carts of different masses. Set the three carts on the track with the carts arranged so that the Velcro bumpers will collide without magnets to push them apart. Push the left cart into the middle cart, which in turn will collide with the right cart. The carts will all stick together. Note the resulting final velocity of the carts.

Experiment 19: Rocket Staging

Use three or more Dynamics Carts (with plungers) to simulate a rocket expelling fuel. Push the plungers in on each cart and attach the carts together in a line on the 7.5' track. Tape can be used to lightly attach the carts to each other or Velcro can be added to the bumpers. Position the carts at one end of the track. The lead cart represents the rocket and the rest of the carts are fuel. Use a meter stick to release the plungers in succession by striking the plunger-release of each cart, beginning with the last fuel cart (furthest from the rocket cart). As each plunger is released, each cart will separate from the rest, one at a time. Note the final speed of the rocket cart compared to its speed when all the fuel is dumped at once.

Experiment 20: Longitudinal Wave

Use six or more Collision Carts on the 7.5 foot track with the adjustable end stops installed at the ends of the track with the magnetic side of the end stops toward the center of the track. Start a longitudinal pulse by displacing one of the carts. The carts will rebound off each other and the end stops. Oscillate the end cart to keep a longitudinal wave going down the track.

Teacher's Guide

Experiment 1: Conservation of Energy in Explosions

Notes on Data Analysis

M1	M2	Position	X1	X2	X1/X2	M2/M1
497.5	500.7	181.0	42.0	41.5	1.01	1.01
497.5	996.4	195.0	56.0	27.5	2.04	2.00
497.5	1494.9	201.5	62.5	21.0	2.98	3.00
995.7	1494.9	189.0	50.0	33.5	1.49	1.50

Answers to Questions

① Momentum is conserved in each case.

② As shown in this lab, the momentum of each cart is the same.

③ $KE_2 = \frac{m_1}{m_2} KE_1$

The lighter cart will have a higher kinetic energy.

④ The starting position does not depend on which cart has the plunger cocked. During the "explosion", the momentum of the carts will be affected by the fact that the plunger is moving at a different velocity than either cart. However, since each plunger eventually ends up moving at the same speed as the cart it is on, there is no difference once the carts are separated.

Experiment 2: Conservation of Momentum in Collisions

➤ **NOTE:** Without some method of actually measuring the velocities of the carts, this lab should be used for qualitative analysis only.

Part I

a. Since the carts have the same mass, they will exchange velocity in each case.

b. The momentum transfer will be proportional to the ratio of the cart masses.

Questions

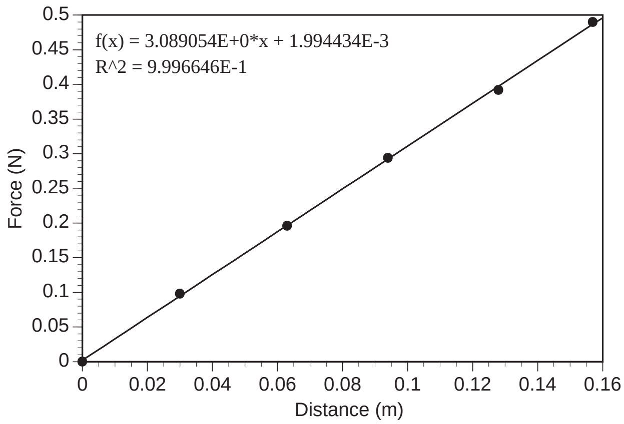
① Each cart loses its momentum. The *total* momentum is unchanged, because the total momentum is zero both before and after the collision.

② The total momentum in this case is still zero both before and after the collision.

Experiment 3: Simple Harmonic Oscillator

Notes on Procedure

⑥ For best results, make sure that the springs are neither over-stretched nor hanging loose. For these tests, we used 10-50g masses only.



Notes on Calculations

① The spring constant k = 3.089 N/m for the springs used here. This value will vary from spring to spring.

② Theoretical values will vary, depending on the value for k and for m. For best results, measure the carts rather than assume their weight to be the stated 500g.

Notes on Comparison

The percent difference between experimental and theoretical values should be less than 2%, and it is not unusual to obtain errors of less than 0.5%.

Notes on Questions

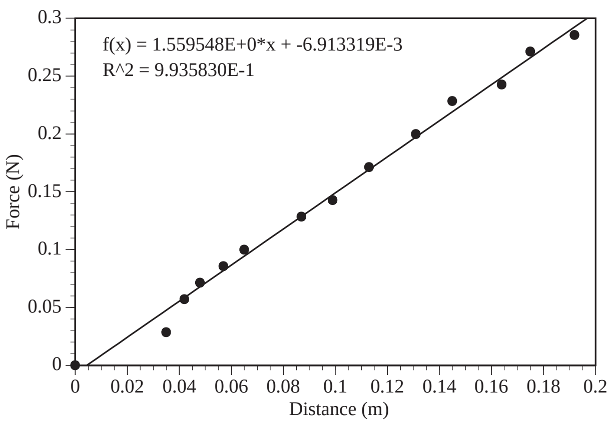
① The period of oscillation increases with mass. The more massive cart oscillates slower.

② The period is not changed, as long as the initial displacement does not exceed the linear region of the spring. You will notice a slight difference if the displacement is enough to permanently deform the spring.

Experiment 4: Oscillations on an Incline

Notes on Procedure

The angle of inclination of the track should be between 5 and 15° for best results. You may want to measure the spring constant by hanging masses directly from the spring (vertically) without the cart. This is a better method than the one described in the experiment guide.



Notes on Calculations

① The spring constant k = 1.5595 for the spring tested here. Actual spring constant will vary, although it should be close to 1.5 for the springs supplied with this apparatus.

② Theoretical values will vary, depending on the value for k and for m. For best results, measure the carts rather than assume their weight to be the stated 500g.

Notes on Questions

① The period does not vary significantly as the angle changes. There is some variation due to nonlinearity in the spring; as the spring is extended at greater angles, the force "constant" is not constant. The contribution due to friction changes with angle, as well.

② The experimental results should agree with theory to within 2%, although it is not unusual to find agreement within less than 1%.

③ The equilibrium position changes as the angle is changed.

④ The period would be the same at 90°, as long as the spring was not overstretched. NOTE: hanging the PASCO dynamics cart from the spring supplied with this equipment will overextend the spring.

Experiment 5: Springs in Series and Parallel

Notes

Keep the angle of the track low, especially if you are using a short (1.2m) track. Otherwise, the carts will go off the end of the track when the springs are in series.

Notes on Calculations

The two springs used for this experiment had spring constants of 1.53 and 1.60.

- In series, the spring constant was 0.76. (k/2)
- In parallel, the spring constant was 3.12 (2k)
- The spring constant was 3.06 (2k) when the springs were attached to the ends of the cart.

Notes on Questions

① The effective spring constant is 2k for springs in parallel.

② The effective spring constant is k/2 for springs in series.

③ The springs are effectively in parallel when they are attached to opposite ends of the cart.

Experiment 6: Newton's Second Law

This lab is intended to be a qualitative lab only. For a quantitative analysis of Newton's second law, see experiment 7.

Notes on Data Analysis

① Acceleration increases with force

② Acceleration decreases with mass.

Notes on Questions

F = ma

Experiment 7: Newton's Second Law II

If the mass used to accelerate the cart is too low, friction will be a very significant source of error. If it is too high, then the time will be short and accurate measurement will be difficult. It would be best for this lab to use a photogate timing system, such as the PASCO ME-9215.

Notes on Questions

① The results of this experiment generally show that F = ma. Errors can be high, due to friction and timing inaccuracy.

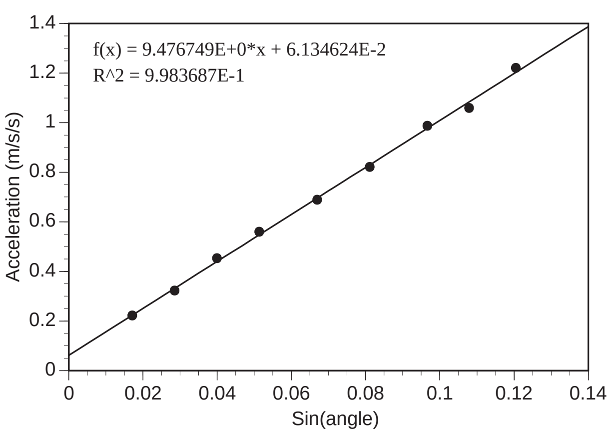
② The force of the hanging weight is larger than the total mass times acceleration. The difference between the two is the force of friction.

③ The hanging mass is accelerating at the same rate as the cart, so its mass must be considered as well as that of the cart.

④ The cart is on a level track, so it is not accelerated by gravity.

Experiment 8: Acceleration Down an Incline

Data Analysis



The value of the slope will be slightly lower than 9.8, due to friction. (Our value 3.3% low.)

Notes on Questions

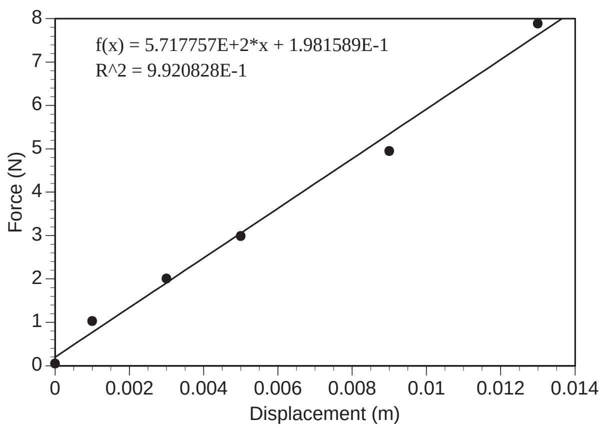
① Assuming that reaction time relatively constant, the percent error due to reaction time would be greater for shorter times and higher angles.

② Changing the mass of the cart will affect the results slightly due to changing frictional characteristics.

Experiment 9: Conservation of Energy

Analysis

①



Notes on Questions

① The initial spring potential energy is larger. (Generally. There are experimental errors, which can make the gravitational energy appear larger than the initial spring potential.) The "lost" energy goes into friction.

② Why not? The increased mass will mean that the cart does not travel as high, but the final gravitational potential energy will be the same.

②-④

k = 572 Spring PE = 0.193336

Angle	Mass	dmax (cm)	h (m)	mgh	%diff
14.57	0.4971	15.1	0.0380	0.1851	-4.28%
11.07	0.4971	19.5	0.0374	0.1824	-5.66%
11.07	0.9926	10.1	0.0194	0.1886	-2.43%
3.026	0.9926	39.0	0.0206	0.2003	3.58%
3.026	0.4971	75.1	0.0396	0.1931	-0.11%

Technical Support

Feed-Back

If you have any comments about this product or this manual please let us know. If you have any suggestions on alternate experiments or find a problem in the manual please tell us. PASCO appreciates any customer feed-back. Your input helps us evaluate and improve our product.

To Reach PASCO

For Technical Support call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

Contacting Technical Support

Before you call the PASCO Technical Support staff it would be helpful to prepare the following information:

• If your problem is computer/software related, note:

Title and Revision Date of software.

Type of Computer (Make, Model, Speed).

Type of external Cables/Peripherals.

• If your problem is with the PASCO apparatus, note:

Title and Model number (usually listed on the label).

Approximate age of apparatus.

A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.)

If possible, have the apparatus within reach when calling. This makes descriptions of individual parts much easier.

• If your problem relates to the instruction manual, note:

Part number and Revision (listed by month and year on the front cover).

Have the manual at hand to discuss your questions.

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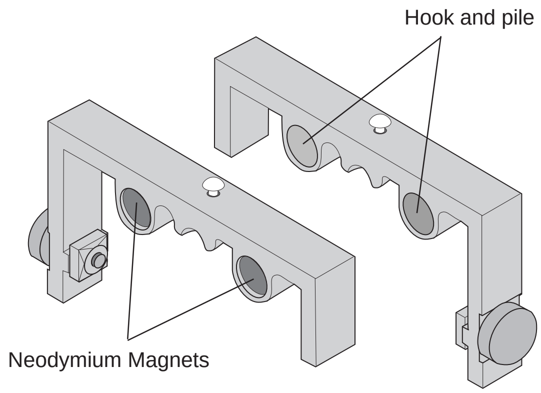
***Instruction Sheet
for the PASCO
Model ME-9469***

ADJUSTABLE END STOP



Introduction

The PASCO Model ME-9469 Adjustable End Stop is designed for use as an accessory to any PASCO Dynamics Track or Introductory Dynamics System.

When used with the magnetic Collision Cart or the optional magnets in the Dynamics Cart end caps the End Stop functions as an elastic collision bumper. It becomes an inelastic bumper in experiments where the hook and pile tabs on the cart contact those of the End Stop. The End Stop can also be used as a solid bumper for the
ME-9430 Dynamics Cart plunger.

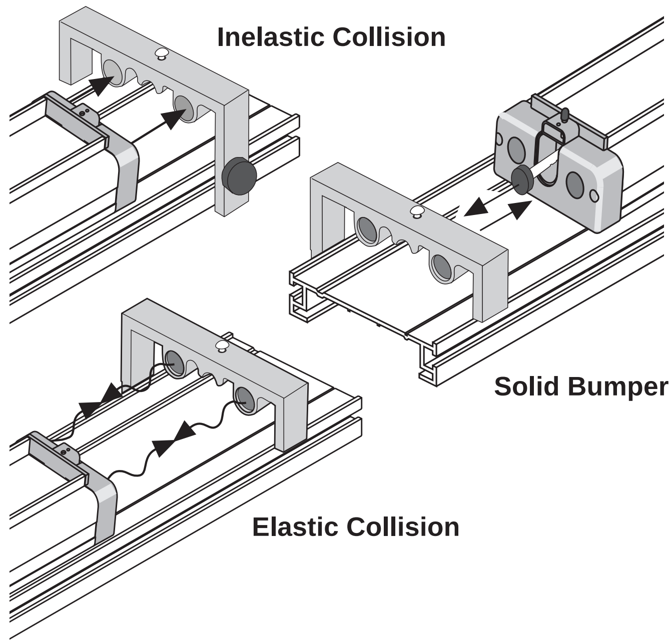
Additional Equipment Required:

- Dynamics Cart Track, such as Model ME-9434 or ME-9435
- Dynamics Cart, such as Model ME-9430

Additional Equipment Recommended:

- Collision Cart, such as Model ME-9454

> ➤ **CAUTION:** The Adjustable End Stop contains two neodymium magnets. Keep this equipment away from any magnetic media.



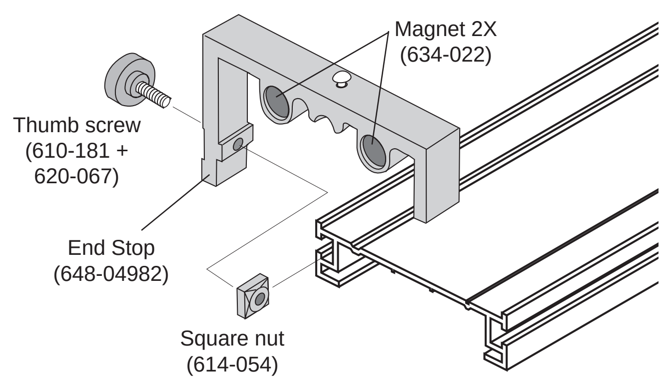
Setup procedure

① Loosen the thumbscrew of the Adjustable End Stop.

② Align the square nut within the groove on the desired side of the Dynamics Cart Track.

> ➤ **NOTE:** The flat side of the square nut must face the outside of the Dynamics Cart Track as shown.

③ Locate the End Stop over the desired position and tighten the thumbscrew.



PASCO® scientific
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Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

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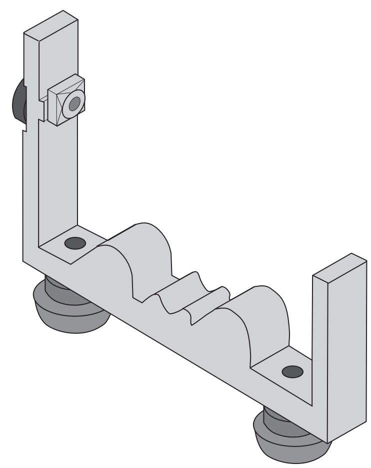
Instruction Sheet for the PASCO Model ME-9470

ADJUSTABLE DYNAMICS TRACK FOOT



Introduction

The PASCO Model ME-9470 Adjustable Dynamics Track Foot is designed for use as an accessory to any PASCO Dynamics Track or Introductory Dynamics System.

The Adjustable Dynamics Track Foot allows for a greater range of adjustment and stability when performing experiments. It also permits the user to level the track by raising or lowering the appropriate end. It may be used in addition to or instead of the existing fixed foot that is supplied as standard equipment on either the ME-9434 or ME-9435 Dynamics Tracks.

Additional Equipment Required:

- Dynamics Cart Track, such as Model ME-9434 or ME-9435
- Dynamics Cart, such as Model ME-9430

Additional Equipment Recommended:

- Collision Cart, such as Model ME-9454

Setup procedure

① Remove the existing fixed foot from the end of the dynamics track.

② Loosen the thumbscrew on the Adjustable Dynamics Track Foot.

③ With the leveling feet aiming away from the underside of the track slide the square nut of the adjustable foot into the slot on the side of the track.

> ➤ **NOTE:** The flat side of the square nut must face the outside of the Dynamics Cart Track as shown.

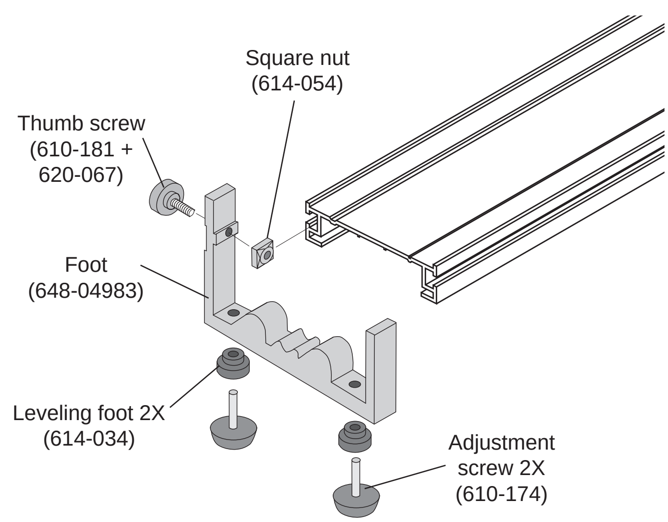
④ Position the foot as desired.

⑤ Retighten the thumbscrew.

⑥ Set the leveling feet for stability at the desired height.

⑦ Tighten the stabilizer nuts against the underside of the foot.

> ➤ **NOTE:** The adjustable foot need only be removed when it is desirable for accessories to be added into the same slot in which the adjustable foot is installed.



Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

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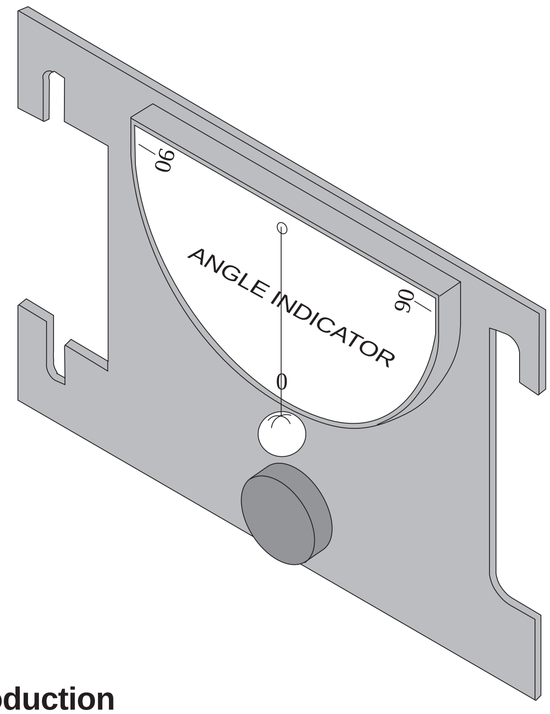
Instruction Sheet for the PASCO Model ME-9495

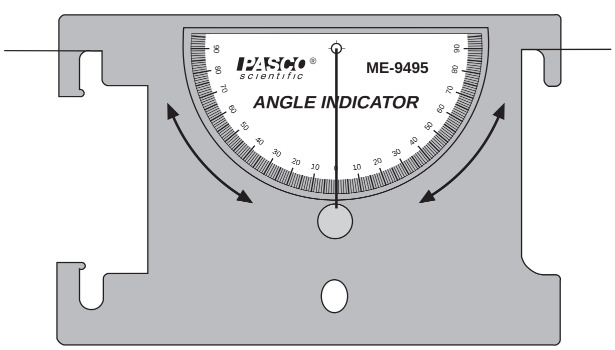
ANGLE INDICATOR



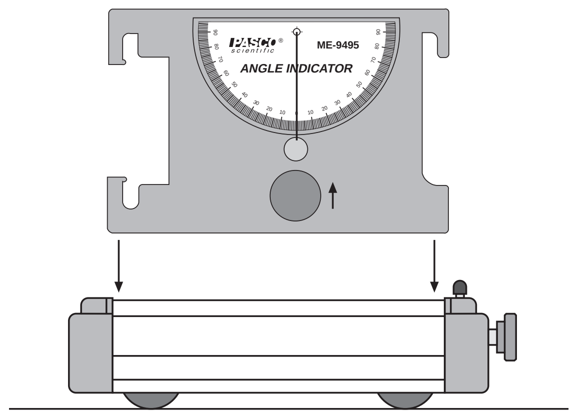
Introduction

The PASCO ME-9495 Angle Indicator is an accessory used for measuring angles from 0° to 90° in two directions. There are four different methods of using the Angle Indicator:

- hand-held, by tying a string to each side of the device.

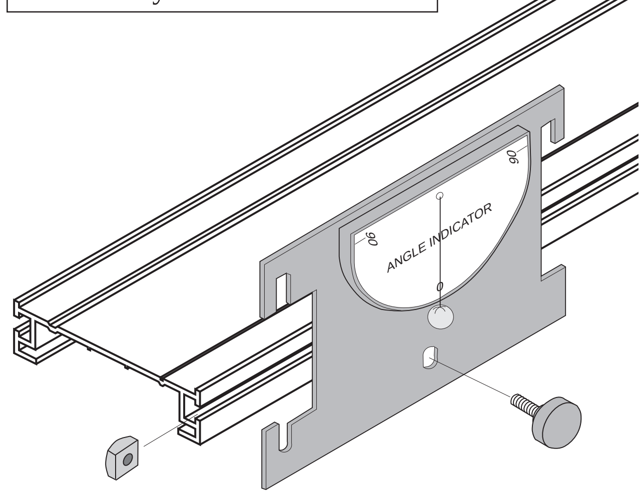


- attached to a PASCO Dynamics Cart, by sliding the device into the slots on the top of the cart. It is necessary to adjust the thumbscrew and square nut as far up as possible on the Angle Indicator.



- attached to the side of a PASCO Dynamics Track.

➤**NOTE:** To store the Angle Indicator, slide it in the slots underneath the Dynamics Track.



This instruction sheet written/edited by:

PASCO scientific ®
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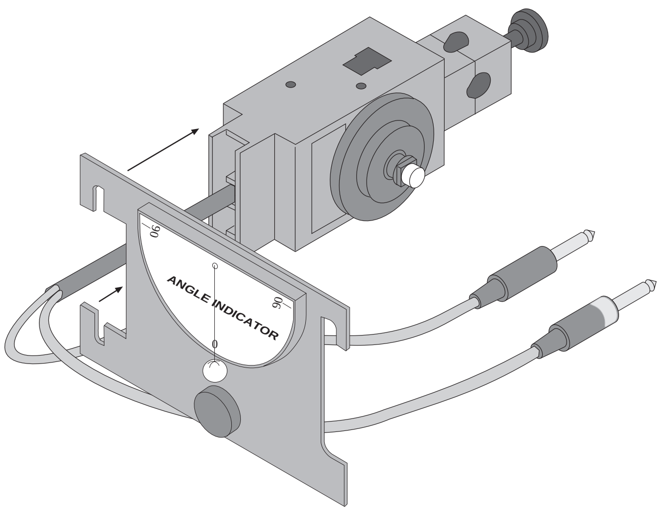
- slipped over the platform on the PASCO CI-6538 Rotary Motion Sensor.



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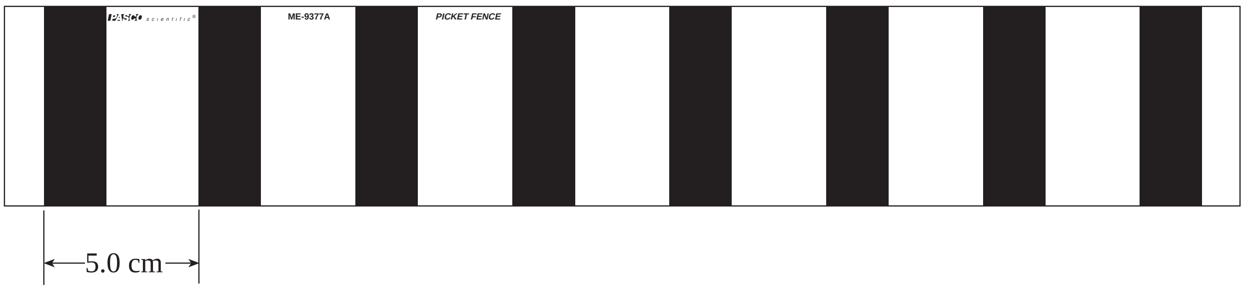
Instruction Sheet for the PASCO Model ME-9377A

012-04083B
12/96
$1.00

PICKET FENCE



Introduction

The PASCO Model ME-9377A Picket Fence is a rectangular piece of clear plastic with evenly spaced opaque bands. It is designed to be used with a photogate for measuring motion.

The edges of the opaque bands are 0.050 meters (5.0 centimeters) apart.

Additional Equipment Needed

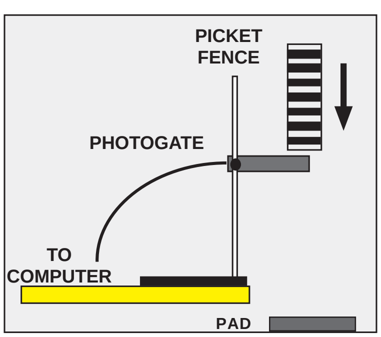
- Photogate
- Computer Interface such as the *ScienceWorkshop*™ 500 or 700 Interface or the Series 6500 Interface

or

- Game Port Interface or Game Port Adapter Cable

Operation

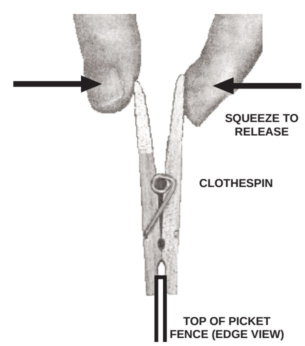
When performing free fall measurements, place a soft pad so it can cushion the fall of the Picket Fence.



➤ Note: For best results, drop the Picket Fence through the photogate vertically. If the Picket Fence is not vertical, the effective distance between the opaque bands may not be 5.0 centimeters.

➤ When releasing the Picket Fence for a free fall measurement, hold the Picket Fence at the top edge between your thumb and forefinger

➤ Hint: You can use a spring-loaded clothes pin or small binder clip to hold the end of the picket fence. Squeeze the pin or clip to release the picket fence.



⚠ Note: Handle the picket fence with care. Do not scratch the surface.

Author: Dave Griffith

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When returning equipment for repair, the units must be packed properly. Carriers will not accept responsibility for damage caused by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

① The packing carton must be strong enough for the item shipped.

② Make certain there are at least two inches of packing material between any point on the apparatus and the inside walls of the carton.

③ Make certain that the packing material cannot shift in the box or become compressed, allowing the instrument come in contact with the packing carton.

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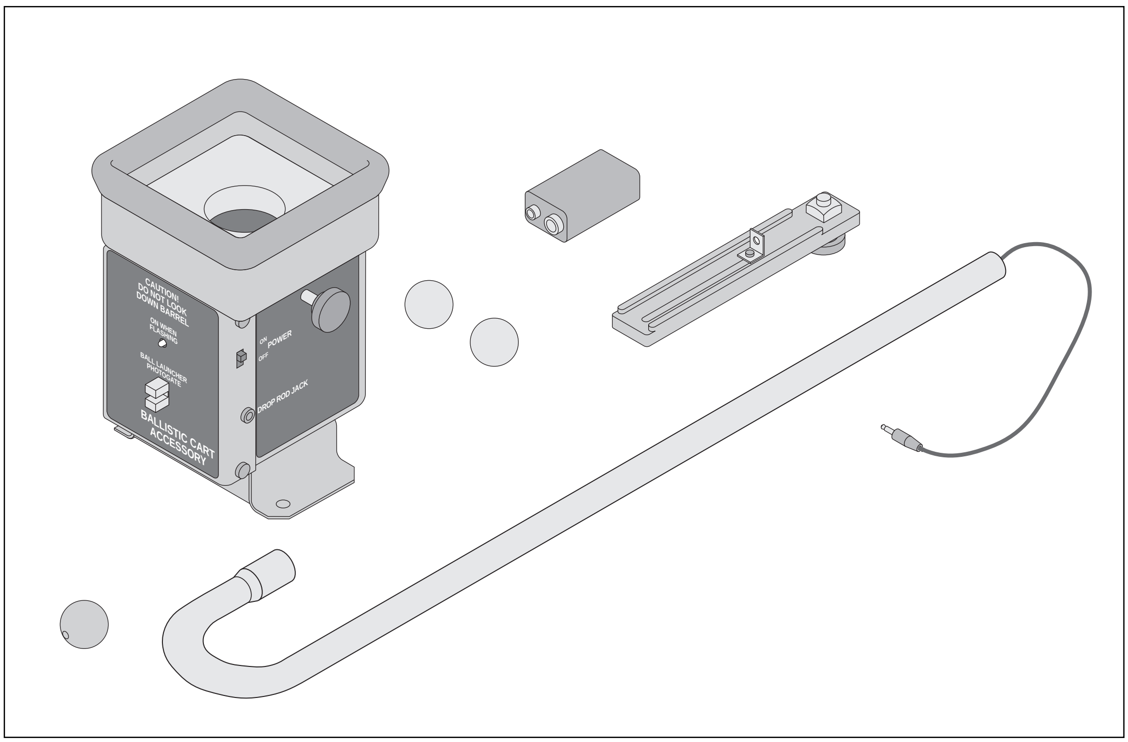
Instruction Manual and Experiment Guide for the PASCO scientific Model ME-9486

012-05460A
7/94

BALLISTIC CART ACCESSORY



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Credits

This manual authored by: Jon Hanks and Eric Ayars

Equipment Return

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➤ **NOTE:**
NO EQUIPMENT WILL BE ACCEPTED FOR RETURN WITHOUT AN AUTHORIZATION.

When returning equipment for repair, the units must be packed properly. Carriers will not accept responsibility for damage caused by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

① The carton must be strong enough for the item shipped.

② Make certain there is at least two inches of packing material between any point on the apparatus and the inside walls of the carton.

③ Make certain that the packing material can not shift in the box, or become compressed, thus letting the instrument come in contact with the edge of the box.

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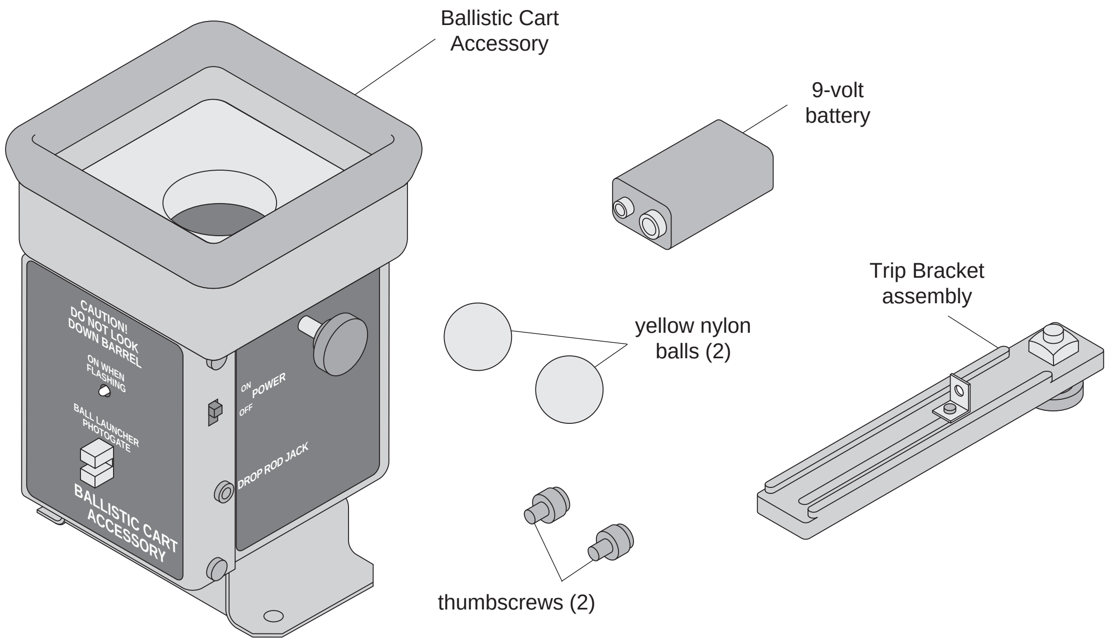
Introduction

The PASCO ME-9486 Ballistic Cart Accessory is used with the PASCO Dynamics Cart and track (ME-9429A or ME-9452) to shoot a plastic ball straight up from the moving cart. If the cart is moving at a constant velocity, the ball will fall back into the catcher on the cart. The ball is released using a photogate so there is no impulse given to the cart upon release as there is in other models which used a string to release the ball. The barrel can be aimed to ensure that the ball is shot vertically. Special no-bounce foam prevents the ball from bouncing back out of the catcher cup.

The PASCO ME-9487 Drop Rod Accessory can be mounted to the Ballistic Cart Accessory so a special plastic ball can be dropped from rest (relative to the cart) above the moving cart. Also the drop rod can be rotated away from the cart so the ball will drop onto the floor to perform bombing runs.

➤ NOTE: It is better to use a 2.2 m track (ME-9452) rather than the 1.2 m track (ME-9429A) because it gives you more room to work.

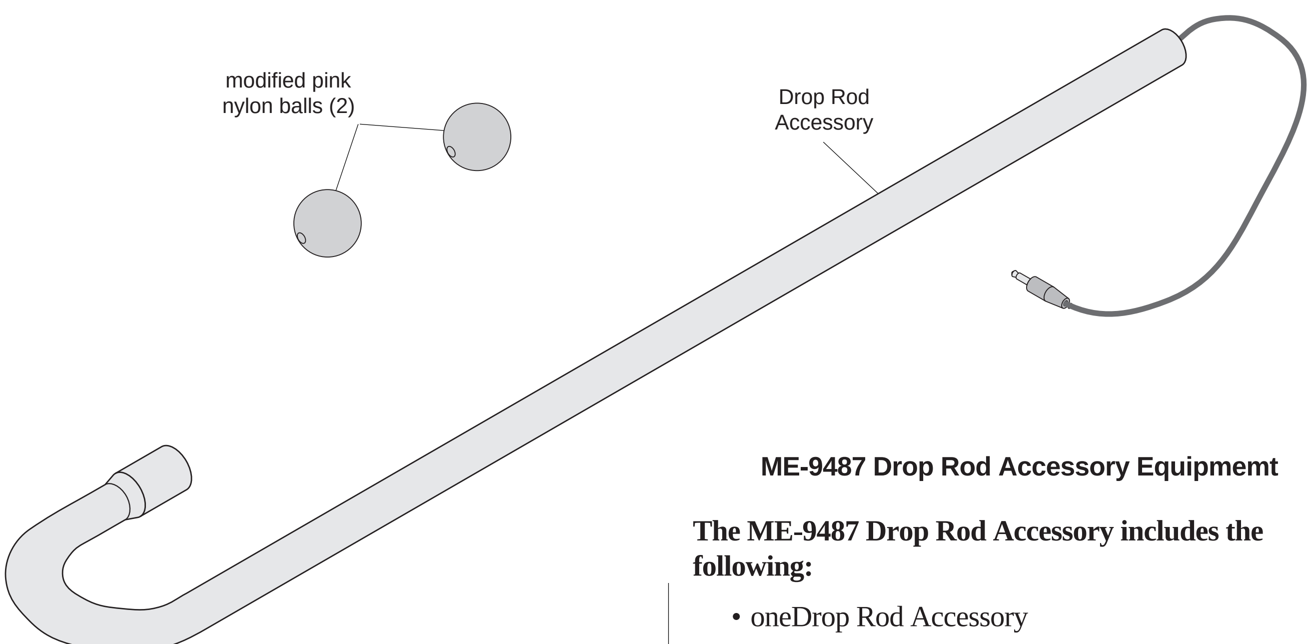
Equipment



ME-9486 Ballistic Cart accessory Equipment

The ME-9486 Ballistic Cart Accessory includes the following:

- one Ballistic Cart Accessory
- one Trip Bracket assembly
- one 9-volt battery
- two yellow nylon balls
- two thumbscrews



ME-9487 Drop Rod Accessory Equipmemt

The ME-9487 Drop Rod Accessory includes the following:

- oneDrop Rod Accessory
- two modified pink nylon balls

Assembly

ME-9486 Ballistic Cart Accessory

Battery Installation

① Turn the unit on its side and install the 9-volt battery in the bottom of the unit. See Figure 1.

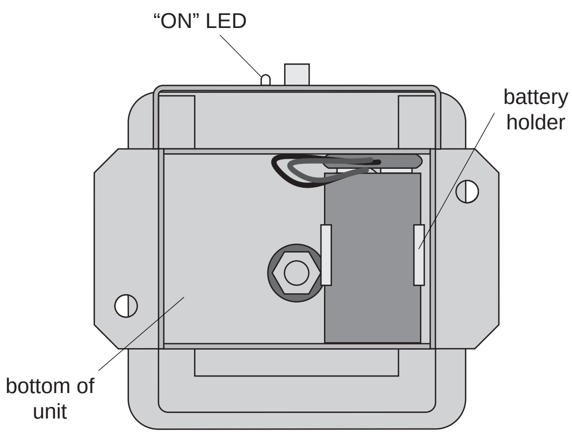


Figure 1: Battery Installation

Attaching the Ballistic Cart Accessory to a Dynamics Cart

① Remove the two mounting screws (see Figure 2) from their storage place on the side of the unit. (There are two extra screws included with the Ballistic Cart Accessory.) Use these screws to attach the Ballistic Cart Accessory to the mass tray of the dynamics cart.

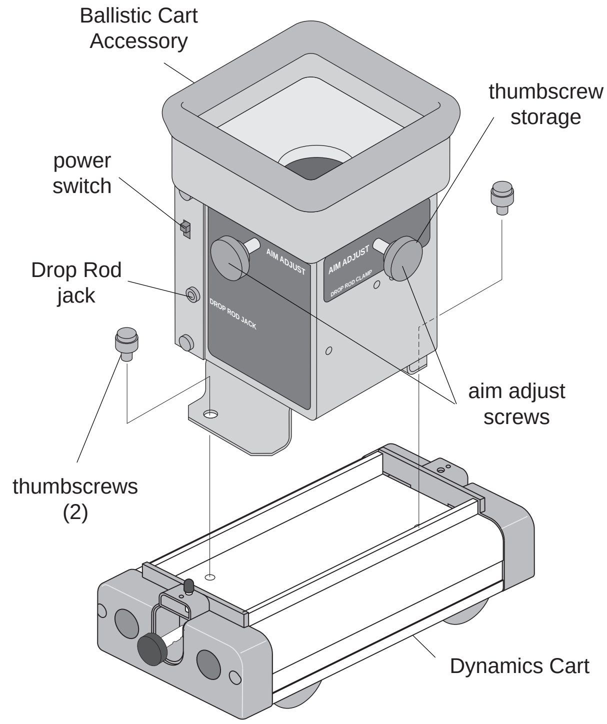
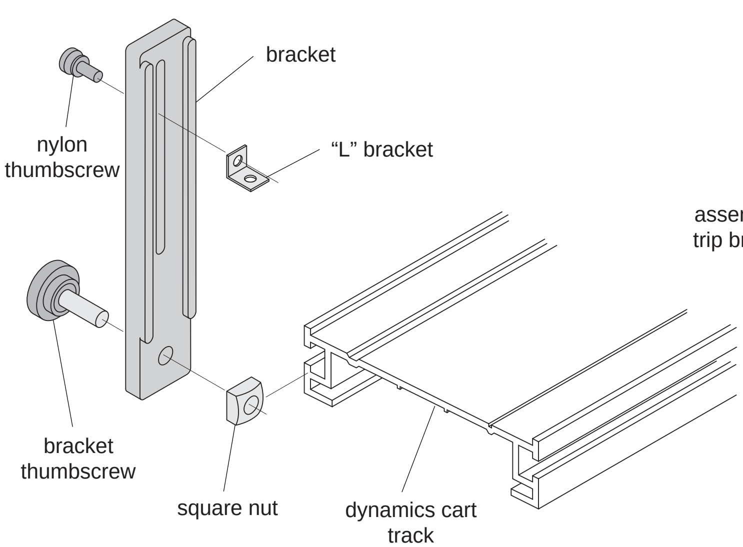


Figure 2: Ballistic Cart Installation

② Slide the photogate trip bracket into the T-slot on the dynamics track. See Figure 3.



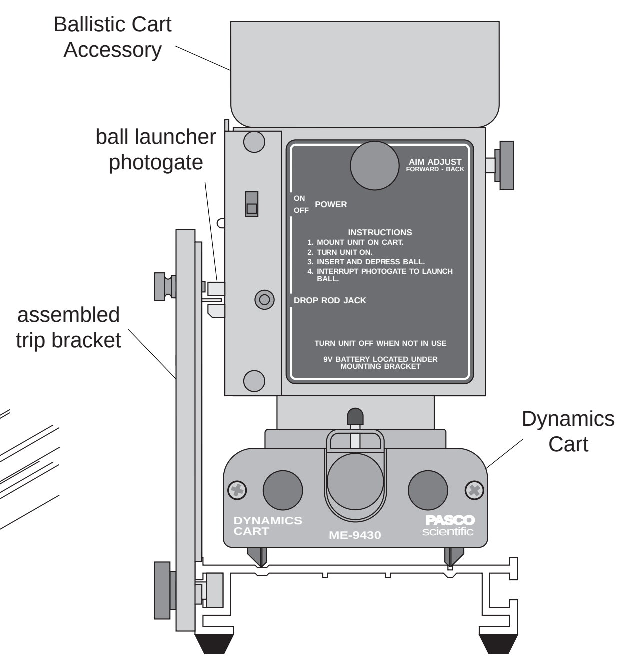


Figure 3: Using the Trip Bracket

Setting Up the Ballistic Cart Accessory

① Move the aim adjusting screws (see Figure 2) in and out to check that the barrel moves freely. Do this by looking down the barrel while adjusting the screws. If the barrel sticks it is because the foam catches it. To remedy this, gently lift up slightly on the edges of the foam to unstick it from the barrel.

② Level the dynamics track. To check if the track is level, place the cart on the track and give it a small push in one direction. Then push it in the opposite direction to see if the cart rolls easier in one direction than the other. Also make the track level from side-to-side by placing the plastic ball at rest on the track to see if it rolls one way or the other.

③ With the cart at rest on the level track, adjust the aim adjust screws until the ball shoots straight up and lands back in the catcher cup. Use a penny or dime to trip the photogate when the cart is at rest. Remember, the power switch must be turned on before the trip switch will operate. The LED will blink while the power is on. Also remember to turn the power switch off before storing the accessory.

➤ **NOTE:** The trip switch must be mounted on the same side as the photogate on the Ballistic Cart. See Figure 3.

ME-9487 Drop Rod Accessory

Drop Rod Installation

① Use the $1^1/_2$ inch metal screws to fasten the drop rod clamp to the side of the Ballistic Cart Accessory. See Figure 4. Screw the thumb screw into the end of the drop rod clamp.

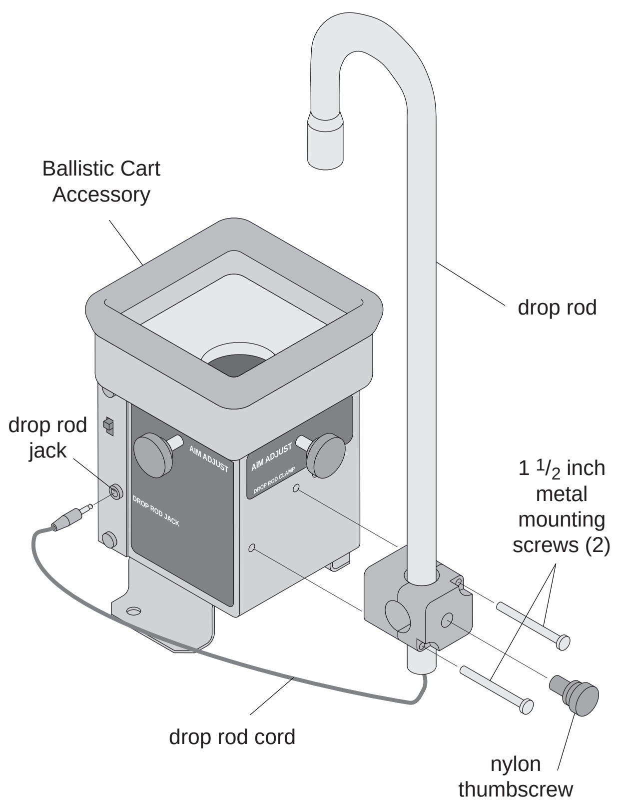


Figure 4: Drop Rod Installation.

② Thread the cord from the drop rod through the drop rod clamp and clamp the end of the drop rod by tightening the thumb screw.

➤ **CAUTION:** Do not over-tighten the screw or the tube may be crushed.

③ Plug the drop rod cord into the drop rod jack on the side of the Ballistic Cart Accessory.

➤ **NOTE:** Plugging this cord in disables the launching mechanism of the Ballistic Cart Accessory so when you want to use the launcher you must unplug the drop rod accessory.

④ Note that the Drop Rod Accessory requires a special ball that has an iron insert. The balls for the Drop Rod Accessory and the Ballistic Cart Accessory are different colors so they can be easily distinguished. To hang the ball from the drop rod, the pin on the drop rod must be inserted into the small hole in the ball. See Figure 5.

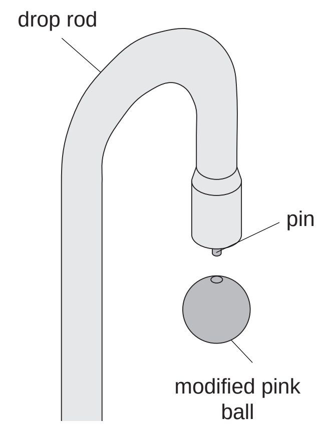


Figure 5: Ball and Drop Rod

Experiment 1: Shoot and Catch - Demonstration

EQUIPMENT NEEDED

– Ballistic Cart Accessory (ME-9486)
– Dynamics Cart and track (ME-9452)

Purpose

This demonstration shows that when the ball is shot vertically upward from the cart while the cart is moving at any constant speed, the ball will land back in the cart.

Procedure

① Prior to the beginning of the demonstration, perform the Setup procedure.

② With the cart at rest on the track, load the ball and trip the release mechanism with a penny or other opaque object. This proves to the students that the ball is being launched straight up.

③ Put the photogate trip bracket near one end of the track, leaving enough room to push the cart up to its maximum speed before it reaches the trip bracket. See Figure 1.1. Load the ball and start the cart from that end of the track by giving the cart a gentle push. The cart will move slowly and the ball will be caught.

④ Return the cart to the end of the track. Load the ball and give the cart a stronger push.

➤ **CAUTION!** You must catch the cart with your hand before the cart reaches the end stop on the track because the cart will derail when it's moving fast. The ball will be caught at any cart speed.

➤ **NOTE:** If you have the Drop Rod Accessory, try putting it on the Ballistic Cart Accessory to act as a reference line. With this reference line, the ball appears to go straight up and down. Without the reference, the ball may appear to go in a parabola.

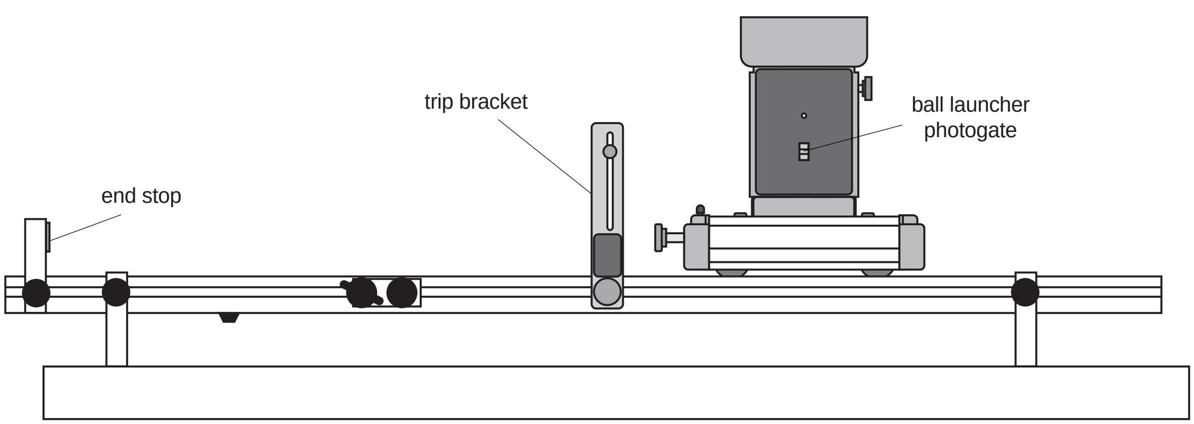


Figure 1.1: Setup for Shoot and Catch

Notes:

Experiment 2: Tunnel - Demonstration

EQUIPMENT NEEDED

– Ballistic Cart Accessory (ME-9486)
– Dynamics Cart and track
– Cardboard box (33 cm {13"} cube) for tunnel (construction details given below)

Purpose

This demonstration shows that the ball can be caught by the cart even if the cart passes through a tunnel while the ball is in the air. The tunnel accentuates the parabolic path of the ball.

Procedure

① Prior to the beginning of the demonstration, perform the Setup procedure.

② Construct a tunnel from a cardboard box: Cut the flaps off two opposing ends of the box. Cut a 15 cm wide, 27 cm high hole in these two opposing ends of the box. See Figure 2.1.

③ Set the box upside-down over the middle of the dynamics track. Check the clearance by running the cart through the tunnel.

④ Position the photogate trip bracket in front of the tunnel so the ball will be launched just before the cart enters the tunnel.

⑤ Load the ball and push the cart toward the tunnel. You may have to practice to get the right speed so the cart will make it through the tunnel before the ball comes down.

➤ **CAUTION!** You must catch the cart with your hand before the cart reaches the end stop on the track because the cart will derail when it's moving fast.

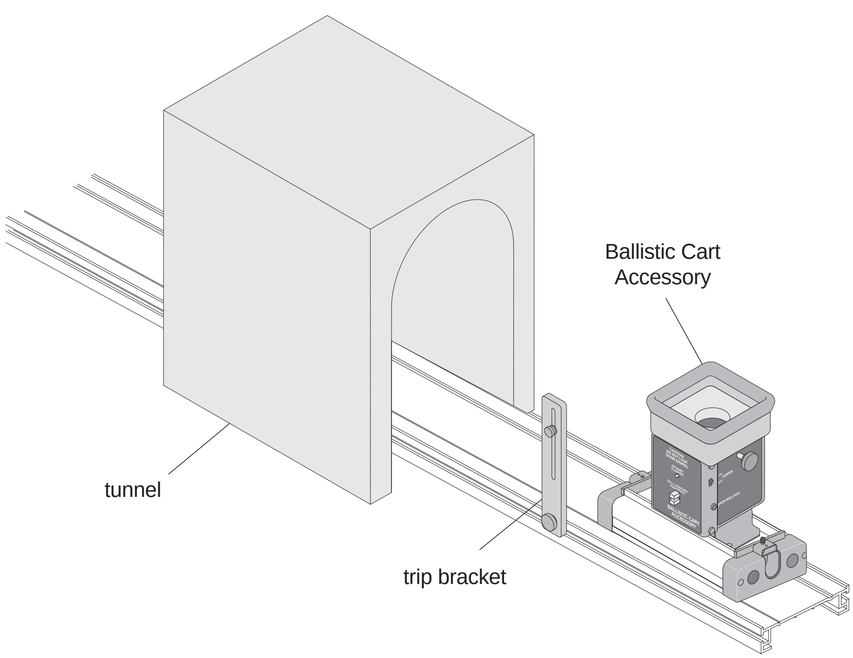


Figure 2.1: Tunnel

Notes:

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Experiment 3: Accelerating Cart - Demonstration

EQUIPMENT NEEDED

– Ballistic Cart Accessory (ME-9486)
– Dynamics Cart and track
– String
– Clamp-on pulley
– 50 gram mass and mass hanger

Purpose

This demonstration shows that when the ball is shot vertically upward from the cart while the cart is accelerating, the ball will not land in the cart.

Procedure

① Prior to the beginning of the demonstration, perform the Setup procedure.

② Clamp the pulley to the end of the track. Attach a string (about 1 meter long) to the cart and pass it over the pulley. Hang about 50 grams on the string. See Figure 3.1.

③ Put the photogate trip bracket in a position where it will launch the ball after the cart has begun to move.

④ Start the cart as far back as possible, load the ball, and let it go. In this case, the ball will fall behind the cart.

➤ **CAUTION!** You must catch the cart with your hand before the cart reaches the end stop on the track because the cart will derail when it's moving fast.

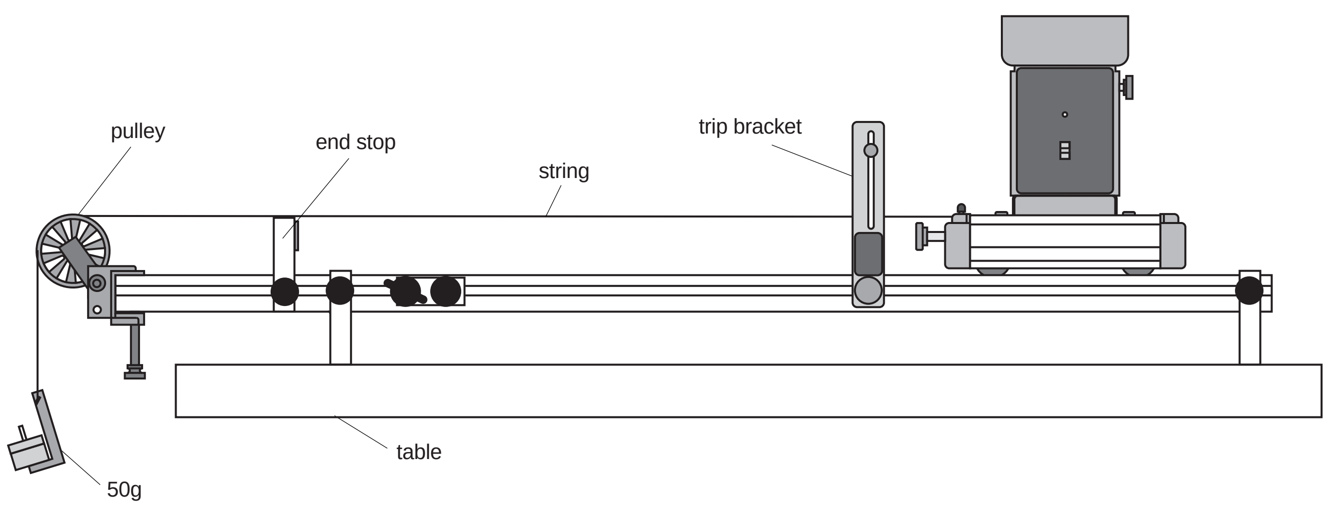


Figure 3.1: Accelerating Cart.

Notes:

Experiment 4: Inclined Plane - Demonstration

EQUIPMENT NEEDED

– Ballistic Cart Accessory (ME-9486)
– Dynamics Cart and track
– Table clamp and rod
– Rod clamp for dynamics track

Purpose

This demonstration shows that a ball launched from a cart that is accelerating down an inclined plane will be caught by the cart regardless of the angle of incline.

Procedure

① Prior to the beginning of the demonstration, perform the Setup procedure.

② Incline the track using the table clamp and rod. See Figure 4.1. Be careful not to choose too high an angle because the cart will reach such a high speed that it will crash at the bottom. For any angle you choose, be sure you catch the cart at the bottom to keep it from derailing and crashing to the floor.

③ Put the photogate trip bracket in a position where it will launch the ball after the cart has begun to move.

④ Start the cart at the top of the incline, load the ball, and release the cart. The ball will land in the cart.

➤ **CAUTION!** Remember to catch the cart!

⑤ Repeat the demonstration for a different angle.

⑥ Start the cart at the bottom of the incline. Give the cart a push uphill so that it travels past the trip bracket.

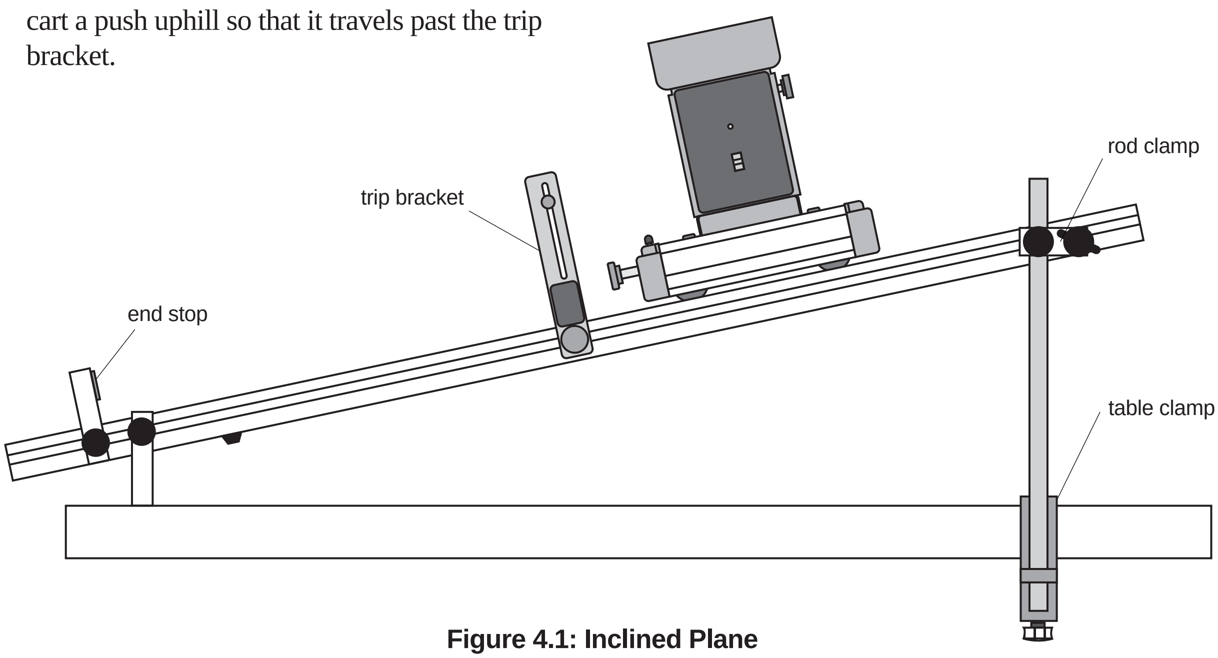


Figure 4.1: Inclined Plane

Notes:

Experiment 5: Drop Ball - Demonstration

EQUIPMENT NEEDED

– Ballistic Cart Accessory (ME-9486)
– Dynamics Cart and track
– Drop Rod Accessory (ME-9487)

Purpose

The purpose of this demonstration is to show that when the ball is dropped from the drop rod while the cart is moving at any constant speed, the ball will land in the cart.

Procedure

① Prior to the beginning of the demonstration, perform the Setup procedure.

② Position the drop rod so that the ball will be directly over the cup. See Figure 5.1.

③ With the cart at rest on the track, hang the ball on the drop rod and trip the release mechanism with a penny or other opaque object. This shows the students that the ball is drops straight down and is caught by the cart.

④ Put the photogate trip bracket near one end of the track, leaving enough room to push the cart up to its maximum speed before it reaches the trip bracket. Hang the ball from the drop rod and give the cart a gentle push.

⑤ Return the cart to the end of the track. Hang the ball from the drop rod and give the cart a stronger push. The ball will be caught at any cart speed.

➤ **CAUTION!** You must catch the cart with your hand before the cart reaches the end stop on the track because the cart will derail when it's moving fast.

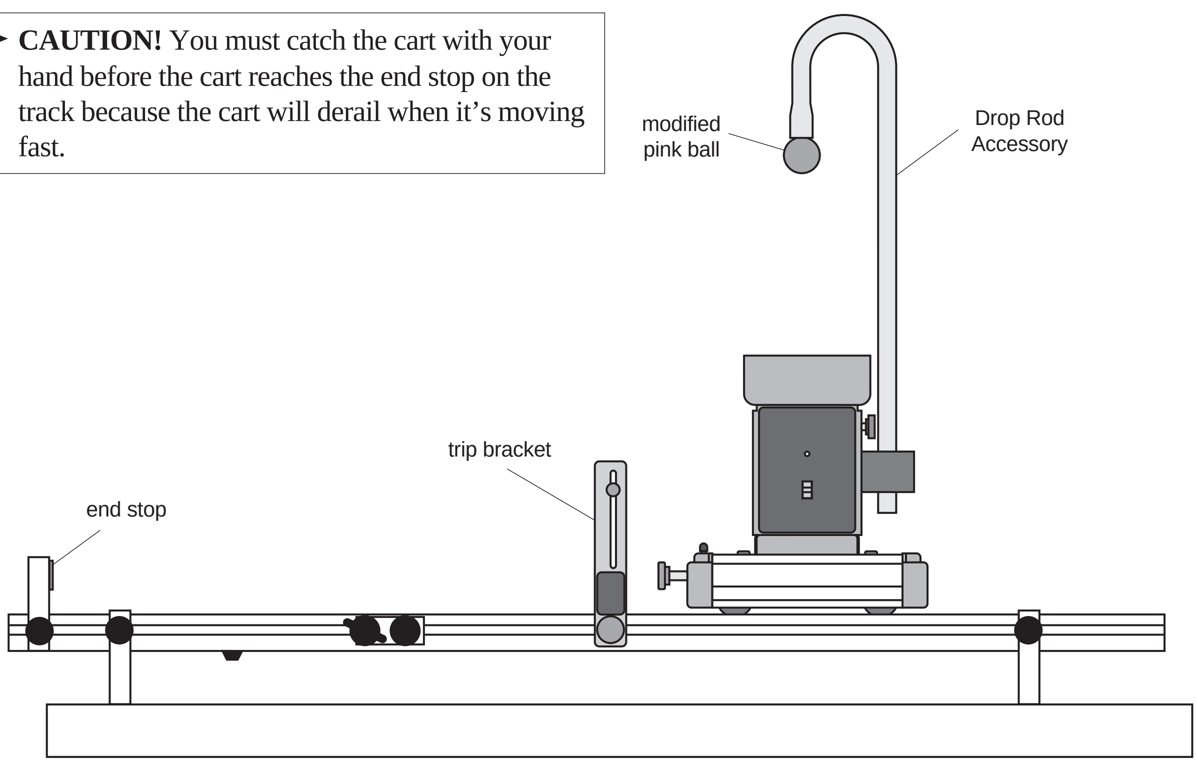


Figure 5.1: Setup for Drop Ball

Notes:

Experiment 6: Accelerating Cart - Demonstration

EQUIPMENT NEEDED

– Ballistic Cart Accessory (ME-9486)
– Dynamics Cart and track
– Drop Rod Accessory (ME-9487)
– String
– Clamp-on pulley
– 50 gram mass and mass hanger

Purpose

This demonstration shows that when the ball is dropped from the drop rod on a cart that is accelerating, the ball will not land in the cart.

Procedure

① Prior to the beginning of the demonstration, perform the Setup procedure.

② Position the drop rod so that the ball will be directly over the cup.

③ Clamp the pulley to the end of the track. Attach a string (about 1 meter long) to the cart and pass it over the pulley. Hang about 50 grams on the string. See Figure 6.1.

④ Put the photogate trip bracket in a position where it will drop the ball after the cart has begun to move.

⑤ Start the cart as far back as possible, hang the ball on the drop rod, and release the cart. In this case, the ball will fall behind the cart.

➤ **CAUTION!** You must catch the cart with your hand before the cart reaches the end stop on the track because the cart will derail when it's moving fast.

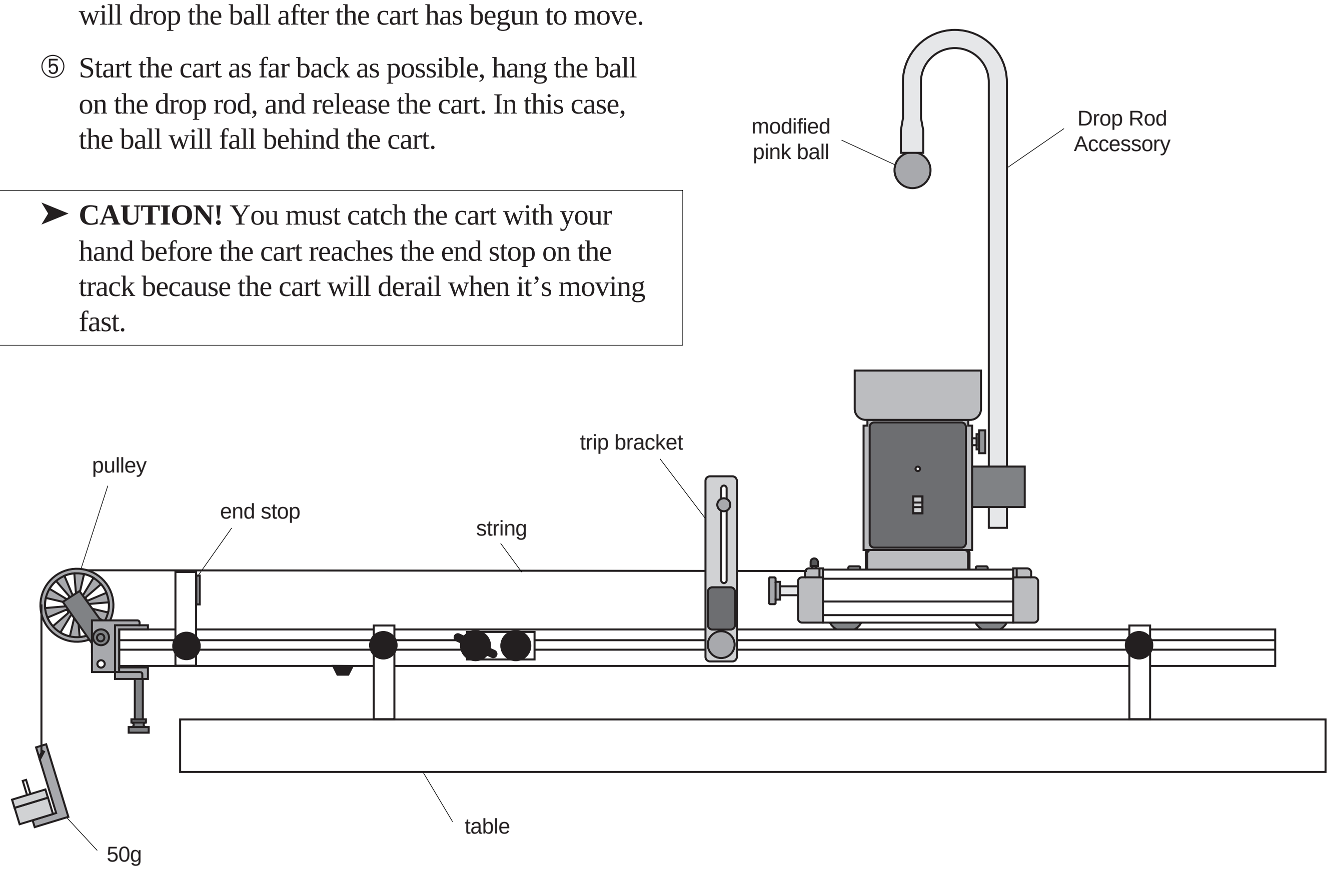


Figure 6.1: Accelerating Cart

Notes:

Experiment 7: Inclined Plane - Demonstration

EQUIPMENT NEEDED

– Ballistic Cart Accessory (ME-9486)
– Dynamics Cart and track
– Drop Rod Accessory (ME-9487)
– Table clamp and rod
– Rod clamp for dynamics track

Purpose

This demonstration shows that a ball dropped from the drop rod on a cart that is accelerating down an inclined plane will be caught by the cart regardless of the angle of incline.

Procedure

① Prior to the beginning of the demonstration, perform the Setup procedure.

② Position the drop rod so that when the track is level, the ball will be directly over the cup.

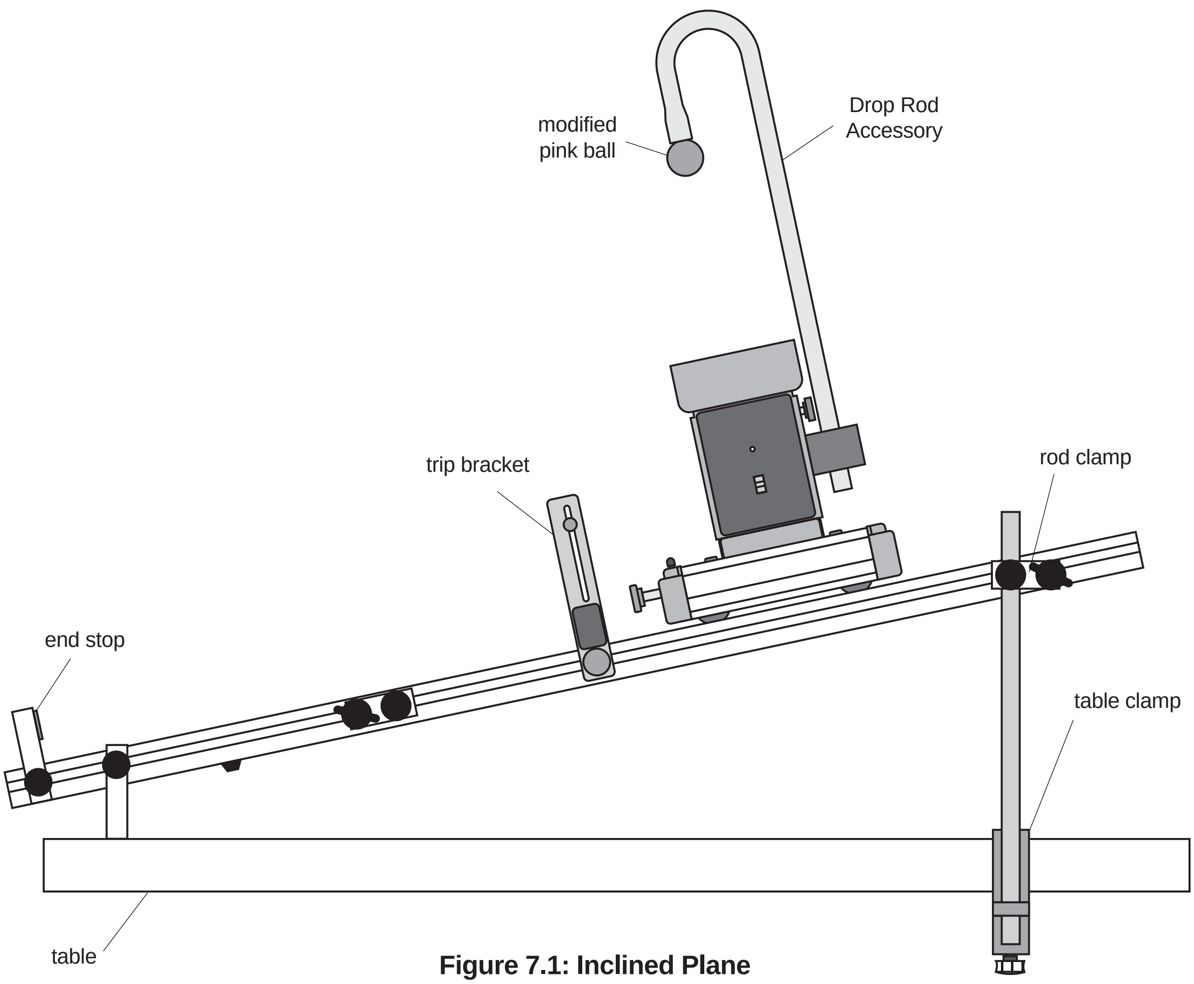


Figure 7.1: Inclined Plane

③ Incline the track (see Figure 7.1) using the table clamp and rod. Be careful not to choose too high an angle because the cart will reach such a high speed that it will crash at the bottom. For any angle you choose, be sure you catch the cart at the bottom to keep it from derailing and crashing to the floor.

④ Put the photogate trip bracket in a position where it will drop the ball after the cart has begun to move.

⑤ Start the cart at the top of the incline, hang the ball on the drop rod, and release the cart. The ball will land in the cart.

➤ **CAUTION!** Remember to catch the cart!

⑥ Repeat the demonstration for a different angle.

Experiment 8: Bombing Run - Demonstration

EQUIPMENT NEEDED

– Ballistic Cart Accessory (ME-9486)
– Dynamics Cart and track
– Drop Rod Accessory (ME-9487)
– Paper cup (for catching ball)

Purpose

This demonstration shows the students that a bomber must release the bomb before the plane is over the target.

Procedure

① Prior to the beginning of the demonstration, perform the Setup procedure.

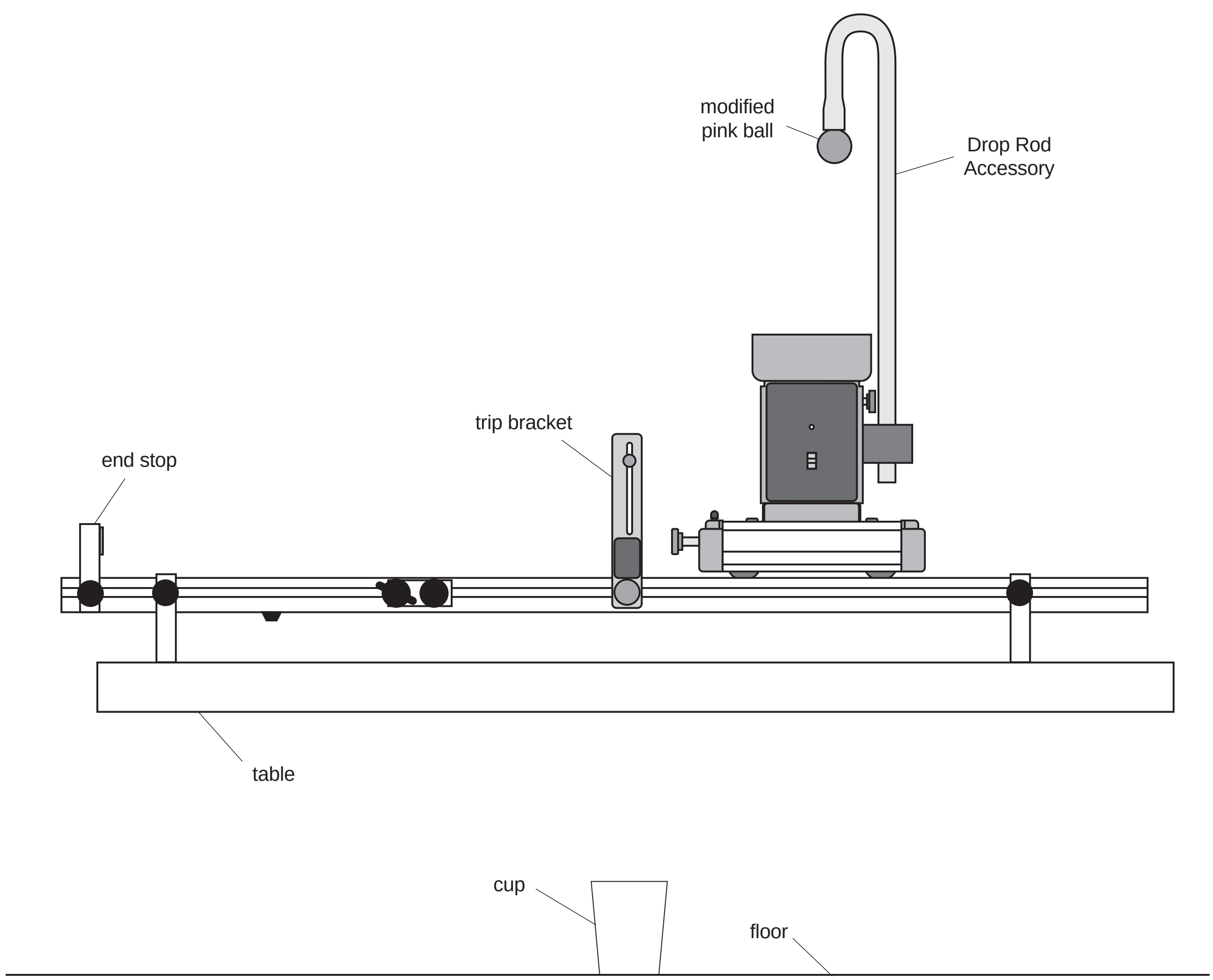


Figure 8.1: Bombing Run

② Align the track with the edge of the table.

③ Position the drop rod so that as the ball drops, it will miss the table and fall to the floor.

④ Position the photogate trip bracket near the middle of the track.

⑤ Place the cart on the track at the position of the trip bracket and place the cup on the floor under the drop rod. Pull the cart back to one end of the track, hang the ball on the drop rod, and push the cart. The ball will be dropped at the moment the cart passes over the cup. See Figure 8.1.

⑥ Discuss with the students the reason the ball misses the cup.

⑦ Move the trip bracket back and try it again.

Experiment 9: Bombing Run (Computerized)

EQUIPMENT NEEDED

– Ballistic Cart Accessory (ME-9486)
– Dynamics Cart and 2.2 m track (ME-9452)
– Drop Rod Accessory (ME-9487)
– Paper cup (for catching ball)
– Physics string (SE-8050) (NOTE: Stiff string is required.)
– Clamp-on pulley
– 200-gram mass and mass hanger
– Photogate and photogate bracket
– Computer
– Plumb bob
– Meter stick

Purpose

In this experiment, the distance from the target that a bomber must release the bomb is calculated and verified.

Procedure

① Prior to the beginning of the experiment, perform the Setup procedure.

② Align the track with the edge of the table.

③ Position the drop rod so that as the ball drops, it will miss the table and fall to the floor.

④ Position the photogate trip bracket near the middle of the track.

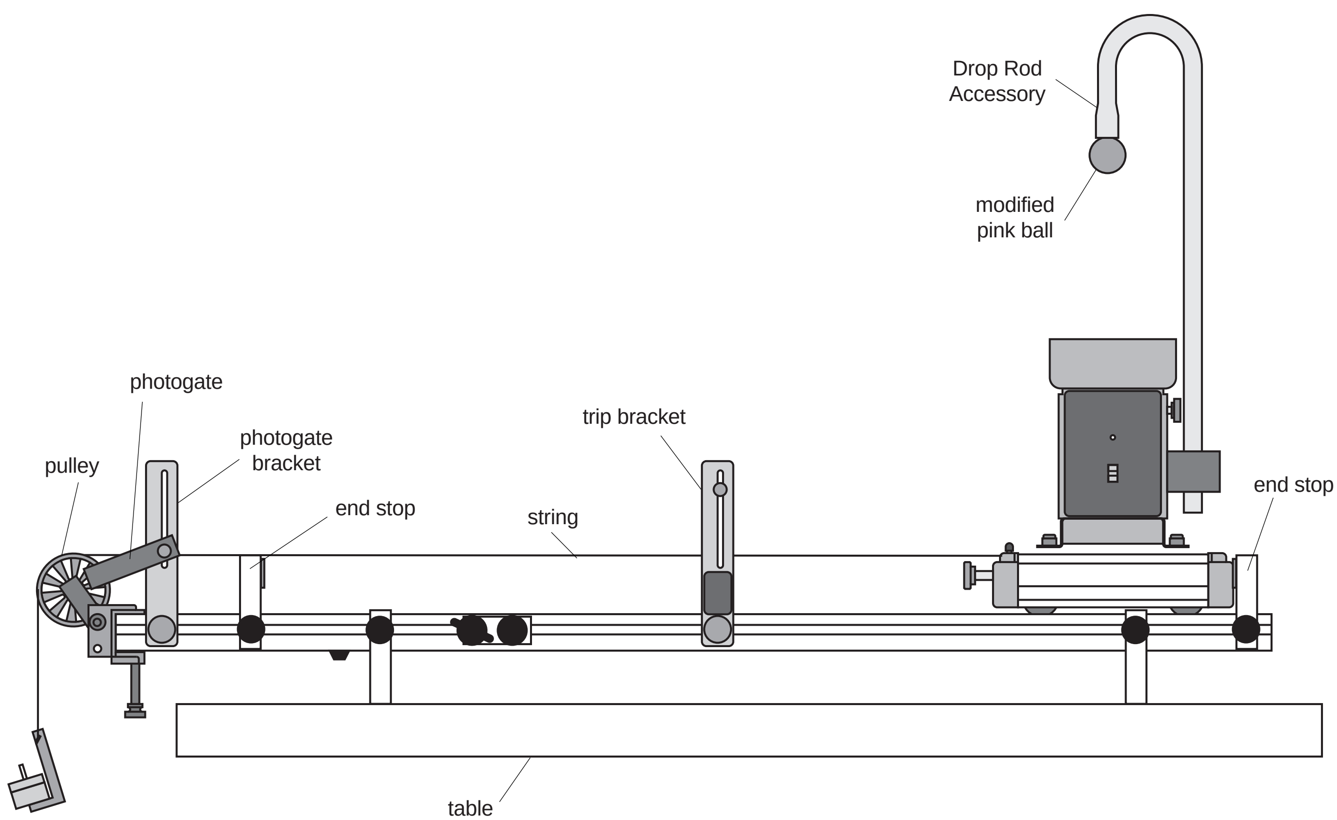


Figure 9.1: Smart Pulley Setup for Bombing Run

⑤ Clamp the pulley on the end of the track. Position the photogate and its bracket over the clamp-on pulley so it acts as a Smart Pulley. See Figure 9.1.

⑥ Tie one end of a 2.2-meter long string to the cart and pass the other end over the pulley and hang about 200 g on it.

➤ **NOTE:** the string must be long enough so the cart can reach the end stop furthest from the pulley. The end stop will mark the position where the cart will be started from rest each time.

⑦ Move the cart toward the pulley until the mass just touches the floor. Then place the trip bracket at the cart's position. This will cause the cart to drop the ball after the cart has reached its constant speed. Note that the stiff string will continue to move forward and not bunch up under the cart. This is the reason for not using thread.

⑧ Without hanging the ball on the drop rod, pull the cart back against the end stop and release it from rest. Record data with the computer and determine the maximum speed, v, of the cart.

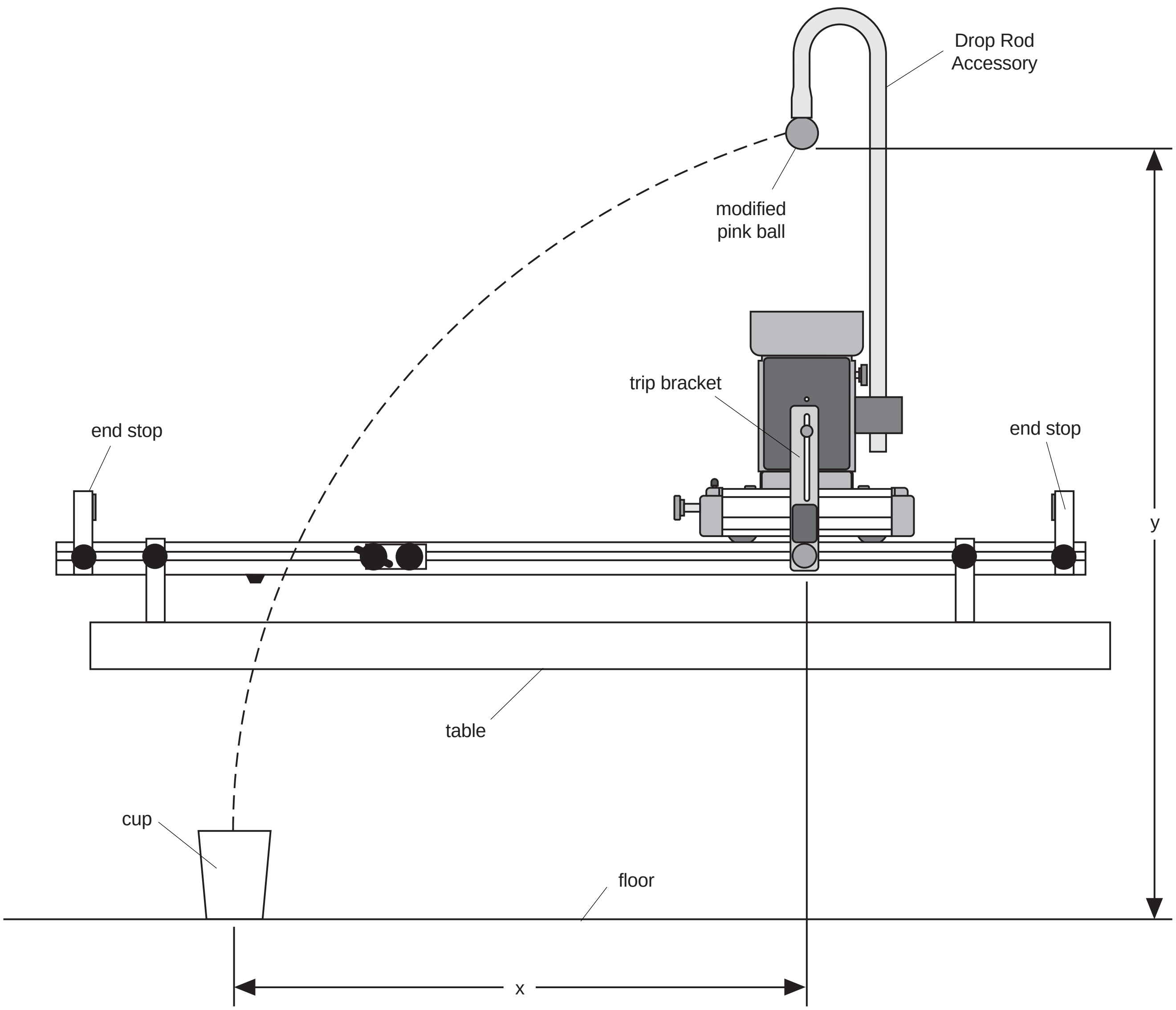


Figure 9.2: Projectile Motion For Bombing Run.

➤ **NOTE:** It is also possible to determine the speed using conservation of energy without a computer. You would need to know the mass of the Ballistic Cart Accessory and measure the distance the hanging mass falls.

⑨ Hang the ball on the drop rod and measure the distance, ***y***, from the bottom of the ball down to the floor. See Figure 9.2.

⑩ The vertical distance, ***y***, that the ball falls is given by

$$y = \frac{1}{2} g t^2$$

Using your measured value for ***y***, calculate the time it takes for the ball to fall.

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

⑪ Calculate the horizontal distance, ***x***, that the ball travels.

$$x = vt$$

This is the position where the ball should land.

⑫ Use a plumb bob and meter stick to measure off the distance, ***x***. Place a paper cup at this position on the floor.

⑬ Hang the ball from the drop rod, pull the cart back against the end stop and release it from rest. Observe whether or not the ball goes into the cup.

Questions

① Did the ball land in the cup? If not, why not?

② What are some of the possible sources of error in this experiment that would cause the ball to miss?

Notes:

Experiment 10: Bombing Run (Non-Computerized)

EQUIPMENT NEEDED

- Ballistic Cart Accessory (ME-9486)
- Dynamics Cart and track (ME-9452)
- Drop Rod Accessory (ME-9487)
- Paper cup (for catching ball)
- String
- Clamp-on pulley
- 50-200g mass and hanger
- Scale
- Plumb bob
- Meter stick

Purpose

In this experiment, the distance from the target that a bomber must release the bomb is calculated and verified. Instead of using a constant-velocity cart, we will use a known acceleration for a known distance to obtain a repeatable velocity at the time of release.

Theory

We can measure the distance that the cart will accelerate before dropping the ball (***d*** in Figure 10.1) and the height ***y*** that the ball will fall. Knowing the mass of the cart and the hanging mass, we can predict where the ball will land.

First, the velocity of the cart after travelling a distance ***d*** from rest will be

$$v_o = \sqrt{2ad}$$

where ***a*** is the acceleration of the system. The horizontal distance ***x*** that the ball will travel during its fall will be

$$x = v_o t_y$$

where ***ty*** is the time it takes for the ball to fall:

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

Combining these terms gives us:

$$x = \sqrt{2ad}\sqrt{\frac{2y}{g}} = 2\sqrt{\frac{ady}{g}}$$

Now, the acceleration of the system is just

$$a = \frac{m}{m + M}\,g$$

where $\boldsymbol{m}$ is the hanging mass and $\boldsymbol{M}$ is the mass of the cart and all attachments including the ball. Substituting this value for acceleration into the equation for $\boldsymbol{x}$ gives us our desired equation:

$$x = 2\sqrt{\frac{mdy}{m + M}}$$

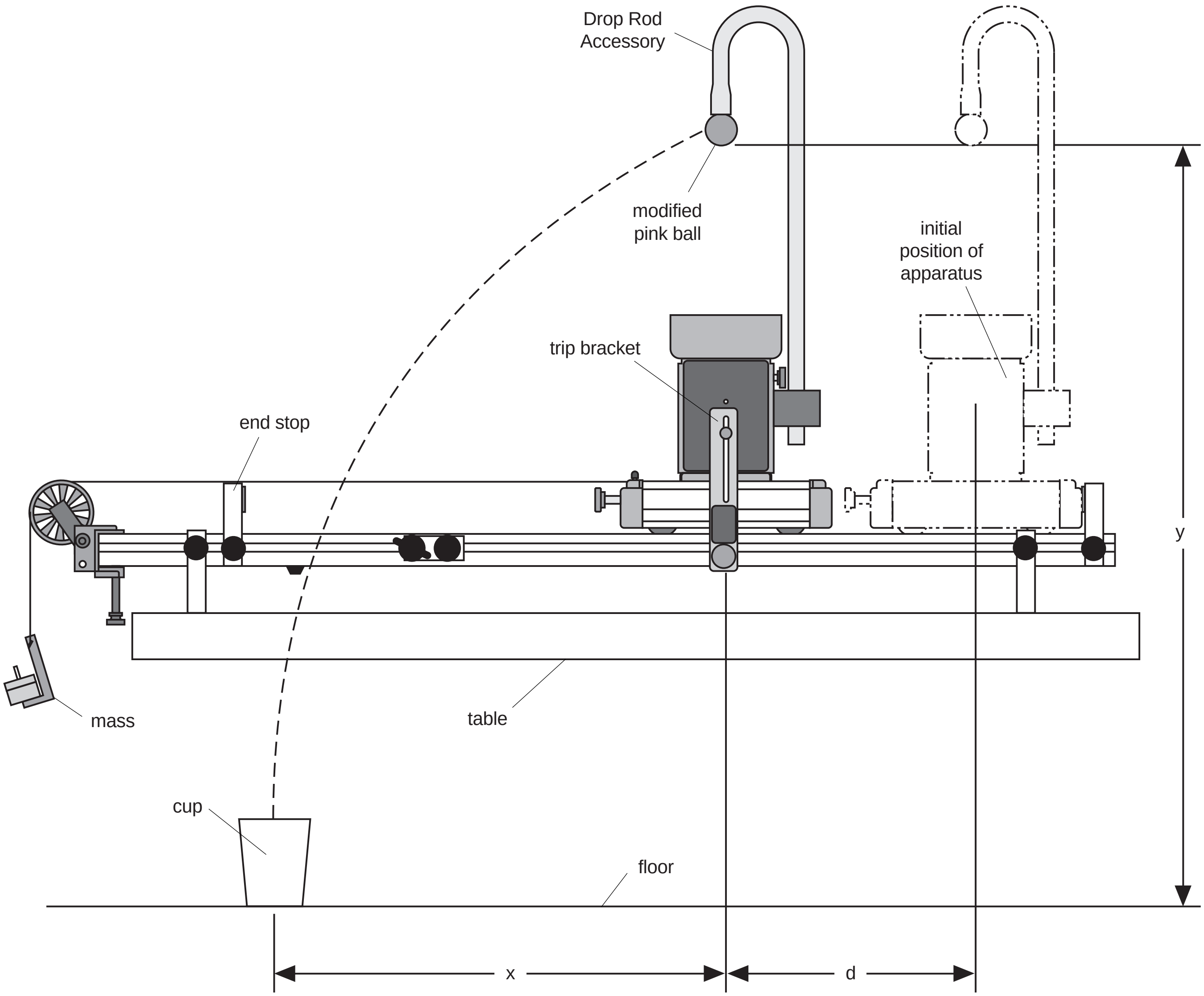


Figure 9.2: Projectile Motion For Bombing Run.

Procedure

① Weigh the cart and its attachments. Record this mass as M. Weigh the hanging mass, and record it as m.

② Set up the equipment as shown in Figure 10.1. You may want to tape a large sheet of paper to the floor on which to mark positions.

③ Hold the cart in its initial position against the end stop. Hang the plumb bob from the ball release point and mark the initial position. Slowly move the cart to where the trip bracket just causes the ball to release, and use the plumb bob to mark this position. Measure the distance between these positions and record as d.

④ Calculate x. Measure this distance from the point at which the ball drops, and mark this location. Place the paper cup on this mark.

⑤ Hold the cart against the end stop. Make sure that the ball is loaded correctly and the Ballistic Cart Accessory is turned on.

⑦ Release the cart, and see if the ball lands in the cup.

Questions

① Did the ball land in the cup? If not, why not?

② What are some of the possible sources of error in this experiment that would cause the ball to miss?

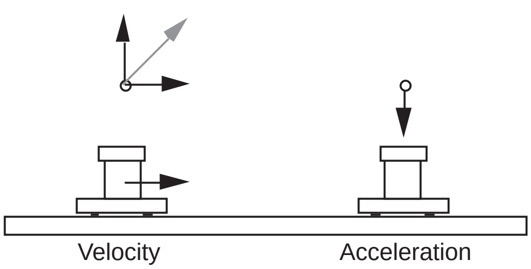
Teacher's Guide

Experiments 4 and 7: Inclined Plane - Demonstration

Why the Ball is Still Caught in the Inclined Plane Experiments

There have been enough questions about these two experiments—including some from people who should know better—that we thought it would be best to explain exactly what was going on and why the ball is still caught.

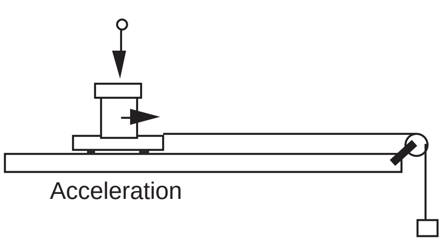
First, let's consider the horizontal case:



The cart and the ball have the same horizontal component of velocity. The vertical component of the ball's velocity does not affect the alignment of the ball and cart, so the ball lands in the cart.

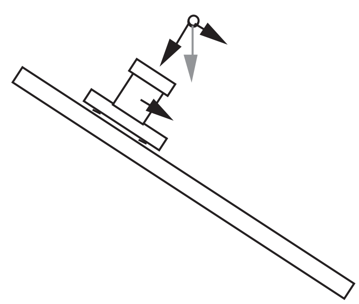
The horizontal component of the acceleration of both cart and ball is the same: zero, which ensures that the ball and cart remain aligned.

Now let's consider the case where the cart is accelerating:



In this case, the ball's acceleration is still only in the vertical plane, but the cart has a horizontal acceleration. This horizontal acceleration changes the velocity of the cart, but not the velocity of the ball. The cart does not remain directly beneath the ball and the ball is not caught.

When the track is tilted, things become a bit more complicated; but if you break the vectors into their components it becomes more clear:



The cart and the ball have the same component of acceleration parallel to the track. Since they have the same *initial* parallel-component velocity and the same acceleration, they will thus *always* have the same parallel-component velocity. The ball will always be on a line with the cart perpendicular to the track, and it will be caught.

Technical Support

Feed-Back

If you have any comments about this product or this manual please let us know. If you have any suggestions on alternate experiments or find a problem in the manual please tell us. PASCO appreciates any customer feed-back. Your input helps us evaluate and improve our product.

To Reach PASCO

For Technical Support call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

Contacting Technical Support

Before you call the PASCO Technical Support staff it would be helpful to prepare the following information:

- If your problem is computer/software related, note:

  Title and Revision Date of software.

  Type of Computer (Make, Model, Speed).

  Type of external Cables/Peripherals.

- If your problem is with the PASCO apparatus, note:

  Title and Model number (usually listed on the label).

  Approximate age of apparatus.

  A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.)

  If possible, have the apparatus within reach when calling. This makes descriptions of individual parts much easier.

- If your problem relates to the instruction manual, note:

  Part number and Revision (listed by month and year on the front cover).

  Have the manual at hand to discuss your questions.

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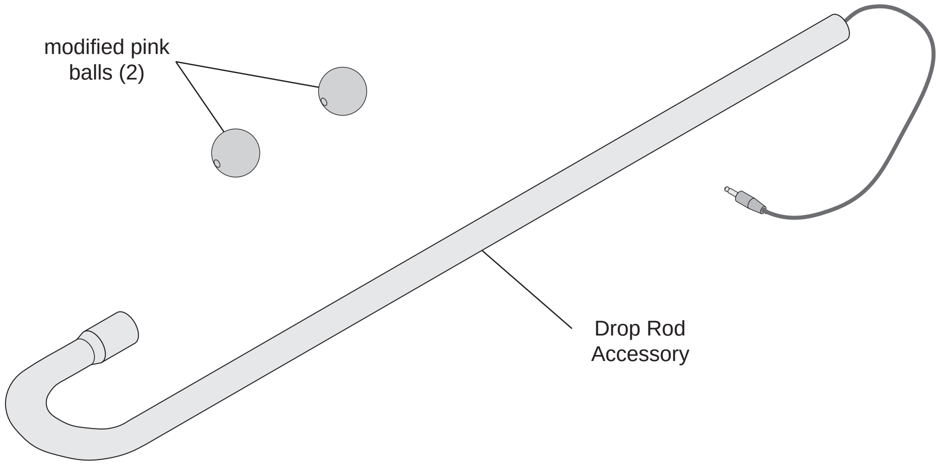
Instruction Sheet for the PASCO Model ME-9487

DROP ROD ACCESSORY



Introduction

The PASCO ME-9487 Drop Rod Accessory can be mounted to the PASCO ME-9486 Ballistic Cart Accessory so a special plastic ball can be dropped from rest (relative to the cart) above the moving cart. Also the drop rod can be rotated away from the cart so the ball will drop onto the floor to perform bombing runs.

Equipment

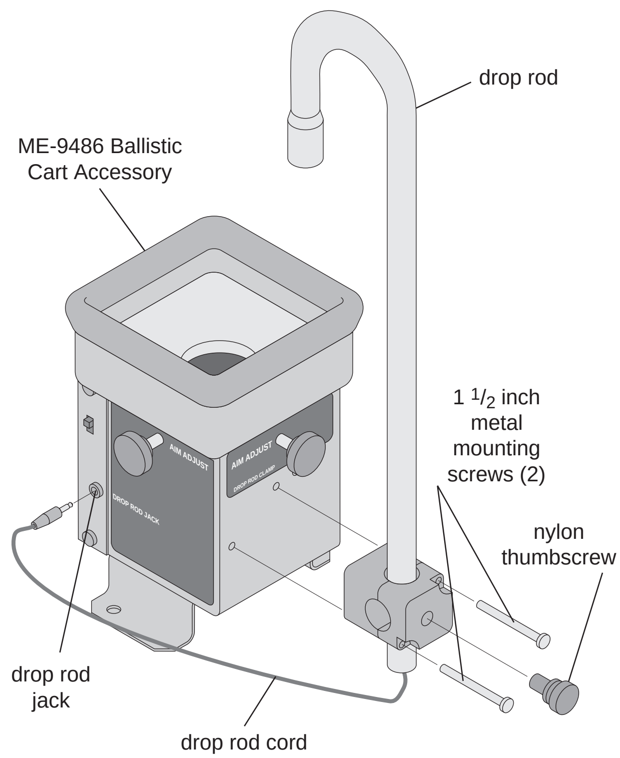
The ME-9487 Drop Rod Accessory includes the following:

- one Drop Rod Accessory
- two modified pink nylon balls

Assembly

Drop Rod Installation

① Use the $1^1/_2$ inch metal screws to fasten the drop rod clamp to the side of the Ballistic Cart Accessory. See Figure 1. Screw the thumb screw into the end of the drop rod clamp.



This instruction sheet written/edited by: Jon Hanks

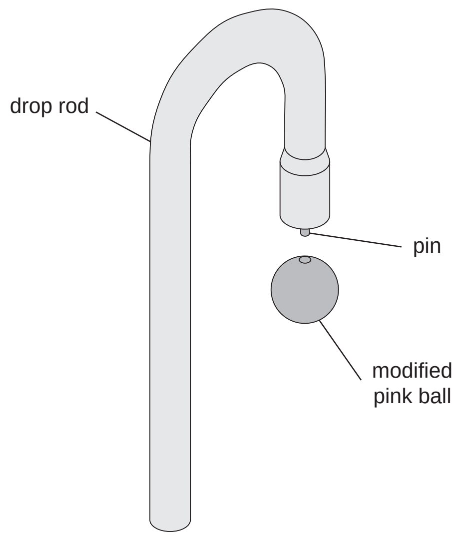


Figure 2: Ball and Drop Rod

② Thread the cord from the drop rod through the drop rod clamp and clamp the end of the drop rod by tightening the thumb screw.

> ➤ **CAUTION:** Do not overtighten the screw because the tube may be crushed.

③ Plug the drop rod cord into the drop rod jack on the side of the Ballistic Cart Accessory.

> ➤ **NOTE:** Plugging this cord in disables the launching mechanism of the Ballistic Cart Accessory so when you want to use the launcher you must unplug the drop rod accessory.

④ Note that the Drop Rod Accessory requires a special ball that has an iron insert. The balls for the Drop Rod Accessory and the Ballistic Cart Accessory are different colors so they can be easily distinguished. To hang the ball from the drop rod, the pin on the drop rod must be inserted into the small hole in the ball. See Figure 2.

Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

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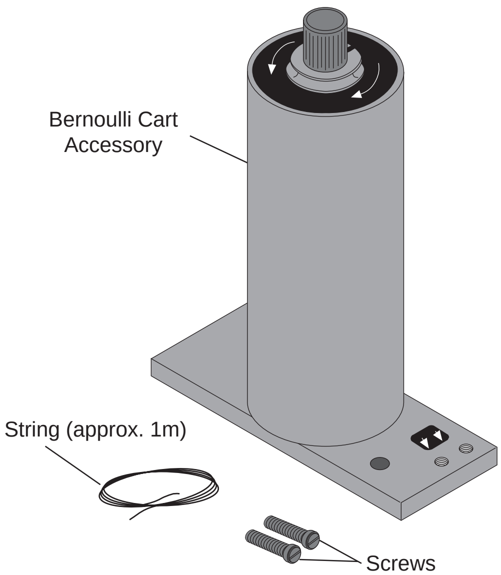
Instruction Sheet for the PASCO Model ME-9481

Bernoulli Cart Accessory



Introduction

The PASCO ME-9481 Bernoulli Cart Accessory attaches to the PASCO Dynamics Cart (ME-9430) or Collision Cart (ME-9454) to demonstrate Bernoulli's Principle. The cart should be used on a PASCO Dynamics Track to minimize friction. A fan (approximately 6-inch to 12-inch diameter) is required to supply moving air.

The Bernoulli Cart Accessory consists of a vertical cylinder that can be rotated rapidly by pulling on a string. (➤ **NOTE:** String for spinning the cylinder and two screws for mounting the apparatus on a PASCO cart are included.) When the fan blows air perpendicularly across the track, the cart moves along the track in a direction corresponding to the direction of rotation of the cylinder.

Theory

According to Bernoulli's Principle, the pressure in an incompressible moving fluid is lowest where the speed of the fluid is highest.

Figure 1 shows the top view of the cylinder mounted on the cart with the cart sitting on the track. The fan is blowing air by the cylinder, perpendicularly across the track. If the cylinder was not rotating, the air-speed passing by the front and back of the cylinder would be the same. The pressure in the front and back would be equal and the cart would not move.

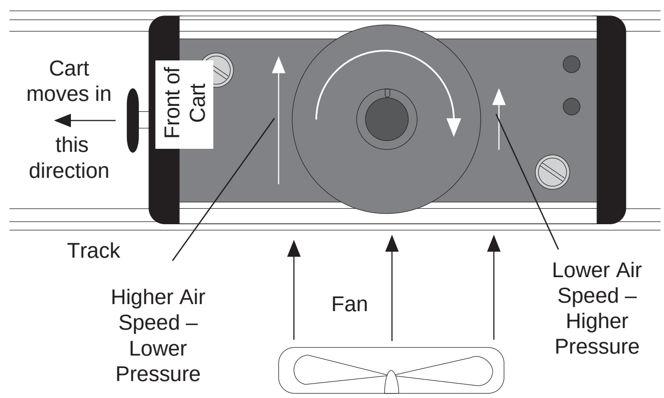


Figure 1A: Top View of Rotating Cylinder

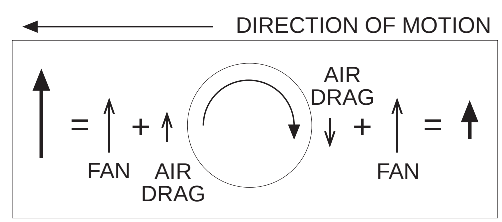


Figure 1B: Air Distribution

When the cylinder is spinning clockwise (ω down) as shown in Figure 1, friction between the cylinder walls and the air causes the speed of the air in front of the cart to become greater than the speed of the air in back of the cart.

According to Bernoulli's Principle, the faster moving air in front of the cart exerts less pressure on the cylinder than the slower moving air in back of the cart. This difference in pressure produces a net force which causes the cart to move forward along the track. If the cylinder is spun in the opposite direction (counterclockwise, ω up), the pressure is less in back of the cart and the cart moves backward.

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Demonstration Preparation

① Mount the Bernoulli Cart Accessory to the cart with the 2 metric M5X0.8 nylon screws. The base of the accessory fits into the mass tray on the cart. (➤NOTE: When not in use, the two screws can be stored on the base of the accessory.) Remove the two screws from their storage holes and put them through the two holes in the base that line up with the screw holes in the cart.

② Tie a knot in one end of the physics string. This will help hold the string in the notch while winding the string onto the pulley.

③ Place the cart on the track and level it carefully to make sure the cart will not roll in any preferred direction. Gently push the cart in each direction to see if it rolls to a stop at approximately the same distance in either direction.

④ Plug in the fan and place it on the table, directing the air flow perpendicular to the track at the location of the cart.

> ➤ **NOTE:** Most fans work better if they are not too close to the track: A large fan should be further than 50 cm from the track. Check your fan to see if the air is pushed forward from the fan blades rather than radially outward from the fan blades. Fans that push the air radially outward have a “dead” spot in the center and will not work for this demonstration.

Demonstration Procedure

① Begin the demonstration with the fan off.

② Place the knotted end of the string in the notch in the pulley at the top of the cylinder as shown in Figure 2. When the string is pulled, the string is supposed to detach from the pulley, allowing the pulley to continue spinning freely, without the string attached.

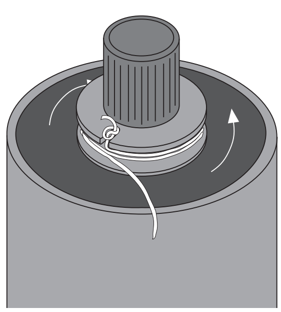

Figure 2: Placement of string in pulley

③ Wind the string onto the pulley by holding the string with one hand and spinning the cylinder with the other hand. Notice that the label on top of the cylinder shows which way the cylinder will rotate when you pull on the string. Note which way you wound the string so you can wind it the opposite direction when you spin it for the second time.

④ While holding the top knob with one hand, pull the string firmly and quickly with the other hand. The string should come off the pulley. The cart will remain stationary because the fan is not on.

⑤ Turn the fan on. The cart will accelerate along the track until it is out of the air flow. You may move the cart back into the air flow and it will again move along the track in the same direction as before. You may also show that the cart stops moving when the air stops by placing a large card between the fan and the cart to block the air.

⑥ Stop the cylinder with your hand and turn the fan off. Wind the string onto the pulley opposite the original direction.

⑦ Pull the string and turn on the fan. The cart will now move in the opposite direction.

> ➤ **NOTE:** If the cart seems to move better in one direction than the other, the track is not level.

Storage

Remove the two screws that hold the accessory to the cart and screw them into the two storage holes on the base. Wind the string around the pulley. The Bernoulli Accessory can be stored upright with the base resting flat on a shelf.

Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

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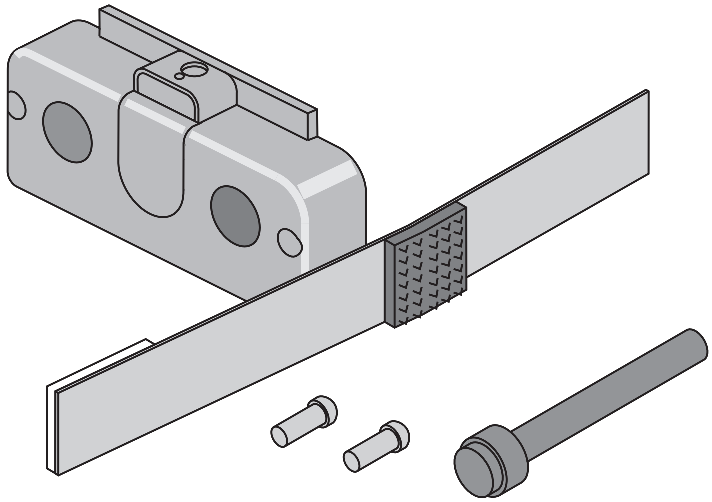
Instruction Sheet
for the PASCO
Model ME-9457

Variable Friction Cart Accessory Kit



Introduction

The PASCO Model ME-9457 Variable Friction Cart Accessory allows the user to modify their existing PASCO Model ME-9430 Dynamics Cart by attaching a variable friction mechanism. When the accessory is incorporated into the cart, greater flexibility in experiments can be obtained.

Equipment Included

- One Friction Cart End Cap
- One 1/4-20 X 5cm inch black nylon thumbscrew.
- One spring steel strip. On one end of the spring steel strip is a Velcro loop pad; on the other end a piece of adhesive foam tape.
- Two 6-32 X 9.5mm thread forming screws.

Additional Equipment Required:

- #1 Phillips point screw driver

This instruction sheet written/edited by: D. Griffith

Setup Procedure:

① Remove the end cap (that does not have a plunger) from your Dynamics Cart. See Figure 1.

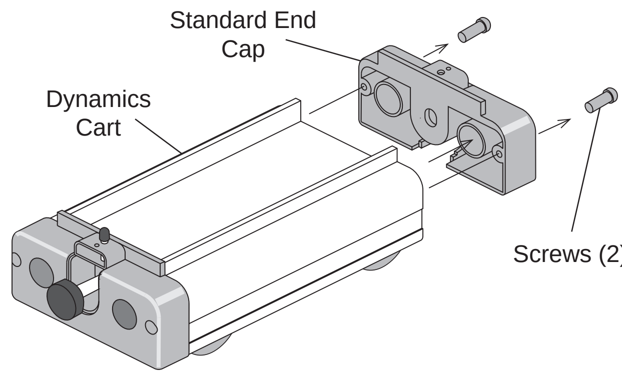


Figure 1 End Cap Removal

➤ **NOTE:** The screws that secure the end cap to the end of the Dynamics Cart are thread forming screws and may require substantial force to remove and reinstall. A #1 Phillips point screw driver is required.

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② Replace the standard end cap with a Friction Cart End Cap (included with this kit) using the same screws. If screws are damaged or lost, use the replacement 6-32 X 9.5mm thread forming screws included with this kit.

③ Remove the protective cover from the adhesive foam on the spring steel strip (also included with this kit). Locate and firmly apply the spring steel strip to the bottom of the Dynamics Cart as shown in Figure 2.

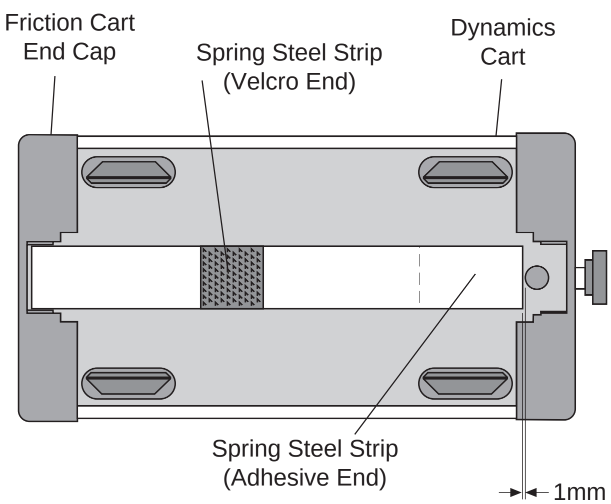

Figure 2 Spring Steel Strip Location

> ➤ **NOTE:** The area on the bottom plate (to which the spring steel strip is applied) must be clean. Note the orientation of Dynamics Cart. Use the hole in the bottom plate as a reference.

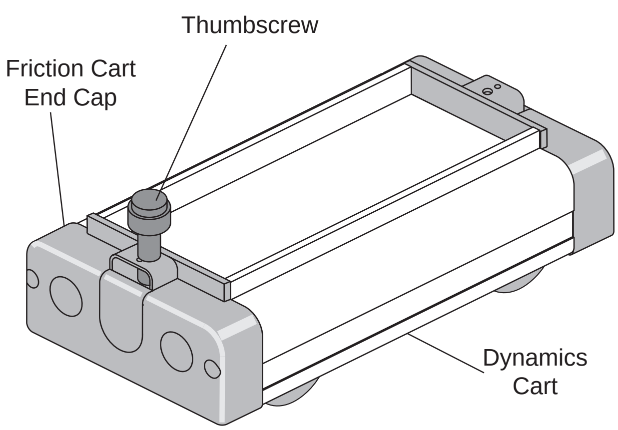

Figure 3 Thumbscrew Assembly

④ Install the 1/4-20 X 5cm thumbscrew into the Friction Cart End Cap as shown in Figure 3.

⑤ Adjust the thumbscrew to vary the friction applied to the Dynamics Cart.

> The PASCO variable friction cart accessory was adapted from a design by:
>
> Stan Micklavzina
> Physics Department
> University of Oregon
> Eugene, Oregon

Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

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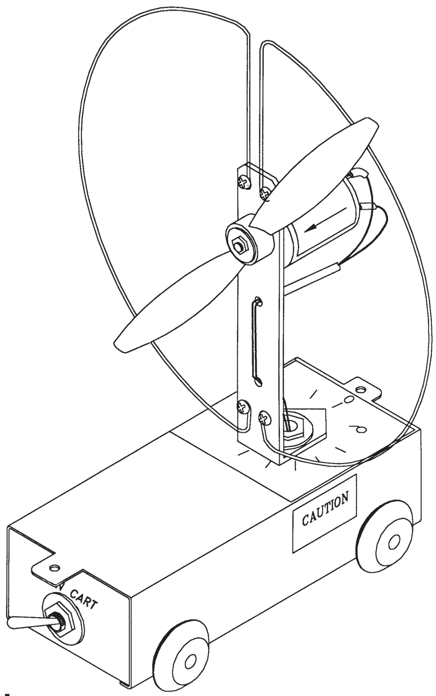
Instruction Sheet
for the PASCO
Model ME-9485

FAN CART



Introduction

The PASCO ME-9485 Fan Cart has the following features:

- The two-speed motor is powered by 4 C-cell batteries.
- The direction of thrust of the fan can be adjusted from zero to 180° to demonstrate force components.
- The cart can be used on a table or floor. Better results are obtained when it is used on the PASCO Dynamics Track (ME-9453 or ME-9480).
- The cart nests on top of the PASCO dynamics cart (ME-9430) to utilize the dynamics cart's plunger and bumpers.
- The sail is attached to the cart by the magnetic strip located on the cart.
- To change the acceleration of the cart, steel masses can be added to the cart by placing them on the magnetic strip.
- String can be attached to the tabs on the ends of the cart.
- Approximate mass of fan cart including 4 alkaline batteries = 480g ± 25g
- Approximate mass of sail = 230g ± 10g.

> ➤ **CAUTION:**
> - Keep fingers and other objects away from the moving fan blade.
> - We recommend the cart be attached to a fixed object with a safety tether to prevent a runaway cart.

Demonstration Using the Fan Cart and Sail

① Place the fan cart at rest on a level dynamics track. To check if the track is level, place the cart on the track and give it a small push in one direction. Then push it in the opposite direction to see if the cart rolls easier in one direction than the other.

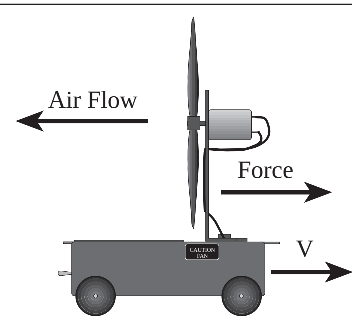


Figure 1: Fan Cart without Sail

② Set the fan angle at zero degrees and turn the fan on to show which way the cart moves without the sail. See Figure 1.

This instruction sheet written by: Ann Hanks

③ Turn the fan off and place the sail on the magnetic pad with the plane of the sail parallel to the plane of the fan.

④ Ask the students to predict which direction the cart will move with the sail attached. Turn on the fan to show the direction the cart moves.

> ➤ **NOTE:** Most students will expect the cart not to move. However, the cart will have a small acceleration opposite to the acceleration without the sail.

Explanation: There is a force on the cart in one direction resulting from the fan pushing the air and there is another force on the cart in the opposite direction resulting from the air hitting the sail. See Figure 2. But when the air hits the sail, the air bounces off the sail, causing more force on the sail than the force of the air on the fan. Therefore, there is a net force on the cart that causes the cart to accelerate.

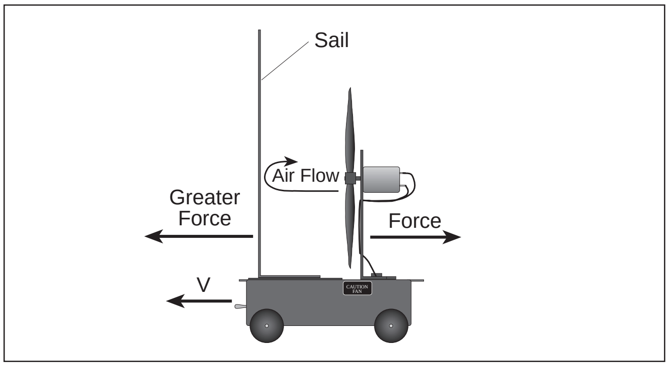


Figure 2: Fan Cart with Sail

⑤ If you want to increase the effect of the air bouncing off the sail, tape a large paper plate to the sail as shown in Figure 3. The curvature of the paper plate will help reverse the direction of the air.

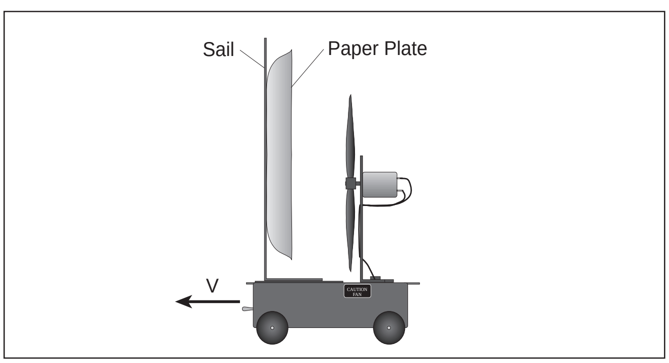


Figure 3: Fan Cart Sail with paper plate

Suggested Experiments

Experiment #1: Use the Sonic Ranger or Tape Timer to measure the acceleration of the cart. Add mass and repeat.

Experiment #2: Determine the force of the fan by connecting the cart to a mass that hangs over a pulley. Adjust the hanging mass until the cart doesn't move. Then turn the fan at an angle and determine the component of the force. This experiment must be performed on the dynamics track so the cart will go in a straight line. (See Figure 4 and 5)

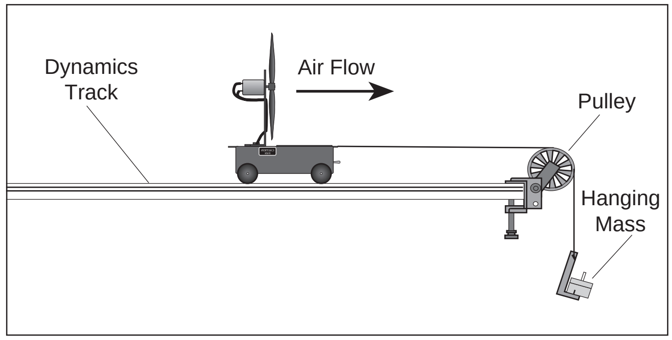


Figure 4: Fan Cart with hanging mass

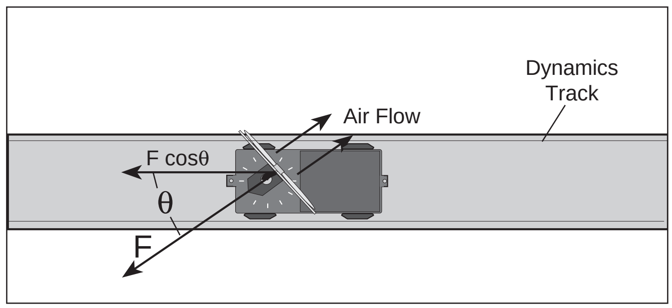


Figure 5: Fan Cart with Fan at angle

Experiment #3: Put the fan cart on a dynamics track and incline the track until the cart cannot climb the incline. (See Figure 6)

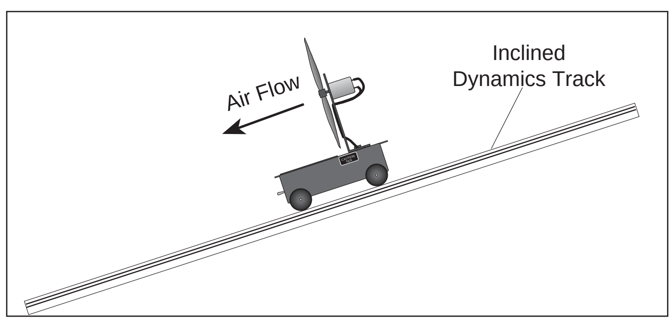


Figure 6: Fan Cart on incline

Experiment #4: Put the fan cart on top of the PASCO Friction Cart and adjust the friction until the cart goes at constant speed.

Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use.

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Technical Support

Feedback

If you have any comments about the product or manual, please let us know. If you have any suggestions on alternate experiments or find a problem in the manual, please tell us. PASCO appreciates any customer feedback. Your input helps us evaluate and improve our product.

To Reach PASCO

For technical support, call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

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e-mail: techsupp@pasco.com

web: www.pasco.com

Contacting Technical Support

Before you call the PASCO Technical Support staff, it would be helpful to prepare the following information:

➤ If your problem is with the PASCO apparatus, note:

- Title and model number (usually listed on the label);
- Approximate age of apparatus;
- A detailed description of the problem/sequence of events (in case you can't call PASCO right away, you won't lose valuable data);
- If possible, have the apparatus within reach when calling to facilitate description of individual parts.

➤ If your problem relates to the instruction manual, note:

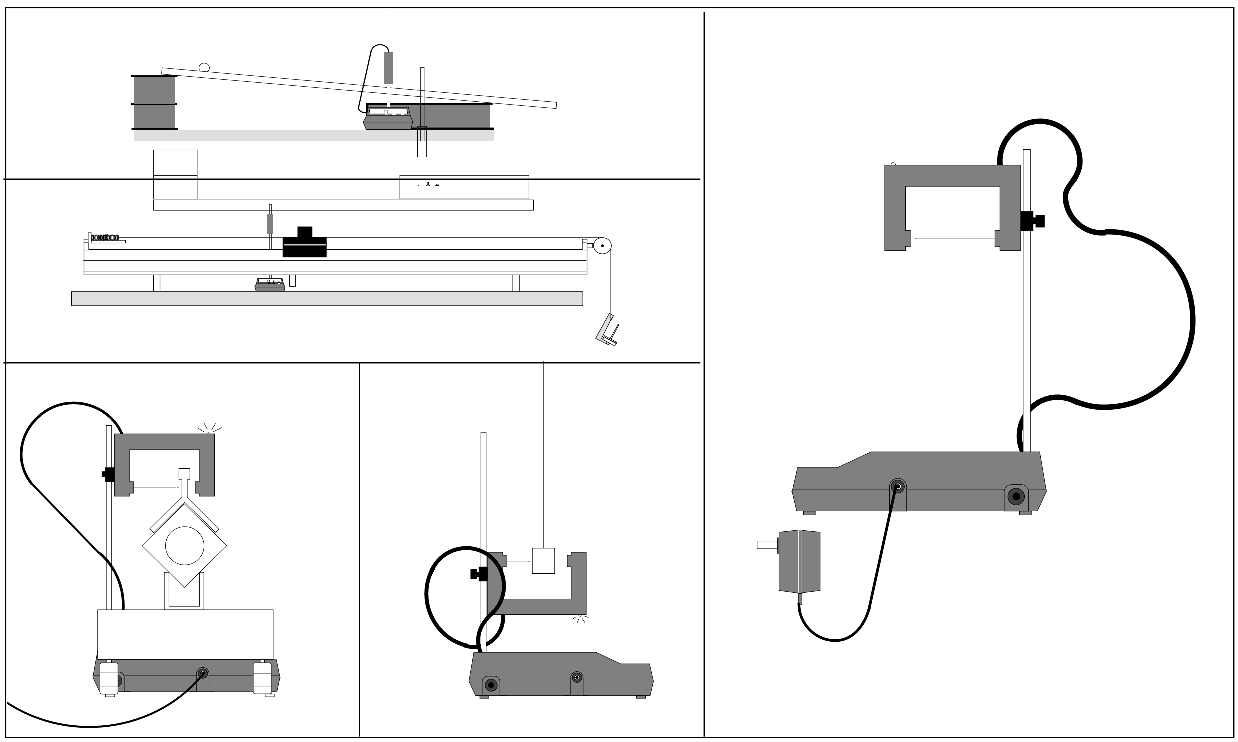
- Part number and revision (listed by month and year on the front cover);
- Have the manual at hand to discuss your questions.

Includes Teacher's Notes and Typical Experiment Results

Instruction Manual and Experiment Guide for the PASCO scientific Model ME-9206A and ME-9215A

012-03326F
10/94

PHOTOGATE TIMERS



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better ways to teach science

Table of Contents

Copyright, Warranty and Equipment Return

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Should the product have to be returned to PASCO scientific for any reason, notify PASCO scientific by letter, phone, or fax BEFORE returning the product. Upon notification, the return authorization and shipping instructions will be promptly issued.

➤ **NOTE:** NO EQUIPMENT WILL BE ACCEPTED FOR RETURN WITHOUT AN AUTHORIZATION FROM PASCO.

When returning equipment for repair, the units must be packed properly. Carriers will not accept responsibility for damage caused by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

① The packing carton must be strong enough for the item shipped.

② Make certain there are at least two inches of packing material between any point on the apparatus and the inside walls of the carton.

③ Make certain that the packing material cannot shift in the box or become compressed, allowing the instrument come in contact with the packing carton.

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Introduction

The PASCO Model ME-9206A and ME-9215A Photogate Timers are accurate and versatile digital timers for the student laboratory. Both models are identical except that the ME-9215A offers two features that the ME-9206A does not have: a memory function and optional 0.1 ms resolution (the standard timing resolution for both timers is1 ms).

The ME-9215A 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 optional 0.1 ms resolution is especially useful in high velocity experiments, such as free fall. Except where specifically stated, the information in this manual refers to both models of the photogate timer, the ME-9206A and the ME-9215A.

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-9204A (or the earlier ME-9204) 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.

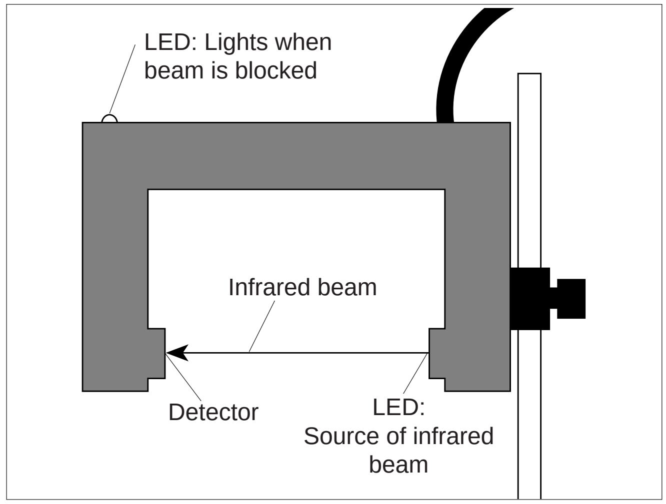


Figure 1 The PASCO Photogate

➤ **NOTES:**

① The Photogate timer can be powered using the included 12 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 an ME-9204 or ME-9204A Accessory Photogate in addition to the Photogate Timer. Check the equipment requirements listed at the beginning of each experiment.

Operation

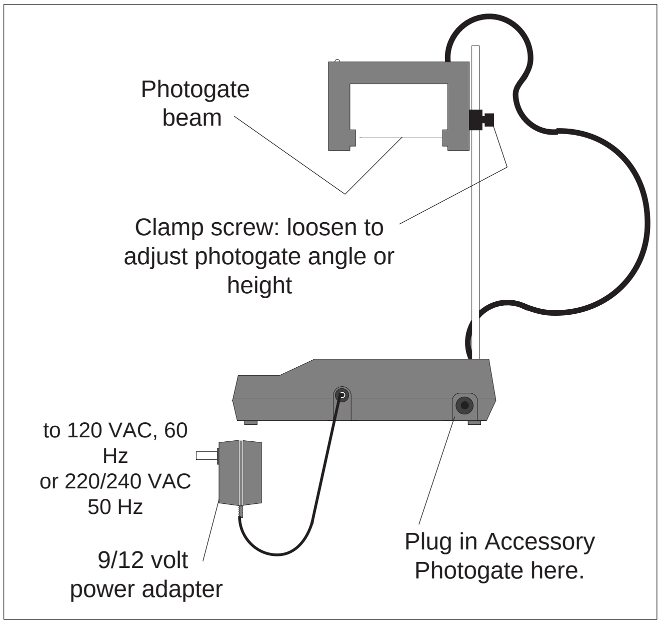


Figure 2 Setting Up the Photogate Timer

To Operate the Photogate Timer:

① Plug the 9/12 volt power adapter into the small receptacle on the side of the timer (see Figure 2) and into a standard 120 VAC, 60 Hz (or 220/240 VAC, 50 Hz) wall outlet.

② Position the photogate 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.

③ If you are using an ME-9204 or ME-9204A Accessory Photogate, plug the phono-plug connector of the accessory photogate into the large receptacle (see Figure 2) on the side of the timer.

④ Slide the mode switch to the desired timing mode: Gate, Pulse, or Pendulum. Each of these modes is described below. If you are using an ME-9215A, select the desired time resolution and switch the MEMORY switch to OFF.

⑤ Press the RESET button to reset the timer to zero.

⑥ 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.

⑦ Press the RESET button again. You're 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.

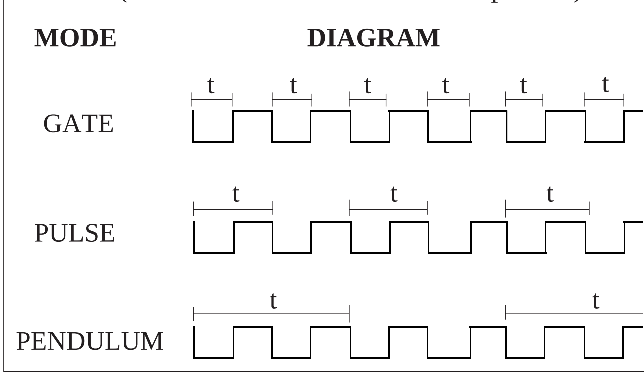
Pulse Mode: In Pulse mode, the timer measures the time between successive interruptions of the photogate. Timing begins when the beam is first blocked and continues until the beam is unblocked and then blocked again. With an accessory photogate plugged into the photogate timer, the timer will measure 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.

Special Features of the ME-9215A

Resolution—Set the timing resolution of the timer to 1 ms or to 0.1 ms with the slide switch on the front panel. In both settings, the timer is accurate to 1%. With 1 ms resolution, the maximum time that can be measured is 20 seconds. With 0.1 ms resolution, the maximum time that can be measured is 2 seconds.

Memory—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.

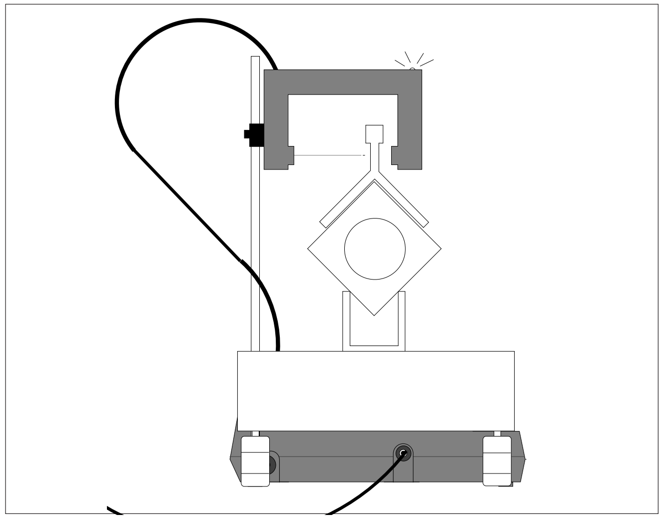


Figure 3 Timing an Air Track Glider

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.

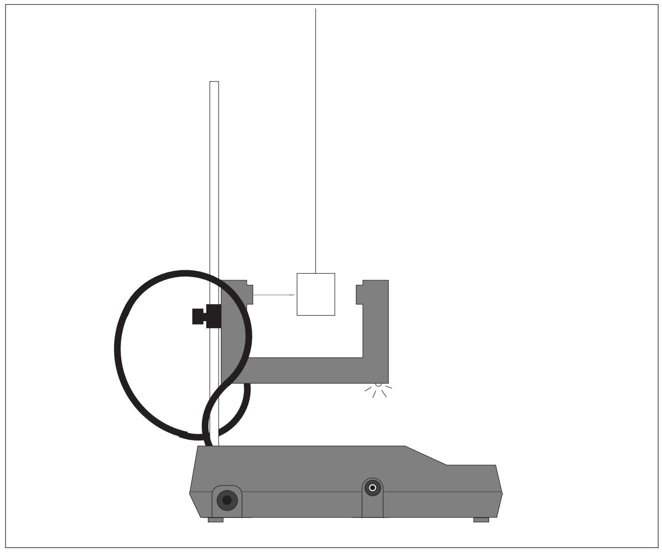


Figure 4 Photogate Timing a Pendulum

Accessories for the Photogate Timer

The following accessories are available to help extend the utility of your model ME-9206A or ME-9215A Photogate Timer. All the accessories work equally well with either model. See the current PASCO catalog for more information.

ME-9204A Accessory Photogate

The ME-9204A Accessory Photogate plugs into the phone jack on the side 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-9207A Free Fall Adapter

For easy and accurate measurements of the acceleration of gravity, the ME-9207 Free Fall Adapter is hard to beat. The Free Fall Adapter plugs directly into the phone plug on the side 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 an ME-9204A 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

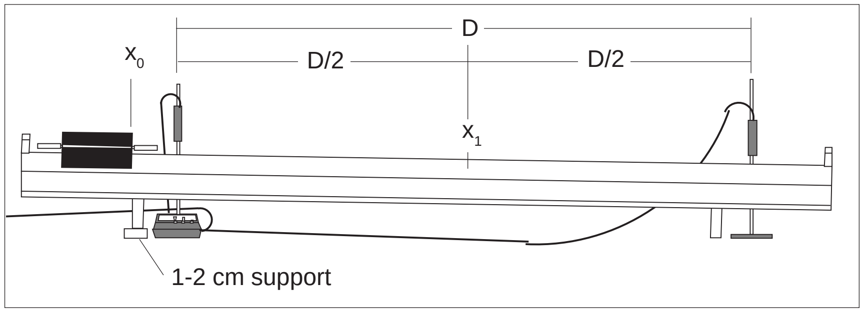


Figure 1.1 Setting Up the Equipment

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 $\mathbf{x_1}$ near the center of the track. Measure the position of $\mathbf{x_1}$ 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 $\mathbf{x_1}$ from the edge of the upper end of the track.

③ Choose a starting point $\mathbf{x_0}$ 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 $\mathbf{x_1}$**,** 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 $\mathbf{x_0}$, then release it. Record time $\mathbf{t_1}$**,** 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 $\mathbf{t_2}$ through $\mathbf{t_5}$**.**

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.

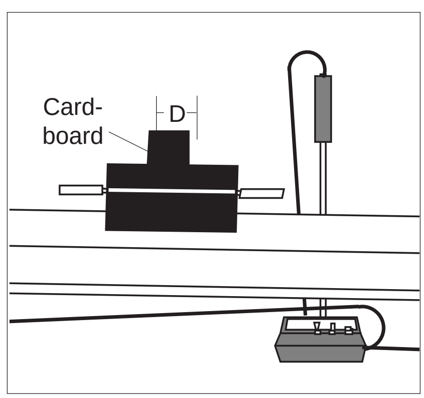


Figure 1.2 Measuring Velocity in Gate Mode

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 $\mathbf{x_1}$. 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 $\mathbf{x_0}$ 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 $\mathbf{t_1}$ through $\mathbf{t_5}$. 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 $\mathbf{t_1}$ through $\mathbf{t_5}$. Record this value as $\mathbf{t_{avg}}$.

② Calculate $\mathbf{v_{avg}} = \mathbf{D/t_{avg}}$. This is the average velocity of the glider in going between the two photogates.

③ Plot a graph of $\mathbf{v_{avg}}$ 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 $\mathbf{x_1}$?

② Can you extrapolate your collected data to determine an even closer approximation to the instantaneous velocity of the glider through point $\mathbf{x_1}$? 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.)

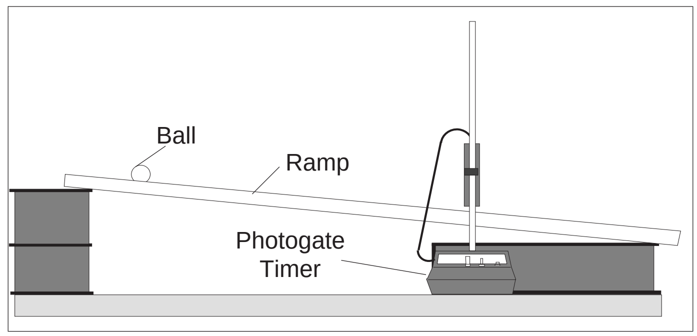


Figure 2.1 Equipment Setup

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.

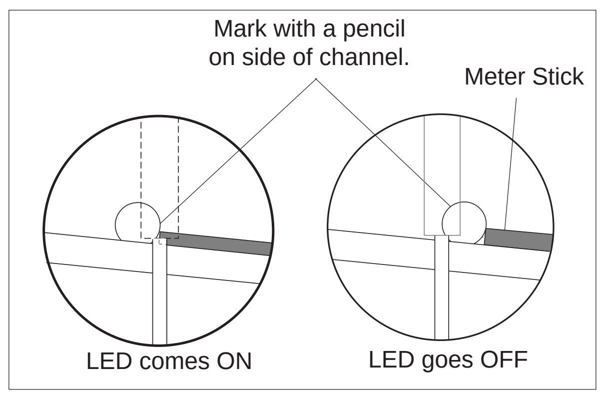


Figure 2.2 Measuring Δd

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.

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?

Table 2.1 Data and Calculations

Distance inside photogate = Δ**d**: ______________________

Distance Travelled	t_1	t_2	t_3	t_4	Average Time	Final Velocity

Questions

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
-Ball and ramp
-Plumb bob
-Meter stick
-Carbon paper

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.

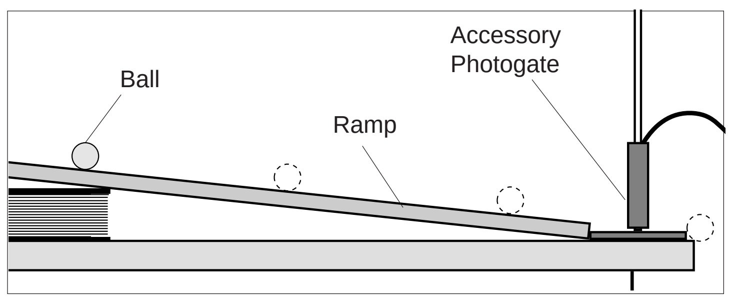


Figure 3.1 Equipment Setup

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.

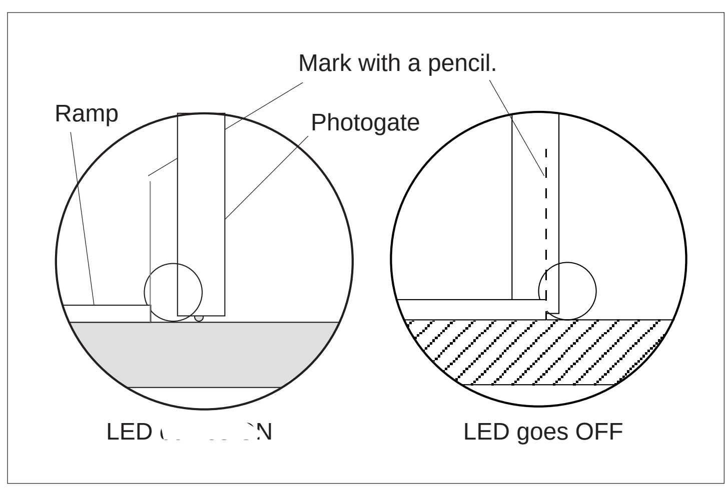


Figure 3.2 Measuring Δd

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.

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 $\mathbf{d}_x$ 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		
$\mathbf{v}_0$ (avg)		

$\Delta\mathbf{d}$ = ____________________

Vertical height, $\mathbf{d}_y$ = ____________________

Average horizontal distance, $\mathbf{d}_x$ = ____________________

Horizontal velocity, $\mathbf{v}_0$ = ____________________

Percentage difference = ____________________

② Divide $\Delta\mathbf{d}$ by your average time to determine $\mathbf{v}_0$, 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 $\mathbf{d}_x$ and $\mathbf{d}_y$:

$$\mathbf{d}_x = \mathbf{v}_0\mathbf{t};\ \mathbf{d}_y = \mathbf{1/2\ at^2};$$

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

④ Compare your two values for $\mathbf{v}_0$. Report the two values and the percentage difference.

Optional

If you have time, choose a value for $\mathbf{d}_x$ and a value for $\mathbf{d}_y$. For what value of $\mathbf{v}_0$ will the ball travel the distance $\mathbf{d}_x$ as it falls the distance $\mathbf{d}_y$? Adjust the height and angle of the ramp and the starting point until you produce the predicted value of $\mathbf{v}_0$. Now run the experiment to see if your calculated values for $\mathbf{d}_x$ and $\mathbf{d}_y$ are correct.

Experiment 4: Newton's Second Law

EQUIPMENT NEEDED:

-Photogate timer with accessory photogate (or two photogate timers)
-Air TrackSystem with one glider
-Masses
-Pulley
-Pulley Mounting Clamp
-Universal Table 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

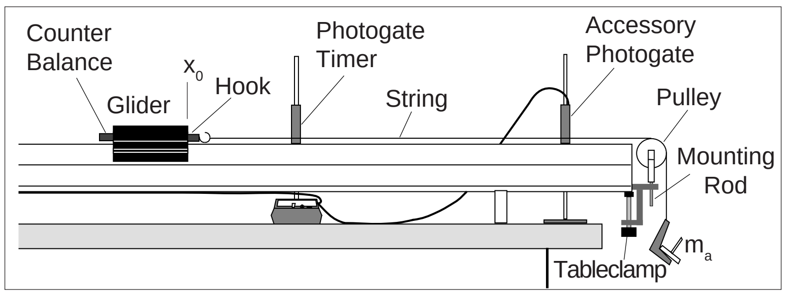


Figure 4.1 Equipment Setup

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.

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 $\mathbf{m_a}$.

⑥ Set your Photogate Timer to GATE mode.

⑦ Choose a starting point $\mathbf{x_0}$ 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 $\mathbf{x_0}$, then release it. Note $\mathbf{t_1}$, the time it took for the glider to pass through the first photogate, and $\mathbf{t_2}$, the time it took for the glider to pass through the second photogate. Repeat this measurement four times. Take the average of your measured $\mathbf{t_1}$'s and $\mathbf{t_2}$'s and record these averages as $\mathbf{t_1}$ and $\mathbf{t_2}$ in Table 4.1. (If you have an ME-9215A Photogate, use the memory function to measure the two times.
If not, someone will need to watch the timer during the experiment and quickly record $\mathbf{t_1}$, before the glider reaches the second photogate.)

⑩ Set the Photogate Timer to PULSE mode.

⑪ Press the RESET button.

⑫ Again, start the glider from $\mathbf{x_0}$. This time measure and record $\mathbf{t_3}$, 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 $\mathbf{t_3}$ in Table 4.1.

⑬ Vary $\mathbf{m_a}$, by moving masses from the glider to the hanger (thus keeping the total mass, $\mathbf{m} + \mathbf{m_a}$, constant.) Record **m** and $\mathbf{m_a}$ and repeat steps 5 through 11. Try at least four different values for $\mathbf{m_a}$.

⑭ Now leave $\mathbf{m_a}$ 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 $\mathbf{v_1}$ and $\mathbf{v_2}$, the average glider velocity as it passed through each photogate.

② Use the equation $\mathbf{a = (v_2 - v_1)/t_3}$ to determine the average acceleration of the glider as it passed between the two photogates.

③ Determine $\mathbf{F_a}$, the force applied to the glider by the hanging mass.
($\mathbf{F_a = m_a g}$; $\mathbf{g}$ = 9.8 m/s^2 = 980 cm/s^2)

Analysis

① Draw a graph showing average acceleration as a function of applied force, $\mathbf{F_a}$.

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 $\mathbf{F_g}$ 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, $\mathbf{F = F_g \sin}\ \theta$, where $\mathbf{F_g}$ 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 $\mathbf{F_g}$ can be calculated.

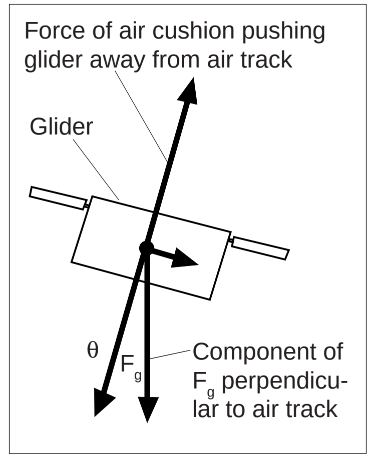


Figure 5.1 Forces Acting on the Glider

Procedure

① Set up the air track as shown in Figure 5.2. Remove the block and level the air track very carefully.

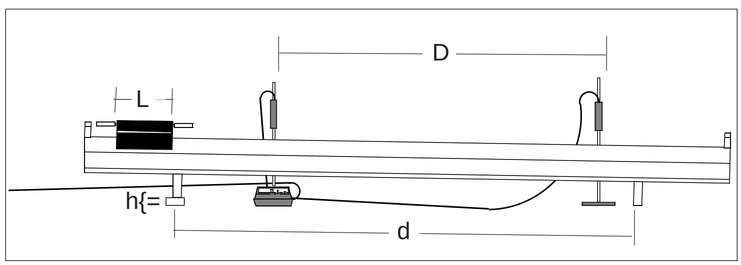


Figure 5.2 Equipment Setup

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 $\mathbf{t_1}$, the time during which the glider blocks the first photogate, and $\mathbf{t_2}$, 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 record $\mathbf{t_1}$ before the glider reaches the second photogate.)

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.

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 $\mathbf{t_1}$ and $\mathbf{t_2}$ to determine $\mathbf{v_1}$ and $\mathbf{v_2}$, 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
$\mathbf{v_2^2 - v_1^2 = 2a(x_2-x_1) = 2aD}$.

④ For each value of mass that you used, take the average of your calculated accelerations to determine $\mathbf{a_{avg}}$.

⑤ For each of your average accelerations, calculate the force acting on the glider along its line of motion ($\mathbf{F = ma_{avg}}$).

⑥ For each measured value of **F**, use the equation $\mathbf{F = F_g \sin\theta}$ to determine $\mathbf{F_g}$.

⑦ Construct a graph of $\mathbf{F_g}$ versus **m,** with **m** as the independent variable (x-axis).

Analysis

Does your graph show a linear relationship between $\mathbf{F_g}$ 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 $\mathbf{F_g = mg}$, 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 $\mathbf{v_2^2 - v_1^2 = 2a(x_2-x_1)}$ 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 relationsip $\mathbf{F_g = mg}$ 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:

$$p_i = m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f} = p_f \ ;$$

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.

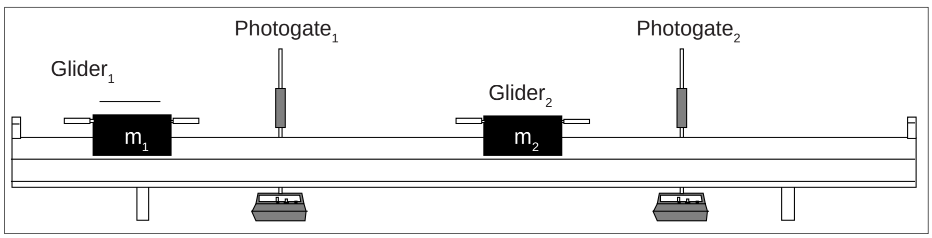


Figure 6.1 Equipment Setup

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:** If you are using ME-9215A Photogate Timers, 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. If not, have someone watching each photogate to record the initial times before the glider passes back through the photogate.

⑥ Repeat the experiment several times, varying the mass of one or both gliders and varying the initial velocity of $glider_1$.

⑦ Try collisions in which the initial velocity of $glider_2$ 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 $(m_1v_{1i} + m_2v_{2i})$	p_f $(m_1v_{1f} + m_2v_{2f})$

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

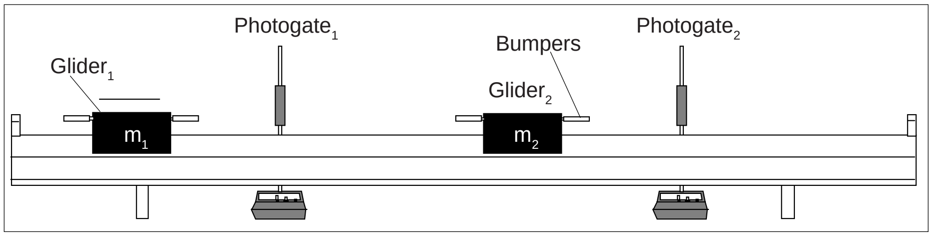


Figure 7.1 Equipment Setup

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.

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:** If you are using ME-9215A Photogate Timers, use the memory function to store the initial times while the final times are being measured. Immediately after the final times are rrecorded, the gliders must be stopped to prevent them from triggering the photogate again due to rebounds. If not, have someone watching each photogate to record the initial times before the glider passes back through the photogate.

⑥ Repeat the experiment several times, varying the mass of one or both gliders and varying the initial velocity of glider$_1$.

⑦ Try collisions in which the initial velocity of glider$_2$ 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 ΔEk 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.

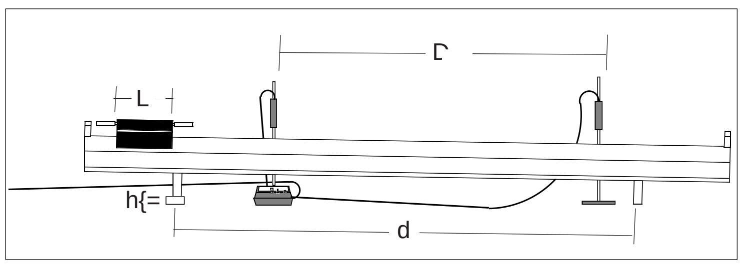


Table 7.1 Data and Calculations

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 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 t1 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}	Δ(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 dimetic energy gained wiht the loss in gravitational potential energy. Was mechanical energy conserved in the motion of the glider?

Experiment 9: Elastic-Kinetic Energy

EQUIPMENT NEEDED:

-Photogate timer
-Weight hanger with weights
-Spring (with a low spring constant)
-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

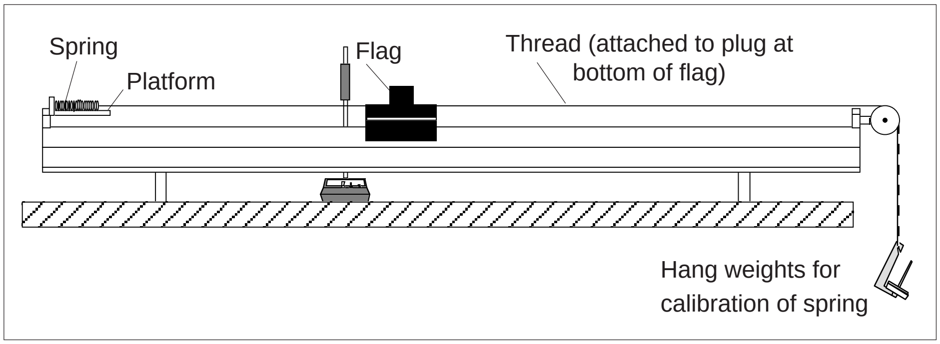


Figure 9.1 Equipment Setup

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.

⑧ 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}.

⑨ 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, $\boldsymbol{\Delta d}$ = ______________

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.

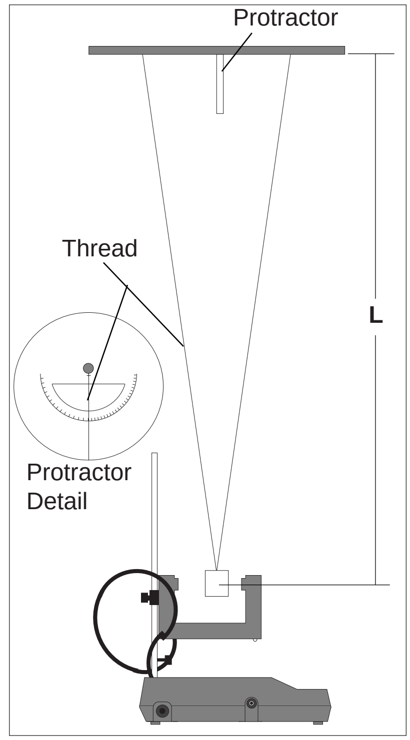


Figure 10.1 Equipment Setup

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.

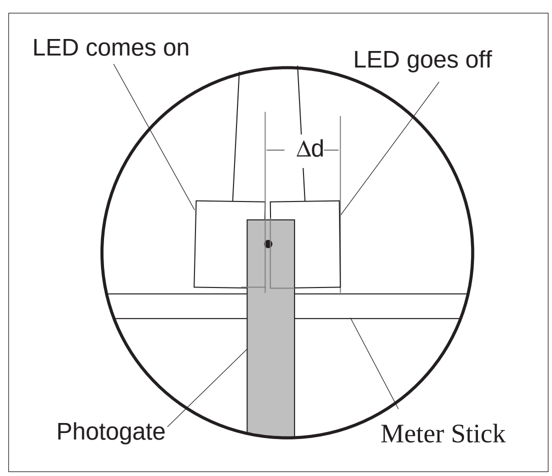


Figure 10.2 Measuring Δd

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 attatch a rigid protractor as shwon on Fig 10.1. This protractor can be created by photocoping the angular readings of a compass onto a piece of white paper before attatching 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.

③ Now adjust the position of the photogate as accurately as you can so that the photogate beam strikes the center of the pendulum bob.

④ Support a meter stick just under the bob, so you can measure the position of the bob but the meter stick does not interfere with the photogate beam (see Figure 10.2). Pull the pendulum bob to one side, then move it slowly through the photogate, along its path of oscillation. There should be no slack in the string. Using the meter stick, note the position of the bob when the photogate beam is first interrupted (the LED lights up) and again when the bob is out of the beam (the LED goes off). Record the difference between these two points as Δd in Table 10.2.

⑤ Now set the Photogate Timer to GATE mode. Pull the bob to one side along its path of oscillation. Again, be sure there is no slack in the string. Measure the angle the string makes with the vertical and record this starting angle as θ in Table 10.2.

⑥ Release the bob so the pendulum oscillates. Record the first times you see on the timer display. This is the time during which the bob blocked the photogate beam as it passed through the photogate. Repeat this measurement several times, starting the bob from the same height each time. Take the average of your measured times and record this value as t in Table 10.2.

⑦ Change the starting height of the bob and repeat steps 4 through 5. Do this for at least five different starting heights.

Data and Calculations

Part 1

① Plot a graph of T versus L, using your measured values from Table 10.1. Is the graph a straight line? If not, try manipulating the data mathematically until you do get a straight line. For example, try plotting T2, L2, etc. When you get a straight line graph, measure the slope of the graph.

Slope =______________________________

Part 2

② For each value of θ, calculate $\Delta h = L - L\cos\theta$.

③ For each value of h, calculate ΔU, the change in gravitational potential energy of the pendulum as it went from the highest point in its swing to the lowest.

$\Delta U = mg\,\Delta h$ =__________________________________

④ For each value of h, calculate Ek, the total kinetic energy of the pendulum as it passed through the lowest point of its swing:

$E_k = 1/2\, mv^2 = 1/2\, m\,(\Delta d/t)^2$ =________________________________

Table 10.1

Δd = _______________

m	L	T

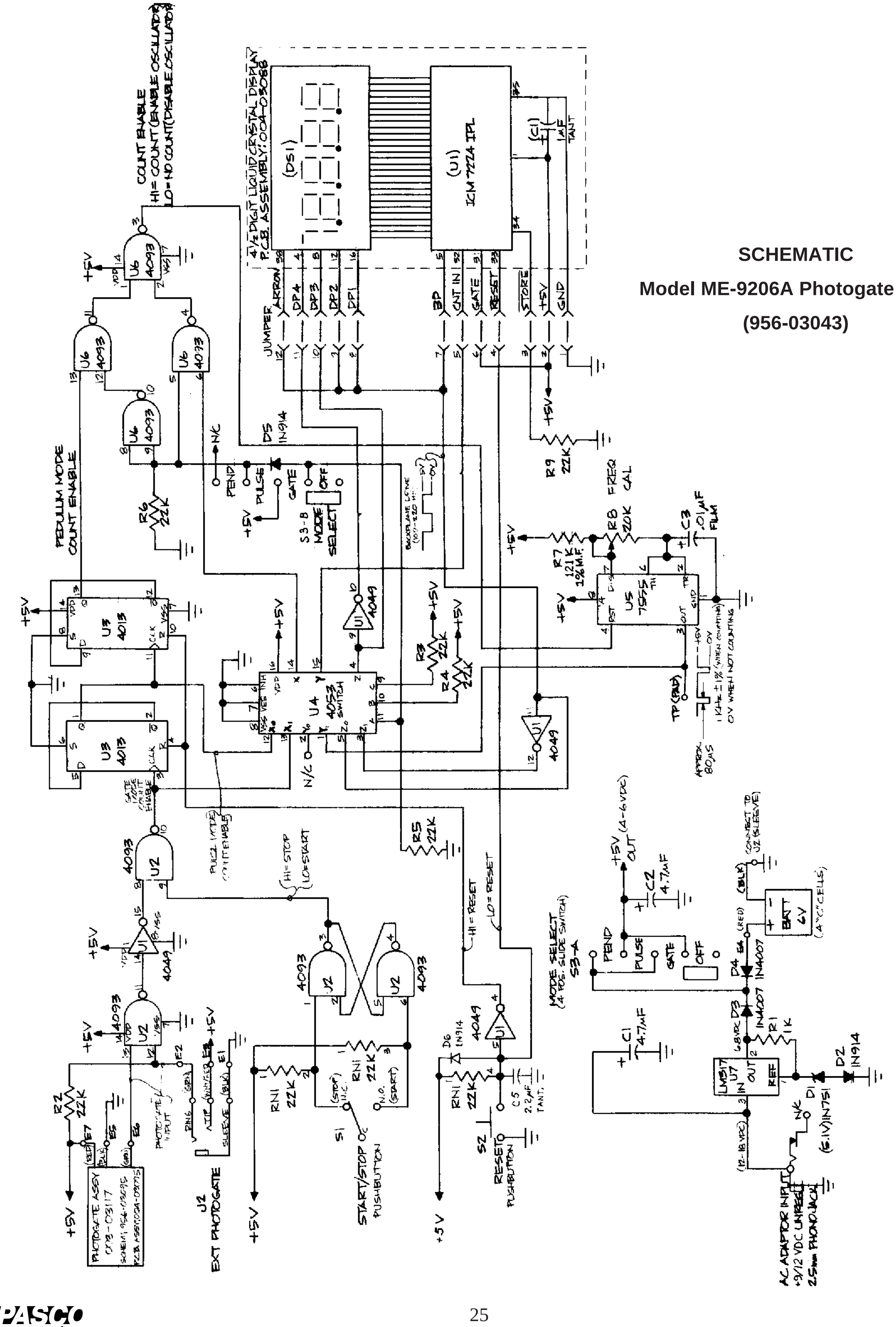
Questions

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.



SCHEMATIC

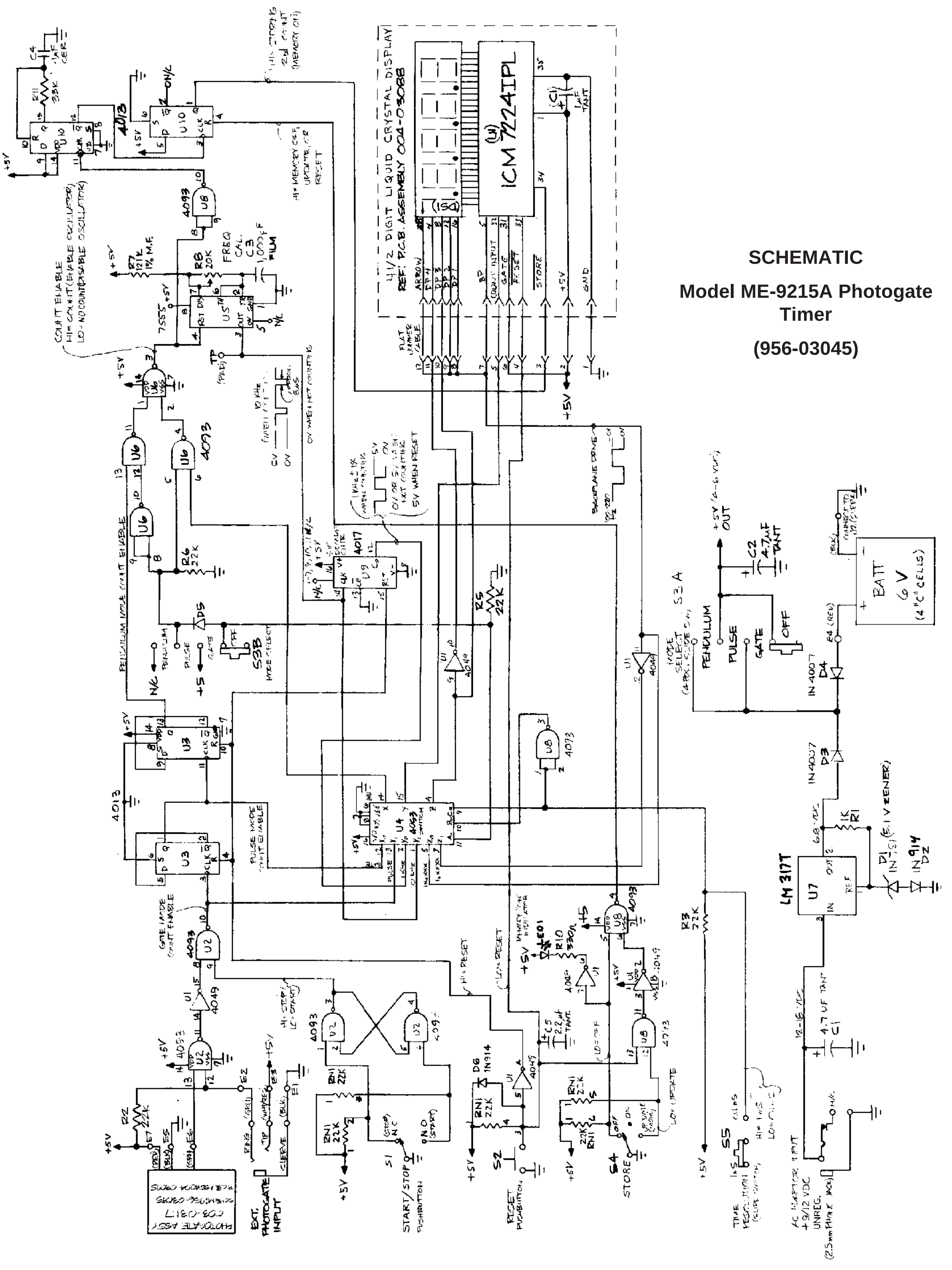
Model ME-9206A Photogate Timer

(956-03043)

SCHEMATIC

Model ME-9215A Photogate Timer

(956-03045)



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 the 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

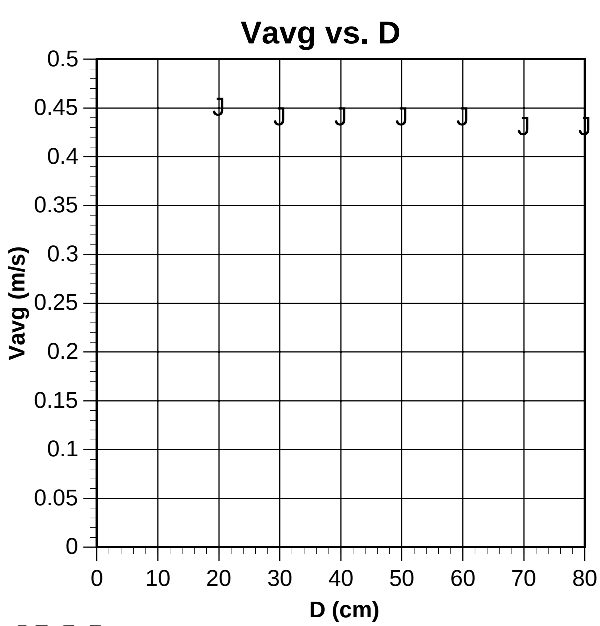
Here are the results for the measurement of average velocities with photogate timers positioned at seven different distances apart.

Table 1.1

X_1 = 100.0 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 fnal velocities of the ball down the incline plane.

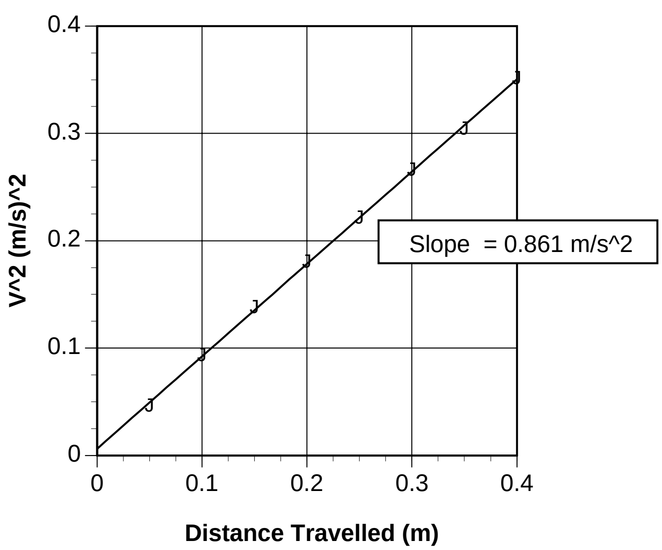
Table 2.1

Δd = 1.6 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.

Final Velocity Squared vs. Distance Travelled Down 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 m/s^2

② $D = \dfrac{0.43\ t^2}{2}$. This is because time can be accurately measured. This is not true for velocity and accceleration 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 continous 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 fnal velocities of the ball down the incline plane.

Table 3.1

Δd (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 neccessary 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.

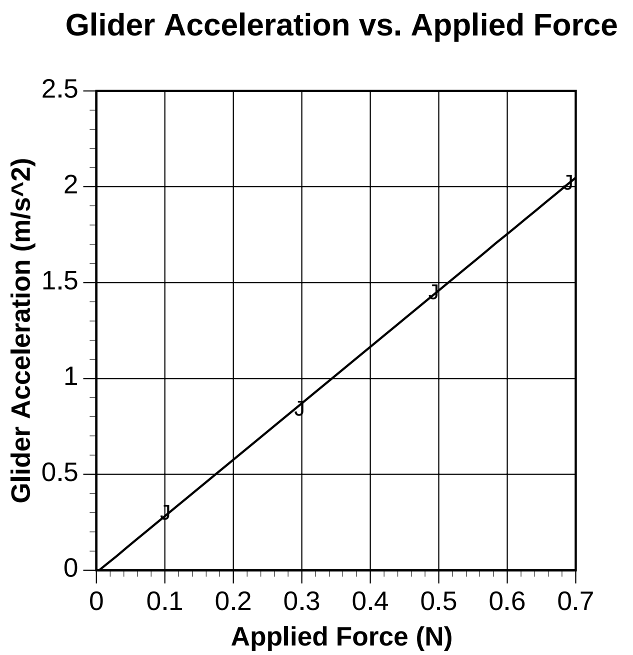
The tables below list the results from two experimental conditions. The value of each parameter was the average derived after five trials.

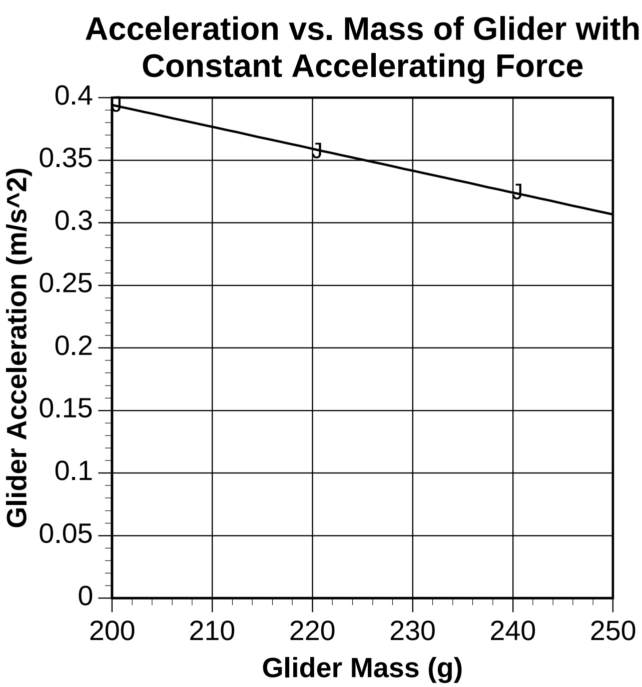
Table 4.1 Constant System Mass

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





Notes - on Analysis

③ yes. The acceleration of the glider is linearly proportional to the applied force. The acceleration of the glider is inversely proprotional 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 accelearation 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 accelearation. One way to include instantaneous accelearation in the axperiement is to reduce the distance between the photogates.

Exp 5 - The Force of Gravity

Notes - on Procedure

④ In order to mantain a constant D throughout the experiement, 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 experiemtnal 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 θ = 0.013 rad

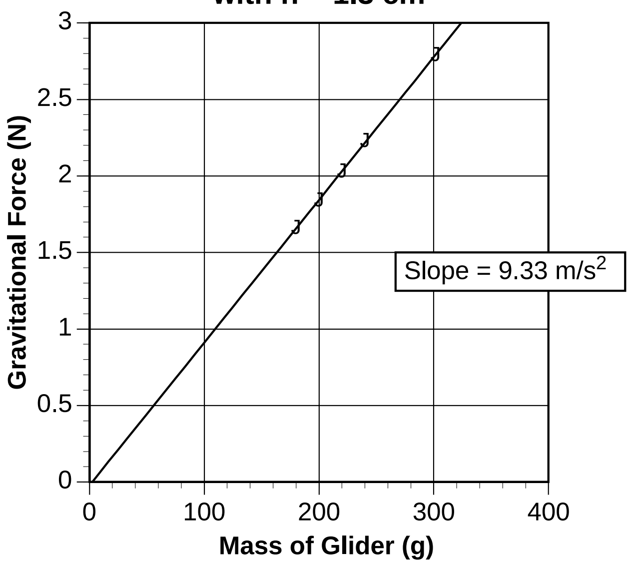
m (g)	t_1 (s)	t_1+t_2 (s)	t_2 (s)	v_1 (m/s)	v_2 (m/s)	a_{avg} (m/s^2)	F_g (N)
180.2	0.35	0.57	0.22	0.36	0.57	0.12	1.66
200.2	0.35	0.57	0.22	0.36	0.57	0.12	1.84
220.2	0.35	0.57	0.22	0.36	0.57	0.12	2.03
240.3	0.35	0.57	0.22	0.36	0.57	0.12	2.23

Table 5.2

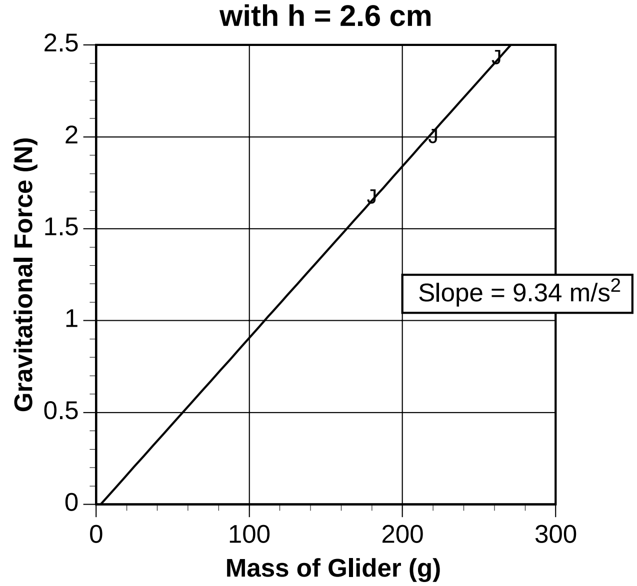
d (cm) = 100 D (cm) = 80 h (cm) = 2.6 L (cm) = 12.6 θ = 0.026 rad

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

Gravitational Force vs. Glider Mass with h = 1.3 cm



Gravitational Force vs. Glider Mass with h = 2.6 cm



Notes - on Analysis

① Yes. Yes. Yes. $g \cong 9.33$ m/s^2 in both cases.This value is approximately 5% below the established value of 9.80 m/s^2.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 experiements 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 gravitional 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 intially.

Table 6.1 Glider 2 is initially Stationary

L_1 = 12.6 cm L_2 = 12.8 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 vibvrations 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 experiement ranged from 1% to 11%. Momentum loss is contributed by equipment setup and the inability to maintain a constant velocity throughout the experiement. It however also points out the fact that mommentum 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 experiemtnal 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 cm L_2 = 12.8 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)	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 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	-0.30332	-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.

Secondly, as the gliders collided, the linear motion of the gliders might be changed to include vibvrations 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 θ= 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)	Δ(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 cm   h = 2.6 cm

D = 80 cm   L = 12.6 cm   θ= 0.026 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)	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 experiemental data indicated that potential energy was consitently transformed into kinetic enery. There was however a loss of 5% to 7% in energy . This is attributed to experiemental 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 experiement is presented to the right.

Figure 9.1 Spring Constant

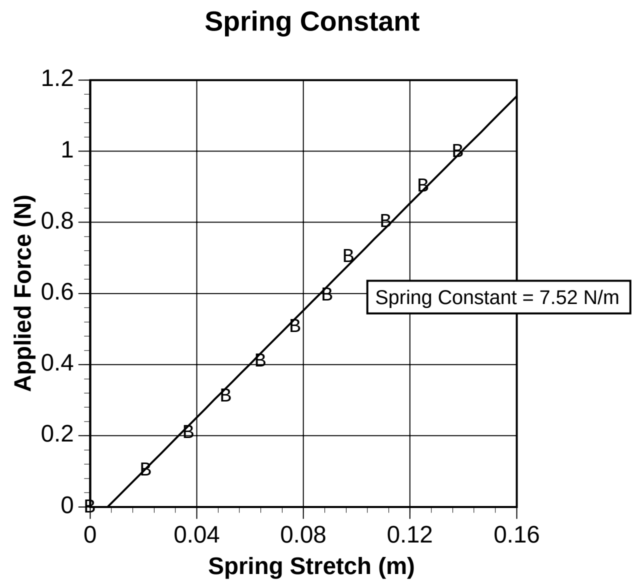


Table 9.2 Potential Energy vs. Kinetic Energy of Spring Mass System

X_1 = 104.2 cm   K = 7.52 N/m   Flag Width = 3.8 cm

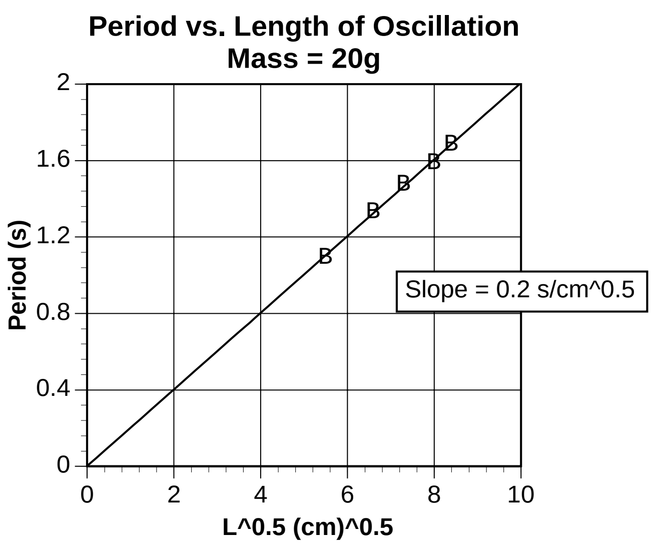
m (g)	Spring Stretch (cm)	t_{avg} (s)	v_{avg} (m/s)	K.E. (J)	P.E. (J)	% Error (%)
211.5	5	0.13	0.29	0.01	0.01	4.6
211.5	10	0.06	0.60	0.04	0.04	0.0
211.5	15	0.04	0.88	0.08	0.08	3.3
211.5	20	0.03	1.18	0.15	0.15	1.9
231.5	5	0.13	0.29	0.01	0.01	-3.7
231.5	10	0.07	0.57	0.04	0.04	0.0
231.5	15	0.04	0.86	0.09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

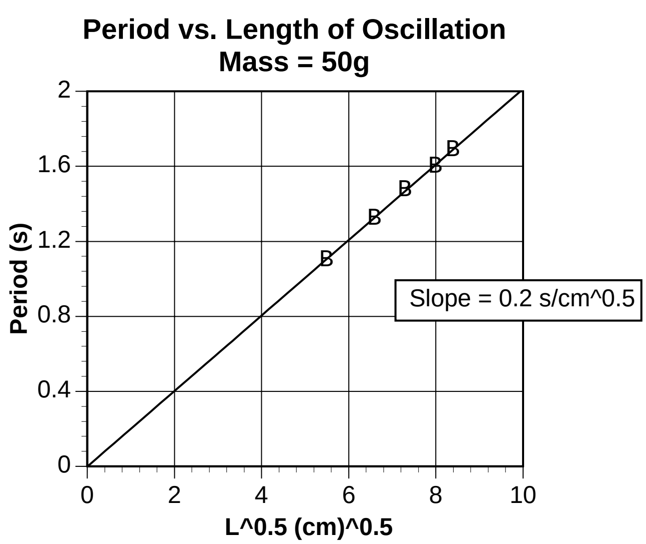
Exp 10- Pendulum Motion

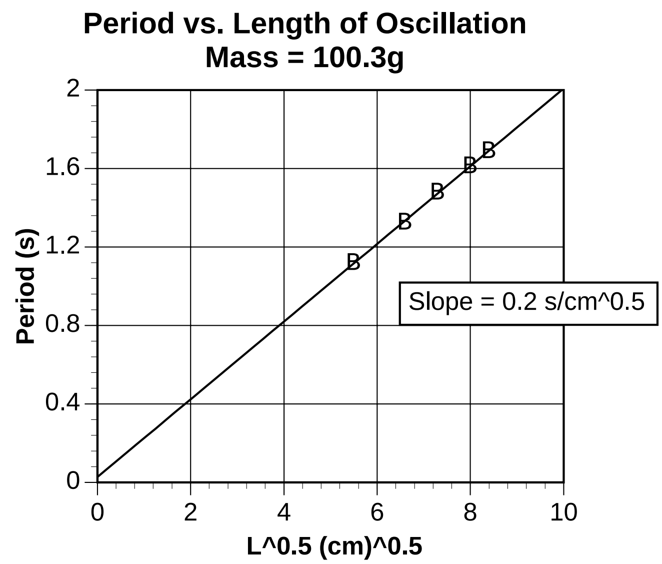
Notes - on Analysis

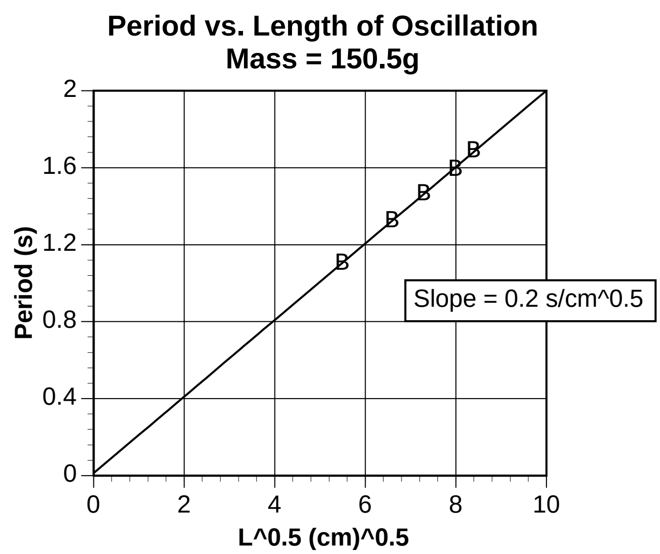
Part 1: Period of Oscillation versus Mass and Length

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 theresults for the conservation of energy with the pendulum dropped at varying heights.

L = 100 cm **Δd** = 2 cm **Mass** = 175.2 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 cyles 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.

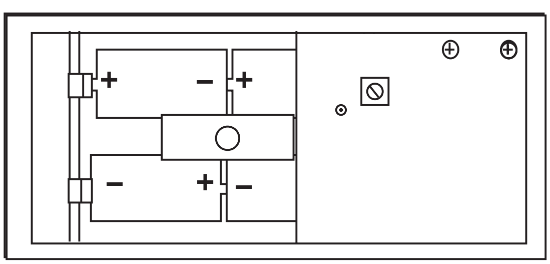
② Remove the thumb screw which holds the battery retainer plate, then lift out the retainer plate and the batteries.

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

Calibration

Although the timer should remain accurate to within 1% over a long period of time, it’s a good idea to check the accuracy once a year, and calibrate the timer if necessary.

To Calibrate the Timer:

① Remove the two screws on the bottom of the timer and lift out the bottom panel.

② Power the timer with the power adapter or a new set of batteries, or check that the total battery voltage (for all four batteries) is at least 5 volts.

③ Switch the timer to one of the timing modes and trigger the photogate. The timer must be counting during calibration.

④ Connect a frequency meter with a known accuracy of 0.5% or better between Test Points 1 and 2 as shown in Figure 6. Test Point 1 is on the printed circuit board pad labeled TP, near the Calibration Adjust potentiometer. Test Point 2 is the negative terminal of the battery indicated in Figure 6. The output at the test point is TTL compatible, however, it is suggested that a 0.47 μf capacitor be placed in series between Test Point 1 and the frequency meter.

⑤ The signal frequency at the test point should be:

ME-9206A 1.000 kHz

ME-9215A 10.000 kHz

⑥ Adjust the Calibration Adjust potentiometer until the frequency is correct.

Inside the Timer with the bottom panel removed.

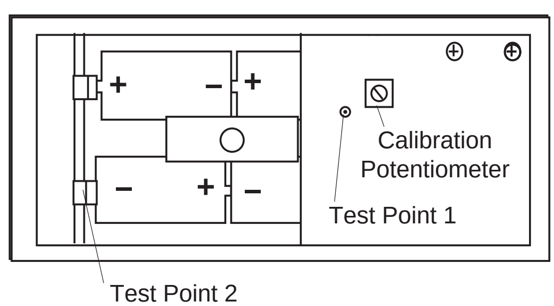


Figure 6 Calibration

Notes

Technical Support

Feed-Back

If you have any comments about this product or this manual please let us know. If you have any suggestions on alternate experiments or find a problem in the manual please tell us. PASCO appreciates any customer feed-back. Your input helps us evaluate and improve our product.

To Reach PASCO

For Technical Support call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

Internet: techsupp@PASCO.com

Contacting Technical Support

Before you call the PASCO Technical Support staff it would be helpful to prepare the following information:

• If your problem is computer/software related, note:

Title and Revision Date of software.

Type of Computer (Make, Model, Speed).

Type of external Cables/Peripherals.

• If your problem is with the PASCO apparatus, note:

Title and Model number (usually listed on the label).

Approximate age of apparatus.

A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.)

If possible, have the apparatus within reach when calling. This makes descriptions of individual parts much easier.

• If your problem relates to the instruction manual, note:

Part number and Revision (listed by month and year on the front cover).

Have the manual at hand to discuss your questions.

012-06375A
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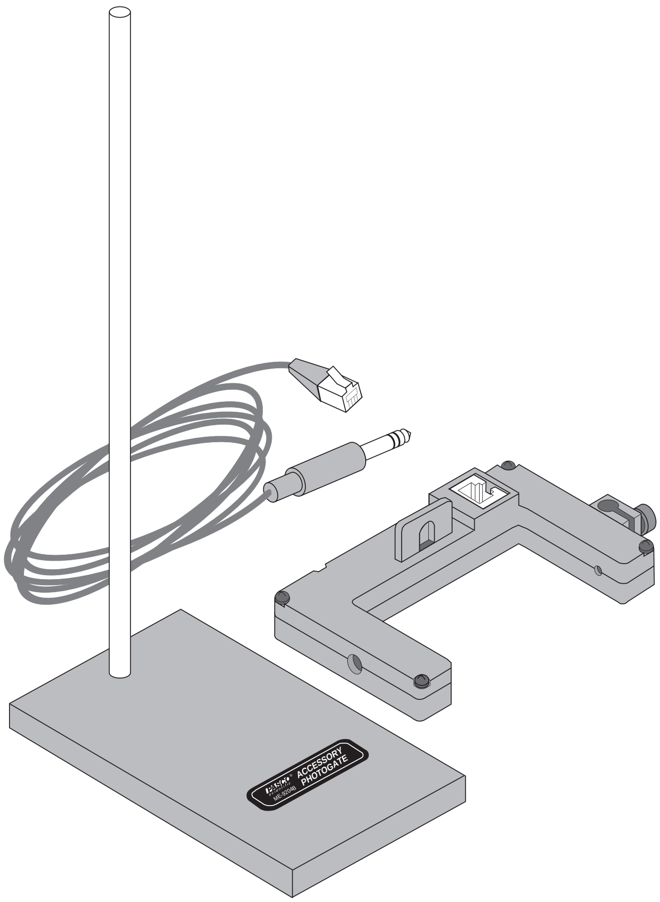
Instruction Sheet
for the PASCO
Model ME-9204B

ACCESSORY PHOTOGATE



Introduction

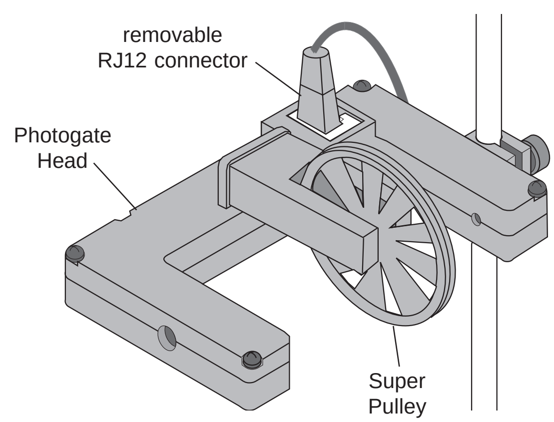
The PASCO Model ME-9204B Accessory Photogate features a Photogate Head with a narrow infrared beam and a fast fall time that provide very accurate signals for timing. When the infrared beam between the source and detector is blocked, the output of the photogate is low, and the red LED (light emitting diode) on the photogate goes on. When the beam is not blocked, the output is high, and the LED is off.

The cable assembly included with the Accessory Photogate is detachable from the unit. One end of the cable is a RJ12 telephone plug that connects to the RJ12 modular jack in the photogate housing. At the other end, a stereo phone plug connects directly into a PASCO Photogate Timer (ME-9206B and ME-9215B) or into any PASCO interface with digital channels (*ScienceWorkshop* 500 I and 700 I). Please note that the ME-9215B has a memory function which allows signals from two photogates (the built-in photogate on the ME-9215B and the ME-9204B) to be stored and retrieved.

The Photogate Head also includes a small rod clamp and thumbscrew for attaching the unit to the base and support rod included with the product, or to any quarter inch diameter support rod.

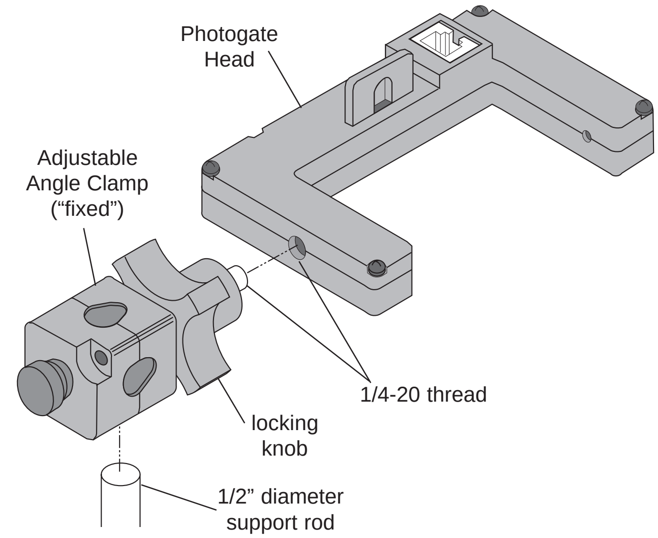
Additional Features

The raised slot on the housing provides a seat for attaching the PASCO ME-9450 Super Pulley.

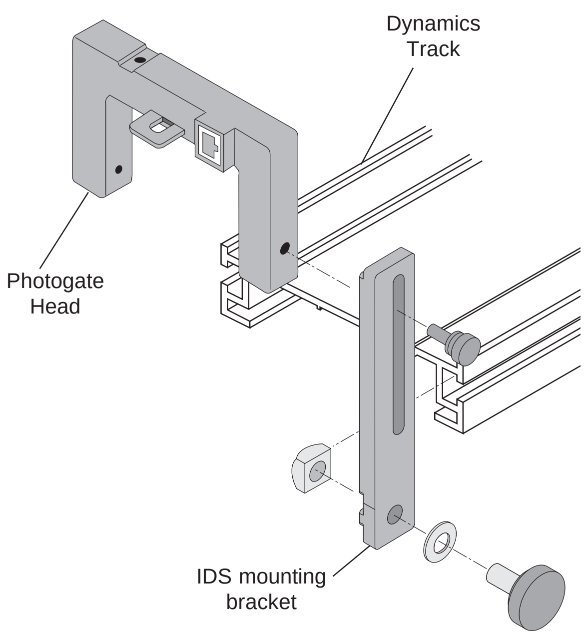


This instruction sheet edited by: Martina Graham

The Photogate Head can be mounted on a support rod of up to half inch in diameter by attaching a PASCO ME-8744 Adjustable Angle Clamp. It is necessary to remove the "mobile" rod clamp from the clamp assembly and secure the "fixed" part of the clamp assembly to the 1/4-20 thread provided in the photogate housing opposite the side of the small rod clamp. Rotate the equipment to the correct orientation and then secure it with the locking knob.



The Photogate Head can also be attached to the side of a PASCO Dynamics Track with an IDS mounting bracket (part of PASCO ME-9471 IDS Photogates and Fences). It is necessary to remove the small rod clamp from the photogate housing.



Operation

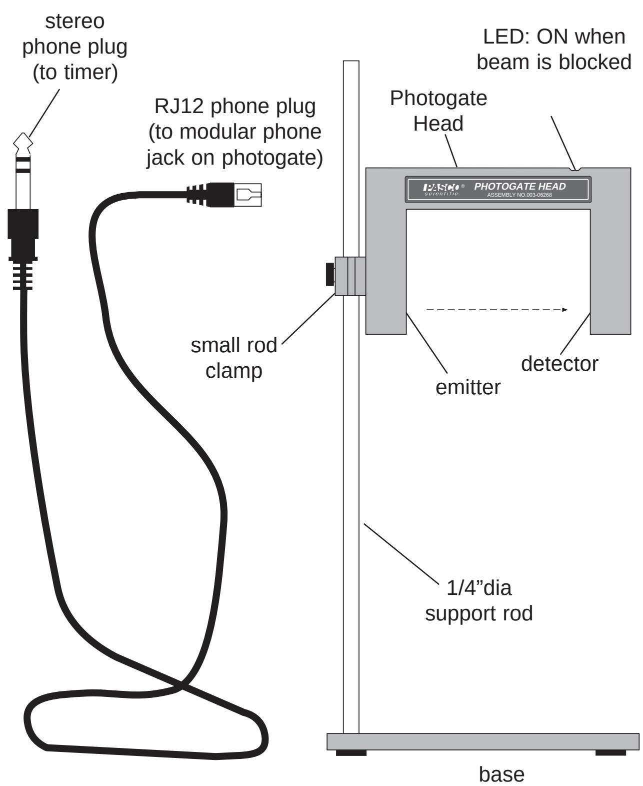
① Clamp the Photogate Head to the support rod.

② Position the photogate so the object to be timed will pass through the photogate, blocking the beam. (See Figure "Photogate with Pendulum"). To minimize parallax error, pass the object as close to the detector as possible, with the line of travel perpendicular to the beam. Loosen the clamp screw to change the angle or height of the photogate.

③ Plug the RJ12 phone plug from the cable assembly into the modular phone jack on the photogate housing.

④ Plug the stereo phone plug at the other end of the cable assembly into the timer, adapter cable, or interface.

⑤ Test the operation of the photogate by watching the LED when the beam is blocked.



Accessory Photogate

NOTES:

- The actual length of an object passing through the photogate may be slightly different than the effective length seen by the photogate. To determine the effective length, push the object through the photogate, and measure the distance moved by the object from where the LED first comes ON to where it goes off. Use this effective length, rather than the actual length, in calculations. For example, if you were measuring the speed of the object, you would divide the effective length by the time during which the object blocked the photogate beam.
- A stereo phone plug extension cord, such as PASCO Model PI-8117, will increase the separation between the photogate and the timer.

Experiments

Refer to the experiment guide that comes with your PASCO equipment (e.g., Introductory Dynamics System).

Photogate Specifications

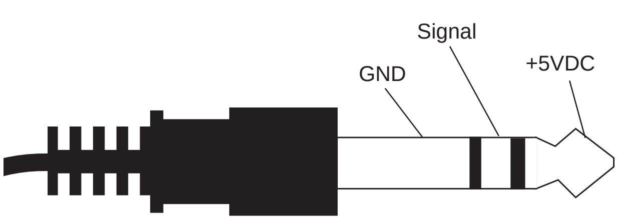
Detector rise time: < 500 ns

Detector fall time: < 50 ns

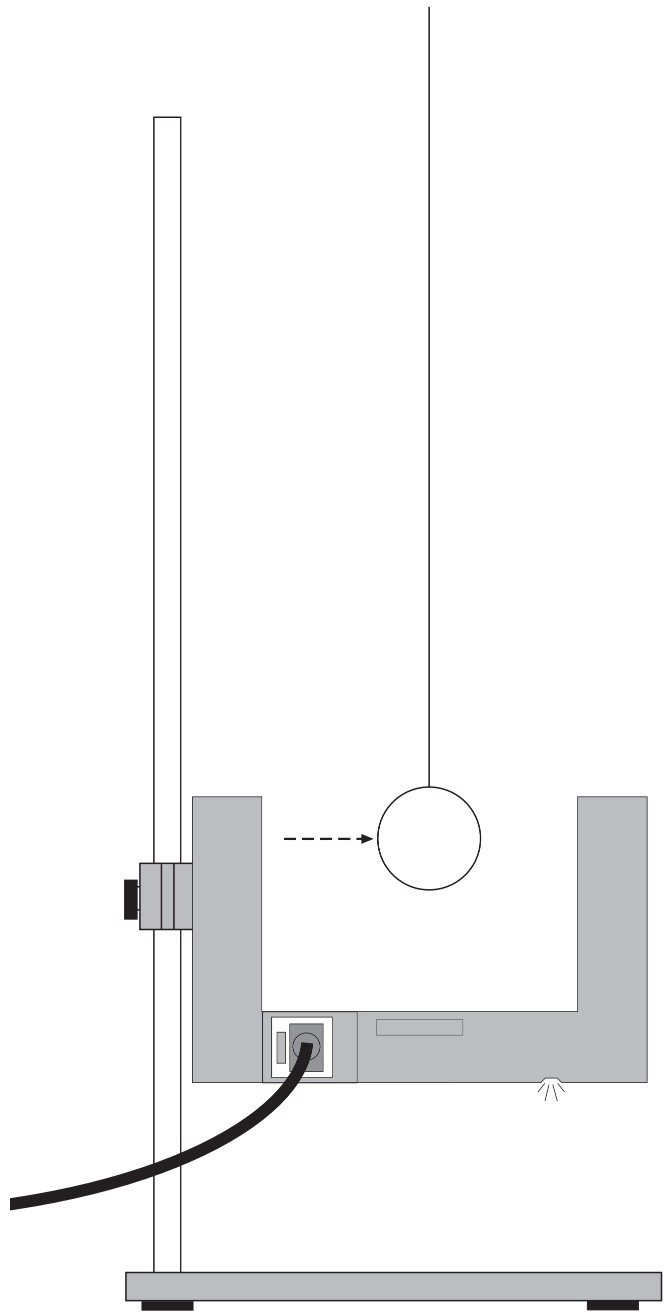
Parallax error: For an object passing within 1 cm of the detector, with a velocity less than 10 m/s, the difference between the true and effective length is less than 1 mm.

Power requirements: 5 VDC ± 5% at 45 mA.

Infrared source: Peak at 880 nm.



Stereo Phone Plug



Photogate with Pendulum

Limited Warranty

PASCO scientific warrants the product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. The warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

Feedback

If you have any comments about the product or manual, please let us know. If you have any suggestions on alternate experiments or find a problem in the manual, please tell us. PASCO appreciates any customer feedback. Your input helps us evaluate and improve our product.

To Reach PASCO

For technical support, call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

fax: (916) 786-3292

e-mail: techsupp@pasco.com

web: www.pasco.com

Includes Teacher's Notes and Typical Experiment Results

Instruction Manual and Experiment Guide for the PASCO scientific Model ME-6830/ME-6831

012-05375B
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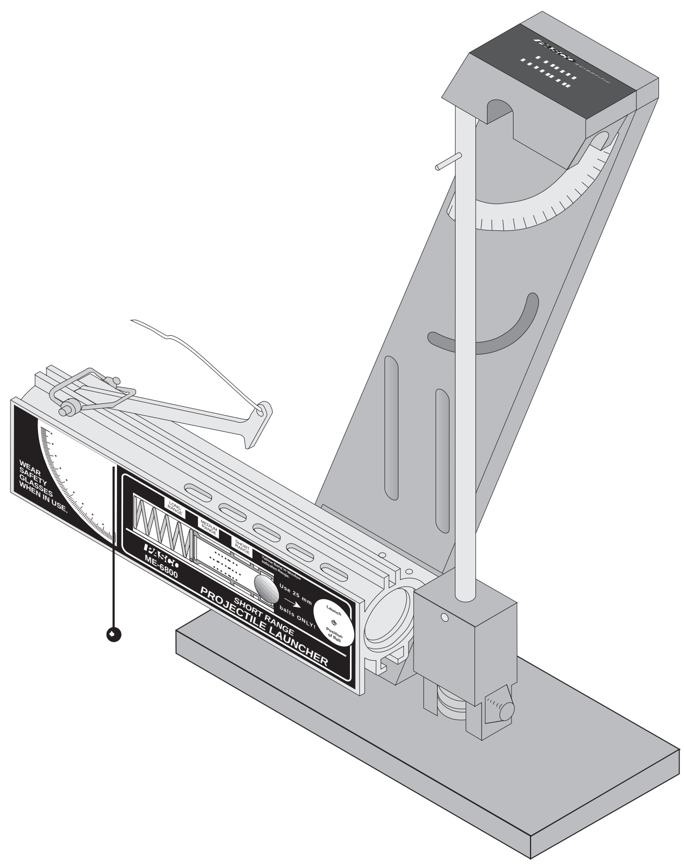
Ballistic Pendulum / Projectile Launcher



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Author: Ann Hanks and Eric Ayers

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③ Make certain that the packing material can not shift in the box, or become compressed, thus letting the instrument come in contact with the edge of the box.

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Introduction

The PASCO ME-6830/ME-6831 Ballistic Pendulum/ Projectile Launcher (BPPL) has been designed for projectile experiments and demonstrations as well as the classic Ballistic Pendulum experiments. The only additional equipment required is a C-clamp for clamping the launcher to a table. The features of the Ballistic Pendulum/Projectile Launcher include:

- **LAUNCH AT ANY ANGLE:** Balls can be launched at any angle from zero to 90 degrees measured from the horizontal. The angle is easily adjusted using thumb screws. The built-in protractor and plumb-bob on the side of the launcher give a convenient and accurate way of determining the angle of inclination.
- **THREE RANGE SETTINGS:** There are three ranges from which to choose. For the Short Range Projectile Launcher these three ranges are approximately 1.2 meters, 3 meters, and 5 meters, when the angle is 45 degrees. For the Long Range Demonstration Projectile Launcher, the three ranges are approximately 2.5 meters, 5 meters, and 8 meters. The difference between these two versions of the Projectile Launcher is the strength of the spring. The long range version is intended for large classroom demonstrations and should not be used with the Ballistic Pendulum base.
- **FIXED ELEVATION INDEPENDENT OF ANGLE:** The Projectile Launcher pivots at the muzzle end so the elevation of the ball as it leaves the barrel does not change as the angle is varied. The base has three sets of slots. The top curved slot is used when it is desired to change the angle and the center two slots are used when it is desired to shoot horizontally only. The bottom mounting holes are for use with the Ballistic Pendulum experiment.
- **REPEATABLE RESULTS:** There is no spin on the ball since the piston keeps the ball from rubbing on the walls as it travels up the barrel. The sturdy base can be secured to a table with a C- clamp (not included) so there is very little recoil. The trigger is pulled with a string to minimize any misalignment caused by other methods of trigger release.

➤ **IMPORTANT:** Experimental results can be further improved by making sure that the ball does not stick to the blue vibration damping ring prior to being launched. This is particularly critical for the long range setting and for launching angles above 30°. To assure the ball does not stick to the ring, push it gently with a pencil from the back of the barrel.

- **BARREL SIGHTS AND SAFETY PRECAUTIONS:** The sights for aiming the Projectile Launcher can be viewed from the back of the launcher by looking through the back end of the barrel.

➤**WARNING:** Never look down the front of the barrel because it may be loaded. To see if the ball is in the barrel and to check whether the Projectile Launcher is cocked, look at the slots in the side of the barrel. The yellow indicator seen through the side slot indicates the position of the piston. The ball can also be seen through these slots when it is in the piston.

- **COMPUTER COMPATIBLE:** Photogates can be attached with the ME-6821 Photogate Mounting Bracket to connect the Projectile Launcher to a computer for measuring the muzzle speed. Also, a photogate at the muzzle and an ME-6810 Time-of-Flight Accessory can be used to time the flight of the ball.
- **COMPACT STORAGE:** The Projectile Launcher stores away in a small space. The ramrod attaches to the Projectile Launcher with Velcro® and the launcher can be turned vertically so it takes up the minimum amount of space on the shelf.
- **RELIABLE BALL-CATCHER MECHANISM:** The sensitive spring-loaded barb-type catch on the pendulum will catch balls with a large range of momenta. In addition, the ball is held in line with the pendulum rod for best accuracy.
- **REMOVABLE PENDULUM:** All moving parts of the pendulum may be removed so that the mass and the center of mass can be easily determined. In addition, the pendulum can be reversed to compare the effects of inelastic and elastic collisions.
- **VARIABLE-MASS PENDULUM:** Masses can be added to the bottom of the pendulum so that meaningful measurements can be taken with either heavy or lightweight balls, over a wide range of velocities.

Equipment

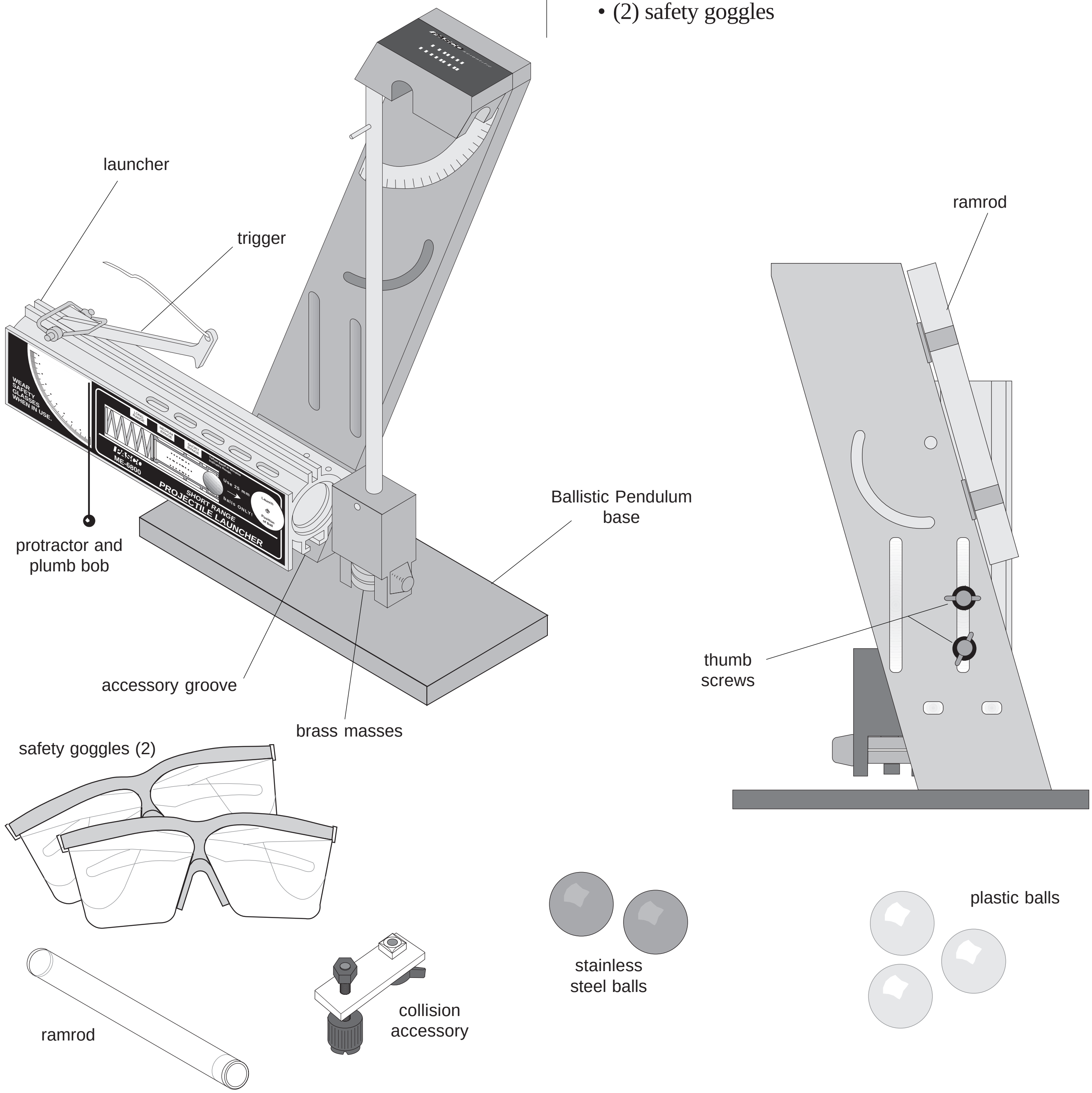
The following is a description of the equipment that is included with various models of the Ballistic Pendulum/ Projectile Launcher.

The ME-6831 Ballistic Pendulum includes the following:

- Ballistic Pendulum base (assembled)
- (2) steel balls

In addition, the ME-6830 Ballistic Pendulum/Projectile Launcher includes:

- Short Range Launcher
- ramrod (Attached with Velcro® to stand)
- collision attachment
- (3) plastic balls
- (2) pendulum brass masses
- (2) safety goggles



General Operation of the Projectile Launcher

① Ready

- Always wear safety goggles when you are in a room where the Projectile Launcher is being used.
- For Projectile Launcher experiments, the base of the Ballistic Pendulum/Projectile Launcher must be clamped to a sturdy table using the clamp of your choice. When clamping to the table, it is often desirable to have the label side of the Launcher even with one edge of the table so a plumb bob can be used to locate the position of the muzzle with respect to the floor.
- The Projectile Launcher can be mounted to the bracket using the curved slot when it is desired to change the launch angle. It can also be mounted to the center two slots in the base if you are only going to launch horizontally, such as into a Dynamics Cart.

② Aim

- The angle of inclination above the horizontal is adjusted by loosening both thumb screws and rotating the Launcher to the desired angle as indicated by the plumb bob and protractor on the side of the Launcher. When the angle has been selected, both thumb screws are tightened.
- You can bore-sight at a target (such as in the Monkey-Hunter demonstration) by looking through the Launcher from the back end when the Launcher is not loaded. There are two sights inside the barrel. Align the centers of both sights with the target by adjusting the angle and position of the Launcher.

③ Load

- Always cock the piston with the ball in the piston. Damage to the piston may occur if the ramrod is used without the ball.
- Place the ball in the piston. Remove the ramrod from its Velcro® storage place on the base. While viewing the range-setting slots in the side of the launcher, push the ball down the barrel with the ramrod until the trigger catches the piston at the desired range setting.
- Remove the ramrod and place it back in its storage place on the base.
- When the Projectile Launcher is loaded, the yellow indicator is visible in one of the range slots in the side of the barrel and the ball is visible in another one of the slots in the side of the barrel. To check to see if the Launcher is loaded, always check the side of the barrel. Never look down the barrel!

④ Shoot

- Before launching the ball, make certain that no person is in the way.
- To shoot the ball, pull straight up on the lanyard (string) that is attached to the trigger. It is only necessary to pull it about a centimeter.
- The spring on the trigger will automatically return the trigger to its initial position when you release it.

⑤ Maintenance and Storage

- No special maintenance of the Projectile Launcher is required.
- Do not oil the launcher!!
- To store the launcher in the least amount of space, adjust its angle to 90 degrees. If the Photogate Mounting Bracket and Photogates are attached to the launcher, the bracket can be slid back along the barrel with the photogates still attached.

Ballistic Pendulum - Theory

Overview

The ballistic pendulum is a classic method of determining the velocity of a projectile. It is also a good demonstration of some of the basic principles of physics.

The ball is fired into the pendulum, which then swings up a measured amount. From the height reached by the pendulum, we can calculate its potential energy. This potential energy is equal to the kinetic energy of the pendulum at the bottom of the swing, just after the collision with the ball.

We cannot equate the kinetic energy of the pendulum after the collision with the kinetic energy of the ball before the swing, since the collision between ball and pendulum is inelastic and kinetic energy is not conserved in inelastic collisions. Momentum is conserved in all forms of collision, though; so we know that the momentum of the ball before the collision is equal to the momentum of the pendulum after the collision. Once we know the momentum of the ball and its mass, we can determine the initial velocity.

There are two ways of calculating the velocity of the ball. The first method (approximate method) assumes that the pendulum and ball together act as a point mass located at their combined center of mass. This method does not take rotational inertia into account. It is somewhat quicker and easier than the second method, but not as accurate.

The second method (exact method) uses the actual rotational inertia of the pendulum in the calculations. The equations are slightly more complicated, and it is necessary to take more data in order to find the moment of inertia of the pendulum; but the results obtained are generally better.

Please note that the subscript "cm" used in the following equations stands for "center of mass."

Approximate Method

Begin with the potential energy of the pendulum at the top of its swing:

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

Where M is the combined mass of pendulum and ball, g is the acceleration of gravity, and Δh is the change in height. Substitute for the height:

$$\Delta h = R(1 - \cos\theta)$$

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

Here R_{cm} is the distance from the pivot point to the center of mass of the pendulum/ball system. This potential energy is equal to the kinetic energy of the pendulum immediately after the collision:

$$KE = \frac{1}{2} M \nu_P^2$$

The momentum of the pendulum after the collision is just

$$P_p = M\nu_P \ ,$$

which we substitute into the previous equation to give:

$$KE = \frac{P_P^2}{2M}$$

Solving this equation for the pendulum momentum gives:

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

This momentum is equal to the momentum of the ball before the collision:

$$P_b = m\nu_b \ .$$

Setting these two equations equal to each other and replacing KE with our known potential energy gives us:

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

Solve this for the ball velocity and simplify to get:

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

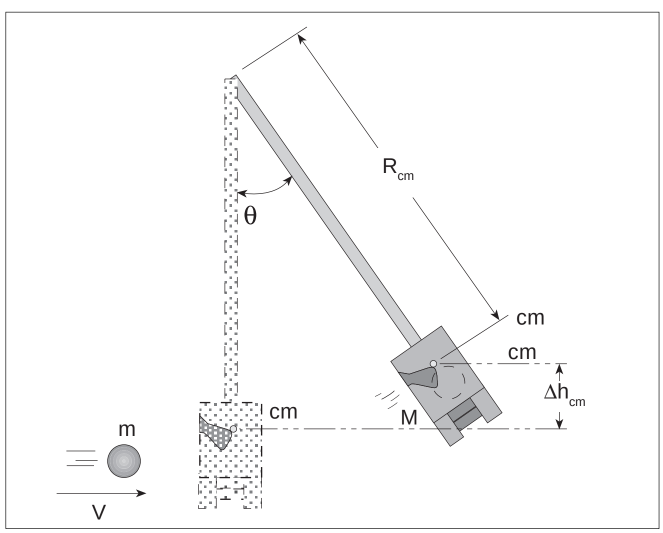


Figure 1

Exact Method

The potential energy is found in a way identical to the way shown previously:

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

For the kinetic energy, we use the equation for angular kinetic energy instead of linear, and substitute into it the equation for angular momentum.

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

$$L_p = I\omega$$

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

Here I is the moment of inertia of the pendulum/ball combination, and ω is the angular velocity immediately after the collision.

As we did previously, solve this last equation for angular momentum:

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

This angular momentum is equal to the angular momentum of the ball before the collision, as measured from the pendulum pivot point.

$$L_b = mR_b^2\omega = mR_b v$$

R_b is the distance from the pendulum pivot to the ball. (This radius is *not* in general equal to R_{cm}, which is the distance from the pivot point to the center of mass for the pendulum/ball system.)

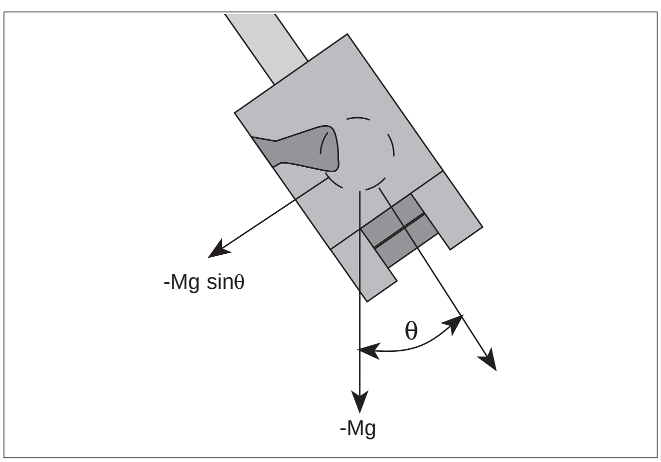


Figure 2

These two angular momenta are equal to each other, so:

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

Solve for v:

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

Now we need to find I, the moment of inertia of the pendulum and ball. To do this, we start with the rotational equivalent of Newton's second law,

$$\tau = I\alpha$$

where τ is torque, I is moment of inertia, and α is angular acceleration. The force on the center of mass of the pendulum is just Mg, and the component of that force directed towards the center of the pendulum swing is (see figure 2):

$$F = -Mg\sin\theta$$

The torque on the pendulum is thus:

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

For small angles θ, $\sin\theta \approx \theta$, so if we make this substitution and solve for α we get:

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

This angular equation is in the same form as the equation for linear simple harmonic motion:

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

So if we compare these two equations, linear and angular, we can see that the pendulum exhibits simple harmonic motion, and that the square of the angular frequency (ω^2) for this motion is just:

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

Solving this for I gives us the 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 have made a small-angle approximation to find this equation for I; but I does not depend on θ. This means that we must measure the period T using small oscillations; but once we have calculated I with that period, we may use that value of I regardless of the amplitude reached during other parts of the experiment.

Installing the Photogate Mounting Bracket

The PASCO Model ME-6821 Photogate Mounting Bracket is an optional accessory to the PASCO Projectile Launchers. It attaches to the front of the launcher and holds one or two photogates in parallel for measuring the muzzle velocity of the ball.

Setup procedure

① Loosen the thumbscrew of the Photogate Mounting Bracket.

② Align the bracket assembly with the front of the Projectile Launcher and slide the square nut down the groove of the barrel until the dowel pin enters the groove.

(The dowel pin acts as an alignment guide and must enter the groove for proper alignment of the bracket.)

> ➤ **NOTE:** The flat side of the square nut must face the inside of the projectile launcher groove as shown.

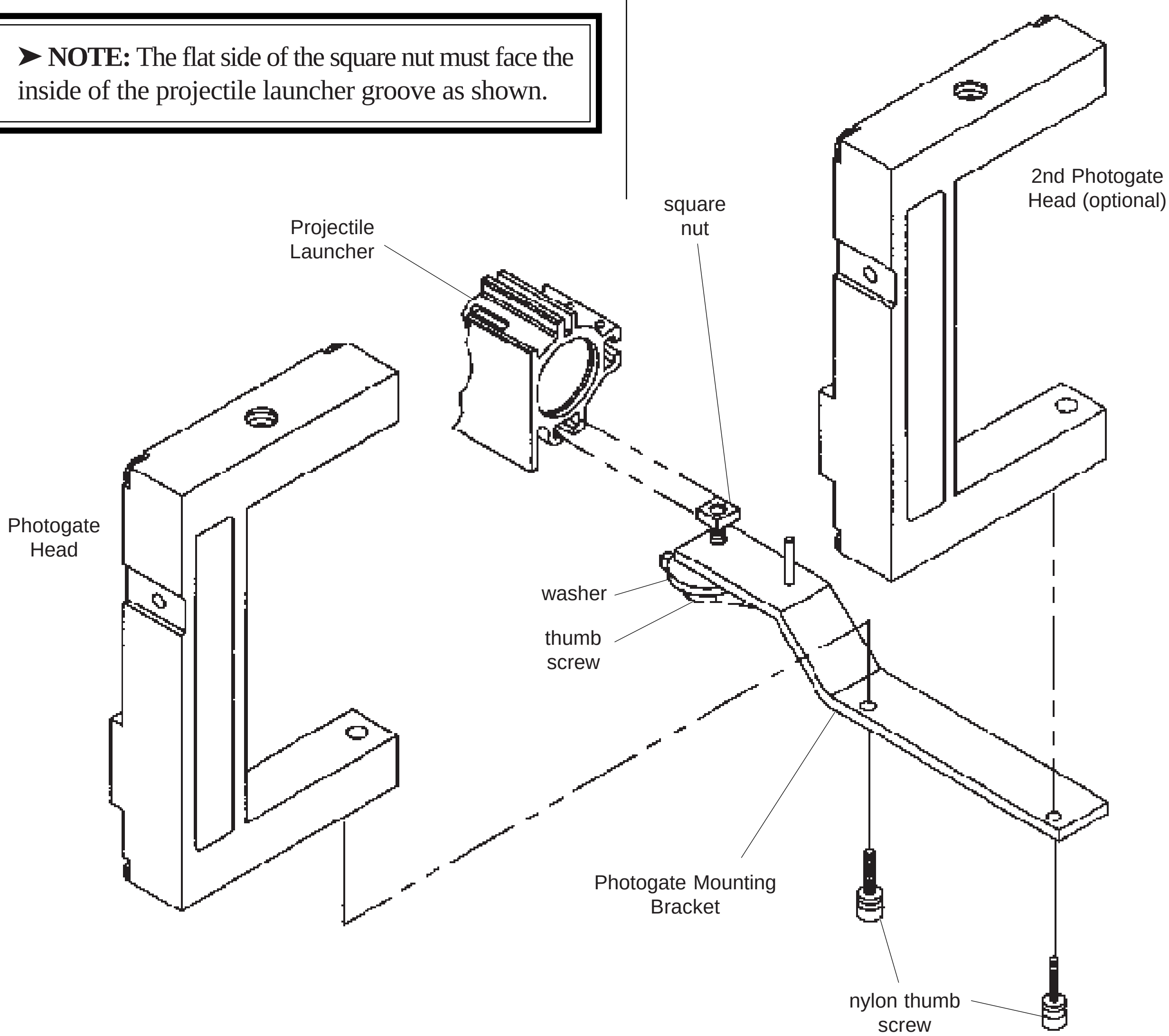
③ Slide the Photogate Mounting Bracket to the desired position and tighten the thumbscrew to secure.

④ Unscrew the small rod clamp from the Photogate Head. (Save the clamp assembly for later use.)

⑤ Attach each photogate to the Mounting Bracket with one of the 6-32x3/8" nylon thumbscrews included with the bracket assembly.

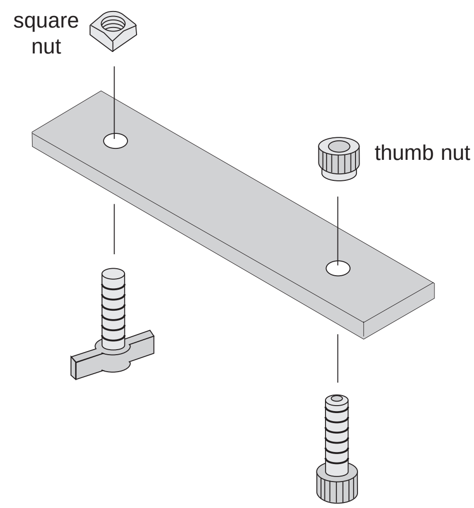
⑥ Slide the Mounting Bracket back until the photogate nearest to the barrel is as close to the barrel as possible without blocking the beam.

⑦ When storing the launcher, the Photogate Mounting Bracket need not be removed. It can be slid back along the barrel with or without the photogates in place, making as compact a package as possible.



Installing the 2-Dimensional Collision Attachment

Introduction



The two dimensional collision attachment consists of 2 screws, 2 nuts, and a flat plastic bar. It is used with the Projectile Launcher to hold a second ball in front of the muzzle so the launched ball will collide with the second ball, creating a 2-dimensional collision.

Assembly

To assemble the collision attachment , insert the screws through the holes and secure with the nuts as shown below.

To mount the collision attachment to the Launcher the square nut slides into the T-shaped channel on the bottom of the barrel. (See Experiment Figure 6.2)

Expectations for the Projectile Launcher

The following are helpful hints and approximate values you may find useful:

① The muzzle speed will vary slightly with angle. The difference between muzzle speed when shot horizontally versus vertically can be anywhere from zero to 8%, depending on the range setting and the particular launcher.

② The scatter pattern may not be smaller on the short range than on the long range as might be expected because the ball doesn't seat as well in the piston at low accelerations.

③ Although the muzzle end of the Projectile Launcher doesn't change height with angle, it is about 30 cm (12 inches) above table level, so if it is desired to use the simple range formula, it is necessary to launch to a table that is at the same height as the muzzle.

④ The scatter pattern is minimized when the Projectile Launcher base is securely clamped to a sturdy table. Any wobble in the table will show up in the data.

⑤ The angle of inclination can be determined to within one- half of a degree.

Expectations for the Ballistic Pendulum

① Angles reached should be repeatable to within half a degree.

② Overall error in measurement of ball velocity should not exceed 2.5% (exact method) or 10% (approximate method).

> ➤ **NOTE**: Adjustable leveling feet are not necessary for good results. Small deviations from the horizontal will not cause significant error.

Experiment 1: Projectile Motion

EQUIPMENT NEEDED:

- Projectile Launcher and plastic ball
- Plumb bob
- meter stick
- carbon paper
- white paper

Purpose

The purpose of this experiment is to predict and verify the range of a ball launched at an angle. The initial velocity of the ball is determined by launching it horizontally and measuring the range and the height of the launcher.

Theory

To predict where a ball will land on the floor when it is launched off a table at some angle above the horizontal, it is necessary to first determine the initial speed (muzzle velocity) of the ball. This can be determined by launching the ball horizontally off the table and measuring the vertical and horizontal distances through which the ball travels. Then the initial velocity can be used to calculate where the ball will land when the ball is launched at an angle.

➤ **NOTE:** For best results, see the notes on "Repeatable Results" in the Introduction.

HORIZONTAL INITIAL VELOCITY:

For a ball launched horizontally off a table with an initial speed, v_o, the horizontal distance travelled by the ball is given by $x = v_0 t$, where t is the time the ball is in the air. Air friction is assumed to be negligible.

The vertical distance the ball drops in time t is given $y = \frac{1}{2}gt^2$

The initial velocity of the ball can be determined by measuring x and y. The time of flight of the ball can be found using:

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

and then the initial velocity can be found using $v_0 = \frac{x}{t}$.

INITIAL VELOCITY AT AN ANGLE:

To predict the range, **x**, of a ball launched with an initial velocity at an angle, θ, above the horizontal, first predict the time of flight using the equation for the vertical motion:

$$y = y_0 + \left(v_0 \sin\theta\right) t - \frac{1}{2}gt^2$$

where $\mathbf{y_o}$ is the initial height of the ball and **y** is the position of the ball when it hits the floor. Then use $x = \left(v_0 \cos\theta\right) t$ to find the range.

Setup

① Clamp the Projectile Launcher to a sturdy table near one end of the table.

② Adjust the angle of the launcher to zero degrees so the ball will be launched horizontally.

Procedure

Part A: Determining the Initial Velocity of the Ball

① Put the plastic ball into the Projectile Launcher and cock it to the long range position. Launch one ball to locate where the ball hits the floor. At this position, tape a piece of white paper to the floor. Place a piece of carbon paper (carbon-side down) on top of this paper and tape it down. When the ball hits the floor, it will leave a mark on the white paper.

② Fire about ten shots.

③ Measure the vertical distance from the bottom of the ball as it leaves the barrel (this position is marked on the side of the barrel) to the floor. Record this distance in Table 1.1.

④ Use a plumb bob to find the point on the floor that is directly beneath the release point on the barrel. Measure the horizontal distance along the floor from the release point to the leading edge of the paper. Record in Table 1.1.

⑤ Measure from the leading edge of the paper to each of the ten dots and record these distances in Table 1.1.

⑥ Find the average of the ten distances and record in Table 1.1.

⑦ Using the vertical distance and the average horizontal distance, calculate the time of flight and the initial velocity of the ball. Record in Table 1.1.

Part B: Predicting the Range of the Ball Launched at an Angle

① Adjust the angle of the Projectile Launcher to an angle between 30 and 60 degrees and record this angle in Table 1.2.

② Using the initial velocity and vertical distance found in the first part of this experiment, assume the ball is launched at the new angle you have just selected and calculate the new time of flight and the new horizontal distance. Record in Table 1.2.

③ Draw a line across the middle of a white piece of paper and tape the paper on the floor so the line is at the predicted horizontal distance from the Projectile Launcher. Cover the paper with carbon paper.

④ Launch the ball ten times.

⑤ Measure the ten distances and take the average. Record in Table 1.2.

Analysis

① Calculate the percent difference between the predicted value and the resulting average distance when launched at an angle.

② Estimate the precision of the predicted range. How many of the final 10 shots landed within this range?

Table 1.1 Determining the Initial Velocity

Vertical distance = ______________ Horizontal distance to paper edge = _____________

Calculated time of flight = __________ Initial velocity = ________________

Trial Number	Distance
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Total Distance	

Table 1.2 Confirming the Predicted Range

Angle above horizontal = _______________ Horizontal distance to paper edge = _____________

Calculated time of flight = ______________ Predicted Range = _____________

Trial Number	Distance
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Total Distance	

Experiment 2: Projectile Motion Using Photogates

EQUIPMENT NEEDED

- Projectile Launcher and plastic ball
- (2) Photogate Heads
- plumb bob
- carbon paper
-Photogate Mounting Bracket
- computer
- meter stick
- white paper

Purpose

The purpose of this experiment is to predict and verify the range of a ball launched at an angle. Photogates are used to determine the initial velocity of the ball.

Theory

To predict where a ball will land on the floor when it is launched off a table at some angle above the horizontal, it is necessary to first determine the initial speed (muzzle velocity) of the ball. This can be determined by launching the ball and measuring the speed using photogates. To predict the range, x, of the ball when it is launched with an initial velocity at an angle q, above the horizontal, first predict the time of flight using the equation for the vertical motion:

$$y = y_0 + \left(v_0 \sin\theta\right) t - \frac{1}{2} g t^2$$

where y_o is the initial height of the ball and y is the position of the ball when it hits the floor. Then use $x = \left(v_0 \cos\theta\right) t$ to find the range.

➤ **NOTE:** For best results, see the notes on "Repeatable Results" in the Introduction.

Setup

① Clamp the Projectile Launcher to a sturdy table near one end of the table.

② Adjust the angle of the Projectile Launcher to an angle between 30 and 60 degrees.

③ Attach the photogate bracket to the launcher and attach two photogates to the bracket. Plug the photogates into a computer or other timer.

Procedure

PART A: Determining the Initial Velocity of the Ball

① Put the plastic ball into the Projectile Launcher and cock it to the long range position.

② Run the timing program and set it to measure the time between the ball blocking the two photogates.

③ Launch the ball three times and take the average of these times. Record in Table 2.1.

④ Using that the distance between the photogates is 10 cm, calculate the initial speed and record it in Table 2.1.

Table 2.1 Initial Speed

Trial Number	Time
1	
2	
3	
Average Time	
Initial Speed	

PART B: Predicting the Range of the Ball Launched at an Angle

① Keep the angle of the Projectile Launcher at the chosen angle.

② Measure the vertical distance from the bottom of the ball as it leaves the barrel (this position is marked on the side of the barrel) to the floor. Record this distance in Table 2.2.

③ Using the initial velocity and vertical distance found, assume the ball is launched at the angle you have selected and calculate the time of flight and the horizontal distance. Record in Table 2.2.

④ Draw a line across the middle of a white piece of paper and tape the paper on the floor so the line is at the predicted horizontal distance from the Projectile Launcher. Cover the paper with carbon paper.

⑤ Launch the ball ten times.

⑥ Measure the ten distances and take the average. Record in Table 2.2.

Analysis

① Calculate the percent difference between the predicted value and the resulting average distance when launched at an angle.

② Estimate the precision of the predicted range. How many of the final 10 shots landed within this range?

Table 2.2 Confirming the Predicted Range

Angle above horizontal = _______________

Horizontal distance to paper edge = _____________

Calculated time of flight= _____________

Predicted Range = _____________

Trial Number	Distance
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Total Distance	

Experiment 3: Projectile Range Versus Angle

EQUIPMENT NEEDED

- Projectile Launcher and plastic ball
- measuring tape or meter stick
- box to make elevation same as muzzle
- graph paper
- plumb bob
- carbon paper
- white paper

Purpose

The purpose of this experiment is to find how the range of the ball depends on the angle at which it is launched. The angle that gives the greatest range is determined for two cases: for launching on level ground and for launching off a table.

Theory

The range is the horizontal distance, x, between the muzzle of the launcher and the place where the ball hits, given by $x = \left(v_0\cos\theta\right) t$, where v_0 is the initial speed of the ball as it leaves the muzzle, θ is the angle of inclination above horizontal, and t is the time of flight. See Figure 3.1.

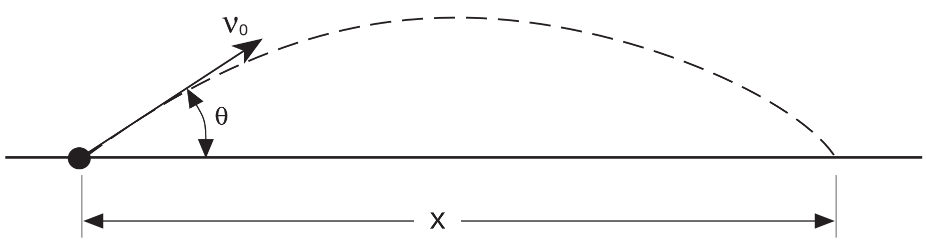


Figure 3.1 Launching on a level surface

For the case in which the ball hits on a place that is at the same level as the level of the muzzle of the launcher, the time of flight of the ball will be twice the time it takes the ball the reach the peak of its trajectory. At the peak, the vertical velocity is zero so

$$v_y = 0 = v_0 \sin\theta - g t_{peak}$$

Therefore, solving for the time gives that the total time of flight is

$$t = 2t_{peak} = 2\frac{v_0 \sin\theta}{g}.$$

For the case in which the ball is launched at an angle off a table onto the floor (See Figure 3.2) the time of flight is found using the equation for the vertical motion:

$$y = y_0 + \left(v_0\sin\theta\right) t - \frac{1}{2}gt^2$$

where y_o is the initial height of the ball and y is the position of the ball when it hits the floor.

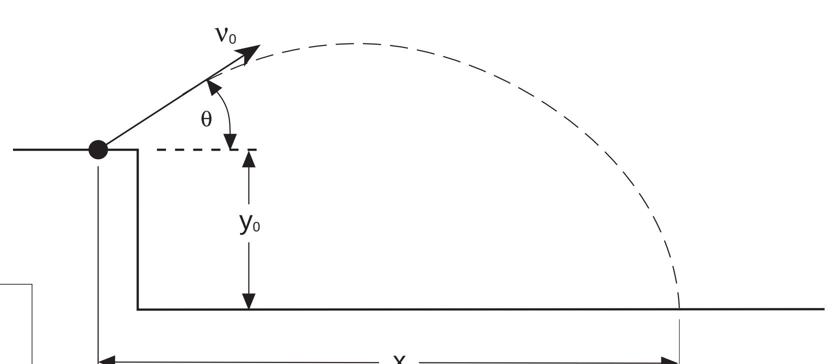


Figure 3.2 Launching off the table

➤ **NOTE:** For best results, see the notes on "Repeatable Results" in the Introduction.

Setup

① Clamp the Projectile Launcher to a sturdy table near one end of the table with the launcher aimed so the ball will land on the table.

② Adjust the angle of the Projectile Launcher to ten degrees.

③ Put the plastic ball into the Projectile Launcher and cock it to the medium or long range position.

> ➤ **NOTE:** In general, this experiment will not work as well on the short range setting because the muzzle velocity is more variable with change in angle.

Launch a ball to locate where the ball hits. Place a box at that location so the ball will hit at the same level as the muzzle of the launcher. See Figure 3.3.

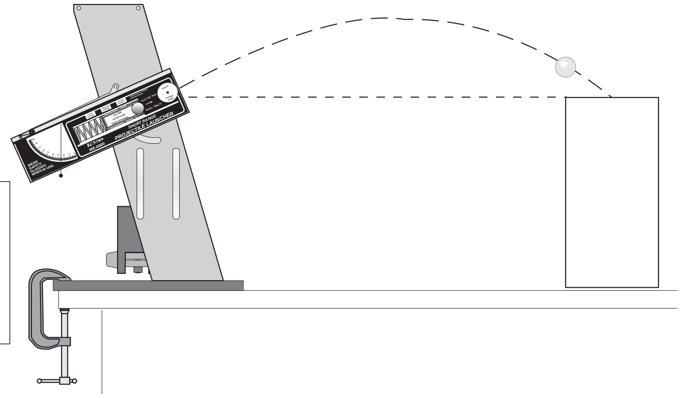


Figure 3.3 Setup to launch on level surface

Procedure

LAUNCHING ON A LEVEL SURFACE

① Fire one shot to locate where the ball hits the box. At this position, tape a piece of white paper to the box. Place a piece of carbon paper (carbon-side down) on top of this paper and tape it down. When the ball hits the box, it will leave a mark on the white paper.

② Fire about five shots.

③ Use a measuring tape to measure the horizontal distance from the muzzle to the leading edge of the paper. If a measuring tape is not available, use a plumb bob to find the point on the table that is directly beneath the release point on the barrel. Measure the horizontal distance along the table from the release point to the leading edge of the paper. Record in Table 3.1.

④ Measure from the leading edge of the paper to each of the five dots and record these distances in Table 3.1.

⑤ Increase the angle by 10 degrees and repeat all the steps.

⑥ Repeat for angles up to and including 80 degrees.

Table 3.1 Launching on a Level Surface

Horizontal. Distance

Angle	10	20	30	40	50	60	70	80
1								
2								
3								
4								
5								
Average								
Paper Dist.								
Total Dist.								

LAUNCHING OFF THE TABLE

Aim the Projectile Launcher so the ball will hit the floor. Repeat the procedure and record the data in Table 3.2.

Table 3.2 Launching off the Table onto the Floor

	Angle	10	20	30	40	50	60	70	80
Horizontal. Distance	1								
	2								
	3								
	4								
	5								
	Average								
	Paper Dist.								
	Total Dist.								

Analysis

① Find the average of the five distances in each case and record in Tables 3.1 and 3.2.

② Add the average distance to the distance to the leading edge of the paper to find the total distance (range) in each case. Record in Tables 3.1 and 3.2.

③ For each data table, plot the range vs. angle and draw a smooth curve through the points.

Questions

① From the graph, what angle gives the maximum range for each case?

② Is the angle for the maximum range greater or less for launching off the Table?

③ Is the maximum range further when the ball is launched off the table or on the level surface?

Experiment 4: Projectile Path

EQUIPMENT NEEDED

- Projectile Launcher and plastic ball
- measuring tape or meter stick
- carbon paper
- white paper
- movable vertical target board (Must reach from floor to muzzle)
- graph paper

Purpose

The purpose of this experiment is to find how the vertical distance the ball drops is related to the horizontal distance the ball travels when the ball is launched horizontally from a table.

Theory

The range is the horizontal distance, x, between the muzzle of the launcher and the place where the ball hits, given by $x = v_0 t$, where vo is the initial speed of the ball as it leaves the muzzle and t is the time of flight.

If the ball is launched horizontally, the time of flight of the ball will be

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

The vertical distance, y, that the ball falls in time t is given by

$$y = \frac{1}{2}gt^2$$

where g is the acceleration due to gravity.

Substituting for t into the equation for y gives

$$y = \left(\frac{g}{2v_0^2}\right)x^2$$

A plot of y versus x^2 will give a straight line with a slope equal to $\frac{g}{2v_0^2}$.

➤ **NOTE:** For best results, see the notes on "Repeatable Results" in the Introduction.

Setup

① Clamp the Projectile Launcher to a sturdy table near one end of the table with the launcher aimed away from the table.

② Adjust the angle of the Projectile Launcher to zero degrees so the ball will be launched horizontally.

③ Fire a test shot on medium range to determine the initial position of the vertical target. Place the target so the ball hits it near the bottom. See Figure 4.1.

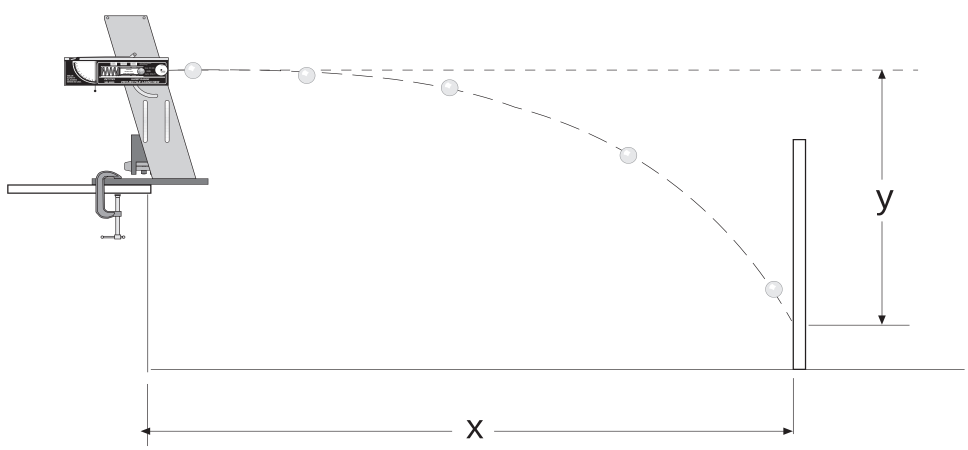


Figure 4.1 Setup

④ Cover the target board with white paper. Tape carbon paper over the white paper.

Procedure

① Measure the vertical height from the floor to the muzzle and record in Table 4.1. Mark this height on the target.

② Measure the horizontal distance from the muzzle of the Projectile Launcher to the target and record in Table 4.1.

③ Launch the ball.

④ Move the target about 10 to 20 cm closer to the launcher.

⑤ Repeat Steps 2 through 4 until the height of the ball when it strikes the target is about 10 to 20 cm below the height of the muzzle.

Table 4.1 Data

Height of Muzzle = _____________

Horizontal (x)	Height (y)	x^2

Analysis

① On the target, measure the vertical distances from the muzzle level mark down to the ball marks and record in Table 4.1.

② Calculate x^2 for all the data points and record in Table 4.1.

③ Plot y vs. x^2 and draw the best-fit straight line.

④ Calculate the slope of the graph and record in Table 4.2.

⑤ From the slope of the graph, calculate the initial speed of the ball as it leaves the muzzle and record in Table 4.2.

⑥ Using any data point for x and y, calculate the time using y and then calculate the initial speed using this time and x. Record the results in Table 4.2.

⑦ Calculate the percent difference between the initial speeds found using these two methods. Record in Table 4.2.

Table 4.2 Initial Speed

Slope of graph	
Initial speed from slope	
Time of flight	
Initial speed from x, y	
Percent Difference	

Questions

① Was the line straight? What does this tell you about the relationship between y and x?

② If you plotted y vs. x, how would the graph differ from the y vs. x^2 graph?

③ What shape is the path of a projectile?

Experiment 5: Conservation of Energy

EQUIPMENT NEEDED

- Projectile Launcher and plastic ball
- plumb bob
- measuring tape or meter stick
- white paper
- carbon paper
- (optional) 2 Photogate Heads and Photogate Mounting Bracket

Purpose

The purpose of this experiment is to show that the kinetic energy of a ball launched straight up is transformed into potential energy.

Theory

The total mechanical energy of a ball is the sum of its potential energy (PE) and its kinetic energy (KE). In the absence of friction, total energy is conserved. When a ball is launched straight up, the initial PE is defined to be zero and the $KE = \frac{1}{2}mv_0^2$, where m is the mass of the ball and vo is the muzzle speed of the ball. See Figure 5.1. When the ball reaches its maximum height, h, the final KE is zero and the $PE = mgh$, where g is the acceleration due to gravity. Conservation of energy gives that the initial KE is equal to the final PE.

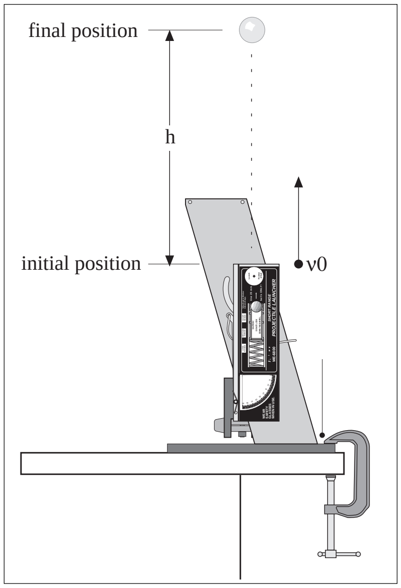


Figure 5.1 Conservation of Energy

To calculate the kinetic energy, the initial velocity must be determined. To calculate the initial velocity, vo, for a ball launched horizontally off a table, the horizontal distance travelled by the ball is given by $x = v_0t$, where t is the time the ball is in the air. Air friction is assumed to be negligible. See Figure 5.2.

The vertical distance the ball drops in time t is given by $y = \frac{1}{2}gt^2$.

The initial velocity of the ball can be determined by measuring x and y. The time of flight of the ball can be found using

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

and then the initial velocity can be found using $v_0 = \frac{x}{t}$.

➤ **NOTE:** For best results, see the notes on "Repeatable Results" in the Introduction.

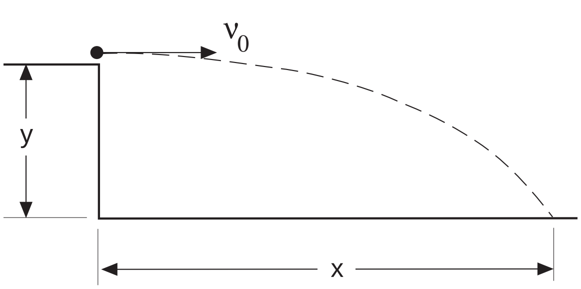


Figure 5.2 Finding the Initial Velocity

Setup

① Clamp the Projectile Launcher to a sturdy table near one end of the table with the launcher aimed away from the table. See Figure 5.1.

② Point the launcher straight up and fire a test shot on medium range to make sure the ball doesn't hit the ceiling. If it does, use the short range throughout this experiment or put the launcher closer to the floor.

③ Adjust the angle of the Projectile Launcher to zero degrees so the ball will be launched horizontally.

Procedure

PART I: Determining the Initial Velocity of the Ball (without photogates)

① Put the plastic ball into the Projectile Launcher and cock it to the medium range position. Fire one shot to locate where the ball hits the floor. At this position, tape a piece of white paper to the floor. Place a piece of carbon paper (carbon-side down) on top of this paper and tape it down. When the ball hits the floor, it will leave a mark on the white paper.

② Fire about ten shots.

③ Measure the vertical distance from the bottom of the ball as it leaves the barrel (this position is marked on the side of the barrel) to the floor. Record this distance in Table 5.1.

④ Use a plumb bob to find the point on the floor that is directly beneath the release point on the barrel. Measure the horizontal distance along the floor from the release point to the leading edge of the paper. Record in Table 5.1.

⑤ Measure from the leading edge of the paper to each of the ten dots and record these distances in Table 5.1.

⑥ Find the average of the ten distances and record in Table 5.1.

⑦ Using the vertical distance and the average horizontal distance, calculate the time of flight and the initial velocity of the ball. Record in Table 5.1.

Alternate Method for Determining the Initial Velocity of the Ball (using photogates)

① Attach the photogate bracket to the launcher and attach two photogates to the bracket. Plug the photogates into a computer or other timer.

② Adjust the angle of the Projectile Launcher to 90 degrees (straight up).

③ Put the plastic ball into the Projectile Launcher and cock it to the long range position.

④ Run the timing program and set it to measure the time between the ball blocking the two photogates.

⑤ Launch the ball three times and take the average of these times. Record in Table 5.2.

⑥ Assuming that the distance between the photogates is 10 cm, calculate the initial speed and record it in Table 5.2.

Table 5.1 Determining the Initial Velocity without Photogates

Vertical distance = ______________ Calculated time of flight= ____________

Horizontal distance to paper edge = ____________ Initial velocity = ______________

Trial Number	Distance
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Total Distance	

Table 5.2 Initial Speed Using Photogates

TRIAL NUMBER	TIME
1	
2	
3	
AVERAGE TIME	
INITIAL SPEED	

Measuring the Height

① Adjust the angle of the launcher to 90 degrees (straight up).

② Launch the ball on the medium range setting several times and measure the maximum height attained by the ball. Record in Table 5.3.

③ Determine the mass of the ball and record in Table 5.3.

Analysis

① Calculate the initial kinetic energy and record in Table 5.3.

② Calculate the final potential energy and record in Table 5.3.

③ Calculate the percent difference between the initial and final energies and record in Table 5.3.

Table 5.3 Results

Maximuim Height of Ball	
Mass of Ball	
Initial Kinetic Energy	
Final Potential Energy	
Percent Difference	

Questions

① How does friction affect the result for the kinetic energy?

② How does friction affect the result for the potential energy?

Experiment 6: Conservation of Momentum In Two Dimensions

EQUIPMENT NEEDED

- Projectile Launcher and 2 plastic balls
- meter stick
- butcher paper
- stand to hold ball
- plumb bob
- protractor
- tape to make collision inelastic
- carbon paper

Purpose

The purpose of this experiment is to show that the momentum is conserved in two dimensions for elastic and inelastic collisions.

Theory

A ball is launched toward another ball which is initially at rest, resulting in a collision after which the two balls go off in different directions. Both balls are falling under the influence of the force of gravity so momentum is not conserved in the vertical direction. However, there is no net force on the balls in the horizontal plane so momentum is conserved in horizontal plane.

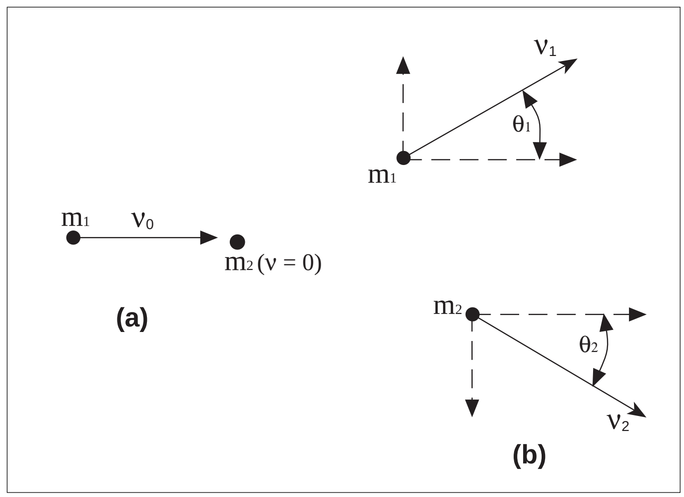


Figure 6.1: (a) Before Collision (b) After Collision

Before the collision, since all the momentum is in the direction of the velocity of Ball #1 it is convenient to define the x-axis along this direction. Then the momentum before the collision is

$$\vec{P}_{before} = m_1 v_0 \hat{x}$$

and the momentum after the collision is

$$\vec{P}_{after} = \left(m_1 v_{1x} + m_2 v_{2x}\right)\hat{x} + \left(m_1 v_{1y} - m_2 v_{2y}\right)\hat{y}$$

where $v_{1x} = v_1 \cos\theta_1$, $v_{1y} = v_1 \sin\theta_1$, $v_{2x} = v_2 \cos\theta_2$, and $v_{2y} = v_2 \sin\theta_2$.

Since there is no net momentum in the y-direction before the collision, conservation of momentum requires that there is no momentum in the y-direction after the collision. Therefore,

$$m_1 v_{1y} = m_2 v_{2y}$$

Equating the momentum in the x-direction before the collision to the momentum in the x-direction after the collision gives

$$m_1 v_0 = m_1 v_{1x} + m_2 v_{2x}$$

In an elastic collision, energy is conserved as well as momentum.

$$\frac{1}{2} m_1 v_0^2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2$$

Also, when energy is conserved, the paths of two balls (of equal mass) after the collision will be at right angles to each other.

➤ **NOTE:** For best results, see the notes on "Repeatable Results" in the Introduction.

Setup

① Clamp the Projectile Launcher to a sturdy table near one end of the table with the launcher aimed inward toward the table.

② Adjust the angle of the Projectile Launcher to zero degrees so the ball will be launched horizontally onto the table. Fire a test shot on the short range setting to make sure the ball lands on the table.

③ Cover the table with butcher paper. The paper must extend to the base of the launcher.

④ Mount collision attachment on the launcher. See Figure 6.2. Slide the attachment back along the launcher until the tee is about 3 cm in front of the muzzle.

⑤ Rotate the attachment to position the ball from side to side. The tee must be located so that neither ball rebounds into the launcher and so both balls land on the table. Tighten the screw to secure the collision attachment to the launcher.

⑥ Adjust the height of the tee so that the two balls are at the same level. This is necessary to ensure that the time of flight is the same for each ball. Fire a test shot and listen to determine if the two balls hit the table at the same time.

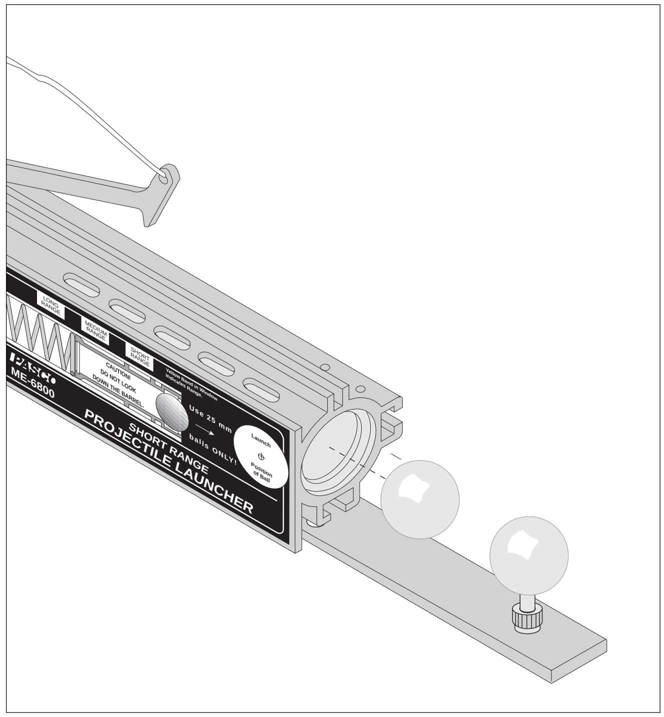


Figure 6.2: Photogate Bracket and Tee

⑦ Place a piece of carbon paper at each of the three sites where the balls will land.

Procedure

① Using one ball, launch the ball straight five times.

② **Elastic collision:** Using two balls, load one ball and put the other ball on the tee. Launch the ball five times.

③ **Inelastic collision:** Using two balls, load one ball and stick a very small loop of tape onto the tee ball. Orient the tape side of the tee ball so it will be struck by the launched ball, causing an inelastic collision. Launch the ball once and if the balls miss the carbon paper, relocate the carbon paper and launch once more. Since the tape does not produce the same inelastic collision each time, it is only useful to record this collision once.

④ Use a plumb bob to locate on the paper the spot below the point of contact of the two balls. Mark this spot.

Analysis

① Draw lines from the point-of-contact spot to the centers of the groups of dots. There will be five lines.

② Measure the lengths of all five lines and record on the paper. Since the time of flight is the same for all paths, these lengths are proportional to the corresponding horizontal velocities. Since the masses are also the same, these lengths are also proportional to the corresponding momentum of each ball.

③ Measure the angles from the center line to each of the outer four lines and record on the paper.

PERFORM THE FOLLOWING THREE STEPS FOR THE ELASTIC COLLISION AND THEN REPEAT THESE THREE STEPS FOR THE INELASTIC COLLISION:

④ For the x-direction, check that the momentum before equals the momentum after the collision. To do this, use the lengths for the momentums and calculate the x-components using the angles. Record the results in Tables 6.1 and 6.2.

Table 6.1 Results for the Elastic Collision

Initial x-momentum		Final x-momentum		% difference	
y-momentum ball 1		y-momentum ball 2		% difference	
Initial KE		Final KE		% difference	

Table 6.2 Results for the Inelastic Collision

Initial x-momentum		Final x-momentum		% difference	
y-momentum ball 1		y-momentum ball 2		% difference	
Initial KE		Final KE		% difference	

⑤ For the y-direction, check that the momenta for the two balls are equal and opposite, thus canceling each other. To do this, calculate the y-components using the angles. Record the results in the Tables.

⑥ Calculate the total kinetic energy before and the total kinetic energy after the collision. Calculate the percent difference. Record the results in the Tables.

Questions

① Was momentum conserved in the x-direction for each type of collision?

② Was momentum conserved in the y-direction for each type of collision?

③ Was energy conserved for the elastic collision?

④ Was energy conserved for the inelastic collision?

⑤ For the elastic collision, was the angle between the paths of the balls after the collision equal to 90 degrees as expected?

⑥ For the inelastic collision, what was the angle between the paths of the balls after the collision? Why is it less than 90º?

Experiment 7: Varying Angle To Maximize Height on a Wall

EQUIPMENT NEEDED

- Projectile Launcher and plastic ball
- measuring tape or meter stick
- white paper
- plumb bob
- carbon paper
- board to protect wall

Purpose

The purpose of this experiment is to find the launch angle which will maximize the height on a vertical wall for a ball launched at a fixed horizontal distance from the wall.

Theory

When the ball is launched at an angle at a fixed distance, x, from a vertical wall, it hits the wall at a height y given by:

$$y = y_0 + (v_0 \sin\theta)\, t - \frac{1}{2} gt^2$$

where y_0 is the initial height of the ball, v_0 is the initial speed of the ball as it leaves the muzzle, θ is the angle of inclination above horizontal, g is the acceleration due to gravity, and t is the time of flight. The range is the horizontal distance, x, between the muzzle of the launcher and the place where the ball hits, given by $x = (v_0 \cos\theta)\, t$. Solving for the time of flight from the equation for x gives

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

Substituting for t in the equation for y gives

$$y = y_0 + x \tan\theta - \frac{gx^2}{2v_0^2 \cos^2\theta}$$

To find the angle that gives the maximum height, y, set dy/dθ equal to zero and solve for the angle.

$$\frac{dy}{d\theta} = x \sec^2\theta - \frac{gx^2 \tan\theta \sec^2\theta}{v_0^2} = 0$$

Solving for the angle gives

$$\tan\theta_{max} = \frac{v_0^2}{gx}$$

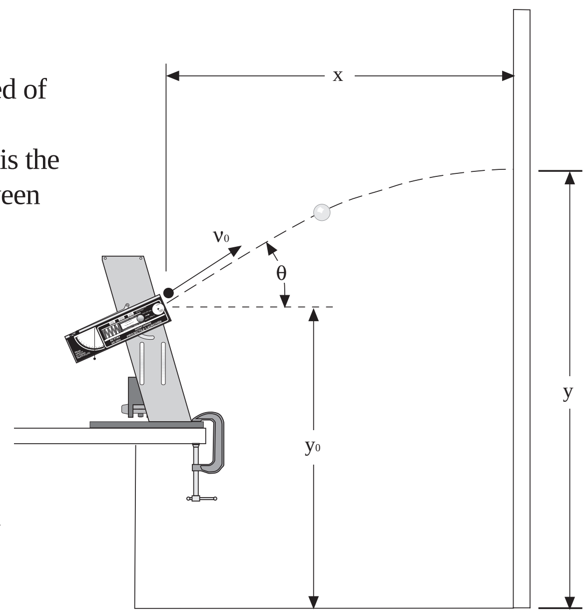


Figure 7.1 Maximizing Height

Since the second derivative is negative for θ_{max}, the angle is a maximum.

To find the initial velocity of the ball, the fixed distance x and the maximum height y_{max} can be used. Solve the y-equation for v_0 and plug in the values for y_{max}, θ_{max}, and x.

➤ **NOTE:** For best results, see the notes on "Repeatable Results" in the Introduction.

Setup

① Clamp the Projectile Launcher to a sturdy table near one end of the table with the launcher facing the wall at a distance of about 2 meters from the wall.

② Put a vertical board up to protect the wall.

③ Test fire the ball (on the long range setting) a few times to find approximately what angle gives the maximum height on the wall. (NOTE: In general, this experiment will not work as well on the short range setting because the muzzle velocity is more variable with change in angle.)

④ Tape a piece of white paper to the board in the region where the ball is hitting. Then cover the white paper with a piece of carbon paper.

Procedure

① Launch the ball at various angles and pinpoint exactly which angle gives the maximum height by checking the marks on the paper.

② Measure the angle that produces the maximum height and record in Table 7.1.

③ Measure the maximum height and record in Table 7.1.

④ Measure the horizontal distance from the muzzle to the vertical board and record in Table 7.1.

⑤ Measure the initial height of the ball where it leaves the muzzle and record in Table 7.1.

Table 7.1 Data and Results

Measured Angle for Max	
Maximum Height	
Horizontal Distance	
Initial Height	
Calculated Initial Velocity	
Calculated Angle for Max	
% Difference Between Angles	

Analysis

① Calculate the initial velocity by solving the y-equation for v_0 and plugging in the values from Table 7.1.

② Calculate the angle for maximum height using the initial velocity calculated in Step 1 and the horizontal distance from the wall to the launcher.

③ Calculate the percent difference between the measured angle and the calculated angle.

Questions

① For the angle which gives the maximum height, when the ball hits the wall, has it already reached the peak of its trajectory?

② For what distance from the wall would the height be maximized at 45º? What would the maximum height be in this case?

Experiment 8: Projectile Velocity—Approximate Method

EQUIPMENT NEEDED:

- launcher
- C-clamp (optional)
- string
- Steel ball
- Mass balance

Purpose:

The muzzle velocity of the projectile launcher is determined by launching the ball into the pendulum and observing the angle to which the pendulum swings.

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

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

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

Setup:

① Attach the Projectile Launcher to the ballistic pendulum mount at the level of the ball catcher. Make sure that the pendulum can hang vertically without touching the launcher.

② Clamp the pendulum base to the table, if a clamp is available. Make sure that the clamp does not interfere with the pendulum swing. (It is possible to get very good results without clamping to the table, as long as the base is held firmly to the table when the ball is fired.)

Procedure:

① Latch the pendulum at 90° so it is out of the way, then load the projectile launcher. 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 do the experiment with a lower or higher angle, add or remove mass to the pendulum. Repeat these test measurements until you are satisfied with the mass of the pendulum.

③ Once you have chosen the mass to use for your experiment, remove the pendulum from the base by unscrewing and removing the pivot axle. Using the mass balance, find the mass of the pendulum and ball together. Record this value as M in table 8.1.

④ Measure the mass of the ball, and record this as m.

⑤ Tie a loop in the string, and hang the pendulum from the loop. (See figure 8.1) With the ball latched in position in the ball catcher, adjust the position of the pendulum in this loop until it balances. Measure the distance from the pivot point to this balance point, and record it as R_{cm}. You may find it easier to do this by balancing the pendulum on the edge of a ruler or similar object.

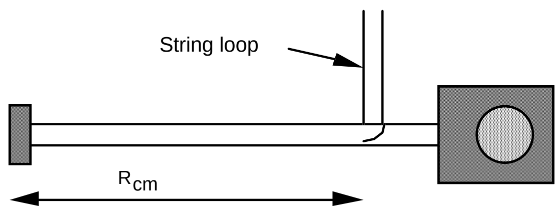


Figure 8.1

⑥ Replace the pendulum in the base, making sure that it is facing the right way. Be sure that the angle indicator is to the right of the pendulum rod.

⑦ Load the launcher, then set the angle indicator to an angle 1-2° less than that reached in step 2. This will nearly eliminate the drag on the pendulum caused by the indicator, since the pendulum will only move the indicator for the last few degrees.

Fire the launcher, and record the angle reached by the pendulum in table 8.1. Repeat this several times, setting the angle indicator to a point 1-2° below the previous angle reached by the pendulum each time.

Calculations

① Find the average angle reached by the pendulum. Record this value in table 8.1.

② Calculate the muzzle velocity of the projectile launcher.

Questions

① Is there another way to measure the muzzle velocity that you could use to check your results? You may want to use another method and compare the two answers.

② What sources of error are there in this experiment? How much do these errors affect your result?

③ It would greatly simplify the calculations (see theory section) if kinetic energy were conserved in the collision between ball and pendulum. What percentage of the kinetic energy is lost in the collision between ball and pendulum? Would it be valid to assume that energy was conserved in that collision?

④ How does the angle reached by the pendulum change if the ball is *not* caught by the pendulum? You may test this by turning the pendulum around so the ball strikes the back of the ball catcher. Is there more energy or less energy transferred to the pendulum?

Table 8.1

M= __________

m= __________

R_{cm}= __________

θ_1	
θ_2	
θ_3	
θ_4	

Average θ= __________

Muzzle Velocity= __________

Experiment 9: Projectile Velocity—Exact Method

EQUIPMENT NEEDED:
- Projectile Launcher and steel ball
- Mass Balance
- ruler
- C-clamp (optional)
- string
- stopwatch

Purpose:

The muzzle velocity of the projectile launcher is determined by launching the ball into the pendulum and observing the angle to which the pendulum swings.

The exact equation for ball velocity, as derived earlier in this manual, is

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

where M is the mass of the pendulum and ball combined, m is the mass of the ball, g is the acceleration of gravity, R_{cm} is the distance from the pivot to the center of mass of the pendulum, R_b is the distance from the pivot 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 of small oscillations of the pendulum and ball and using the equation

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

where T is the period.

Setup:

① Attach the projectile launcher to the ballistic pendulum mount at the level of the ball catcher. Make sure that the pendulum can hang vertically without touching the launcher.

② Clamp the pendulum base to the table, if a clamp is available. Make sure that the clamp does not interfere with the pendulum swing. (It is possible to get very good results without clamping to the table, as long as the base is held firmly to the table when the ball is fired.)

Procedure:

① Latch the pendulum at 90° so it is out of the way, then load the projectile launcher. 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 do the experiment with a lower or higher angle, add or remove mass to the pendulum. Repeat these test measurements until you are satisfied with the mass of the pendulum.

③ Once you have chosen the mass to use for your experiment, remove the pendulum from the base by unscrewing and removing the pivot axle. Using the mass balance, find the mass of the pendulum and ball together. Record this value as M in table 9.1.

④ Measure the mass of the ball, and record this as m.

⑤ Tie a loop in the string, and hang the pendulum from the loop. (See figure 9.1) With the ball latched in position in the ball catcher, adjust the position of the pendulum in this loop until it balances. Measure the distance from the pivot point to this balance point, and record it as R_{cm}. You may find it easier to do this by balancing the pendulum on the edge of a ruler or similar object.

⑥ Measure the distance between the pivot point and the center of the ball. Record this as R_b.

⑦ Replace the pendulum in the base, making sure that it is facing the right way. Be sure that the angle indicator is to the right of the pendulum rod.

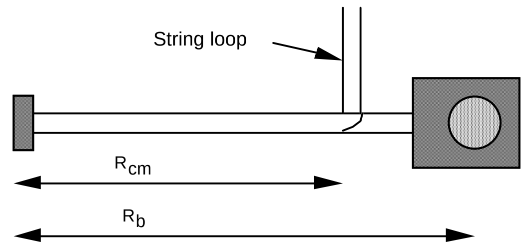


Figure 9.1

⑧ Remove the launcher so that the pendulum can swing freely. With the ball in the pendulum, give it an initial displacement of 5° or less. Using the stopwatch, time how long it takes to go through at least ten oscillations. Divide this time by the number of oscillations, and record your result as T in table 9.1.

⑨ Calculate the value of I, and record it in table 9.1.

⑩ Load the launcher, then set the angle indicator to an angle 1-2° less than that reached in step 2. This will nearly eliminate the drag on the pendulum caused by the indicator, since the pendulum will only move the indicator for the last few degrees.

⑪ Fire the launcher, and record the angle reached by the pendulum in table 8.1. Repeat this several times, setting the angle indicator to a point 1-2° below the previous angle reached by the pendulum each time.

Calculations

① Find the average angle reached by the pendulum. Record this value in table 8.1.

② Calculate the muzzle velocity of the projectile launcher.

Questions

① Is there another way to measure the muzzle velocity that you could use to check your results? You may want to use another method and compare the two answers.

② What sources of error are there in this experiment? How much do these errors affect your result?

③ It would greatly simplify the calculations (see theory section) if kinetic energy were conserved in the collision between ball and pendulum. What percentage of the kinetic energy is lost in the collision between ball and pendulum? Would it be valid to assume that energy was conserved in that collision?

④ Does increasing the pendulum mass increase or decrease the efficiency of the energy transfer in the collision? Try it.

⑤ Experiment 8 uses an approximate equation for velocity:

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

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 equation gave better results?

Table 9.1

M= ______

m= ______

R_{cm}= ______

R_b= ______

T= ______

I= ______

θ_1	
θ_2	
θ_3	
θ_4	

Average θ= ______

Muzzle Velocity= ______

Experiment 10 (Demo): Do 30° and 60° Give the Same Range?

EQUIPMENT NEEDED

- Projectile Launcher and steel ball
- box to make elevation same as muzzle

Purpose

The purpose of this demonstration is to show that the range of a ball launched at 30· is the same as one launched at 60· if the ball is launched on a level surface.

Theory

The range is the horizontal distance, x, between the muzzle of the launcher and the place where the ball hits, given by $x = \left(v_0 \cos\theta\right) t$ where v_0 is the initial speed of the ball as it leaves the muzzle, θ is the angle of inclination above horizontal, and t is the time of flight.

If the ball hits on a place that is at the same level as the level of the muzzle of the launcher, the time of flight of the ball will be twice the time it takes the ball the reach the peak of its trajectory:

$$t = 2t_{peak} = 2\,\frac{v_0 \sin\theta}{g}$$

where g is the acceleration due to gravity.

Substituting for t into the equation for x gives

$$x = \frac{2v_0^2 \sin\theta \cos\theta}{g}$$

and using a trigonometry identity gives

$$x = \frac{2v_0^2 \sin 2\theta}{g}$$

The ranges for the angles 30º and 60· are the same since

$$\sin(60^\circ) = \sin(120^\circ).$$

➤ **NOTE:** For best results, see the notes on "Repeatable Results" in the Introduction.

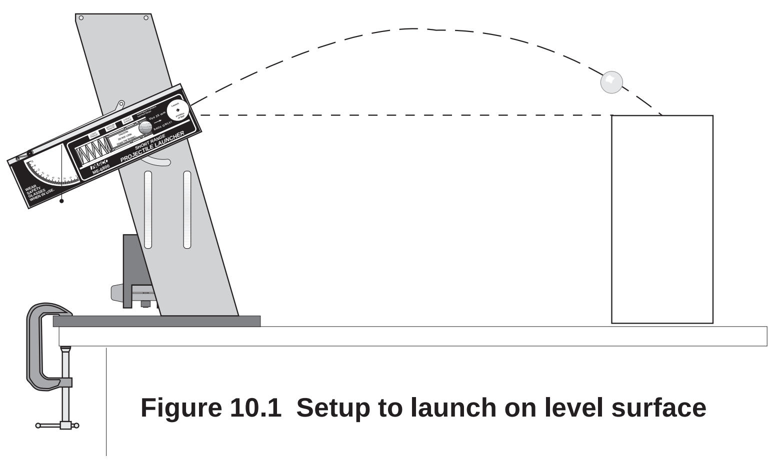


Figure 10.1 Setup to launch on level surface

Setup

① Clamp the Projectile Launcher to a sturdy table near one end of the table with the launcher aimed so the ball will land on the table.

② Adjust the angle of the Projectile Launcher to 30 degrees.

③ Put the steel ball into the Projectile Launcher and cock it to the medium or long range position.

➤ **NOTE:** In general, this experiment will not work as well on the short range setting because the muzzle velocity is more variable with change in angle.)

④ Launch a ball to locate where the ball hits. Place an inverted box at that location so the ball will hit at the same level as the muzzle of the launcher. See Figure 10.1.

Procedure

① Launch the ball at 30 degrees to demonstrate that the ball lands on the box.

② Change the angle of the launcher to 60 degrees and launch the ball again. Call attention to the fact that the ball again lands on the box. Thus the ranges are the same.

③ Change the angle to 45 degrees and launch the ball again to show that the ball now lands further away, missing the box.

④ Ask the question: What other pairs of angles will have a common range? This demonstration can be done for any two angles which add up to 90 degrees: 20 and 70, or 35 and 55, etc.

Experiment 11 (Demo): Simultaneously Launch Two Balls Horizontally at Different Speeds

EQUIPMENT NEEDED

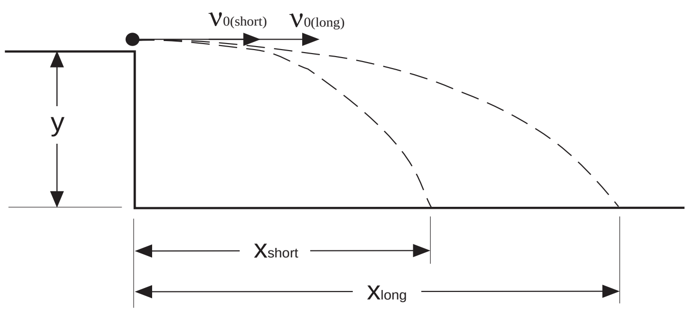
- (2) Projectile Launchers and (2) plastic balls

Purpose

The purpose of this demonstration is to show that regardless of the initial speed of the balls launched horizontally off a table, the balls will hit the floor at the same time.

Theory

Two balls are launched horizontally from the same table (from the same height, y). The muzzle speeds of the two balls are different.



The vertical and horizontal motions of a projectile are independent of each other. The horizontal distance, x, travelled by the ball is dependent on the initial speed, v_0, and is given by $x = v_0 t$, where t is the time of flight. The time of flight depends only on the vertical distance the ball falls since $y = \frac{1}{2}gt^2$. Since the vertical distance is the same each ball, the time of flight must be the same for each ball.

➤ **NOTE:** For best results, see the notes on "Repeatable Results" in the Introduction.

Setup

① Clamp two Projectile Launchers adjacent to each other on a sturdy table. The launchers should both be aimed in the same direction, away from the table so the balls will land on the floor.

② Adjust the angle of each Projectile Launcher to zero degrees so the balls will be launched horizontally off the table.

Procedure

① Put a plastic ball into each Projectile Launcher and cock one launcher to the short range position and cock the other launcher to the long range position.

② Ask the class to be quiet and listen for the balls striking the floor. Tell them if they hear only one click, that means the balls hit the floor simultaneously.

③ Put both lanyards in the same hand and pull them at the same time so the balls are launched simultaneously.

④ After the balls hit the floor, ask the class if they heard one click or two.

Experiment 12 (Demonstration): Launching Through Hoops

EQUIPMENT NEEDED

- Projectile Launcher and plastic ball
- (2) Photogates
- 2-meter stick
-5 ring clamps on stands
- Photogate Mounting Bracket

Purpose

The purpose of this demonstration is to show that the path of a ball launched horizontally from a table is parabolic.

Theory

The range is the horizontal distance, x, between the muzzle of the launcher and the place where the ball hits, given by

$$x = v_0 t$$

where vo is the initial speed of the ball as it leaves the muzzle and t is the time of flight.

The vertical position, y, of the ball at time t is given by

$$y = y_0 - \frac{1}{2}gt^2$$

where y_0 is the initial height of the ball and g is the acceleration due to gravity.

➤ **NOTE:** For best results, see the notes on "Repeatable Results" in the Introduction.

Setup

① Before the demonstration begins, find the initial velocity for the range setting to be used. Attach the photogates and use a computer to find the initial velocity or launch the ball horizontally and measure x and y to find the initial velocity. See experiments 1 and 2.

② To prepare to demonstrate, clamp the Projectile Launcher to the demonstration table with the launcher aimed away from the table so the ball will land on the floor.

③ Adjust the angle of the launcher to zero degrees so it will launch horizontally.

Procedure

① In front of the class, measure the initial height of the ball at muzzle level.

② Calculate the horizontal and vertical positions of the ball each 1/10 second until it hits the floor.

t (sec)	$x = v_0 t$ (cm)	$y = y_0 - (1/2)gt^2$ (cm)
0.1		
0.2		
0.3		
0.4		
0.5		

③ Lay the 2-meter stick on the floor in a straight line away from the launcher. Remove the back mounting screw from the launcher base so the back of the launcher can be rotated upward. Look through the back of the launcher and align the sights and the end of the 2m stick so the 2m stick is aligned with the path of the ball. Relevel the launcher.

④ Measure off each set of x and y and place a ring clamp on a stand at each position (See Figure 12.1). If possible it is best to adjust the last two ring stands at an angle from the vertical so the ball will not have to pass through them at an oblique angle. A cup may be placed at the end of the path to catch the ball.

⑤ Launch the ball through the rings.

⑥ Ask the class what shape of curve is formed by the rings.

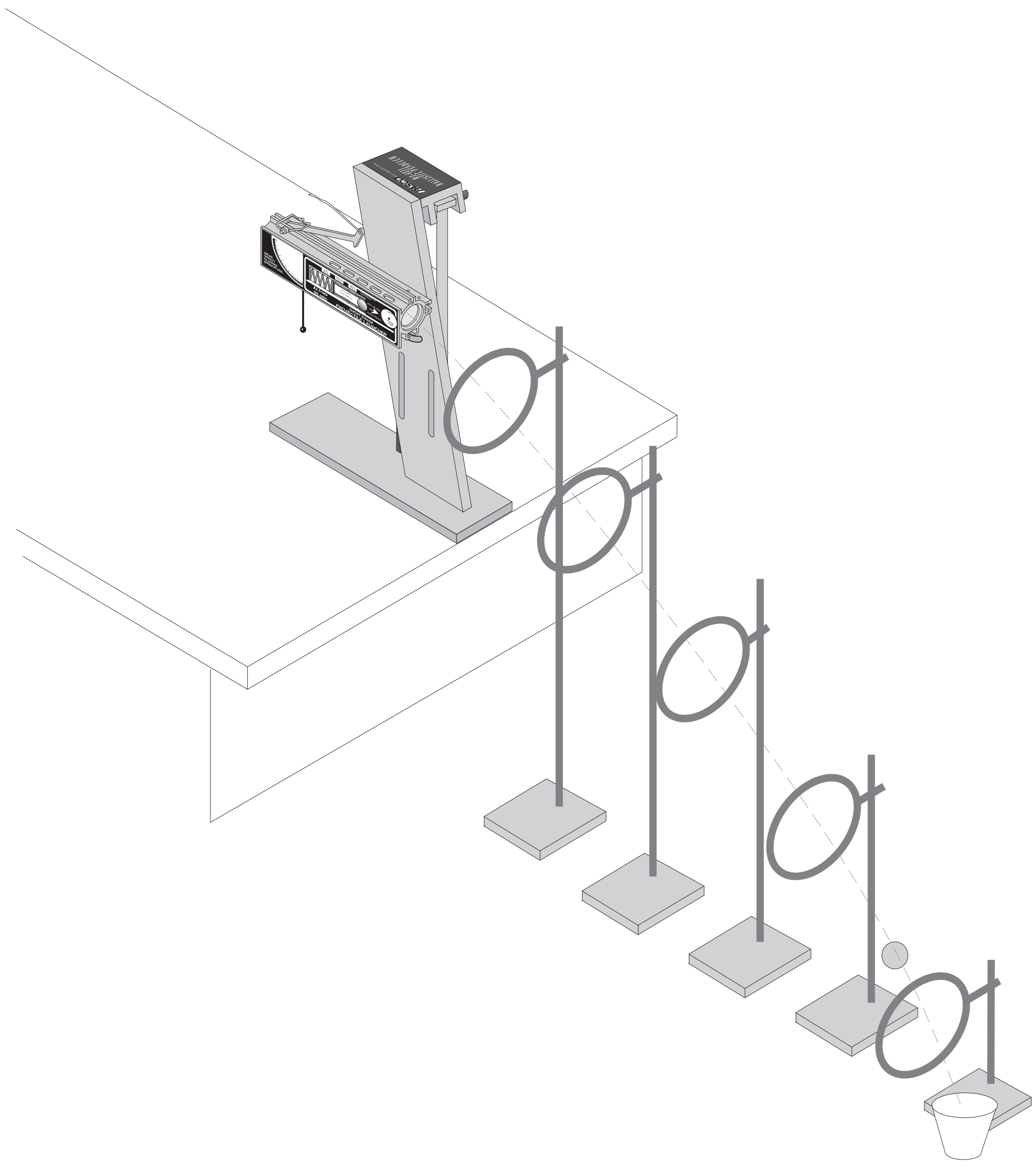


Figure 12.1 Placing the rings

Experiment 13: (Demonstration): Elastic and Inelastic Collisions

EQUIPMENT NEEDED:

- Projectile Launcher
- plastic or steel ball
- Ballistic Pendulum

Purpose

The purpose of this demonstration is to show the difference in kinetic energy transfer between an elastic and an inelastic collision.

Theory

The amount of kinetic energy transferred between colliding objects depends on the elasticity of the collision. By reversing the pendulum so that the ball bounces off instead of catching, it is possible to demonstrate this effect.

Procedure

① Fire the ball into the pendulum and record the angle reached.

② Remove the pendulum, and reinstall it in the reversed position (ball opening away from launcher)

③ Fire the same ball at the same launcher setting and note the angle reached. The collision between ball and pendulum is not perfectly elastic, so kinetic energy is still not conserved. However, the collision is more nearly elastic than the completely inelastic collision in step 1, so there will be a greater transfer of kinetic energy.

Teachers Guide

Experiment 1: Projectile Motion

Procedure

➤ **NOTE:** For best results, make sure that the projectile launcher is clamped securely to a firm table. Any movement of the gun will result in inconsistent data.

A) The muzzle velocity of the gun tested for this manual was 6.5 m/s (Short range launcher at maximum setting, nylon ball)

B) To find the range at the chosen angle, it is necessary to solve the quadratic equation given in the theory section. You may wish for the students to do this, or you may provide them with the solution:

$$t=\frac{v_0\sin\theta+\sqrt{(v_0\sin\theta)^2+2g(y_0-y)}}{g}$$

Analysis

① The difference depended on the angle at which the gun was fired. The following table gives typical results:

Angle	Predicted Range	Actual Range	Percent Error
30	5.22	5.19	0.57%
45	5.30	5.16	2.64%
60	4.35	4.23	2.87%
39	5.39	5.31	1.48%

➤ **NOTE:** The maximum angle is not 45° in this case, nor is the range at 60° equal to that at 30°. This is because the initial height of the ball is not the same as that of the impact point. The maximum range for this setup (with the launcher 1.15 m above ground level) was calculated to be 39°, and this was experimentally verified as well.

② Answers will vary depending on the method of estimating the precision. The primary source of error is in ignoring the effect of air resistance.

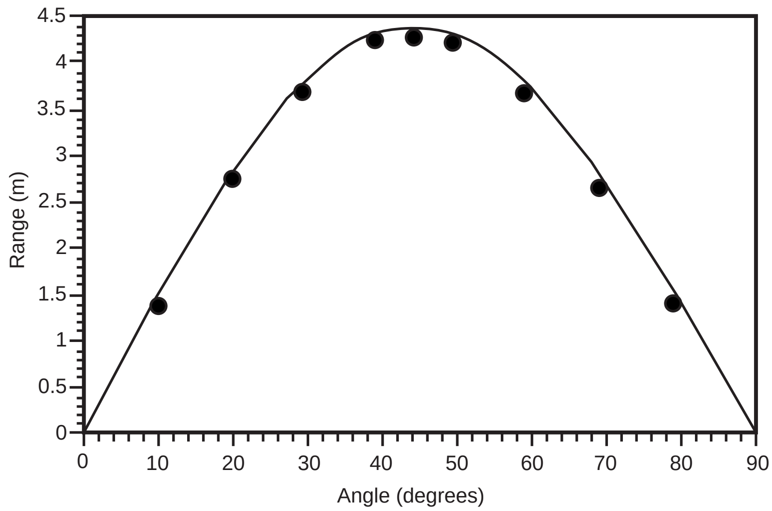
Experiment 2: Projectile Motion Using Photogates

➤ **NOTE:** Other than the method of determining initial velocity, this experiment and experiment 1 are equivalent.

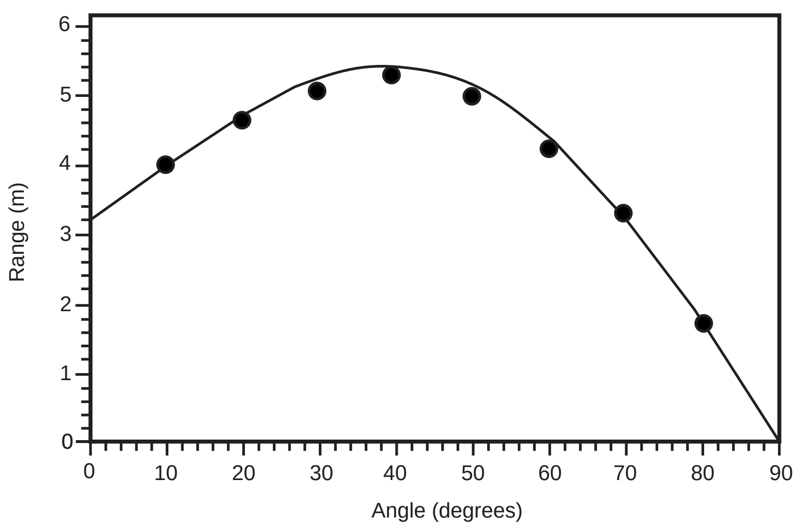
Experiment 3: Projectile Range Versus Angle

Procedure

Launching off a level surface:



Launching off a table:



➤ **NOTE:** The curves shown are for the calculated ranges in each case. The data points are the actual measured ranges.

Questions:

① On a level surface, the maximum range is at 45°. For a non-level surface, the angle of maximum range depends on the initial height of the projectile. For our experimental setup, with an initial height of 1.15 m, the maximum range is at 40°. (Theoretical value 39°)

② The angle of maximum range decreases with table height.

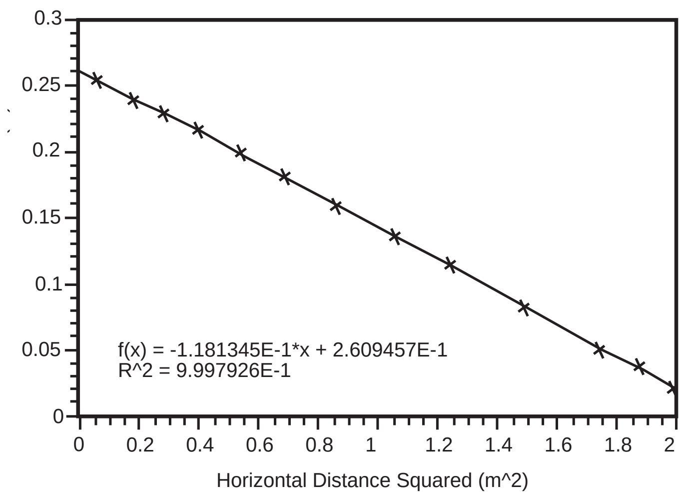
③ The maximum distance increases with table height.

Experiment 4: Projectile Path

Analysis

① Alternately, measure your distances from the ground up.

③ Vertical distances measured from the ground up for this graph. The intercept is the height of the launcher above ground when done this way.



④ The slope (measuring from the ground) is -0.118 for this test. (Measuring down from the initial height will give the same value, only positive.) In either case, the slope is

$$\frac{g}{2v_0^2}$$

⑤ The slope calculated here gives us an initial velocity of 6.44 m/s. This compares favorably with the velocity calculated in experiments 1 and 2.

⑥⑦ Results will vary with this method: the point of the exercise is that individual measurements are not as accurate as a large number of measurements and a curve fit.

Questions

① Yes. This tells us that y is a function of x^2.

② A plot of y versus x would be parabolic instead of linear.

③ The projectile moves in a parabolic curve. (neglecting air friction)

Experiment 5: Conservation of Energy

Analysis

① Using the photogate method, we found that the initial speed of the ball was 4.93 m/s. (Nylon ball, short range launcher at medium setting) The ball mass was 9.6 g, so our total kinetic energy was 0.117 J.

② The ball reached an average height of 1.14 m. Potential energy was then 0.107 J.

③ Energy lost was 8.5% of original energy.

➤ **NOTE:** It seems rather unlikely that this much energy is lost merely to air resistance; especially when one considers the extraordinarily good results on labs 3 and 4. It is more likely that the error here enters the calculations in the actual measurement of initial velocity and height.

Experiment 6: Conservation of Momentum in Two Dimensions

Setup

② It is best to arrange things so that you can use medium range rather than short. The medium-range setting gives more predictable results than the short-range setting.

Analysis

④⑥ Results for the x component of momentum should be within 5% of initial values. The total y component should be small compared to the x component; percent deviation may not be a valid indication of accuracy.

Questions

①② Momentum is conserved on both axes.

③ Kinetic energy is nearly conserved in the elastic collision. There is some loss due the fact that the collision is not completely elastic.

④ Energy is conserved for the inelastic collision; but kinetic energy is not.

⑤ The angle should be nearly 90°. (Our tests had angles of about 84°)

⑥ In the inelastic case, the angle will be less than in the elastic case. The exact angle will depend on the degree of inelasticity, which will depend on the type and amount of tape used.

Experiment 7: Varying Angle to Maximize Height on a Wall

Procedure

① You should be able to measure the angle of maximum height to within 2% either way.

④ Measure the distance to the front edge of the ball.

⑤ Measure the initial height to the center of the ball.

Analysis

① The initial velocity should be close to the initial velocity determined by other methods. You may wish to determine the initial velocity by the method in lab 1, and use that value in your calculations for the rest of this experiment.

③ Measured and calculated should agree to within 3%.

Questions

① The ball will have passed its peak by the time it reaches the wall. To show this, take the derivative of y with respect to x:

$$y = y_0 + x\tan\theta_{max} - \frac{gx^2}{2v_0^2\cos^2\theta_{max}}$$

$$\frac{dy}{dx} = \tan\theta_{max} - \frac{gx}{v_0^2\cos^2\theta_{max}}$$

Substitute $\theta_{max} = \tan^{-1}\left(\frac{v_0^2}{gx_{max}}\right)$

$$\frac{dy}{dx} = \frac{v_0^2}{gx_{max}} - \frac{gx}{v_0^2\cos^2\left[\tan^{-1}\left(\frac{v_0^2}{gx_{max}}\right)\right]}$$

Substitute $\cos\left[\tan^{-1}\left(\frac{a}{b}\right)\right] = \frac{b}{\sqrt{a^2+b^2}}$ and simplify.

$$\frac{dy}{dx} = \frac{v_0^2}{gx_{max}} - \frac{gx}{v_0^2\left(\frac{gx_{max}}{\sqrt{v_0^4+g^2x_{max}^2}}\right)^2} = \frac{v_0^2}{gx_{max}} - \frac{x\left(v_0^4+g^2x_{max}^2\right)}{v_0^2+gx_{max}^2}$$

$$\frac{dy}{dx} = \frac{v_0^2}{gx_{max}} - \frac{v_0^2x}{gx_{max}^2} - \frac{xg}{v_0^2}$$

When $x = x_{max}$, the value of this derivative is negative.

$$\left|\frac{dy}{dx}\right|_{x_{max}} = -\frac{gx_{max}}{v_0^2}$$

② Solve the equation for maximum angle to determine x.

$$\tan\theta_{max} = \frac{v_0^2}{gx} \Rightarrow x = \frac{v_0^2}{g}$$

Substitute this value into the equation for y to determine the maximum height.

$$y = y_0 + \frac{v_0^2}{g} - \frac{g\left(\frac{v_0^2}{g}\right)}{v_0^2} = y_0 + \frac{v_0^2}{g} - \frac{v_0^2}{g}$$

$$y = y_0$$

Experiment 8: Projectile Velocity—Approximate Method

Procedure

② The exact mass used is not critical. Pick a value that gives a fairly large swing for best results.

⑤ With the steel ball and extra masses on the pendulum, the balance point will be somewhere on the catcher block itself. This makes it difficult to use string, but it is easy to find the center of mass by balancing the pendulum on a straightedge.

⑧ The angle reached by the pendulum should not vary more than 1° between successive trials at most.

Calculations

② Use the equation given in the theory section for the approximate method.

Questions

① The best other method of measuring velocity is described in the first part of experiment 1.

② The greatest source of error is the equation used. This is an approximate equation, based on the assumption that the masses involved are point masses. The amount of effect this equation has on the results will depend on the exact geometry of the pendulum and ball, and should be between 5-8%.

③ Typically, 70% of the kinetic energy of the ball is lost. It is not valid to assume that KE is conserved!

④ More energy is transferred in a more elastic collision.

Experiment 9: Projectile Velocity—Exact Method

Procedure

② The exact mass used is not critical. Pick a value that gives a fairly large swing for best results.

⑤ With the steel ball and extra masses on the pendulum, the balance point will be somewhere on the catcher block itself. This makes it difficult to use string, but it is easy to find the center of mass by balancing the pendulum on a straightedge.

⑧ Measure this period as exactly as possible, using the smallest measurement angle that is practical.

⑪ The angle reached by the pendulum should not vary more than 1° between successive trials at most.

Calculations

② Use the equation given in the theory section for the exact method.

Questions

① The best other method of measuring velocity is described in the first part of experiment 1.

② Sources of error include friction, measurement error, and Murphy's Law.

③ Typically, 70% of the kinetic energy of the ball is lost. It is not valid to assume that KE is conserved!

④ The energy transfer is less efficient when there is a larger difference in the masses involved.

⑤ The approximate method will give results that are typically 5-7% higher than their actual values. The more "pointlike" the mass of the pendulum, the more accurate the approximate method.

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Includes
Teacher's Notes
and
Typical
Experiment Results

Instruction Manual and Experiment Guide for the PASCO scientific Model ME-6810

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③ Make certain that the packing material cannot shift in the box or become compressed, allowing the instrument come in contact with the packing carton.

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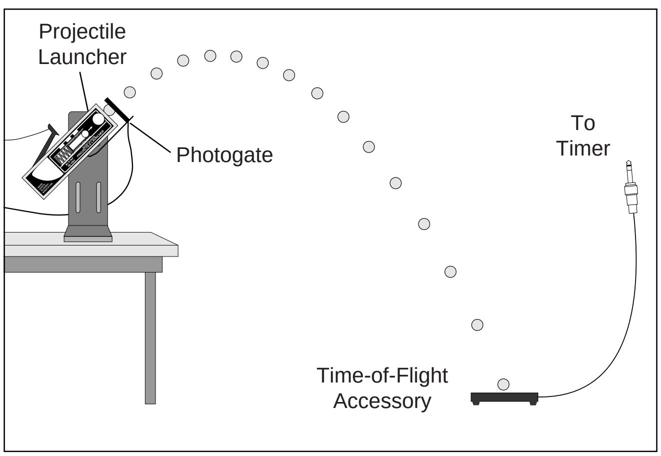
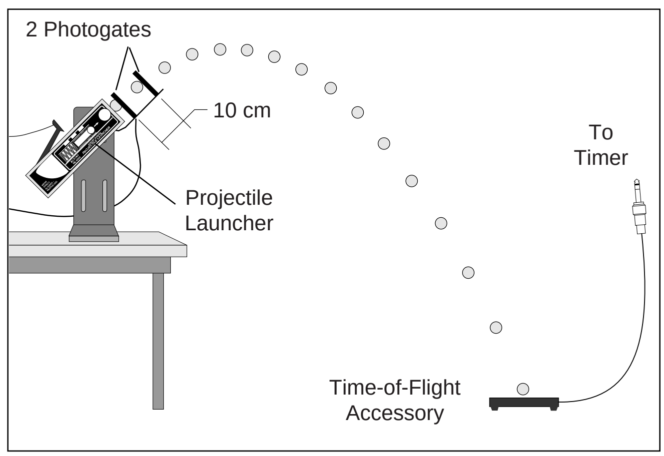
Introduction

The PASCO ME-6810 Time-Of-Flight Accessory is for use with PASCO Projectile Launchers. It consists of a piezo-electric speaker circuit mounted on a 20 x 20 centimeter plastic plate. The plate has a signal cable with a 6 mm (1/4”) stereo phone plug. When a ball hits the plate, the speaker circuit generates a Photogate-like pulse. The cable sends the signal to a timer. The Time-Of-Flight Accessory is designed to be used with a PASCO Photogate Timer, or a PASCO Computer Interface such as the *Science Workshop™ Interface* for Macintosh® or Windows® or the Series 6500 Interface for MS-DOS®.

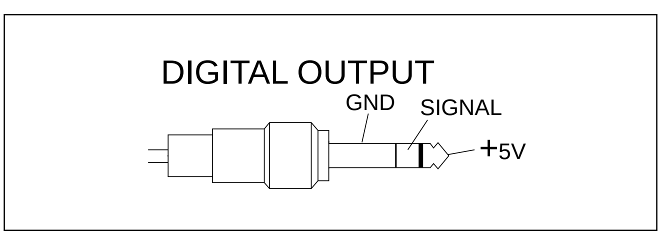
Setup and Operation



Time of Flight Only –
Setup Using a Single Photogate



Time of Flight and Initial Speed –
Setup Using Two Photogates



> ➤ **CAUTION:**
> Use **ONLY *25 mm plastic* balls** or ***16 mm steel* balls**. 25 mm steel balls will damage the unit!

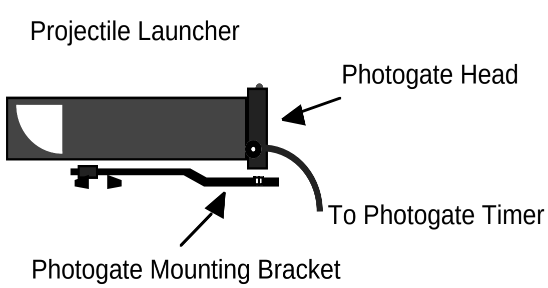
The Time-Of-Flight Accessory can be used to measure the time of flight of a projectile, or the time of flight and the initial speed of the projectile as described as follows:

Equipment Required	Time of Flight		Initial Speed	
	Photogate	Computer Interface	Photogate	Computer Interface
Time-of-Flight Accessory (ME-6810)	x	x	x	x
Projectile Launcher (ME-6800 or ME-6801)	x	x	x	x
Photogate Timer (ME-9206A or ME-9215A	x		x	
Photogate Mounting Bracket (ME-6821)	x	x	x	x
Photogate (ME-9204A or ME-9498)		x	x	2
Science Workshop 700 or Series 6500 Interface		x		
ruler	x	x		
Phone Jack Extender Cable (PI-8117) (may be required to connect the Time-of-Flight Accessory to the Photogate Timer or computer interface if you are using the Long Range Projectile Launcher (ME-6801)	x	x		x

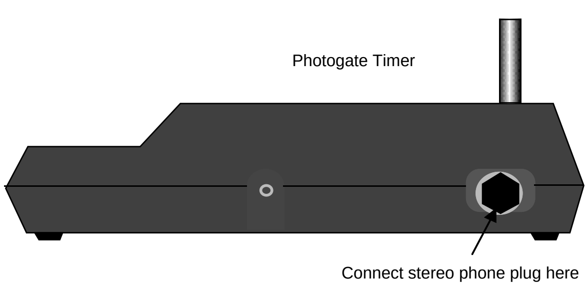
Procedure

Time of Flight with Photogate Timer

Remove the Photogate Head from the support rod of the Photogate Timer. Put the Photogate Mounting Bracket onto the Projectile Launcher and mount the Photogate Head at the front of the launcher.



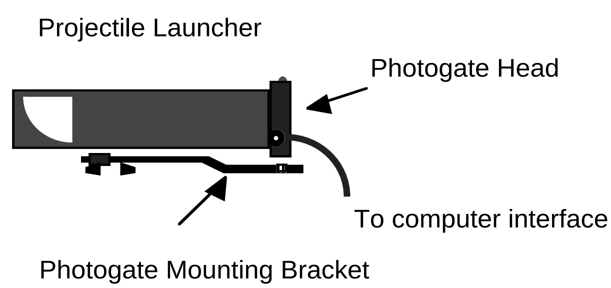
Connect the Time-Of-Flight Accessory stereo phone plug into the side of the Photogate Timer.



Set the Photogate Timer to PULSE mode to measure the time of flight of the projectile from the launcher to the pad.

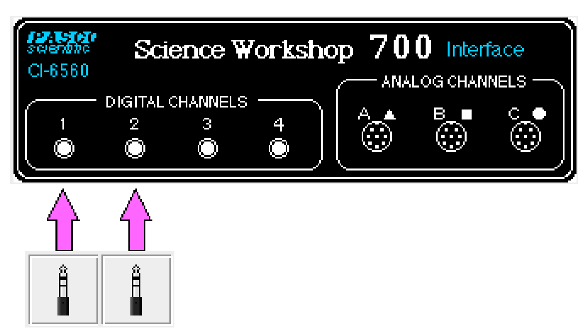
Time of Flight with Computer Interface

Put the Photogate Mounting Bracket onto the Projectile Launcher and mount the Photogate at the front of the launcher.



Connect the Photogate's stereo phone plug into Digital Channel 1 on the interface.

Connect the Time-Of-Flight Accessory stereo phone plug into Digital Channel 2 on the interface.

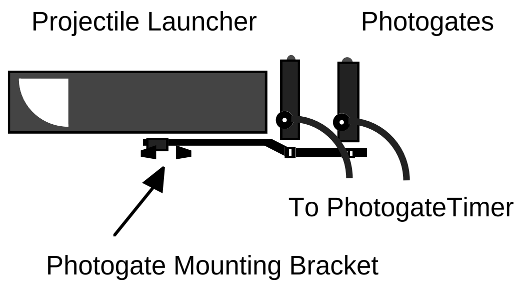


Use the computer program that came with your interface to measure the time of flight of the projectile from the launcher to the pad.

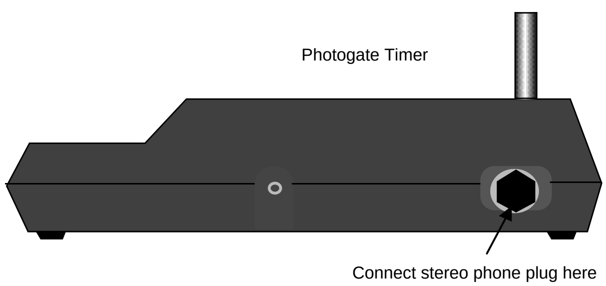
(See the Appendix for more information about using a computer program to time the projectile.)

Initial Speed with Photogate Timer

Remove the Photogate Head from the support rod of the Photogate Timer. Put the Photogate Mounting Bracket onto the Projectile Launcher and mount the Photogate Timer's Photogate Head at the closest position on the front of the Projectile Launcher. Mount the other Photogate at the farthest position on the mounting bracket.



Connect the second Photogate's stereo phone plug into the side of the Photogate Timer.



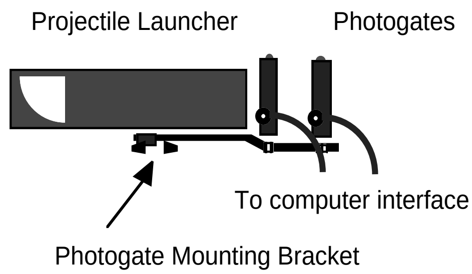
Set the Photogate Timer to PULSE mode to measure the time of the projectile from the first Photogate to the second Photogate.

Measure the distance from Photogate to Photogate. Use this distance and the measured time between the Photogates to calculate the initial speed of the projectile.

> ➤ **NOTE:** The Photogate Timer can measure time of flight OR initial speed of the projectile.

Initial Speed and Time of Flight with Computer Interface

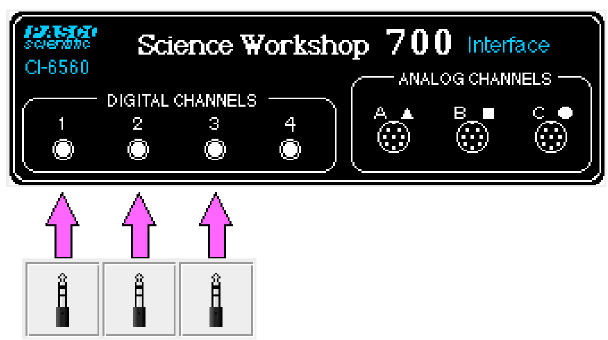
Put the Photogate Mounting Bracket onto the Projectile Launcher and mount one Photogate at the closest position to the front of the launcher. Mount the second Photogate at the farthest position on the bracket.



Connect the stereo phone plug from the Photogate that is CLOSEST to the Projectile Launcher into Digital Channel 1 on the interface.

Connect the stereo phone plug of the second Photogate into Digital Channel 2 on the interface.

Connect the Time-Of-Flight Accessory stereo phone plug into Digital Channel 3 on the interface.



Use the computer program that came with your interface to measure the initial speed and the overall time of flight of the projectile from the launcher to the pad.

(See the Appendix for more information about using a computer program to time the projectile.)

Other

Time-Of-Flight Accessory and Game Port Interface Box

Time of Flight

Use the same equipment as for the Time of Flight with computer interface, but substitute the PASCO CI-6588 Game Port Interface Box for the computer interface.

Use a computer program such as *Precision Timer* to measure the time of flight of the projectile.

Initial Speed

Set up the equipment as for Initial Speed with Photogate Timer, but substitute the Game Port Interface Box for the Photogate Timer. Connect the Photogate that is mounted closest to the front of the Projectile Launcher into Port 1 on the Game Port Interface Box. Connect the second Photogate's stereo phone plug into Port 2 on the Game Port Interface Box.

Use a computer program such as *Precision Timer* to measure the time between Photogates for the projectile. Use the distance between the Photogates and the measured time to calculate the projectile's initial speed.

Initial Speed and Time of Flight

> ➤ **NOTE:** Measuring Initial Speed AND Time of Flight requires a Game Port Interface Box with more than two digital ports, or the PASCO CI-6820 Four-to-One Adapter Box.

Set up the equipment as for the Initial Speed and Time of Flight with computer interface, but substitute the Game Port Interface Box for the computer interface. If you have a Game Port Interface Box with only two digital ports, connect a Four-to-One Adapter Box into Port 1 on the Game Port Interface Box. Connect the Photogates and Time-Of-Flight Accessory into the adapter box.

Use a computer program such as *Precision Timer* to measure the time between Photogate one and Photogate two and between Photogate two and the timer plate of the Time-Of-Flight Accessory (Gate 3). The time between Photogate one and Photogate two can be used to calculate the initial speed of the projectile. The sum of the time between Photogate one and Photogate two, and between Photogate two and the timer plate gives the overall time of flight of the projectile.

Time-Of-Flight Accessory and Game Port Adapter Cable

Time Of Flight

Use the same equipment as for the Time of Flight with Game Port Interface Box, but substitute the PASCO CI-9402 Game Port Adapter Cable for the Game Port Interface Box.

Use a computer program such as *Precision Timer* to measure the time of flight of the projectile.

Initial Speed

Set up the equipment as for the Initial Speed with Game Port Interface Box, but substitute the Game Port Adapter Cable for the Game Port Interface Box.

Use a computer program such as *Precision Timer* to measure the time between Photogates for the projectile. Use the distance between the Photogates and the measured time to calculate the projectile's initial speed.

Initial Speed and Time of Flight

> ➤ **NOTE:** Measuring Initial Speed AND Time of Flight requires a Game Port Adapter Cable and Four-to-One Adapter Box.

Set up the equipment as for the Initial Speed and Time of Flight with computer interface, but substitute the Game Port Adapter Cable for the Computer Interface. Connect a Four-to-One Adapter Box into Port 1 on the Game Port Adapter Cable. Connect the Photogates and Time-Of-Flight Accessory into the adapter box.

Use a computer program such as *Precision Timer* to measure the time between Photogate one and Photogate two and between Photogate two and the timer plate of the Time-Of-Flight Accessory (Gate 3). The time between Photogate one and Photogate two can be used to calculate the initial speed of the projectile. The sum of the time between Photogate one and Photogate two, and between Photogate two and the timer plate gives the overall time of flight of the projectile.

Experiment 1: Time of Flight and Initial Velocity

EQUIPMENT NEEDED

– *Science Workshop* 700 Interface,
  Series 6500 Interface, or Photogate Timer
– Time-of-Flight Accessory (ME-6810)
– Phone Jack Extender Cable (PI-8117)
– Projectile Launcher and Ball
– Photogate Mounting Bracket (ME-6821)
– Photogate Head (ME-9498)

Purpose

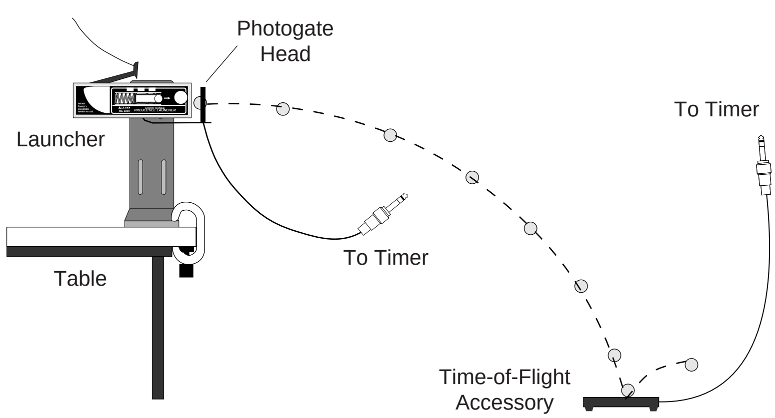
The purpose of this experiment is to show that the time of flight of a ball launched horizontally off a table does not change as the initial velocity is varied.

Theory

A ball launched horizontally off a table of height **h** has no initial velocity in the vertical direction. So the ball takes the same amount of time to reach the ground as a ball that drops from rest from the same height. $h = \left(\frac{1}{2}\right)gt^2$ gives the time of flight, which is independent of the initial velocity.

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

Setup



① Clamp the Projectile Launcher to one end of a sturdy table with the launcher aimed away from the table.

② Adjust the angle of the Projectile Launcher to zero degrees (0°) so the ball will be launched horizontally.

③ Attach the Photogate Mounting Bracket to the Launcher and attach the Photogate to the bracket. Plug the Photogate into the computer interface.

④ Connect the Time-of-Flight Accessory into the computer interface using the extender cable.

⑤ Run the timing program and set it to measure the time between blocking of two Photogates (one Photogate and the timer plate of the Time-of-Flight Accessory).

Procedure

① Put the plastic ball into the Projectile Launcher and cock it to the short range position.

② Test fire the ball to determine where to place the timer plate on the floor. Put the timer plate on the floor where the ball hits.

③ Shoot the ball on the short range position and record the time of flight in Table 1.1.

④ Repeat Steps 1 through 3 for medium range and long range. Are the times the same?

⑤ Set the angle of the launcher to 30° and shoot it again on the long range setting. Move the timer plate to the new landing position so the ball will hit the plate. Shoot again and record the time of flight in Table 1.1. Is this time the same as the others?

Table 1.1 Results

Range	Time
Short	
Medium	
Long	
Long at 30°	

Experiment 2: Horizontal Distance

EQUIPMENT NEEDED

– *Science Workshop* 700 Interface,
Series 6500 Interface, or Photogate Timer
– Time of Flight Accessory (ME-6810)
– Projectile Launcher and Ball
– (2) Photogate Heads (ME-9498)
– Plumb Bob (SE-8728)
– carbon paper
– Phone Jack Extender Cable (PI-8117)
– Photogate Mounting Bracket (ME-6821)
– measuring tape or meter stick
– white paper

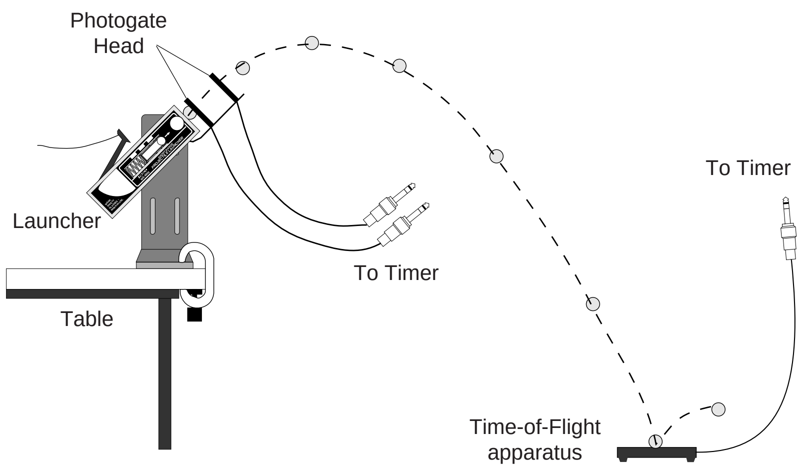
Purpose

The purpose of this experiment is to use the time of flight and the initial velocity to predict the horizontal distance traveled by a ball shot off a table at an angle.

Theory

A ball is launched off a table from a height h at an angle θ above the horizontal. The horizontal distance, x, traveled by the ball is given by $x = v_0 \cos\theta\, t$ where v_0 is the initial velocity of the ball and t is the time of flight.

Setup



① Clamp the Projectile Launcher to one end of a sturdy table with the launcher aimed away from the table.

② Adjust the angle of the Projectile Launcher to any desired angle. Record the angle in Table 2.1.

③ Attach the Photogate Mounting Bracket to the Launcher and connect the Photogates to the computer interface.

④ Connect the Time-of-Flight Accessory to the computer interface using the extender cable.

⑤ Run the timing program and set it to measure the time between the three successive signals (two Photogates and the timer plate of the Time-of-Flight Accessory).

Procedure

① Put the plastic ball into the Projectile Launcher and cock it.

② Test fire the ball to determine where to place the timer plate on the floor. Put the timer plate on the floor where the ball hit.

③ Tape a piece of white paper and a piece of carbon paper to the plate to record where the ball lands.

④ Shoot the ball and record the times between Photogates in Table 2.1.

⑤ Shoot the ball 9 more times to determine the average horizontal distance traveled.

⑥ Use the Plumb Bob to find the place on the floor directly below the muzzle of the launcher. Measure the horizontal distance along the floor to the leading edge of the paper on the plate. Record this distance in Table 2.1.

⑦ Remove the carbon paper and measure from the leading edge of the paper to each of the dots on the paper. Record in Table 2.1.

Analysis

① Find the average of the ten distances in Table 2.1 and record in Table 2.1.

② Add the distance to the leading edge of the paper to the average and record in Table 2.2.

③ Calculate the time of flight by adding the time between Photogates 1 and 2 and the time between Photogates 2 and the timer plate and record in Table 2.2.

④ Calculate the initial velocity using the time between Photogates 1 and 2 and the distance between the Photogates (10 cm). Record in Table 2.2.

⑤ Calculate the horizontal distance using the time, initial velocity, and angle and record in Table 2.2.

⑥ Calculate the percent difference between the measured distance and the calculated distance and record in Table 2.2.

Table 2.1 Data

Angle = ________________

Time between Photogates = ___________

Time between second Photogate and timer plate = ___________

Distance to paper = _________

Distance
1
2
3
4
5
6
7
8
9
10
Average =

Table 2.2 Results

Total distance	
Time of flight	
Initial velocity	
Calculated distance	
% difference	

Experiment 3: Horizontal Velocity is Constant

EQUIPMENT NEEDED

– *Science Workshop* 700 Interface,
  Series 6500 Interface, or Photogate Timer
– Time-of-Flight Accessory (ME-6810)
– Projectile Launcher and Ball
– Photogate Mounting Bracket (ME-6821)
– measuring tape or meter stick
– Phone Jack Extender Cable (PI-8117)
– Photogate Head (ME-9498)
– Plumb Bob (SE-8728)
– vertical target board

Purpose

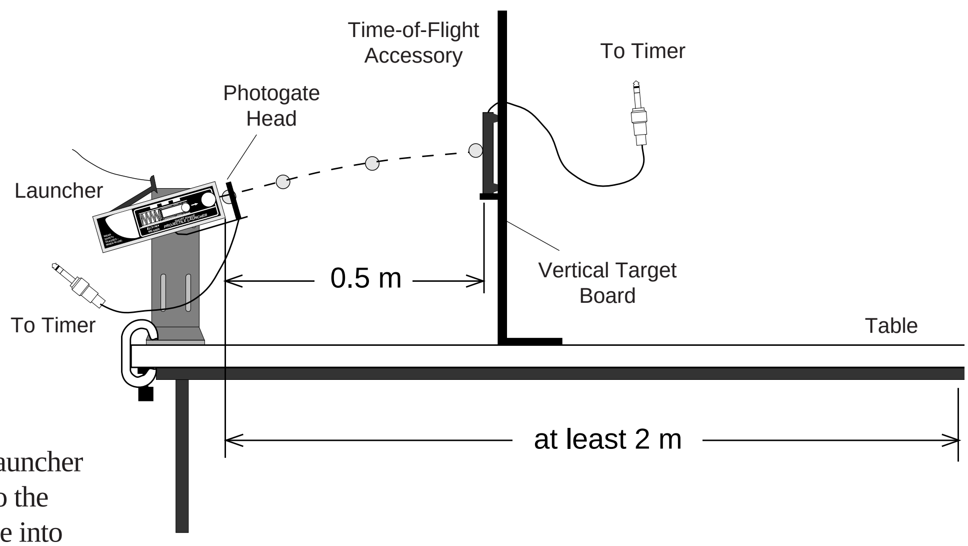
The purpose is to show that the horizontal velocity of a projectile is constant throughout its flight.

Theory

For projectile motion, the horizontal and vertical motions are separate. In the vertical direction, the projectile accelerates downward as gravity pulls on it. But in the horizontal direction, there is no acceleration and the component of the velocity in the horizontal direction is constant (neglecting friction).

The horizontal velocity can be found by measuring the horizontal distance and the time of flight.
$v_x = \frac{x}{t}$.

Setup



① Clamp the Projectile Launcher to one end of a sturdy table with the launcher aimed along the length of the table.

② Adjust the angle of the Projectile Launcher to any desired angle.

③ Attach the Photogate Mounting Bracket to the launcher and attach the Photogate to the bracket. Plug the Photogate into Channel 1 on the computer interface.

④ Connect the Time-of-Flight Accessory to the computer interface. Use the extender cable if necessary.

⑤ Run the timing program and set it to measure the time between blocking of two Photogates (one Photogate and the timer plate of the Time-of-Flight Accessory).

⑥ Set up the vertical target board about 0.5 m in front of the Projectile Launcher. Use the Plumb Bob to aid with the measurement of the exact distance between the muzzle of the launcher and the timer plate. Record the distance in Table 3.1.

Procedure

① Load and cock the launcher to the long range position.

② Fire a test shot to see where the ball hits the vertical target. Hold the timer plate against the vertical board at the place where the ball hit.

③ Shoot the ball again and record the time of flight in Table 3.1.

④ Move the vertical target to 1 m, 1.5 m, and 2 m in succession, finding the time of flight for each position and recording in Table 3.1.

Analysis

Calculate the horizontal velocity for each position. Is the velocity constant?

Table 3.1 Data and Results

Distance	Time	Horizontal Velocity

PASCO scientific ®

Teacher's Guide

Experiment 1: Time of Flight and Initial Velocity

Notes on Setup:

② It is important that the launcher be exactly horizontal. Use a spirit level for best results.

③,④ You may use one of several timing options for this experiment. Consult the manual for your computer interface, and then connect things so that the Photogate starts the timer and the timer plate of the Time-of-Flight Accessory stops it. Alternately, you may use the PASCO ME-9215A or ME-9206A Photogate Timers.

Notes on Procedure:

④ The times will be nearly the same, if the launcher is horizontal. You will notice a systematic error if the launcher is not exactly horizontal.

⑤ Setting the launcher to some angle other than 0° will affect the time significantly.

Experiment 2: Horizontal Distance

Notes on Setup:

③-⑤ You may use any compatible computer interface. If your interface allows only one or two digital inputs, then use the CI-6820 four-to-one adapter. In any case, you will want to arrange things so that you can record the times between the two Photogate signals and the time between the second Photogate and the timer plate.

Notes on Analysis:

③ Depending on your interface program, the time given for each event may be the total time since the first event, rather than the time since the last event.

④ The initial velocity should be close to that measured in other experiments (See launcher manual experiments 1 and 2, for example.)

⑥ Difference should be less than 5%.

Experiment 3: Horizontal Velocity is Constant

Notes on Setup:

③-⑤ Consult your interface manual if necessary. The system should be set up in such a way that the computer measures the time between the Photogate and the timer plate.

⑥ The "Vertical Target Board" can be any convenient moveable vertical object.

Notes on Analysis:

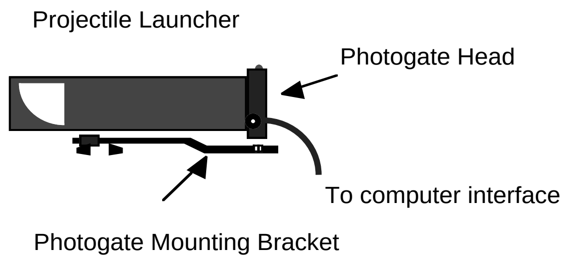
The velocity is not constant. It is nearly constant, but this equipment is sensitive enough to observe the change in velocity due to air resistance. This air resistance will result in your measured velocity being slightly lower at longer distances. You may ignore this effect if you wish, or you may want for the students to further investigate the air resistance.

Appendix: Using the Time-Of-Flight Accessory with a PASCO Computer Interface

Time of Flight with the *Science Workshop Interface* for Macintosh or Windows

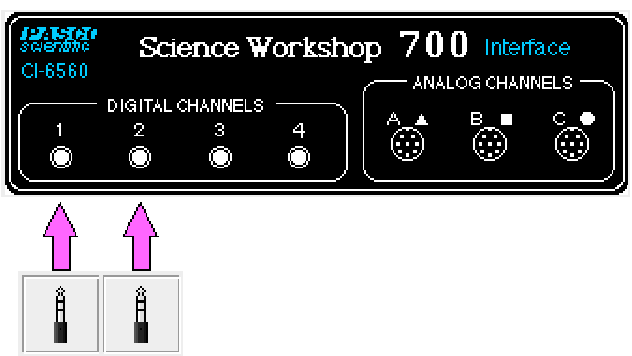
- Refer to the *Setup and Operation* section for details about the equipment needed.

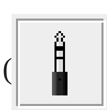
① Attach the Photogate Mounting Bracket onto the Projectile Launcher and mount the Photogate at the front of the launcher.

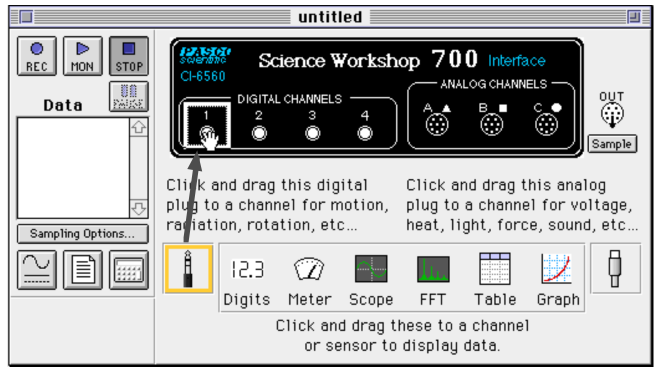


② Connect the Photogate's stereo phone plug into Digital Channel 1 on the interface.

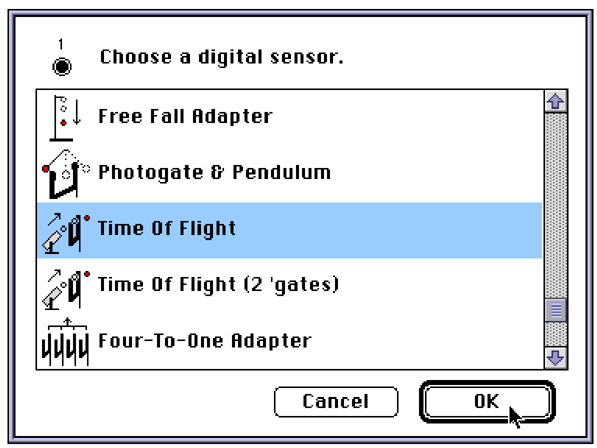
③ Connect the Time-Of-Flight Accessory stereo phone plug into Digital Channel 2 on the interface.



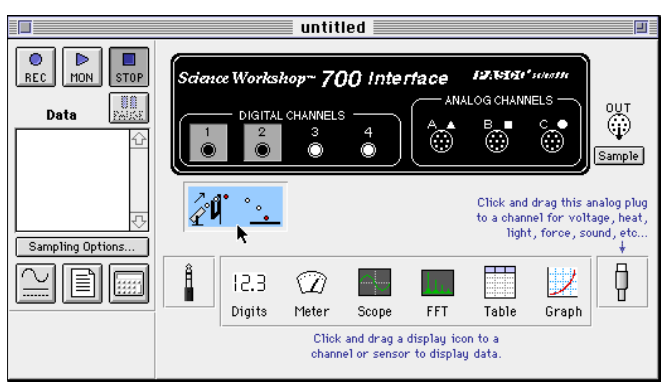
④ Start the *Science Workshop* program. In the Experiment Setup window, click-and-drag the digital sensor plug icon () to the Digital Channel 1 icon.



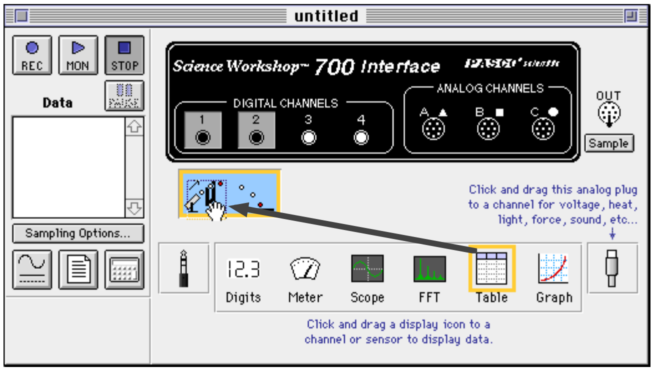
⑤ Select "Time of Flight" from the list of digital sensors. Click "OK" to return to the Experiment Setup window.



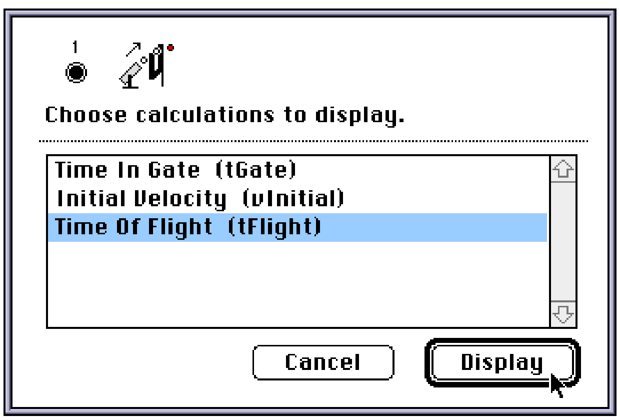
- The sensor icon will appear in the Experiment Setup window.



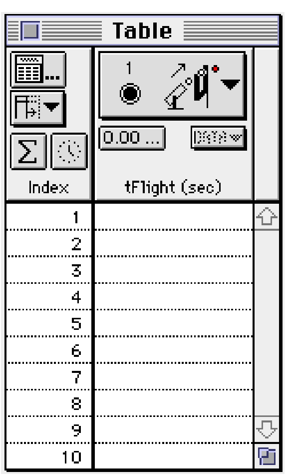
⑥ Click and drag the Table display icon to the sensor icon.



⑦ Select "Time of Flight (tFlight)" from the list of calculations to display. Click "Display" to return to the Experiment Setup window.



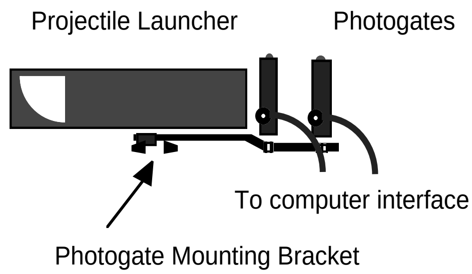
- The Table display will show "tFlight (sec)".



Time of Flight and Initial Speed with the *Science Workshop Interface* for Macintosh or Windows

- Refer to the *Setup and Operation* section for details about the equipment needed.

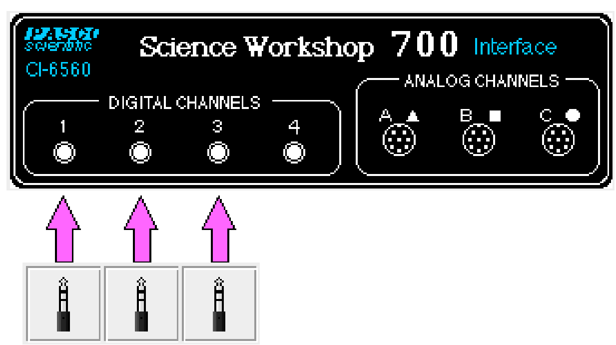
① Attach the Photogate Mounting Bracket onto the Projectile Launcher and mount one Photogate at the closest position to the front of the launcher. Mount the second Photogate in the farthest position from the front of the projectile launcher.

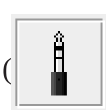


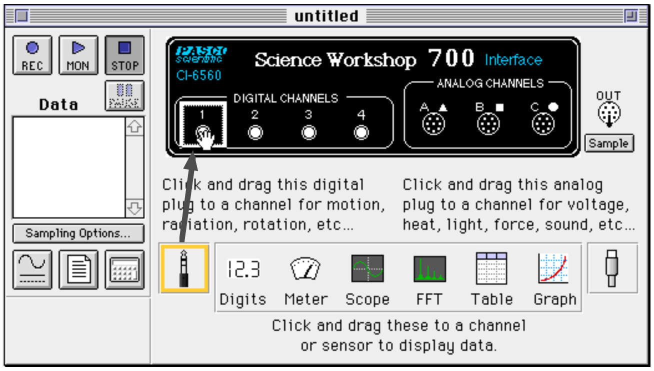
② Connect the first Photogate's stereo phone plug into Digital Channel 1 on the interface.

③ Connect the second Photogate's stereo phone plug into Digital Channel 2 on the interface.

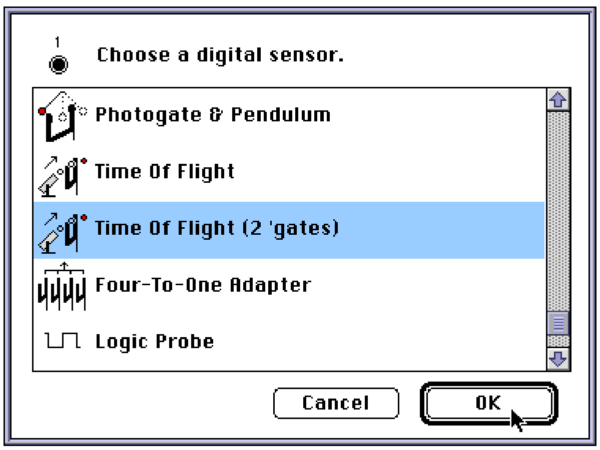
④ Connect the Time-Of-Flight Accessory stereo phone plug into Digital Channel 3 on the interface.



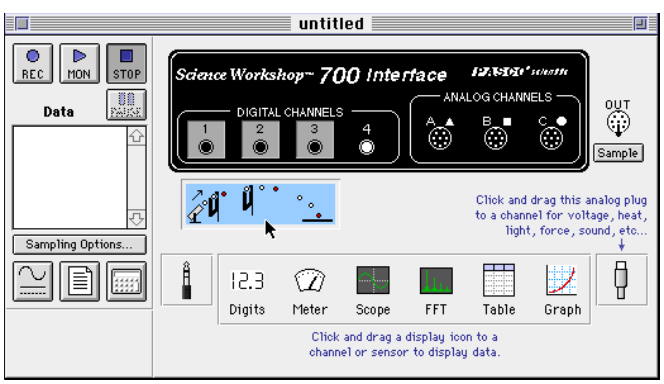
⑤ Start the *Science Workshop* program. In the Experiment Setup window, click-and-drag the digital sensor plug icon () to the Digital Channel 1 icon.



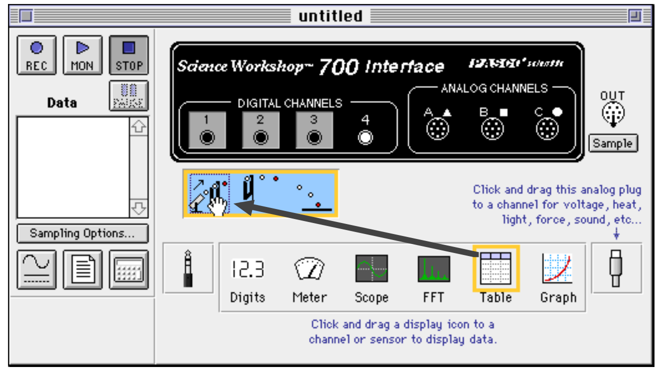
⑥ Select “Time of Flight (2 ‘gates)” from the list of digital sensors. Click “OK” to return to the Experiment Setup window.



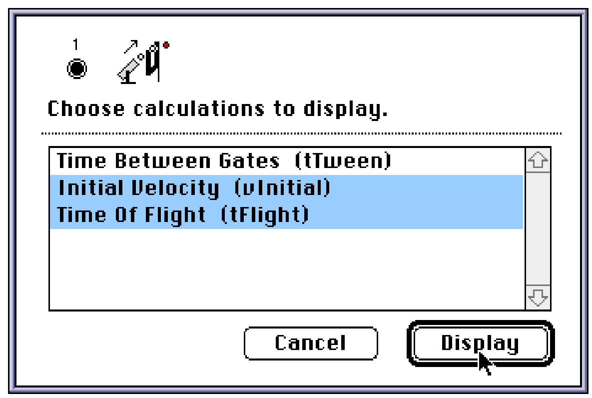
- The sensor icon will appear in the Experiment Setup window.



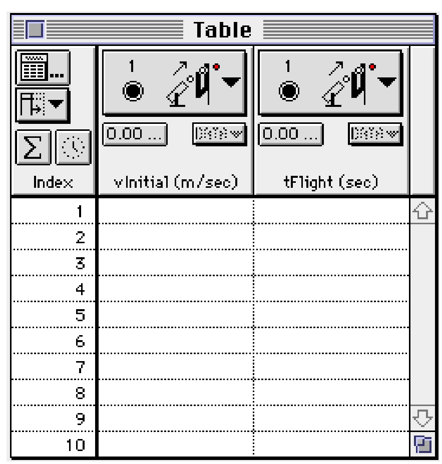
⑦ Click and drag the Table display icon to the sensor icon.



⑧ Select “Initial Velocity (vInitial)” and “Time of Flight (tFlight)” from the list of calculations to display. (Hold down the SHIFT key to select more than one calculation at the same time.) Click “Display” to return to the Experiment Setup window.



- The Table display will show “vInitial (m/sec)” and “tFlight (sec)”.



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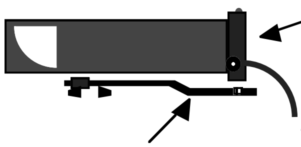
Time of Flight with the Series 6500 Interface and the *Precision Timer* Program (MS-DOS)

- Refer to the *Setup and Operation* section for details about the equipment needed.

① Attach the Photogate Mounting Bracket onto the Projectile Launcher and mount the Photogate at the front of the launcher.



② Connect the Photogate's stereo phone plug into Digital Channel 1 on the interface.

③ Connect the Time-Of-Flight Accessory stereo phone plug into Digital Channel 2 on the interface.

④ Start the *Precision Timer* program. Select "P-Pulse Timing Modes" from the Main Menu.

⑤ In the PULSE TIMING MODES menu, select "A-Pulse 1-2".

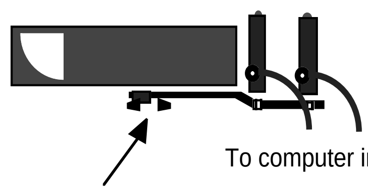
⑥ Select "N-Normal Time Display" in the "DISPLAY OPTIONS – Pulse 1-2 Mode" menu.

- This option will display the time of flight of the projectile from the Photogate to the timer plate of the Time-Of-Flight Accessory.

Time of Flight and Initial Speed with the Series 6500 Interface and the *Precision Timer* Program (MS-DOS)

- Refer to the *Setup and Operation* section for details about the equipment needed.

① Attach the Photogate Mounting Bracket onto the projectile launcher and mount one Photogate at the closest position to the front of the launcher. Mount the second Photogate in the farthest position from the front of the launcher.



② Connect the first Photogate's stereo phone plug into Digital Channel 1 on the interface.

③ Connect the second Photogate's stereo phone plug into Digital Channel 2 on the interface.

④ Connect the Time-Of-Flight Accessory stereo phone plug into Digital Channel 3 on the interface.

⑤ Start the *Precision Timer* program. Select "P-Pulse Timing Modes" from the Main Menu.

⑥ In the PULSE TIMING MODES menu, select "B-Pulse 1-2 and 2-3".

⑦ Select "N-Normal Time Display" in the "DISPLAY OPTIONS – Pulse 1-2 and 2-3 Mode" menu.

- This option will display the time of the projectile from the first Photogate to the second Photogate, and the time from the second Photogate to the timer plate of the Time-Of-Flight Accessory (gate 3).

Technical Support

Feed-Back

If you have any comments about this product or this manual please let us know. If you have any suggestions on alternate experiments or find a problem in the manual please tell us. PASCO appreciates any customer feed-back. Your input helps us evaluate and improve our product.

To Reach PASCO

For Technical Support call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

email: techsupp@PASCO.com

Tech support fax: (916) 786-3292

Contacting Technical Support

Before you call the PASCO Technical Support staff it would be helpful to prepare the following information:

• If your problem is computer/software related, note:

Title and Revision Date of software.

Type of Computer (Make, Model, Speed).

Type of external Cables/Peripherals.

• If your problem is with the PASCO apparatus, note:

Title and Model number (usually listed on the label).

Approximate age of apparatus.

A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.)

If possible, have the apparatus within reach when calling. This makes descriptions of individual parts much easier.

• If your problem relates to the instruction manual, note:

Part number and Revision (listed by month and year on the front cover).

Have the manual at hand to discuss your questions.

Instruction Manual and
Experiment Guide for
the PASCO scientific
Model ME-8950

012-05293E
8/97

COMPLETE ROTATIONAL SYSTEM

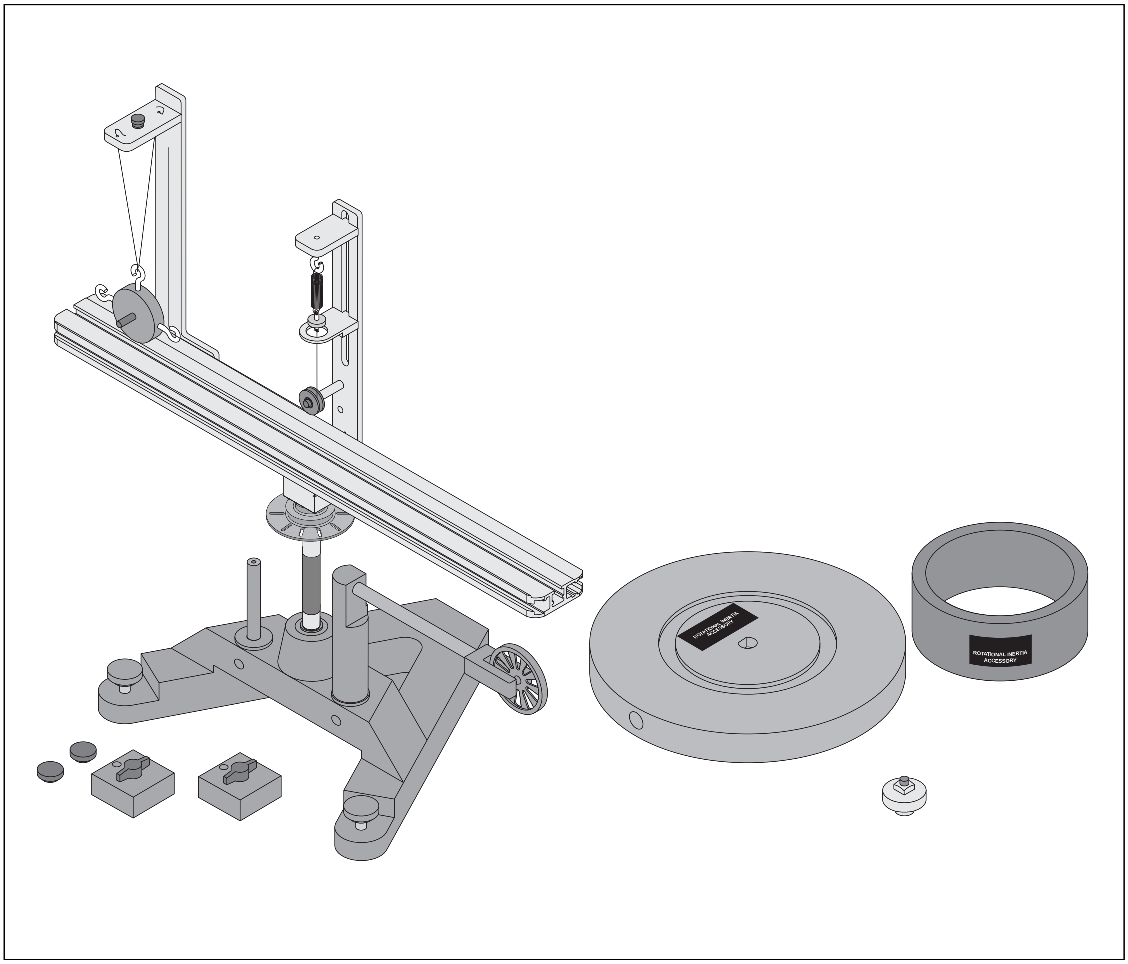


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Table of Contents

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Credits

This manual authored by: Ann and Jon Hanks

This manual edited by: Ann and Jon Hanks

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Should the product have to be returned to PASCO scientific for any reason, notify PASCO scientific by letter, phone, or fax BEFORE returning the product. Upon notification, the return authorization and shipping instructions will be promptly issued.

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When returning equipment for repair, the units must be packed properly. Carriers will not accept responsibility for damage caused by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

① The packing carton must be strong enough for the item shipped.

② Make certain there are at least two inches of packing material between any point on the apparatus and the inside walls of the carton.

③ Make certain that the packing material cannot shift in the box or become compressed, allowing the instrument come in contact with the packing carton.

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Introduction

PASCO's Complete Rotational System provides a full range of experiments in centripetal force and rotational dynamics. The system consists of three separate components:

Description

The ME-8951 Rotating Platform consists of a sturdy 4 kg base with low friction bearings and a rotating arm which serves as a versatile base for rotation experiments. This platform is a general purpose base upon which you may mount anything (having a mass under 3 kg) you wish to rotate. The T-slots in the track supply a convenient way to mount objects to the track using thumbscrews and square nuts. To use the Centripetal Force Accessory (ME-8952) or the Rotational Inertia Accessory (ME-8953), each must be mounted on this base. A photogate/pulley mount and two 300 g masses are also included.

The ME-8952 Centripetal Force Accessory is comprised of two vertical posts which can be mounted to the Rotating Platform with thumbscrews. These posts are adjustable and can be positioned virtually anywhere along the length of the platform. The radius indicator is at the center of the apparatus so it can be clearly seen while the apparatus is rotating. This accessory requires the Rotating Platform (ME-8951) to operate. The PASCO Centripetal Force Accessory can be used to experiment with centripetal force and conservation of angular momentum. For the centripetal force experiments it is possible to vary the mass and radius to see the resulting change in the centripetal force. The force can also be held constant while other quantities are varied. The Centripetal Force Accessory is powered by hand and the rate of rotation can be counted manually or read by a computer. Variable hanging masses are included.

The ME-8953 Rotational Inertia Accessory includes a disk and a metal ring. The disk can be mounted to the rotating base in a variety of positions and at any radius. This accessory requires the Rotating Platform (ME-8951) to operate. The Rotational Inertia Accessory allows you to perform rotational inertia experiments and conservation of angular momentum experiments.

About This Manual

The following Equipment section describes each component in detail and the subsequent Assembly section provides instructions for component assembly and setup.

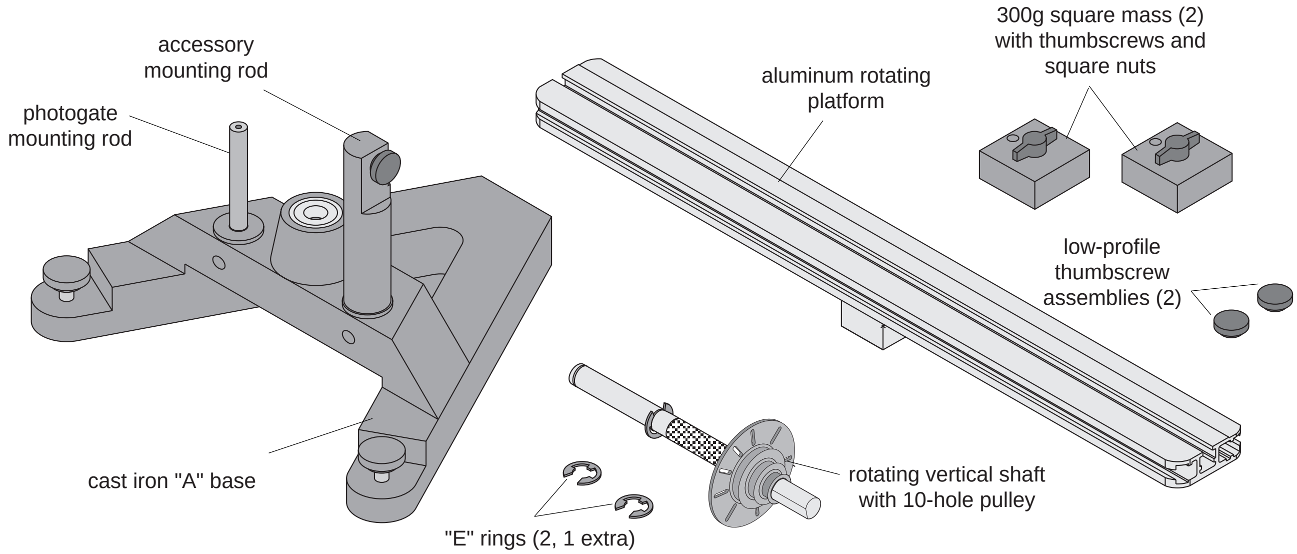
The Experiment section contains several experiments that can illustrate some of the basic theory of centripetal force, rotational inertia, etc.

Computer Timing

You can use a computer with a PASCO Smart Pulley to measure the motion of the apparatus. Some of the experiments describe how to use the MS-DOS version of Smart Pulley Timer. If you are using the Apple II version of Smart Pulley Timer, the procedure for using the program will be similar.

If you are using a computer interface that comes with its own software (such as the Series 6500 Interface for IBM or Apple II, the CI-6550 Computer Interface for Macintosh, or the CI-6700 MacTimer Timing Interface), refer to the interface manuals for instructions on how to use the software with the Smart Pulley.

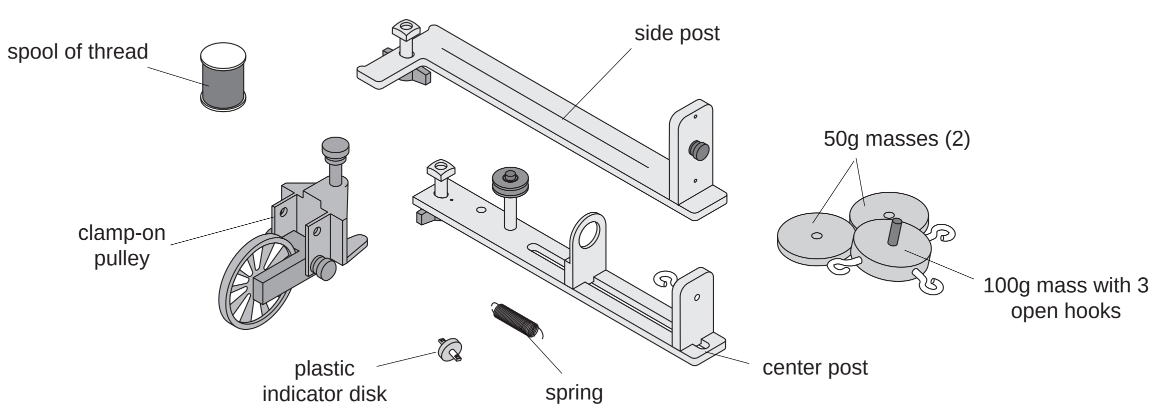
Equipment



ME-8951 Rotating Platform Equipment

The ME-8951 Rotating Platform Includes the following:

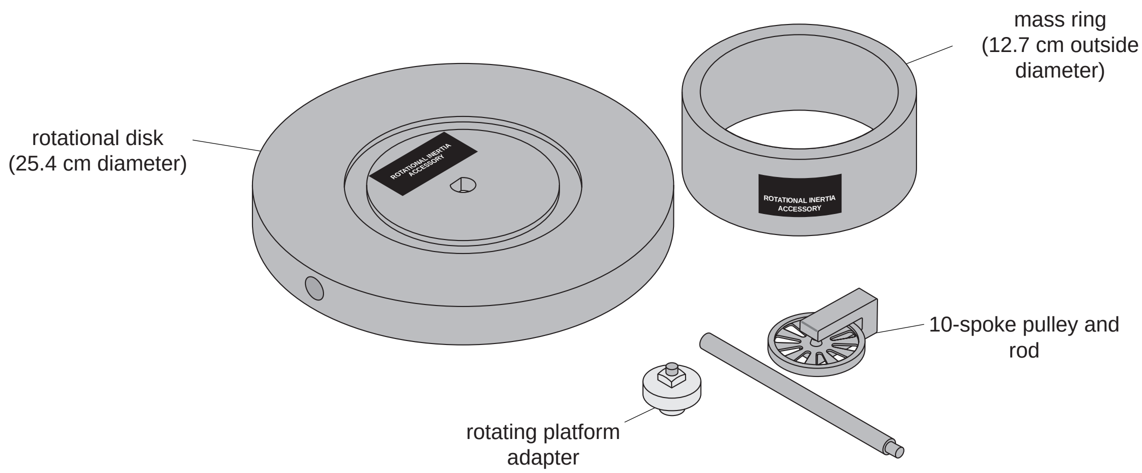
- PASCO cast iron “A” base with rotating shaft and pulley with 10 holes
- aluminum track
- two square masses (about 300 g) with thumb screw and square nut
- two additional low-profile screws and square nuts to act as stops for the square mass in the Conservation of Angular Momentum experiment
- accessory mounting rod for mounting the 10-spoke pulley or the optional Smart Pulley photogate head
- accessory mounting rod for mounting PASCO Photogate (ME-9498A, ME-9402B or later)



ME-8952 Centripetal Force Accessory Equipment

The ME-8952 Centripetal Force Accessory includes:

- center post that supports an indicator mechanism which consists of a small pulley, a movable spring holder, a movable indicator, a spring, and a plastic indicator disk
- side post for hanging hooked mass
- mass (100 g) with 3 open hooks
- 2 additional 50 gram masses
- clamp-on pulley
- 1 spool of thread



ME-8953 Rotational Inertia Accessory Equipment

The ME-8953 Rotation Inertia Accessory includes:

- disk with bearings in the center
- ring (12.7 cm diameter)
- adapter to connect disk to platform
- 10-spoke pulley and rod

Other Equipment Needed:

The following is a list of equipment recommended for the experiments described in this manual. See the PASCO catalog for more information.

- Projectile Launcher
- Projectile Collision Accessory
- Smart Pulley (with Smart Pulley Timer software, or a compatible computer interface)
- string
- mass and hanger set
- balance (for measuring mass)
- calipers
- stopwatch

Miscellaneous Supplies:

- meter stick
- graph paper
- carbon paper
- white paper
- rubber bands
- paper clips

Assembly

ME-8951 Rotating Platform

Assembling the Rotating Platform

① Insert the cylindrical end of the shaft into the bearings on the top-side of the A-shaped iron base. Secure the shaft in place by inserting the "E" ring in the slot at the bottom of the shaft. See Figure 1.

② Mount the track to the shaft and tighten the thumb screw against the flat side of the “D” on the shaft. See Figure 1.

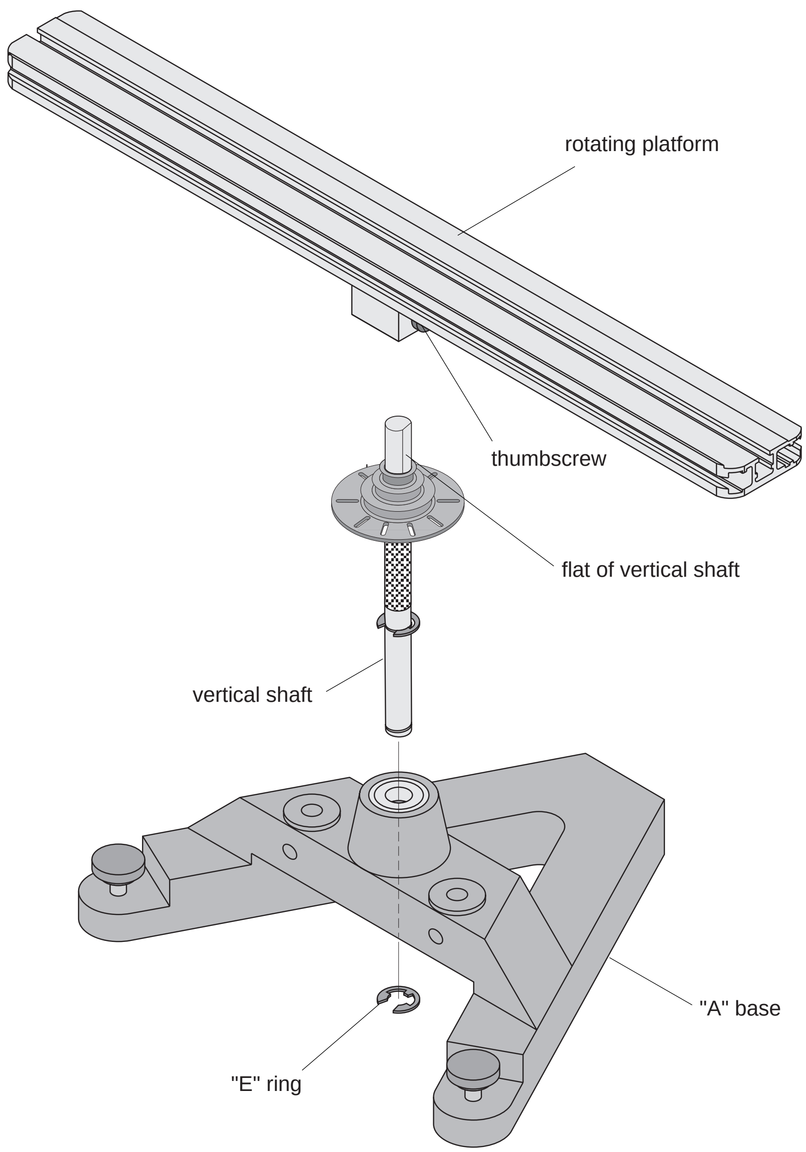


Figure 1: Attaching the Vertical Shaft to the Base and Rotating Platform Assembly

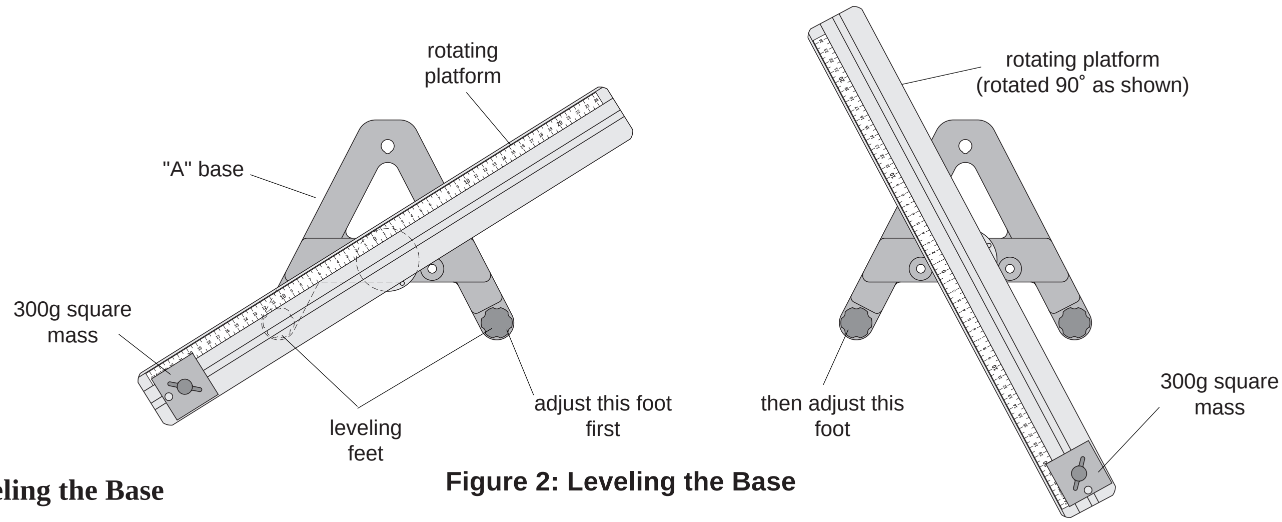


Figure 2: Leveling the Base

Leveling the Base

Some experiments (such as the Centripetal Force experiments) require the apparatus to be extremely level. If the track is not level, the uneven performance will affect the results. To level the base, perform the following steps:

① Purposely make the apparatus unbalanced by attaching the 300 g square mass onto either end of the aluminum track. Tighten the screw so the mass will not slide. If the hooked mass is hanging from the side post in the centripetal force accessory, place the square mass on the same side.

② Adjust the leveling screw on one of the legs of the base until the end of the track with the square mass is aligned over the leveling screw on the other leg of the base. See Figure 2.

③ Rotate the track 90 degrees so it is parallel to one side of the “A” and adjust the other leveling screw until the track will stay in this position.

④ The track is now level and it should remain at rest regardless of its orientation.

Installing the Optional Smart Pulley Photogate Head

The black plastic rod stand is designed to be used in two ways:

- It can be used to mount a Smart Pulley photogate head to the base in the correct position to use the 10 holes in the pulley on the rotating shaft to measure angular speed.
- It can be used to mount a Smart Pulley (with the pulley and rod) to the base to run a string over the pulley.

To Use the Photogate Head Only:

① To install, first mount the black rod to the base by inserting the rod into either hole adjacent to the center shaft on the base.

② Mount the Smart Pulley photogate head horizontally with the cord side down. Align the screw hole in the photogate head with the screw hole in the flat side of the black rod. Secure the photogate head with the thumb screw. See Figure 3.

③ Loosen the thumb screw on the base to allow the black rod to rotate. Orient the rod and photogate head so the infrared beam passes through the holes in the pulley. If the photogate head is powered by a computer, you can tell when the photogate is blocked by watching the LED indicator on the end of the photogate. The photogate head should not be rubbing against the pulley. When the head is in the correct position, tighten the bottom screw to fix the rod in place.

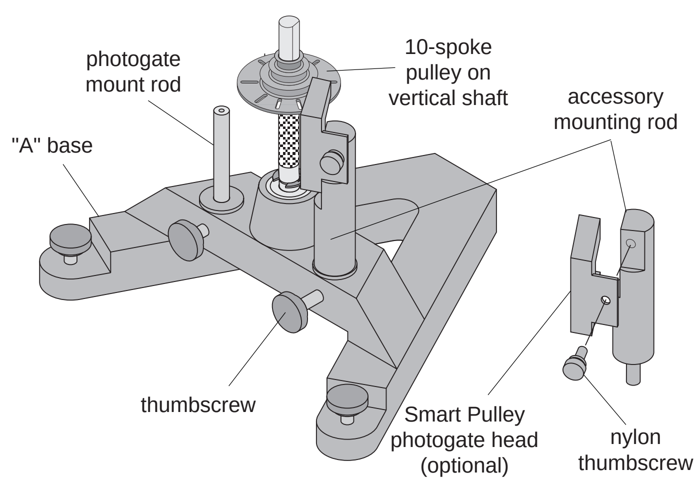


Figure 3: Using the Accessory Mounting Rod With the Smart Pulley

To use the entire Smart Pulley with rod or the Super Pulley with rod:

① Insert the Smart Pulley rod into the hole in the black rod and tighten the set screw against the Smart Pulley rod. See Figure 4.

② Rotate the black rod so the string from the pulley on the center shaft is aligned with the slot on the Smart Pulley.

③ Adjust the position of the base so the string passing over the Smart Pulley will clear the edge of the table.

To mount a PASCO Photogate on "A" base:

① Mount PASCO Photogate on threaded end of rod (rod height may be adjusted with thumbscrew).

② Slide non-threaded end of photogate mount into hole in base, clamp in place with thumbscrew.

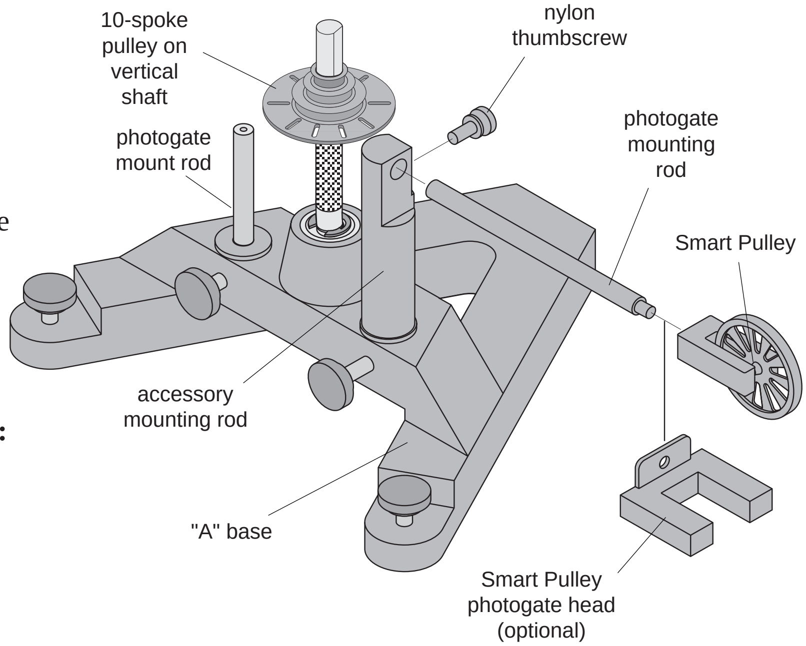


Figure 4: Using the Accessory Mounting Rod With the Photogate Mounting Rod and/or Smart Pulley

ME-8952 Centripetal Force Accessory

Center Post Assembly

Assemble the center post as shown in Figure 5:

① Attach one end of the spring to the spring bracket and connect the indicator disk to the other end of the spring. Insert the spring bracket into the slot on the center post and tighten the thumb screw.

② Tie one end of a string (about 30 cm long) to the bottom of the indicator disk and tie a loop in the other end of the string.

③ Insert the indicator bracket into the slot on the center post, placing it below the spring bracket. Tighten the thumb screw.

④ Attach the pulley in the higher of the two holes on the center bracket.

⑤ Insert the thumb screw at the bottom of the center post and attach the square nut.

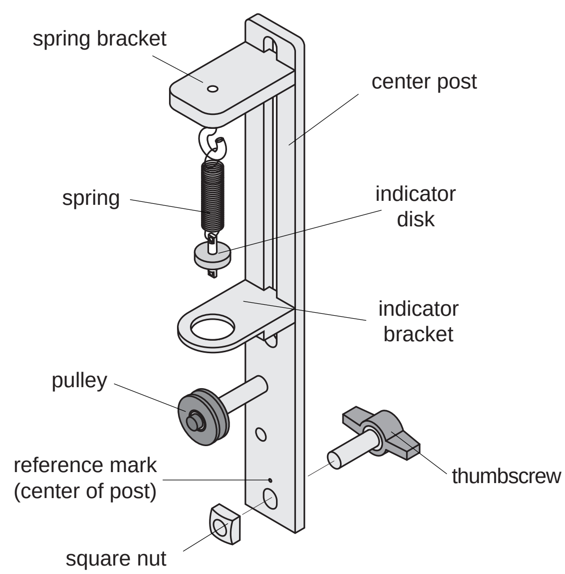


Figure 5: Center Post Assembly

Side Post Assembly

Assemble the side post as shown in Figure 6:

① Insert the thumb screw at the bottom of the side post and attach the square nut.

② Using a string about 30 cm long, tie the string around the screw head on the top of the side post. Then thread the other end of the string down through one of the holes in the top of the side post and then back up through the other hole. Do not pull the string taut.

③ Loosen the screw on the top of the side post and wrap the loose end of the string around the threads of the screw and tighten the screw.

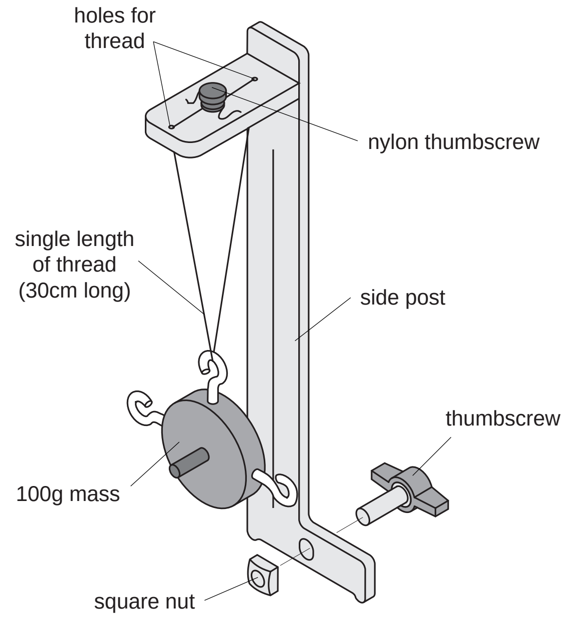


Figure 6: Side Post Assembly

Threading the Centripetal Force Accessory

① Mount the center post in the T-slot on the side of the track that has the rule. Align the line on the center post with the zero mark on the rule and tighten the thumb screw to secure it in place. Then mount the side post on the same side of the track. See Figure 7.

② Hang the object from the string on the side post and adjust the height of the object so the string coming from the center post will be level.

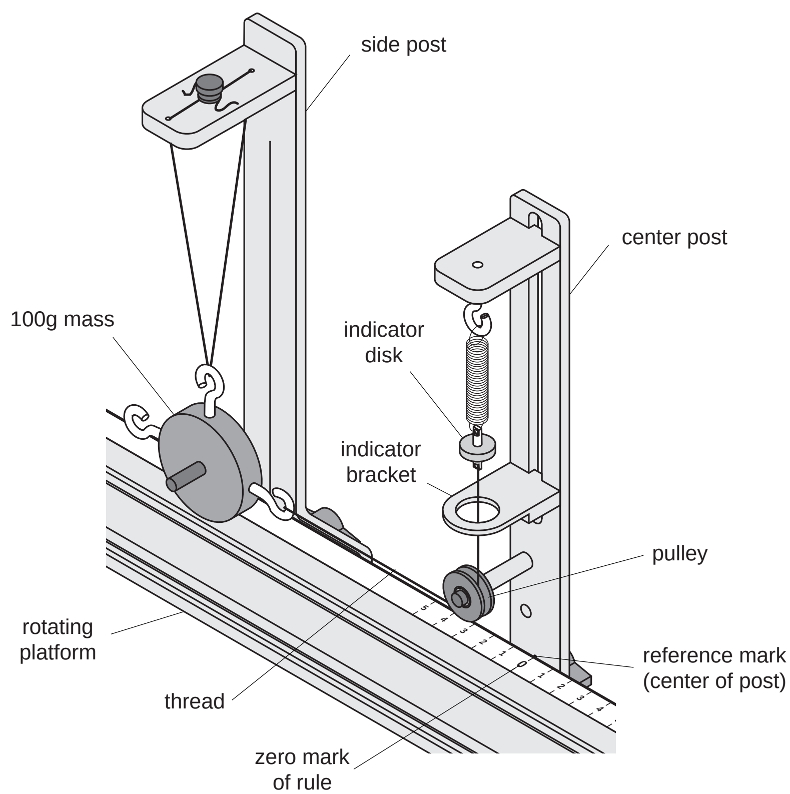


Figure 7: Threading the Centripetal Force Accessory

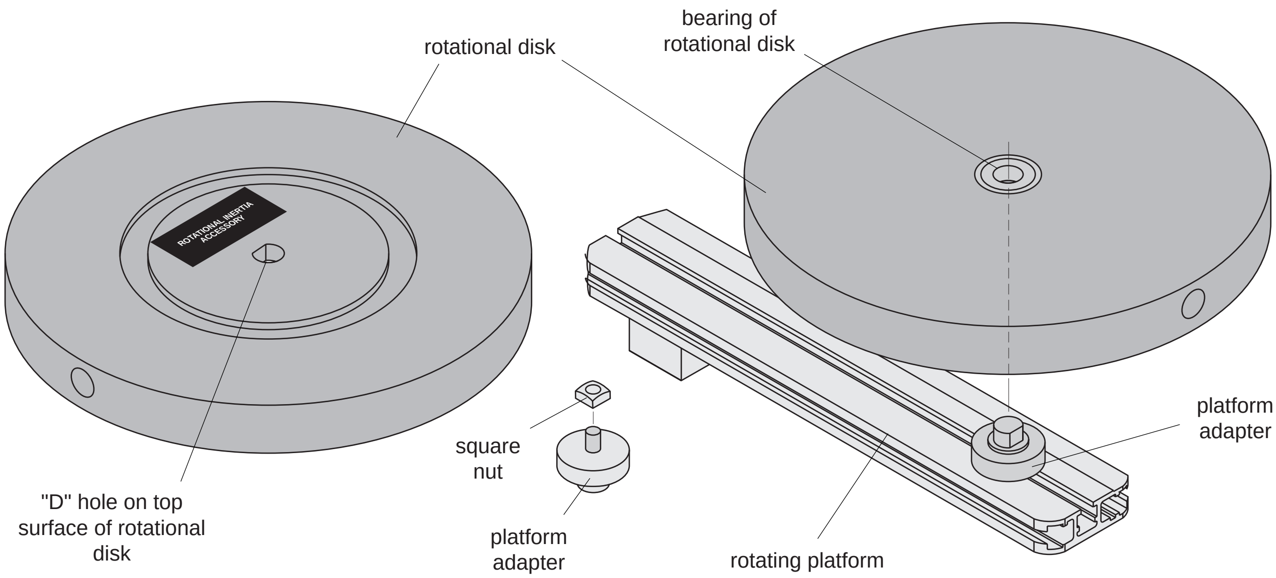


Figure 8: Rotational Inertia Accessory Including Platform Adapter Assembly

ME-8953 Rotational Inertia Accessory

Rotational Inertia Accessory Assembly

Little assembly is required to use the Rotational Inertia Accessory. The rotational disk can be placed directly onto the axle of the rotating base or can be used with the rotating platform via the included platform adapter.

Platform Adapter Assembly

① Attach the square nut (supplied with the Rotational Inertia Accessory) to the platform adapter.

② Position the platform adapter at the desired radius as shown in Figure 8.

③ Grip the knurled edge of the platform adapter and tighten.

The rotating disk can be mounted in a variety of positions using any of the four holes on the rotation disk.

- Two “D” holes exist on the edge of the disk, located at 180˚ from one another.
- One “D” hole is located at the center on the top surface (the surface with the metal ring channel and the PASCO label) of the disk.
- One hole is located at the center on the bottom surface of the disk and is actually the inner race of a bearing. This enables the rotational disk to rotate (in either direction) in addition to other rotating motions applied to your experiment setup.

Experiment 1: Conservation of Angular Momentum: Ball Shot Into Catcher on Rotating Track

EQUIPMENT NEEDED

- Rotating Platform (ME-8951)
- Projectile Launcher (ME-6800)
- Projectile Collision Accessory (ME-6815)
- Smart Pulley Photogate
- Smart Pulley Timer software
- Rubber band
- white paper and carbon paper
- thread
- meter stick
- mass and hanger set

Purpose

The muzzle velocity of the Projectile Launcher can be determined by shooting the ball into the catcher mounted on the track and conserving angular momentum during the collision. This result can be checked by finding the muzzle velocity of the Launcher by shooting the ball horizontally off the table.

Theory

A ball is launched horizontally and embeds in the catcher mounted on the platform. The platform then rotates. See Figure 1.1.

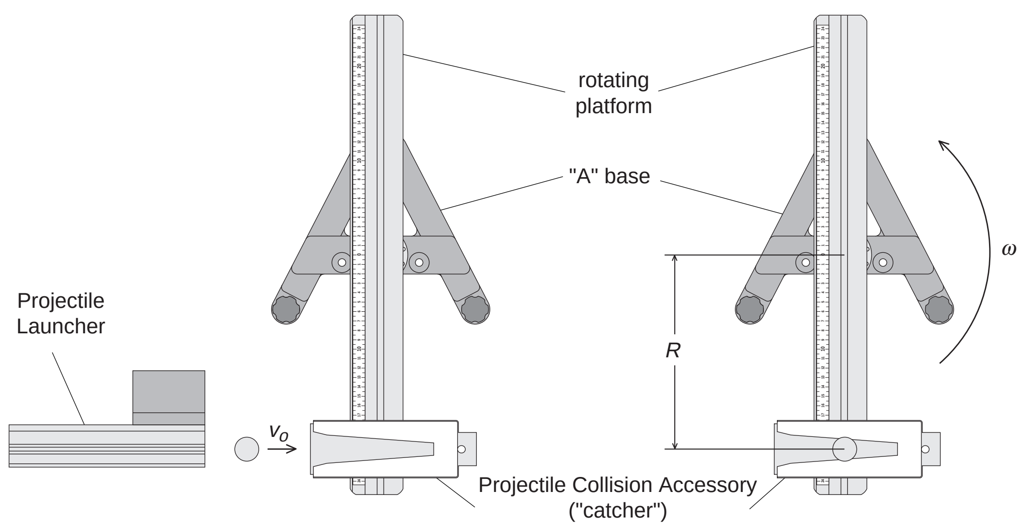


Figure 1.1 Conservation of Angular Momentum

Angular momentum is conserved during the collision but energy is not conserved. The angular momentum before the collision is equal to the angular momentum after the collision:

$$L = m_b v_0 R = I\omega$$

where m_b is the mass of the ball, v_o is the muzzle velocity of the ball, R is the distance between the ball and the axis of rotation, I is the rotational inertia of the catcher, ball, and track after the collision, and ω is the angular velocity of the system immediately after the collision. Solving for the muzzle velocity of the ball gives:

$$v_0 = \frac{I\omega}{m_b R}$$

To find the rotational inertia experimentally, a known torque is applied to the object and the resulting angular acceleration is measured. Since $\tau = I\alpha$,

$$I = \frac{\tau}{\alpha}$$

where α is the angular acceleration which is equal to a/r and τ is the torque caused by the weight hanging from the thread which is wrapped around the base of the apparatus.

$$\tau = rT$$

where r is the radius of the cylinder about which the thread is wound and T is the tension in the thread when the apparatus is rotating.

Applying Newton's Second Law for the hanging mass, m, gives (See Figure 1.2).

$$\Sigma F = mg - T = ma$$

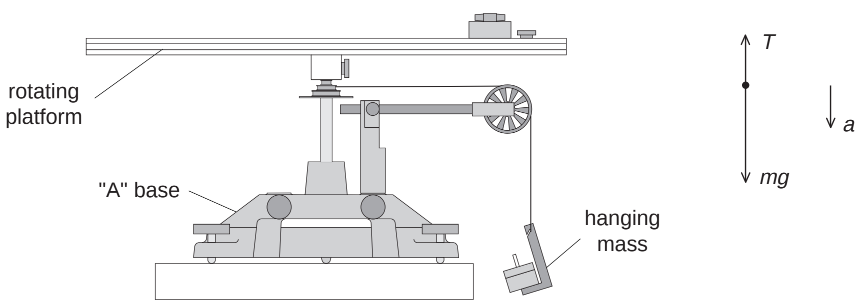


Figure 1.2: Rotational Apparatus and Free-Body Diagram

So, solving for the tension in the thread gives:

$$T = m(g - a)$$

So, once the linear acceleration of the mass (m) is determined, the torque and the angular acceleration can be obtained for the calculation of the rotational inertia.

For comparison, the initial speed (muzzle velocity) of the ball is determined by shooting the ball horizontally off the table onto the floor and measuring the vertical and horizontal distances through which the ball travels.

For a ball shot horizontally off a table with an initial speed, v_o, the horizontal distance traveled by the ball is given by $x = v_o t$, where t is the time the ball is in the air. No air friction is assumed.

The vertical distance the ball drops in time t is given by $y = \frac{1}{2}gt^2$.

The initial velocity of the ball can be determined by measuring x and y. The time of flight of the ball can be found using:

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

and then the muzzle velocity can be found using $v_o = x/t$.

Part I: Determining the initial velocity of the ball

Setup

① Clamp the Projectile Launcher to a sturdy table near one end of the table.

② Adjust the angle of the Projectile Launcher to zero degrees so the ball will be shot off horizontally. See Figure 1.3.

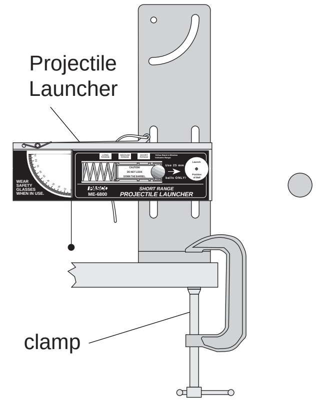


Figure 1.3 Projectile Launcher Setup

Procedure

① Put the ball into the Projectile Launcher and cock it to the long range position. Fire one shot to locate where the ball hits the floor. At this position, tape a piece of white paper to the floor. Place a piece of carbon paper (carbon-side down) on top of this paper and tape it down. When the ball hits the floor, it will leave a mark on the white paper.

② Fire about ten shots.

③ Measure the vertical distance from the bottom of the ball as it leaves the barrel (this position is marked on the side of the barrel) to the floor. Record this distance in Table 1.1.

④ Use a plumb bob to find the point on the floor that is directly beneath the release point on the barrel. Measure the horizontal distance along the floor from the release point to the leading edge of the paper. Record in Table 1.1.

⑤ Measure from the leading edge of the paper to each of the ten dots and record these distances in Table 1.1.

⑥ Find the average of the ten distances and record in Table 1.1.

⑦ Using the vertical distance and the average horizontal distance, calculate the time of flight and the initial velocity of the ball. Record in Table 1.1 and Table 1.4.

Table 1.1 Determining the Initial Velocity

Vertical distance = ________________

Horizontal distance to edge of paper = ________________

Initial velocity = ________________

Trial Number	Distance
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Total Distance	

Alternate Method: Determining the Muzzle Velocity with Photogates

① Attach the photogate bracket to the Launcher and attach two photogates to the bracket. Plug the photogates into a computer or other timer.

② Put the ball into the Projectile Launcher and cock it to the long range position.

③ Run the timing program and set it to measure the time between the ball blocking the two photogates.

④ Shoot the ball three times and take the average of these times. Record in Table 1.2.

⑤ Using that the distance between the photogates is 10 cm, calculate the initial speed and record it in Table 1.2 and Table 1.4.

Table 1.2 Initial Speed Using Photogates

Trial Number	Time
1	
2	
3	
Average Time	
Initial Speed	

Part II: Conservation of Angular Momentum

Setup

① Find the mass of the ball and record it in Table 1.3.

② Attach the ball catcher to the track using a rubber band as shown in Figure 1.4.

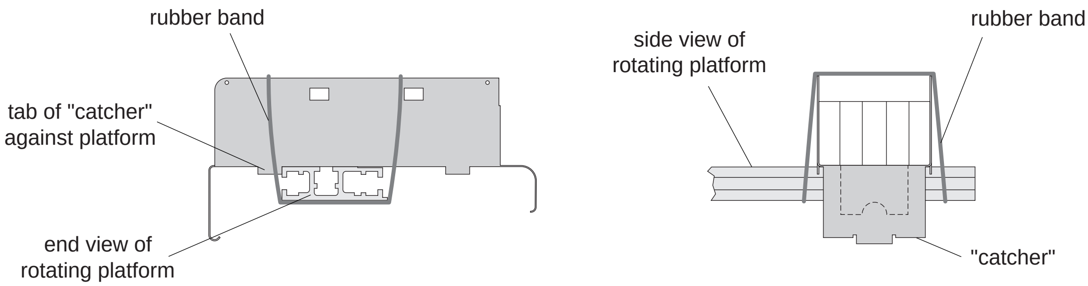


Figure 1.4: Attaching the Catcher to the Track

③ With the Projectile Launcher mounted as it was in Part I, aim the launcher directly down the middle of the ball catcher using the sights inside the projectile launcher. Clamp the launcher to the table.

④ Attach the Smart Pulley photogate to the base, using the black rod. Connect the photogate to a computer and run Smart Pulley Timer.

Procedure

① Load the Launcher with the steel ball on the long range setting.

② Make sure the rotating platform is at rest and fire the ball into the catcher. Record the angular speed of the platform in Table 1.3. Repeat for a total of five shots.

③ Measure the distance from the axis of rotation to the ball in the catcher and record in Table 1.3.

Table 1.3 Data Mass of Ball

Angular Speed

Part III: Determining the Rotational Inertia

Setup

① Attach a Smart Pulley with rod to the base using the black rod.

② Wind a thread around the pulley on the center shaft and pass the thread over the Smart Pulley.

Procedure

Accounting For Friction

Because the theory used to find the rotational inertia experimentally does not include friction, it will be compensated for in this experiment by finding out how much mass over the pulley it takes to overcome kinetic friction and allow the mass to drop at a constant speed. Then this “friction mass” will be subtracted from the mass used to accelerate the apparatus.

From the Main Menu select <V>, display velocity

To find the mass required to overcome kinetic friction run “Display Velocity”:

① Select <V>-Display Velocity <RETURN>; <A>-Smart Pulley/Linear String <RETURN>; <N>-Normal Display <RETURN>.

② Put just enough mass hanging over the pulley so that the velocity is constant to three significant figures.

③ Press <RETURN> to stop displaying the velocity. Record this friction mass in Table 1.4.

Finding the Acceleration of the Apparatus

To find the acceleration, put about 30 g (Record the exact hanging mass in Table 1.4) over the pulley and run “Motion Timer”:

① Select <M>-Motion Timer <RETURN>. Wind the thread up and let the mass fall from the table to the floor, hitting <RETURN> just before the mass hits the floor.

② Wait for the computer to calculate the times and then press <RETURN>.

To find the acceleration, graph velocity versus time:

③ Choose <G>-Graph Data <RETURN>; <A>-Smart Pulley/Linear String <RETURN>; <V>-Velocity vs. Time <R>-Linear Regression <SPACEBAR> (toggles it on) <S>-Statistics <SPACEBAR> <RETURN>.

④ The graph will now be plotted and the slope = m will be displayed at the top of the graph. This slope is the acceleration. Push <RETURN> and <X> twice to return to the Main Menu.

Measure the Radius

① Using calipers, measure the diameter of the cylinder about which the thread is wrapped and calculate the radius.

② Record the radius in Table 1.4.

Table 1.4 Rotational Inertia Data

Friction Mass	
Hanging Mass	
Slope	
Radius	

Analysis

① Calculate the average of the angular speeds in Table 1.3 and record the result in Table 1.5.

② Calculate the rotational inertia:

- Subtract the “friction mass” from the hanging mass used to accelerate the apparatus to determine the mass, *m*, to be used in the equations.
- Calculate the experimental value of the rotational inertia and record it in Table 1.5.

③ Using the average angular speed, the rotational inertia, and the distance, *r*, calculate the muzzle velocity of the ball and record it in Table 1.5.

④ Calculate the percent difference between the muzzle velocities found in Parts I and II. Record in Table 1.5.

Table 1.5 Results

Average Angular Speed	
Rotational Inertia	
Calculated Muzzle Velocity, v_0	
Muzzle Velocity	
% Difference	

Questions

① What percentage of the kinetic energy is lost in the collision? Use the masses and velocities to calculate this percentage.

$$\%\,Lost = \frac{KE_{before} - KE_{after}}{KE_{before}}\ X\ 100\%$$

Experiment 2: Rotational Inertia of a Point Mass

EQUIPMENT REQUIRED

- Precision Timer Program
- paper clips (for masses < 1 g)
- triple beam balance
- mass and hanger set
- 10-spoke pulley with photogate head
- calipers

Purpose

The purpose of this experiment is to find the rotational inertia of a point mass experimentally and to verify that this value corresponds to the calculated theoretical value.

Theory

Theoretically, the rotational inertia, I, of a point mass is given by $I = MR^2$, where M is the mass, R is the distance the mass is from the axis of rotation.

To find the rotational inertia experimentally, a known torque is applied to the object and the resulting angular acceleration is measured. Since $\tau = I\alpha$,

$$I = \frac{\tau}{\alpha}$$

where α is the angular acceleration which is equal to a/r and τ is the torque caused by the weight hanging from the thread which is wrapped around the base of the apparatus.

$$\tau = rT$$

where r is the radius of the cylinder about which the thread is wound and T is the tension in the thread when the apparatus is rotating.

Applying Newton's Second Law for the hanging mass, m, gives (see Figure 2.1).

$$\Sigma F = mg - T = ma$$

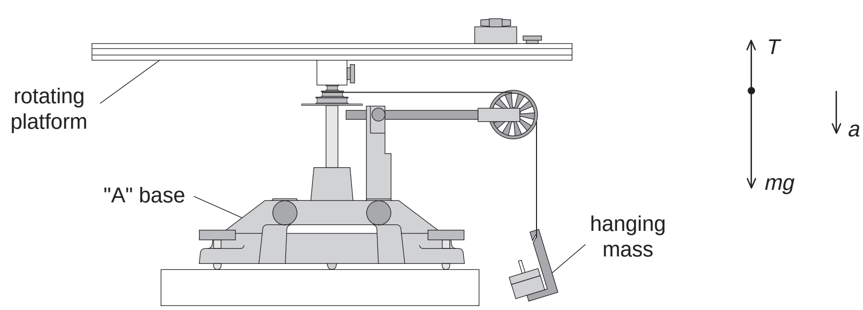


Figure 2.1: Rotational Apparatus and Free-Body Diagram

Solving for the tension in the thread gives:

$$T = m(g - a)$$

Once the linear acceleration of the mass (m) is determined, the torque and the angular acceleration can be obtained for the calculation of the rotational inertia.

Setup

① Attach the square mass (point mass) to the track on the rotating platform at any radius you wish.

② Mount the Smart Pulley to the base and connect it to a computer. See Figure 2.2.

③ Run the Smart Pulley Timer program.

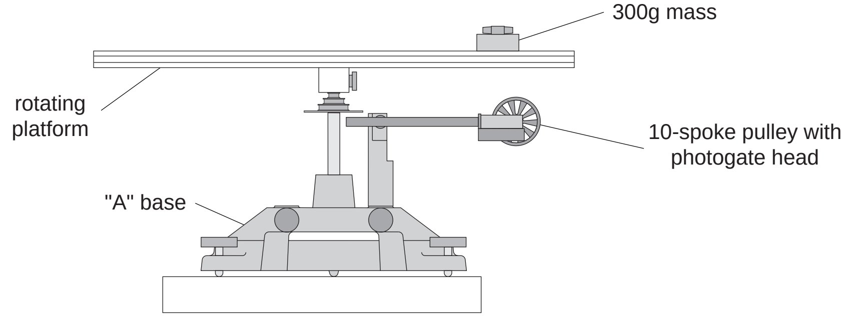


Figure 2.2: Rotational inertia of a point mass

Procedure

Part I: Measurements For the Theoretical Rotational Inertia

Table 2.1: Theoretical Rotational Inertia

Mass	
Radius	

① Weigh the square mass to find the mass M and record in Table 2.1.

② Measure the distance from the axis of rotation to the center of the square mass and record this radius in Table 2.1.

Part II: Measurement For the Experimental Method

Accounting For Friction

Because the theory used to find the rotational inertia experimentally does not include friction, it will be compensated for in this experiment by finding out how much mass over the pulley it takes to overcome kinetic friction and allow the mass to drop at a constant speed. Then this “friction mass” will be subtracted from the mass used to accelerate the ring.

① To find the mass required to overcome kinetic friction run “Display Velocity”: <V>-Display Velocity <RETURN>; <A>-Smart Pulley/Linear String <RETURN>; <N>-Normal Display <RETURN>.

② Put just enough mass hanging over the pulley so that the velocity is constant to three significant figures. Then press <RETURN> to stop displaying the velocity.

Finding the Acceleration of the Point Mass and Apparatus

① To find the acceleration, put about 50 g over the pulley and run “Motion Timer”: <M>-Motion Timer <RETURN> Wind the thread up and let the mass fall from the table to the floor, hitting <RETURN> just before the mass hits the floor.

② Wait for the computer to calculate the times and then press <RETURN>. To find the acceleration, graph velocity versus time: <G>-Graph Data <RETURN>; <A>-Smart Pulley/Linear String <RETURN>; <V>-Velocity vs. Time <R>-Linear Regression <SPACEBAR> (toggles it on) <S>-Statistics <SPACEBAR> <RETURN>.

③ The graph will now be plotted and the slope = m will be displayed at the top of the graph. This slope is the acceleration. Record it in Table 2.2. Push <RETURN> and <X> twice to return to the Main Menu.

Table 2.2: Rotational Inertia Data

	Point Mass and Apparatus	Apparatus Alone
Friction Mass		
Hanging Mass		
Slope		
Radius		

Measure the Radius

① Using calipers, measure the diameter of the cylinder about which the thread is wrapped and calculate the radius. Record in Table 2.2.

Finding the Acceleration of the Apparatus Alone

Since in **Finding the Acceleration of the Point Mass and Apparatus** the apparatus is rotating as well as the point mass, it is necessary to determine the acceleration, and the rotational inertia, of the apparatus by itself so this rotational inertia can be subtracted from the total, leaving only the rotational inertia of the point mass.

① Take the point mass off the rotational apparatus and repeat **Finding the Acceleration of the Point Mass and Apparatus** for the apparatus alone.

➤ NOTE: that it will take less “friction mass” to overcome the new kinetic friction and it is only necessary to put about 20 g over the pulley in **Finding the Acceleration of the Point Mass and Apparatus**.

② Record the data in Table 2.2.

Calculations

① Subtract the “friction mass” from the hanging mass used to accelerate the apparatus to determine the mass, m, to be used in the equations.

② Calculate the experimental value of the rotational inertia of the point mass and apparatus together and record in Table 2.3.

③ Calculate the experimental value of the rotational inertia of the apparatus alone. Record in Table 2.3.

④ Subtract the rotational inertia of the apparatus from the combined rotational inertia of the point mass and apparatus. This will be the rotational inertia of the point mass alone. Record in Table 2.3.

⑤ Calculate the theoretical value of the rotational inertia of the point mass. Record in Table 2.3.

⑥ Use a percent difference to compare the experimental value to the theoretical value. Record in Table 2.3.

Table 2.3: Results

Rotational Inertia for Point Mass and Apparatus Combined	
Rotational Inertia for Apparatus Alone	
Rotational Inertia for Point Mass (experimental value)	
Rotational Inertia for Point Mass (theoretical value)	
% Difference	

Experiment 3: Centripetal Force

EQUIPMENT NEEDED

- Centripetal Force Accessory (ME-8952)
- Rotating Platform (ME-8951)
- stopwatch
- balance
- graph paper (2 sheets)
- mass and hanger set
- string

Purpose

The purpose of this experiment is to study the effects of varying the mass of the object, the radius of the circle, and the centripetal force on an object rotating in a circular path.

Theory

When an object of mass *m*, attached to a string of length *r*, is rotated in a horizontal circle, the centripetal force on the mass is given by:

$$F = \frac{mv^2}{r} = mr\omega^2$$

where v is the tangential velocity and ω is the angular speed ($v = r\,\omega$). To measure the velocity, the time for one rotation (the period, T) is measured. Then:

$$v = \frac{2\pi r}{T}$$

and the centripetal force is given by:

$$F = \frac{4\pi^2 mr}{T^2}$$

Setup

Level the "A" base and rotating platform as described in the ME-8951 assembly section on page 5.

Procedure

Part I: Vary Radius (constant force and mass)

① The centripetal force and the mass of the hanging object will be held constant for this part of the experiment. Weigh the object and record its mass in Table 3.1. Hang the object from the side post and connect the string from the spring to the object. The string must pass under the pulley on the center post. See Figure 3.1.

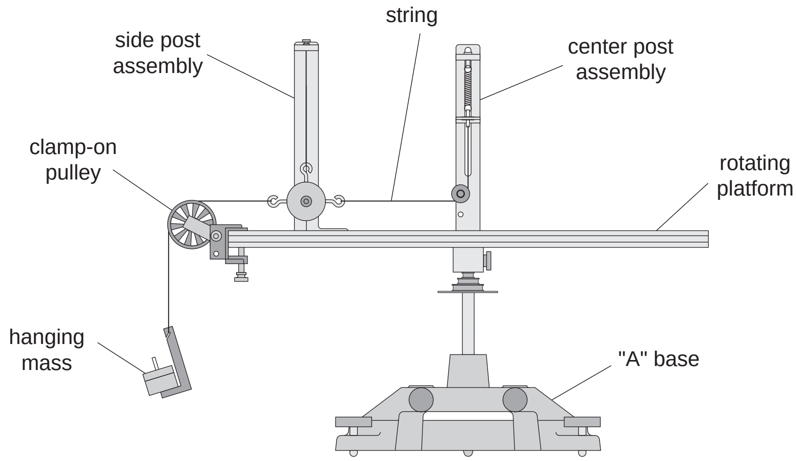


Figure 3.1: Centripetal Force Apparatus

② Attach the clamp-on pulley to the end of the track nearer to the hanging object. Attach a string to the hanging object and hang a known mass over the clamp-on pulley. Record this mass in Table 3.1. This establishes the constant centripetal force.

③ Select a radius by aligning the line on the side post with any desired position on the measuring tape. While pressing down on the side post to assure that it is vertical, tighten the thumb screw on the side post to secure its position. Record this radius in Table 3.1.

④ The object on the side bracket must hang vertically: On the center post, adjust the spring bracket vertically until the string from which the object hangs on the side post is aligned with the vertical line on the side post.

⑤ Align the indicator bracket on the center post with the orange indicator.

⑥ Remove the mass that is hanging over the pulley and remove the pulley.

⑦ Rotate the apparatus, increasing the speed until the orange indicator is centered in the indicator bracket on the center post. This indicates that the string supporting the hanging object is once again vertical and thus the hanging object is at the desired radius.

⑧ Maintaining this speed, use a stopwatch to time ten revolutions. Divide the time by ten and record the period in Table 3.1.

⑨ Move the side post to a new radius and repeat the procedure. Do this for a total of five radii.

Table 3.1: Varying the Radius

Mass of the object = ____________

Mass hanging over the pulley = ____________

Slope from graph = ____________

Radius	Period (T)	T^2

Analysis

① The weight of the mass hanging over the pulley is equal to the centripetal force applied by the spring. Calculate this force by multiplying the mass hung over the pulley by “g” and record this force at the top of Table 3.2.

② Calculate the square of the period for each trial and record this in Table 3.1.

③ Plot the radius versus the square of the period. This will give a straight line since:

$$r = \left(\frac{F}{4\pi^2 m}\right) T^2$$

④ Draw the best-fit line through the data points and measure the slope of the line. Record the slope in Table 3.1.

⑤ Calculate the centripetal force from the slope and record in Table 3.2.

⑥ Calculate the percent difference between the two values found for the centripetal force and record in Table 3.2.

Table 3.2: Results (varying raduis)

Centripetal Force = mg	
Centripetal Force From Slope	
Percent Difference	

Part II: Vary Force (constant radius and mass)

The radius of rotation and the mass of the hanging object will be held constant for this part of the experiment.

① Weigh the object and record its mass in Table 3.3. Hang the object from the side post and connect the string from the spring to the object. The string must pass under the pulley on the center post.

② Attach the clamp-on pulley to the end of the track nearer to the hanging object. Attach a string to the hanging object and hang a known mass over the clamp-on pulley. Record this mass in Table 3.3. This determines the centripetal force.

③ Select a radius by aligning the line on the side post with any desired position on the measuring tape. While pressing down on the side post to assure that it is vertical, tighten the thumb screw on the side post to secure its position. Record this radius in Table 3.3.

④ The object on the side bracket must hang vertically: On the center post, adjust the spring bracket vertically until the string from which the object hangs on the side post is aligned with the vertical line on the side post.

⑤ Align the indicator bracket on the center post with the orange indicator.

⑥ Remove the mass that is hanging over the pulley and remove the pulley.

⑦ Rotate the apparatus, increasing the speed until the orange indicator is centered in the indicator bracket on the center post. This indicates that the string supporting the hanging object is once again vertical and thus the hanging object is at the desired radius.

⑧ Maintaining this speed, use a stopwatch to time ten revolutions. Divide the time by ten and record the period in Table 3.3.

⑨ To vary the centripetal force, clamp the pulley to the track again and hang a different mass over the pulley. Keep the radius constant and repeat the procedure from Step #4. Do this for a total of five different forces.

Table 3.3: Varying the Centripetal Force

Mass of the object = ________________

Radius = ________________

Slope from graph = ________________

Mass Over Pulley	Centripetal Force = mg	Period (T)	$\frac{1}{T^2}$

Analysis

① The weight of the mass hanging over the pulley is equal to the centripetal force applied by the spring. Calculate this force for each trial by multiplying the mass hung over the pulley by "g" and record the results in Table 3.3.

② Calculate the inverse of the square of the period for each trial and record this in Table 3.3.

③ Plot the centripetal force versus the inverse square of the period. This will give a straight line since:

$$F = \frac{4\pi^2 mr}{T^2}$$

④ Draw the best-fit line through the data points and measure the slope of the line. Record the slope in Table 3.3.

⑤ Calculate the mass of the object from the slope and record in Table 3.4.

⑥ Calculate the percent difference between the two values found for the mass of the object and record in Table 3.4.

Table 3.4: Results (varying the centripetal force)

Mass of Object (from scale)	
Mass of Object (from slope)	
Percent Difference	

Part III: Vary Mass (constant radius and force)

The centripetal force and the radius of rotation will be held constant for this part of the experiment.

① Weigh the object with the additional side masses in place. Record its mass in Table 3.5. Hang the object from the side post and connect the string from the spring to the object. The string must pass under the pulley on the center post.

② Attach the clamp-on pulley to the end of the track nearer to the hanging object. Attach a string to the hanging object and hang a known mass over the clamp-on pulley. Record this mass in Table 3.5. This establishes the constant centripetal force.

③ Select a radius by aligning the line on the side post with any desired position on the measuring tape. While pressing down on the side post to assure that it is vertical, tighten the thumb screw on the side post to secure its position. Record this radius in Table 3.5.

④ The object on the side bracket must hang vertically: On the center post, adjust the spring bracket vertically until the string from which the object hangs on the side post is aligned with the vertical line on the side post.

⑤ Align the indicator bracket on the center post with the orange indicator.

⑥ Remove the mass that is hanging over the pulley and remove the pulley.

⑦ Rotate the apparatus, increasing the speed until the orange indicator is centered in the indicator bracket on the center post. This indicates that the string supporting the hanging object is once again vertical and thus the hanging object is at the desired radius.

⑧ Maintaining this speed, use a stopwatch to time ten revolutions. Divide the time by ten and record the period in Table 3.5.

⑨ Vary the mass of the object by removing the side masses. Keep the radius constant and measure the new period. Weigh the object again and record the mass and period in Table 3.5.

Table 3.5: Varying the Mass of the Object

Mass hanging over pulley = ____________

Centripetal Force = mg = ____________

Radius = ____________

Mass of Object	Period (T)	Calculated Centripetal Force	% Difference

Analysis

① The weight of the mass hanging over the pulley is equal to the centripetal force applied by the spring. Calculate this force by multiplying the mass hung over the pulley by “g” and record the result at the top of Table 3.5.

② Calculate the centripetal force for each trial using:

$$F = \frac{4\pi^2 mr}{T^2}$$

and record this in Table 3.5.

③ Calculate the percent difference between the calculated centripetal force for each trial and *mg*. Record in Table 3.5.

Questions

① When the radius is increased, does the period of rotation increase or decrease?

② When the radius and the mass of the rotating object are held constant, does increasing the period increase or decrease the centripetal force?

③ As the mass of the object is increased, does the centripetal force increase or decrease?

Notes:

Experiment 4: Conservation of Angular Momentum Using a Point Mass

EQUIPMENT REQUIRED

- Smart Pulley Timer Program
- Rotational Inertia Accessory (ME-8953)
- Rotating Platform (ME-8951)
- Smart Pulley
- balance

Purpose

A mass rotating in a circle is pulled in to a smaller radius and the new angular speed is predicted using conservation of angular momentum.

Theory

Angular momentum is conserved when the radius of the circle is changed.

$$L = I_i\omega_i = I_f\omega_f$$

where I_i is the initial rotational inertia and ω_i is the initial angular speed. So the final rotational speed is given by:

$$\omega_f = \frac{I_i}{I_f}\,\omega_i$$

To find the rotational inertia experimentally, a known torque is applied to the object and the resulting angular acceleration is measured. Since $\tau = I\alpha$,

$$I = \frac{\tau}{\alpha}$$

where α is the angular acceleration which is equal to a/r and τ is the torque caused by the weight hanging from the thread which is wrapped around the base of the apparatus.

$$\tau = rT$$

where r is the radius of the cylinder about which the thread is wound and T is the tension in the thread when the apparatus is rotating.

Applying Newton's Second Law for the hanging mass, m, gives (See Figure 4.1)

$$\Sigma F = mg - T = ma$$

Solving for the tension in the thread gives:

$$T = m(g - a)$$

Once the linear acceleration of the mass (m) is determined, the torque and the angular acceleration can be obtained for the calculation of the rotational inertia.

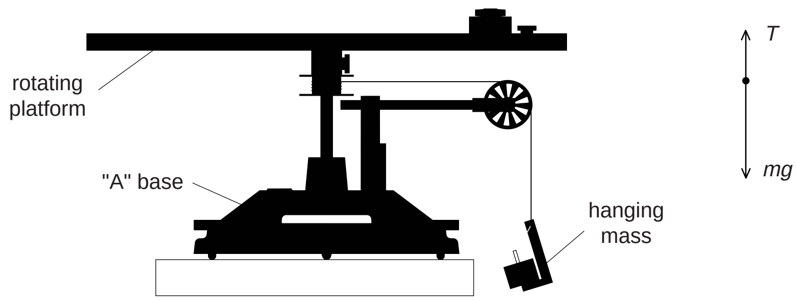


Figure 4.1: Rotational Apparatus and Free-Body Diagram

Part I: Conservation of Angular Momentum

Setup

① Level the apparatus using the square mass on the track as shown in the leveling instructions in the Assembly Section.

② Slide a thumb screw and square nut into the T-slot on the top of the track and tighten it down at about the 5 cm mark. This will act as a stop for the sliding square mass. See Figure 4.2.

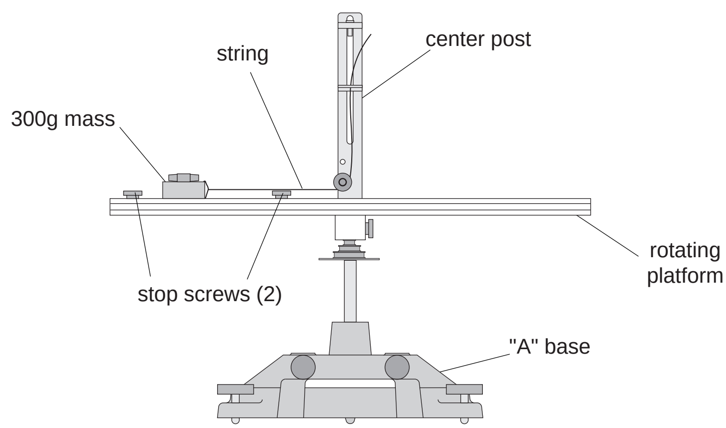


Figure 4.2: Set-up for conservation of angular momentum

③ With the side of the square mass that has the hole oriented toward the center post, slide the square mass onto the track by inserting its square nut into the T-slot, but do not tighten the thumb screw; the square mass should be free to slide in the T-slot.

④ Slide a second thumb screw and square nut into the T-slot and tighten it down at about the 20 cm mark. Now the square mass is free to slide between the two limiting stops.

⑤ Move the pulley on the center post to its lower position. Remove the spring bracket from the center post and set it aside.

⑥ Attach a string to the hole in the square mass and thread it around the pulley on the center post and pass it through the indicator bracket.

⑦ Mount the Smart Pulley photogate on the black rod on the base and position it so it straddles the holes in the pulley on the center rotating shaft.

⑧ Run the Smart Pulley Timer program.

Procedure

① Select <M>-Motion Timer <RETURN>.

② Hold the string just above the center post. With the square mass against the outer stop, give the track a spin using your hand. After about 25 data points have been taken, pull up on the string to cause the square mass to slide from the outer stop to the inner stop.

③ Continue to hold the string up and take about 25 data points after pulling up on the string. Then push <RETURN> to stop the timing.

④ When the computer finishes calculating the times, graph the rotational speed versus time: <A>-Data Analysis Options <RETURN>; <G>-Graph Data <RETURN>; <E>-Rotational Apparatus <RETURN>; <V>-Velocity vs. Time <RETURN>.

⑤ After viewing the graph, press <RETURN> and choose <T> to see the table of the angular velocities. Determine the angular velocity immediately before and immediately after pulling the string. Record these values in Table 4.1.

⑥ Repeat the experiment a total of three times with different initial angular speeds. Record these values in Table 4.1.

Table 4.1: Data

	Angular Speeds	
Trial Number	Initial	Final
1		
2		
3		

Part II: Determining the Rotational Inertia

Measure the rotational inertia of the apparatus twice: once with the square mass in its initial position and once with it in its final position.

Setup

① Attach a Smart Pulley with rod to the base using the black rod.

② Wind a thread around the pulley on the center shaft and pass the thread over the Smart Pulley. See Figure 4.3.

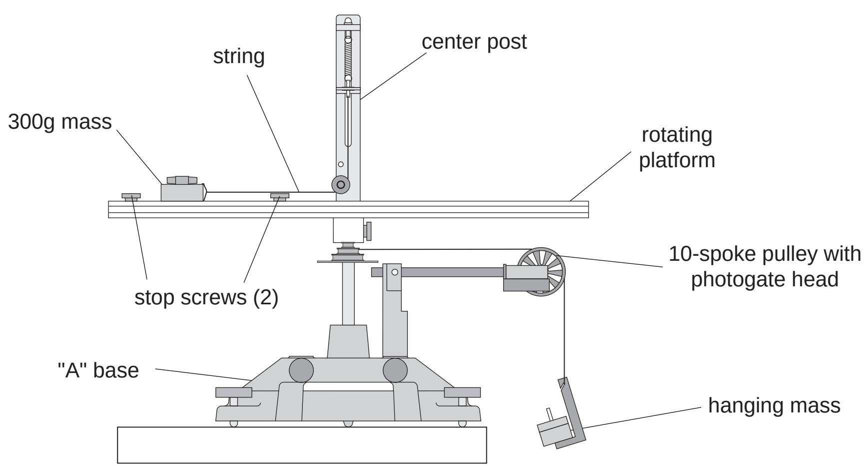


Figure 4.3: Set-up for determining of rotational inertia

Procedure

Accounting For Friction

Because the theory used to find the rotational inertia experimentally does not include friction, it will be compensated for in this experiment by finding out how much mass over the pulley it takes to overcome kinetic friction and allow the mass to drop at a constant speed. Then this “friction mass” will be subtracted from the mass used to accelerate the apparatus.

① To find the mass required to overcome kinetic friction run “Display Velocity”: <V>-Display Velocity <RETURN> <A>-Smart Pulley/Linear String <RETURN> <N>-Normal Display <RETURN>.

② Put just enough mass hanging over the pulley so that the velocity is constant to three significant figures. Then press <RETURN> to stop displaying the velocity. Record this friction mass in Table 1.4.

Finding the Acceleration of the Apparatus

① To find the acceleration, put about 30 g (Record the exact hanging mass in Table 1.4) over the pulley and run “Motion Timer”: <M>-Motion Timer <RETURN>. Wind the thread up and let the mass fall from the table to the floor, hitting <RETURN> just before the mass hits the floor.

② Wait for the computer to calculate the times and then press <RETURN>. To find the acceleration, graph velocity versus time: <G>-Graph Data <RETURN>; <A>-Smart Pulley/Linear String <RETURN>; <V>-Velocity vs. Time <R>-Linear Regression <SPACEBAR> (toggles it on) <S>-Statistics <SPACEBAR> <RETURN>.

③ The graph will now be plotted and the *slope* = *m* will be displayed at the top of the graph. This slope is the acceleration. Push <RETURN> and <X> twice to return to the Main Menu.

Measure Radius

① Using calipers, measure the diameter of the cylinder about which the thread is wrapped and calculate the radius. Record the radius in Table 4.2.

Table 4.2 Rotational Inertia Data

	Mass at Outer Stop	Mass at Inner Stop
Friction Mass		
Hanging Mass		
Slope		
Radius		
Rotational Inertia		

Analysis

① Calculate the rotational inertia's:

- Subtract the "friction mass" from the hanging mass used to accelerate the apparatus to determine the mass, *m*, to be used in the equations.
- Calculate the experimental values of the rotational inertia and record it in Table 4.3.

② Calculate the expected (theoretical) values for the final angular velocity and record these values in Table 4.3.

Table 4.3: Results

	Trial #1	Trial #2	Trial #3
Theoretical Angular Speed			
% Difference			

③ For each trial, calculate the percent difference between the experimental and the theoretical values of the final angular velocity and record these in Table 4.3.

Questions

Calculate the rotational kinetic energy $\left(KE_i = \frac{1}{2}I_i\omega_i^2\right)$ before the string was pulled. Then calculate the rotational kinetic energy $\left(KE_f = \frac{1}{2}I_f\omega_f^2\right)$ after the string was pulled.

Which kinetic energy is greater?

Why?

Notes:

Experiment 5: Rotational Inertia of Disk and Ring

EQUIPMENT REQUIRED

- Precision Timer Program
- Rotational Inertia Accessory (ME-9341)
- Smart Pulley
- calipers
- mass and hanger set
- paper clips (for masses < 1 g)
- triple beam balance

Purpose

The purpose of this experiment is to find the rotational inertia of a ring and a disk experimentally and to verify that these values correspond to the calculated theoretical values.

Theory

Theoretically, the rotational inertia, I, of a ring about its center of mass is given by:

$$I = \frac{1}{2}M\left(R_1^{\,2} + R_2^{\,2}\right)$$

where M is the mass of the ring, R_1 is the inner radius of the ring, and R_2 is the outer radius of the ring. See Figure 5.1.

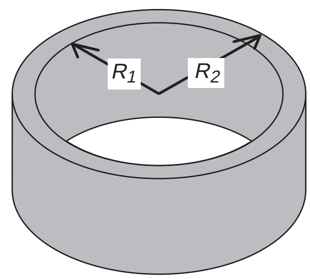


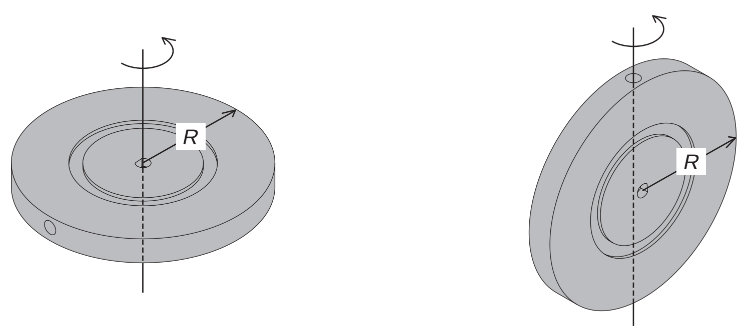
Figure 5.1: Ring

The rotational inertia of a disk about its center of mass is given by:

$$I = \frac{1}{2}MR^2$$

where M is the mass of the disk and R is the radius of the disk. The rotational inertia of a disk about its diameter is given by:

$$I = \frac{1}{4}MR^2$$



Disk about center of Mass **Disk about Diameter**

Figure 5.2:

To find the rotational inertia experimentally, a known torque is applied to the object and the resulting angular acceleration is measured. Since $\tau = I\alpha$,

$$I = \frac{\tau}{\alpha}$$

where α is the angular acceleration which is equal to *a/r* and τ is the torque caused by the weight hanging from the thread which is wrapped around the base of the apparatus.

$$\tau = rT$$

where *r* is the radius of the cylinder about which the thread is wound and *T* is the tension in the thread when the apparatus is rotating.

Applying Newton's Second Law for the hanging mass, *m*, gives (See Figure 5.3)

$$\Sigma F = mg - T = ma$$

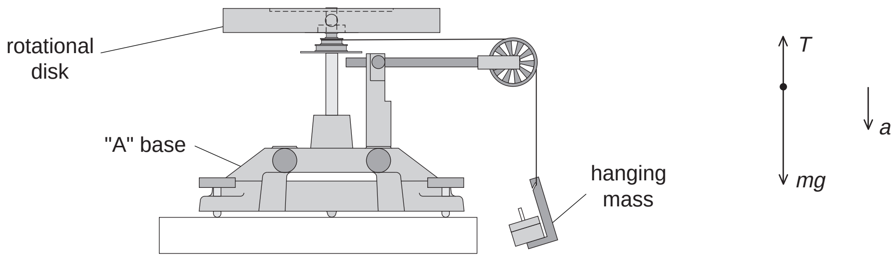


Figure 5.3: Rotational Apparatus and Free-Body Diagram

Solving for the tension in the thread gives:

$$T = m(g - a)$$

Once the linear acceleration of the mass (*m*) is determined, the torque and the angular acceleration can be obtained for the calculation of the rotational inertia.

Setup

① Remove the track from the Rotating Platform and place the disk directly on the center shaft as shown in Figure 5.4. The side of the disk that has the indentation for the ring should be up.

② Place the ring on the disk, seating it in this indentation.

③ Mount the Smart Pulley to the base and connect it to a computer.

④ Run the Smart Pulley Timer program.

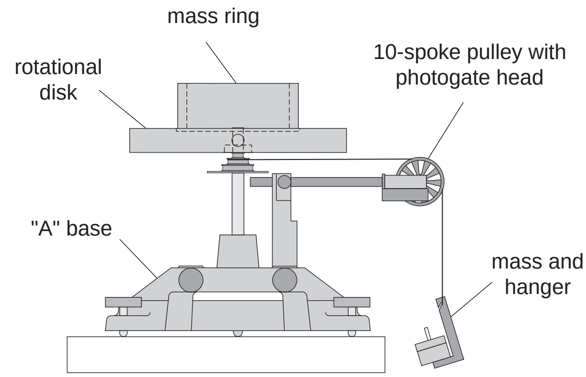


Figure 5.4: Set-up for Disk and Ring

Procedure

Measurements for the Theoretical Rotational Inertia

① Weigh the ring and disk to find their masses and record these masses in Table 5.1.

② Measure the inside and outside diameters of the ring and calculate the radii R_1 and R_2. Record in Table 5.1.

③ Measure the diameter of the disk and calculate the radius *R* and record it in Table 5.1.

Table 5.1: Theoretical Rotational Inertia

Mass of Ring	
Mass of Disk	
Inner Radius of Ring	
Outer Radius of Ring	
Radius of Disk	

Measurements for the Experimental Method

Accounting For Friction

Because the theory used to find the rotational inertia experimentally does not include friction, it will be compensated for in this experiment by finding out how much mass over the pulley it takes to overcome kinetic friction and allow the mass to drop at a constant speed. Then this “friction mass” will be subtracted from the mass used to accelerate the ring.

① To find the mass required to overcome kinetic friction run “Display Velocity”: <V>-Display Velocity <RETURN>; <A>-Smart Pulley/Linear String <RETURN>; <N>-Normal Display <RETURN>.

② Put just enough mass hanging over the pulley so that the velocity is constant to three significant figures. Then press <RETURN> to stop displaying the velocity. Record the friction mass in Table 5.2.

Table 5.2: Rotational Inertia Data

	Ring and Disk Combined	Disk Alone	Disk Vertical
Friction Mass			
Hanging Mass			
Slope			
Radius			

Finding the Acceleration of Ring and Disk

① To find the acceleration, put about 50 g over the pulley and run “Motion Timer”: <M>-Motion Timer <RETURN> Wind the thread up and let the mass fall from the table to the floor, hitting <RETURN> just before the mass hits the floor.

② Wait for the computer to calculate the times and then press <RETURN>. To find the acceleration, graph velocity versus time: <G>-Graph Data <RETURN>; <A>-Smart Pulley/Linear String <RETURN;> <V>-Velocity vs. Time <R>-Linear Regression <SPACEBAR> (toggles it on) <S>-Statistics <SPACEBAR> <RETURN>.

③ The graph will now be plotted and the slope = m will be displayed at the top of the graph. This slope is the acceleration. Record in Table 5.2.

④ Push <RETURN> and <X> twice to return to the Main Menu.

Measure the Radius

① Using calipers, measure the diameter of the cylinder about which the thread is wrapped and calculate the radius. Record in Table 5.2.

Finding the Acceleration of the Disk Alone

Since in **Finding the Acceleration of Ring and Disk** the disk is rotating as well as the ring, it is necessary to determine the acceleration, and the rotational inertia, of the disk by itself so this rotational inertia can be subtracted from the total, leaving only the rotational inertia of the ring.

① To do this, take the ring off the rotational apparatus and repeat **Finding the Acceleration of Ring and Disk** for the disk alone.

➤ **NOTE:** that it will take less "friction mass" to overcome the new kinetic friction and it is only necessary to put about 30 g over the pulley in **Finding the Acceleration of Ring and Disk**.

Disk Rotating on an Axis Through Its Diameter

Remove the disk from the shaft and rotate it up on its side. Mount the disk vertically by inserting the shaft in one of the two "D"-shaped holes on the edge of the disk. See Figure 5.5.

➤ **WARNING!** Never mount the disk vertically using the adapter on the track. The adapter is too short for this purpose and the disk might fall over while being rotated.

Repeat steps **Measure the Radius** and **Finding the Acceleration of the Disk Alone** to determine the rotational inertia of the disk about its diameter. Record the data in Table 5.2.

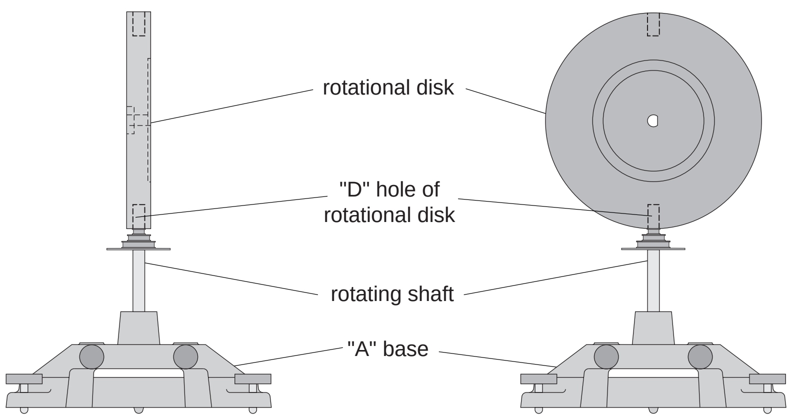


Figure 5.5: Disk mounted vertically

Calculations

Record the results of the following calculations in Table 5.3.

① Subtract the "friction mass" from the hanging mass used to accelerate the apparatus to determine the mass, *m*, to be used in the equations.

② Calculate the experimental value of the rotational inertia of the ring and disk together.

③ Calculate the experimental value of the rotational inertia of the disk alone.

④ Subtract the rotational inertia of the disk from the total rotational inertia of the ring and disk.

This will be the rotational inertia of the ring alone.

⑤ Calculate the experimental value of the rotational inertia of the disk about its diameter.

⑥ Calculate the theoretical value of the rotational inertia of the ring.

⑦ Calculate the theoretical value of the rotational inertia of the disk about its center of mass and about its diameter.

⑧ Use a percent difference to compare the experimental values to the theoretical values.

Table 5.3: Results

Rotational Inertia for Ring and Disk Combined	
Rotational Inertia for Disk Alone (experimental value)	
Rotational Inertia for Ring (experimental value)	
Rotational Inertia for Vertical Disk (experimental value)	
Rotational Inertia for Disk (theoretical value)	
Rotational Inertia for Ring (theoretical value)	
Rotational Inertia for Vertical Disk (theoretical value)	
% Difference for Disk	
% Difference for Ring	
% Difference for Vertical Disk	

Notes:

Experiment 6: Rotational Inertia of Disk Off-Axis (Fixed/Rotating)

EQUIPMENT REQUIRED

- Precision Timer Program
- Rotational Inertia Accessory (ME-8953)
- Smart Pulley
- calipers
- mass and hanger set
- paper clips (for masses < 1 g)
- triple beam balance

Purpose

The purpose of this experiment is to find the rotational inertia of a disk about an axis parallel to the center of mass axis.

Theory

Theoretically, the rotational inertia, I, of a disk about a perpendicular axis through its center of mass is given by:

$$I_{cm} = \frac{1}{2} MR^2$$

where M is the mass of the disk and R is the radius of the disk. The rotational inertia of a disk about an axis parallel to the center of mass axis is given by:

$$I = I_{cm} + Md^2$$

where d is the distance between the two axes.

In one part of this experiment, the disk is mounted on its ball bearing side which allows the disk to freely rotate relative to the track. So as the track is rotated, the disk does not rotate relative to its center of mass. Since the disk is not rotating about its center of mass, it acts as a point mass rather than an extended object and its rotational inertia reduces from:

$$I = I_{cm} + Md^2 \text{ to } I = Md^2$$

To find the rotational inertia experimentally, a known torque is applied to the object and the resulting angular acceleration is measured. Since $\tau = I\alpha$,

$$I = \frac{\tau}{\alpha}$$

where α is the angular acceleration which is equal to a/r and τ is the torque caused by the weight hanging from the thread which is wrapped around the base of the apparatus.

$$\tau = rT$$

where r is the radius of the cylinder about which the thread is wound and T is the tension in the thread when the apparatus is rotating.

Applying Newton's Second Law for the hanging mass, *m*, gives (See Figure 6.1)

$$\Sigma F = mg - T = ma$$

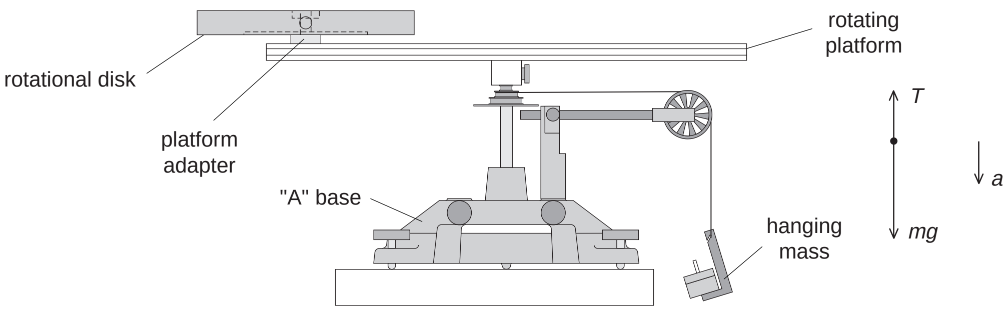


Figure 6.1: Rotational Apparatus and Free-Body Diagram

Solving for the tension in the thread gives:

$$T = m(g - a)$$

Once the linear acceleration of the mass (m) is determined, the torque and the angular acceleration can be obtained for the calculation of the rotational inertia.

Setup

① Set up the Rotational Accessory as shown in Figure 6.2. Mount the disk with its bearing side up. Use the platform adapter to fasten the disk to the track at a large radius.

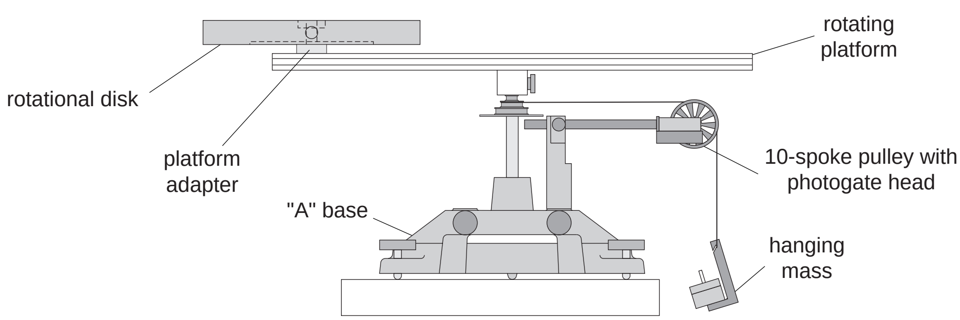


Figure 6.2: Set-up for Disk Off-Axis

② Mount the Smart Pulley to the base and connect it to a computer.

③ Run the Smart Pulley Timer program.

Measurements For the Theoretical Rotational Inertia

Record these measurements in Table 6.1.

① Weigh the disk to find the mass M.

② Measure the diameter and calculate the radius R.

③ Measure the distance, d, from the axis of rotation to the center of the disk.

Table 6.1: Theoretical Rotational Inertia

Mass of Disk	
Radius of Disk	
Distance Between Parallel Axis	

Measurements For the Experimental Method

Accounting For Friction

Because the theory used to find the rotational inertia experimentally does not include friction, it will be compensated for in this experiment by finding out how much mass over the pulley it takes to overcome kinetic friction and allow the mass to drop at a constant speed. Then this “friction mass” will be subtracted from the mass used to accelerate the ring.

① To find the mass required to overcome kinetic friction run “Display Velocity”: <V>-Display Velocity <RETURN>; <A>-Smart Pulley/Linear String <RETURN>; <N>-Normal Display <RETURN>.

② Put just enough mass hanging over the pulley so that the velocity is constant to three significant figures. Then press <RETURN> to stop displaying the velocity. Record the friction mass in Table 6.2.

Finding the Acceleration of Disk and Track

Table 6.2: Rotational Inertia Data

	Fixed Disk and Track Combined	Track Alone	Rotating Disk and Track Combined
Friction Mass			
Hanging Mass			
Slope			
Radius			

① To find the acceleration, put about 50 g over the pulley and run “Motion Timer”: <M>-Motion Timer <RETURN>. Wind the thread up and let the mass fall from the table to the floor, hitting <RETURN> just before the mass hits the floor.

② Wait for the computer to calculate the times and then press <RETURN>. To find the acceleration, graph velocity versus time: <G>-Graph Data <RETURN>; <A>-Smart Pulley/Linear String <RETURN>; <V>-Velocity vs. Time <R>-Linear Regression <SPACEBAR> (toggles it on) <S>-Statistics <SPACEBAR> <RETURN> The graph will now be plotted and the *slope* = *m* will be displayed at the top of the graph. This slope is the acceleration. Push <RETURN> and <X> twice to return to the Main Menu. Record this slope in Table 6.2.

Measure the Radius

① Using calipers, measure the diameter of the cylinder about which the thread is wrapped and calculate the radius. Record in Table 6.2.

Finding the Acceleration of Track Alone

Since in **Finding the Acceleration of Disk and Track** the track is rotating as well as the disk, it is necessary to determine the acceleration, and the rotational inertia, of the track by itself so this rotational inertia can be subtracted from the total, leaving only the rotational inertia of the disk.

① To do this, take the disk off the rotational apparatus and repeat **Finding the Acceleration of Disk and Track** for the track alone.

➧ **NOTE:** It will take less “friction mass” to overcome the new kinetic friction and it is only necessary to put about 30 g over the pulley in **Finding the Acceleration of Disk and Track**.

Disk Using Ball Bearings (Free Disk)

Mount the disk upside-down at the same radius as before. Now the ball bearings at the center of the disk will allow the disk to rotate relative to the track. Repeat **Accounting For Friction** and **Finding the Acceleration of Disk and Track** for this case and record the data in Table 6.2.

Calculations

Record the results of the following calculations in Table 6.3.

① Subtract the “friction mass” from the hanging mass used to accelerate the apparatus to determine the mass, m, to be used in the equations.

② Calculate the experimental value of the rotational inertia of the fixed disk and track combined.

③ Calculate the experimental value of the rotational inertia of the track alone.

④ Subtract the rotational inertia of the track from the rotational inertia of the fixed disk and track. This will be the rotational inertia of the fixed disk alone.

⑤ Calculate the experimental value of the rotational inertia of the fixed disk and track combined.

⑥ Subtract the rotational inertia of the track from the rotational inertia of the free disk and track. This will be the rotational inertia of the free disk alone.

⑦ Calculate the theoretical value of the rotational inertia of the fixed disk off axis.

Table 6.3: Results

Rotational Inertia for Fixed Disk and Track Combined	
Rotational Inertia for Track Alone	
Rotational Inertia for Fixed Disk Off-Axis (experimental value)	
Rotational Inertia for Free Disk and Track Combined	
Rotational Inertia for Free Disk Alone (experimental value)	
Rotational Inertia for Fixed Disk Off-Axis (theoretical value)	
Rotational Inertia for Point Mass (theoretical value)	
% Difference for Fixed	
% Difference for Free Disk	

⑧ Calculate the theoretical value of a point mass having the mass of the disk.

⑨ Use a percent difference to compare the experimental values to the theoretical values.

Notes:

Experiment 7: Conservation of Angular Momentum

EQUIPMENT REQUIRED

- Smart Pulley Timer Program
- Rotational Inertia Accessory (ME-8953)
- Rotating Platform (ME-8951)
- Smart Pulley Photogate
- balance

Purpose

A non-rotating ring is dropped onto a rotating disk and the final angular speed of the system is compared with the value predicted using conservation of angular momentum.

Theory

When the ring is dropped onto the rotating disk, there is no net torque on the system since the torque on the ring is equal and opposite to the torque on the disk. Therefore, there is no change in angular momentum. Angular momentum is conserved.

$$L = I_i\omega_i = I_f\omega_f$$

where I_i is the initial rotational inertia and ω_i is the initial angular speed. The initial rotational inertia is that of a disk

$$\left(\frac{1}{2}\right) M_1R^2$$

and the final rotational inertia of the combined disk and ring is

$$I_f = \frac{1}{2}M_1\, R^{2 + \frac{1}{2}M_2\left(r_1^{\,2} + r_2^{\,2}\right)}$$

So the final rotational speed is given by

$$\omega_f = \frac{M_1\, R^2}{M_1\, R^{2 + M_2\left(r_1^{\,2} + r_2^{\,2}\right)}}\, \omega_i$$

Setup

① Level the apparatus using the square mass on the track.

② Assemble the Rotational Inertia Accessory as shown in Figure 7.1. The side of the disk with the indentation for the ring should be up.

③ Mount the Smart Pulley photogate on the black rod on the base and position it so it straddles the holes in the pulley on the center rotating shaft.

④ Run the Smart Pulley Timer program.

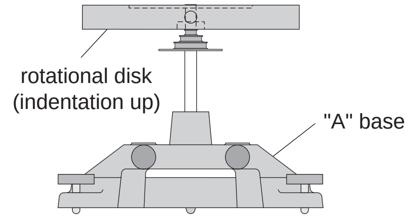


Figure 7.1: Assembly for Dropping Ring onto Disk

Procedure

① Select <M>-Motion Timer <RETURN>.

② Hold the ring just above the center of the disk. Give the disk a spin using your hand. After about 25 data points have been taken, drop the ring onto the spinning disk See Figure 7.2.

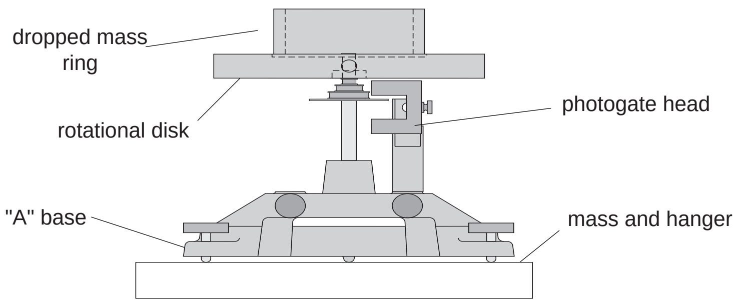


Figure 7.2: Experiment Setup

③ Continue to take data after the collision and then push <RETURN> to stop the timing.

④ When the computer finishes calculating the times, graph the rotational speed versus time. <A>-Data Analysis Options <RETURN> <G>-Graph Data <RETURN> <E>-Rotational Apparatus <RETURN> <V>-Velocity vs. Time <RETURN>

⑤ After viewing the graph, press <RETURN> and choose <T> to see the table of the angular velocities. Determine the angular velocity immediately before and immediately after the collision. Record these values in Table 7.1.

⑥ Weigh the disk and ring and measure the radii. Record these values in Table 7.1.

Analysis

① Calculate the expected (theoretical) value for the final angular velocity and record this value in Table 7.1.

② Calculate the percent difference between the experimental and the theoretical values of the final angular velocity and record in Table 7.1.

Table 7.1: Data and Results

Initial Angular Speed	
Final Angular Speed (experimental value)	
Mass of Disk	
Mass of Ring	
Inner Radius of Ring	
Outer Radius of Ring	
Radius of Disk	
Final Angular Speed (theoretical value)	
% Difference Between Final Angular Speeds	

Questions

① Does the experimental result for the angular speed agree with the theory?

② What percentage of the rotational kinetic energy lost during the collision? Calculate this and record the results in Table 7.1.

$$\%KE\ Lost = \frac{\frac{1}{2}I_i\omega_i^2 - \frac{1}{2}I_f\omega_f^2}{\frac{1}{2}I_i\omega_i^2}$$

Notes:

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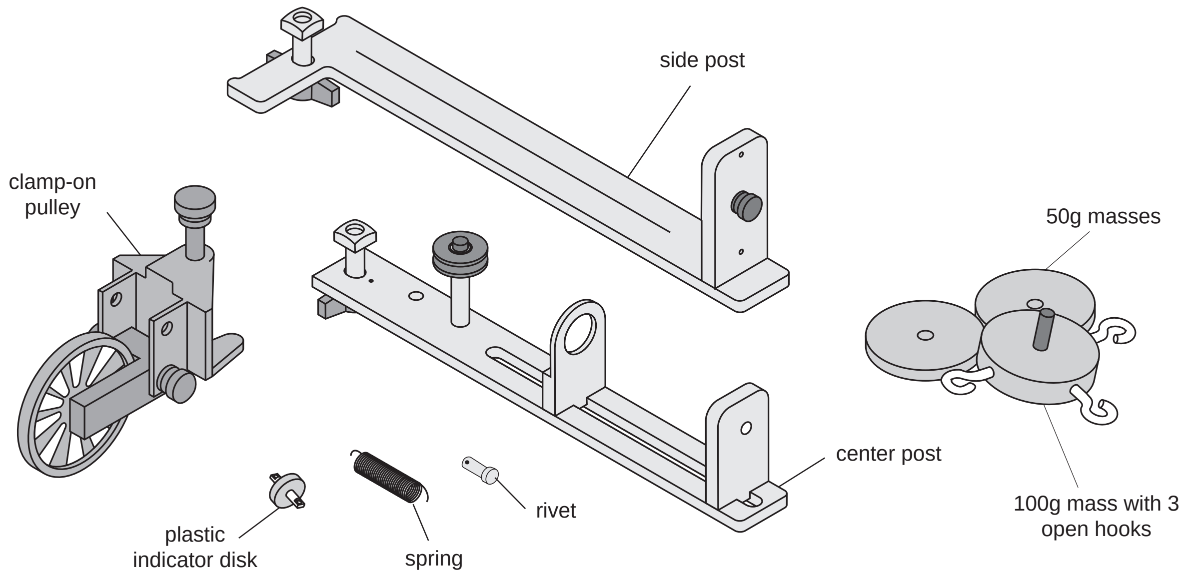
Instruction Sheet for the PASCO Model ME-8952

Centripetal Force Accessory



Introduction

The ME-8952 Centripetal Force Accessory is comprised of two vertical posts which can be mounted to the Rotating Platform with thumbscrews. These posts are adjustable and can be positioned virtually anywhere along the length of the platform. The radius indicator is at the center of the apparatus so it can be clearly seen while the apparatus is rotating. The PASCO Centripetal Force Accessory can be used to experiment with centripetal force and conservation of angular momentum. For the centripetal force experiments it is possible to vary the mass and radius to see the resulting change in the centripetal force. The force can also be held constant while other quantities are varied. The Centripetal Force Accessory is powered by hand and the rate of rotation can be counted manually or read by a computer. Variable hanging masses are included. This accessory requires the Rotating Platform (ME-8951) to operate.

See the Complete Rotational Manual for experiment guide.

Equipment

The ME-8952 Centripetal Force Accessory includes:

- center post that supports an indicator mechanism which consists of a small pulley, a movable spring holder, a movable indicator, a rivet, a spring, and a plastic indicator disk
- side post for hanging hooked mass
- mass (100 g) with 3 open hooks
- 2 additional 50 gram masses
- clamp-on pulley

This instruction sheet written by: Ann and Jon Hanks and edited by: Eric Ayars

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Center Post Assembly

Assemble the center post as shown in Figure 1:

① Drop the rivet through the hole in the top of the spring bracket. Connect one end of the spring to the hole in the end of the rivet. Connect the plastic indicator disk to the other end of the spring.

② Tie one end of a string (about 30 cm long) to the bottom of the plastic indicator disk and tie a loop in the other end of the string.

③ Insert the indicator bracket into the slot on the center post, placing it below the spring bracket. Tighten the thumb screw.

④ Attach the pulley in the higher of the two holes on the center bracket.

⑤ Insert the thumbscrew at the bottom of the center post and attach the square nut.

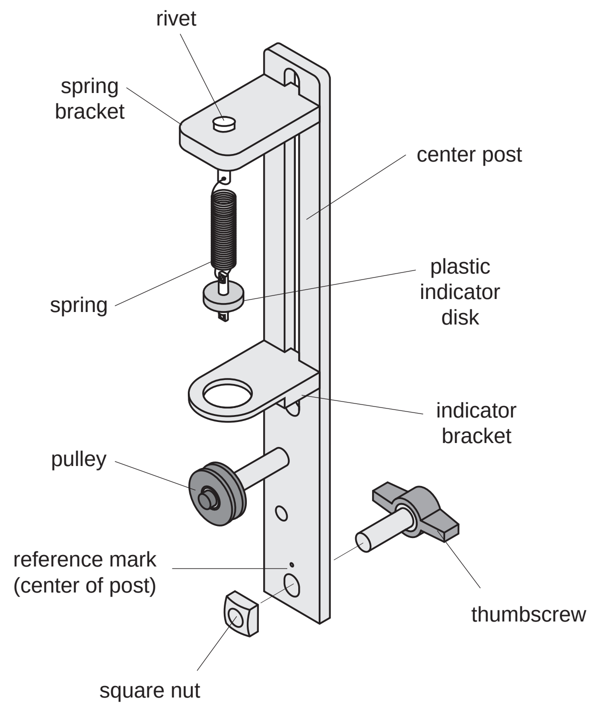

Figure 1: Center Post Assembly

Side Post Assembly

Assemble the side post as shown in Figure 2:

① Insert the thumb screw at the bottom of the side post and attach the square nut.

② Using a string about 30 cm long, tie the string around the screw head on the top of the side post. Then thread the other end of the string down through one of the holes in the top of the side post and then back up through the other hole. Do not pull the string taut.

③ Loosen the screw on the top of the side post and wrap the loose end of the string around the threads of the screw and tighten the screw.

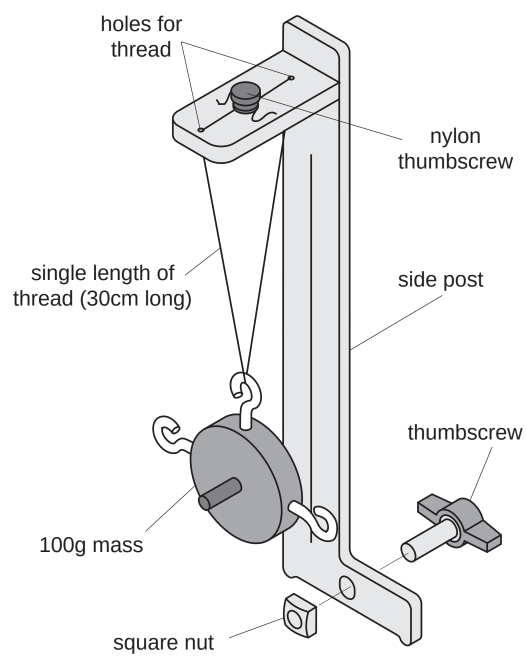

Figure 2: Side Post Assembly

Threading the Centripetal Force Accessory

① Mount the center post in the T-slot on the side of the track that has the rule. Align the line on the center post with the zero mark on the rule and tighten the thumb screw to secure it in place. Then mount the side post on the same side of the track. See Figure 3.

② Hang the object from the string on the side post and adjust the height of the object so the string coming from the center post will be level.

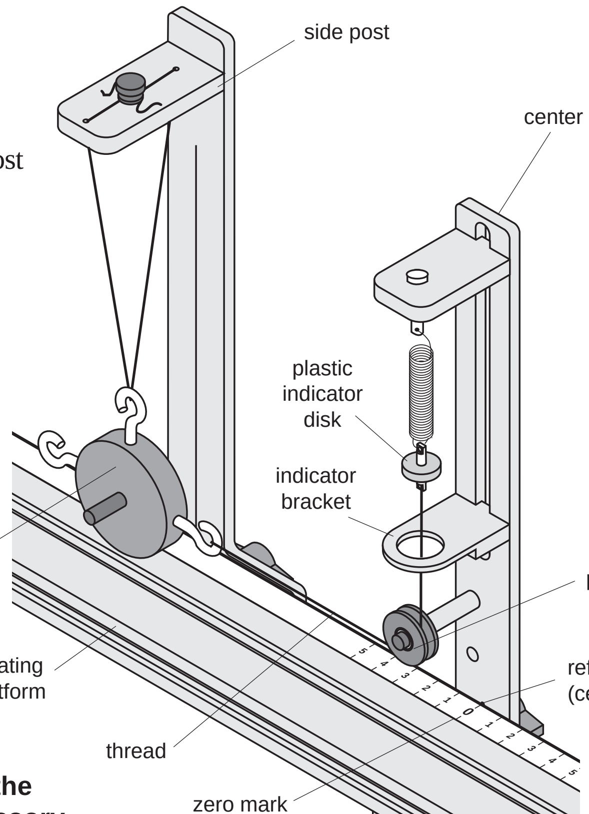

Figure 3: Threading the Centripetal Force Accessory

Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

Equipment Return

Should this product have to be returned to PASCO scientific, for whatever reason, notify PASCO scientific by letter or telephone BEFORE returning the product. Upon notification, the return authorization and shipping instructions will be promptly issued.

> ➤ **NOTE:** NO EQUIPMENT WILL BE ACCEPTED FOR RETURN WITHOUT AN AUTHORIZATION.

When returning equipment for repair, the unit must be packed properly. Carriers will not accept responsibility for damage caused by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

① The carton must be strong enough for the item shipped.

② Make certain there is at least two inches of packing material between any point on the apparatus and the inside walls of the carton.

③ Make certain that packing material cannot shift in the box, or become compressed, thus letting the instrument come in contact with the edge of the box.

Technical Support

Feed-Back

If you have any comments about this product or this manual please let us know. If you have any suggestions on alternate experiments or find a problem in the manual please tell us. PASCO appreciates any customer feed-back. Your input helps us evaluate and improve our product.

To Reach PASCO

For Technical Support call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

Internet: techsupp@PASCO.com

Contacting Technical Support

Before you call the PASCO Technical Support staff it would be helpful to prepare the following information:

- If your problem is computer/software related, note:

  Title and Revision Date of software.

  Type of Computer (Make, Model, Speed).

  Type of external Cables/Peripherals.

- If your problem is with the PASCO apparatus, note:

  Title and Model number (usually listed on the label).

  Approximate age of apparatus.

  A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.)

  If possible, have the apparatus within reach when calling. This makes descriptions of individual parts much easier.

- If your problem relates to the instruction manual, note:

  Part number and Revision (listed by month and year on the front cover).

  Have the manual at hand to discuss your questions.

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email: techsupp@PASCO.com

Tech support fax: (916) 786-3292

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  Type of Computer (Make, Model, Speed).

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- If your problem is with the PASCO apparatus, note:

  Title and Model number (usually listed on the label).

  Approximate age of apparatus.

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- If your problem relates to the instruction manual, note:

  Part number and Revision (listed by month and year on the front cover).

  Have the manual at hand to discuss your questions.

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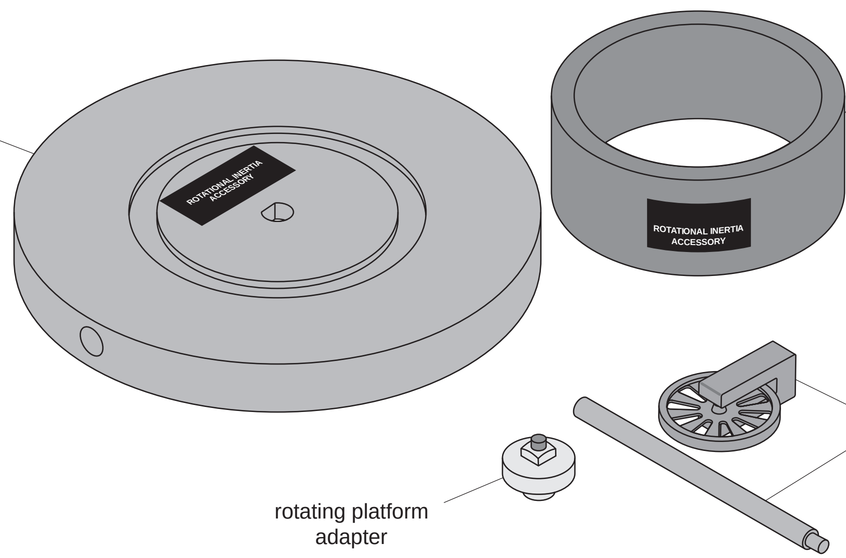
Instruction Sheet for the PASCO Model ME-8953

Rotational Inertia Accessory



Introduction

The ME-8953 Rotational Inertia Accessory allows you to perform rotational inertia and angular momentum experiments. It includes a disk which can be mounted to the rotating base in a variety of positions and at a wide range of radii.

This accessory requires the PASCO ME-8951 Rotating Platform to operate.

See the Complete Rotational System Manual for experiment guide.

Equipment

The ME-8953 Rotation Inertia Accessory includes:

- disk with bearings in the center
- ring (12.7 cm diameter)
- adapter to connect disk to platform
- 10-spoke pulley and rod
- 1 spool of thread

Rotational Inertia Accessory Assembly

Little assembly is required to use the Rotational Inertia Accessory. The rotational disk can be placed directly onto the axle of the rotating base or can be used with the rotating platform via the included platform adapter.

Platform Adapter Assembly

① Attach the square nut (supplied with the Rotational Inertia Accessory) to the platform adapter.

② Position the platform adapter at the desired radius as shown in Figure 1.

③ Grip the knurled edge of the platform adapter and tighten.

The rotating disk can be mounted in a variety of positions using any of the four holes on the rotation disk.

This instruction sheet written by: Ann and Jon Hanks and edited by: Eric Ayars

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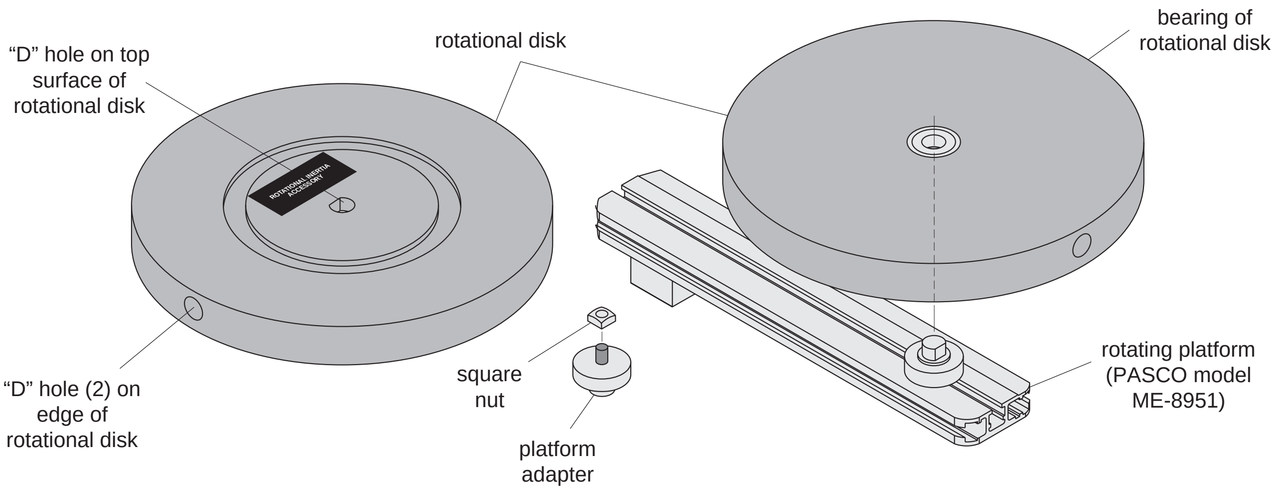

Figure 1: Rotational Inertia Accessory Including Platform Adapter Assembly

- Two "D" holes exist on the edge of the disk, located at 180˚ from one another.
- One "D" hole is located at the center on the top surface (the surface with the metal ring channel and the PASCO label) of the disk.
- One hole is located at the center on the bottom surface of the disk and is actually the inner race of a bearing. This enables the rotational disk to rotate (in either direction) in addition to other rotating motions applied to your experiment setup.

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① The carton must be strong enough for the item shipped.

② Make certain there is at least two inches of packing material between any point on the apparatus and the inside walls of the carton.

③ Make certain that packing material cannot shift in the box, or become compressed, thus letting the instrument come in contact with the edge of the box.

012-06757B
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Instruction Sheet
for the PASCO
Model CI-6742

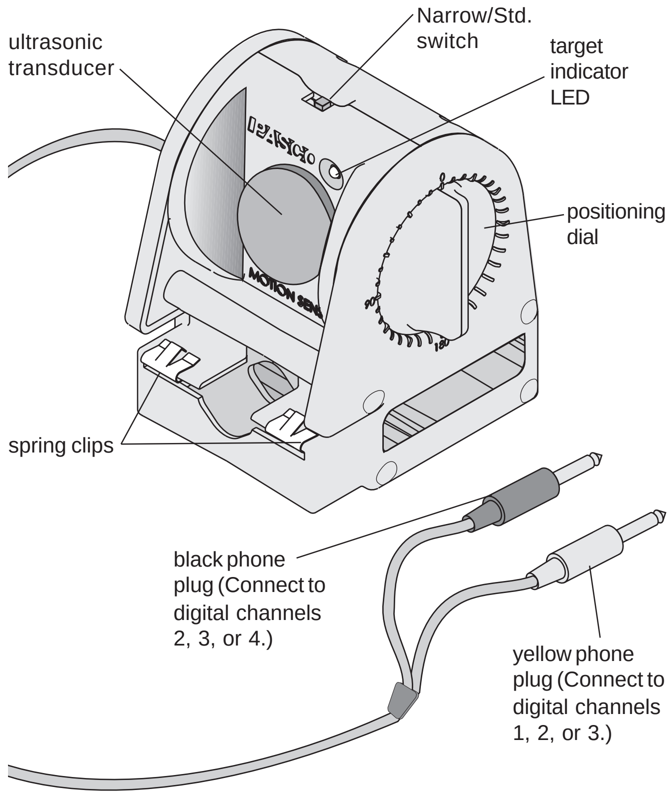
Motion Sensor II

Introduction

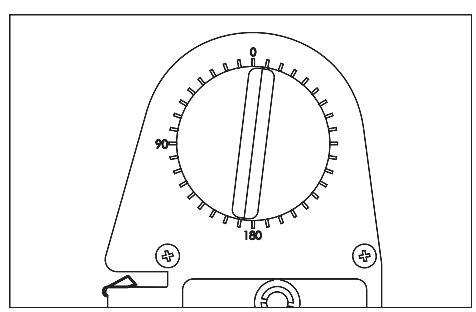
The PASCO CI-6742 Motion Sensor II is a sonar ranging device with a sensing range of 0.15 to about 8 meters. When used with an interface, the Motion Sensor II emits ultrasonic pulses and detects pulses returned as echoes from the target. The *ScienceWorkshop* program calculates the distance to the object from the speed of sound and half the sonic pulse round trip time. The program can also calculate velocity and acceleration from the distance and time measurements. The trigger rate for the Motion Sensor can be set in the *ScienceWorkshop* program to trigger as few as 5 times per second (for recording relatively slow events over large distances) or for as many as 120 times per second (for quick events such as a free-fall experiment).

The CI-6742 Motion Sensor II has several improved features, compared to the CI-6529 Motion Sensor:

- reduced minimum distance of operation
- reduced sensitivity to false targets
- front panel LED that lights when the Motion Sensor acquires the target
- additional mounting and positioning options
- compatibility with Texas Instruments® and Casio® scientific calculator-sensor interfaces
- compatibility with ULI interfaces



Important Operating Note: When operating in the Std. mode, it may be necessary to tilt the transducer up 5-10 degrees for best performance, as shown.



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Equipment

Included:

- PASCO CI-6742 Motion Sensor II
- detachable cable with two color-coded phone plugs

Additional Equipment Required:

- computer and *ScienceWorkshop 500*, *700*, or *750* Interface
  or
- scientific calculator and sensor interface (Texas Instruments or Casio) and cable (PASCO part no. 514-06862)
  or
- ULI Interface and cable (PASCO part no. 514-06933)

Using the Motion Sensor II

1. Insert the yellow phone plug into digital channel 1 (or 1, 2, or 3 for *ScienceWorkshop* series *700* and *750* interfaces). Insert the black phone plug into digital channel 2 (or 2, 3, or 4 for *Science Workshop* series *700* and *750* interfaces).

Note: The Motion Sensor can be connected to any two adjacent digital channels on the interface, with the yellow plug in the channel with the lower number. The yellow plug carries the transmit signal from the *ScienceWorkshop* interface to the sensor, and the black plug carries the return, echo signal, from the sensor to the *Science Workshop* interface.

2. Run the *ScienceWorkshop* program. In the Experiment Setup window, set up the *ScienceWorkshop* interface and sensor so the Motion Sensor is connected to the correct digital channels of the interface.

Note: You can set up the Motion Sensor II in *ScienceWorkshop* program (2.x series) by dragging the digital plug icon to channel 1 if the phone plugs are inserted into channels 1 and 2 on the interface box, or by double-clicking the Motion Sensor icon in the list of sensors (3.x series).

Note: With the *700* and *750* interfaces, two Motion Sensors may be used at the same time.

3. Set the *Narrow/Standard (Std.)* switch based on your application. For experiments that involve sensing distances of 2 meters or less with highly reflective targets (such as a typical Dynamics Track experiment), set the switch to *Narrow*. This setting reduces sensitivity to false targets near the track and sensitivity to air track noise. For experiments that involve longer distances or poorly reflecting targets (such as match-graph experiments), set the switch to *Std.*

Note: When using the *Std.* switch setting it may be necessary to tilt the sensor up 5-10 degrees to avoid seeing reflections from a table surface or the front of the housing as a target.

4. For most experiments, the internal calibration in *ScienceWorkshop* will be adequate. However for maximum accuracy the Motion Sensor II may be calibrated as follows:

a. Double-click on the Motion Sensor icon to open the Digital Sensor Setup dialog box.

b. Aim the Motion Sensor II at a stationary target one meter away (the default calibration distance).

c. Click **Calibrate**. The Motion Sensor II will click a few times per second during the calibration process. The program will calculate the speed of sound based on the default calibration distance (one meter) and the round trip time of the pulses and echoes.

Note: If the Motion Sensor does not detect a target, the Interface may stop trying to calibrate. Should this occur, realign the target of the sensor and try again.

5. Change the trigger rate (if necessary) by clicking the *up/down* arrows to the right of the Trigger Rate pop-up menu, or click the pop-up menu and select the Trigger Rate you need. (The Trigger Rate may need to be increased from the default 20 Hz for fast events like collisions or free-fall experiments in order to achieve the necessary resolution.)

*6***.** Open a Graph display in *ScienceWorkshop.*

7. Start monitoring data.

Note: When the *ScienceWorkshop* program is set to monitor or record data, the Motion Sensor II transducer will be triggered to produce the ultrasonic pulses that are used by *ScienceWorkshop* to determine the location of the target.

*8***.** Adjust the angle of the transducer, the *Narrow/Std.* mode, and the trigger rate as necessary to achieve the optimal signal.

Note: The LED will light when the Motion Sensor II acquires the target.

*9***.** You are now ready to record data.

Mounting the Motion Sensor II on PASCO equipment

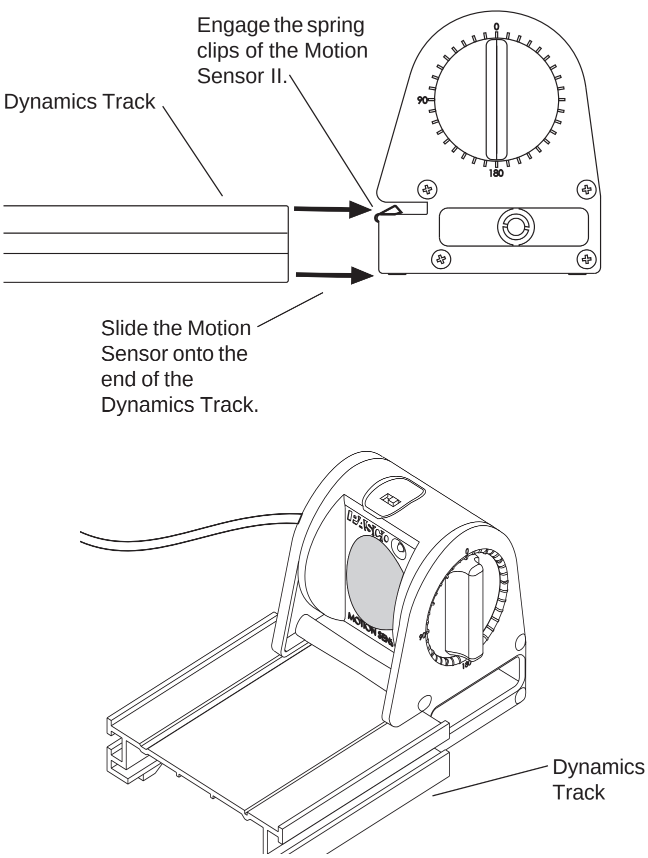

Figure 1
Mounting the Motion Sensor II on a Dynamics Track

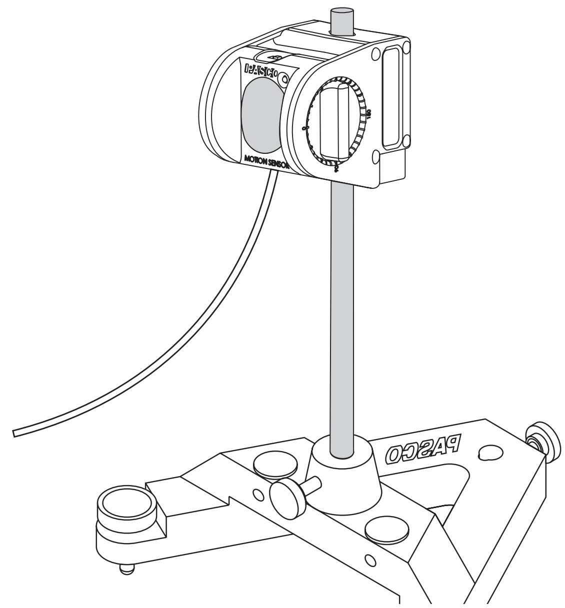

Figure 2
Mounting the Motion Sensor II on a rod stand

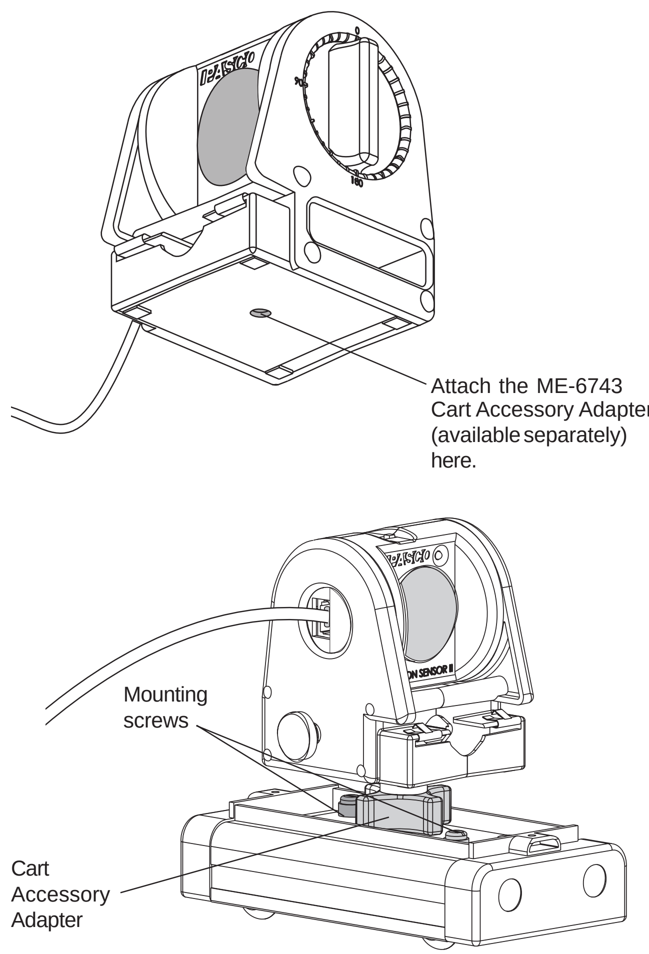

Figure 3
Mounting the Motion Sensor II onto a Dynamics Cart

Operation with CBL and EA-100 systems

An accessory cable (available separately, PASCO part no. 514-06862) is required for operation of the Motion Sensor II with a Texas Instruments CBL System™ or a Casio EA-100 Data Analyzer™.
An accessory cable (available separately, PASCO part no. 514-06933) is required for operation of the Motion Sensor II with a ULI interface.

Theory of Operation

When triggered, the module produces a burst of 16 pulses at a frequency of about 49 KHz. This produces an audible click from the electrostatic transducer which functions as both a speaker and a microphone. The time between the *trigger* rising edge and the *echo* rising edge is proportional to the distance. The trip time for sound in air is about 0.3 ms/m, so an object at a distance of 0.6 m produces a round-trip time delay of 3.6 ms. The sound intensity decreases with distance, and for a round trip the attenuation can be large enough for the receiver to miss the echo. Therefore the gain of the receiver's amplifier is increased in discrete amounts in 11 steps where the maximum gain is reached in 38 ms. This increases the usable distance to about 8 meters with a highly reflective target. Operating the receiver at reduced gain at the beginning of the cycle reduces the circuit's sensitivity to false echoes.

Note: This instruction sheet was written assuming that the user is familiar with *ScienceWorkshop*. Users can gain familiarity by working through the tutorials provided with *ScienceWorkshop*.

Motion Sensor II CI-6742

Tested To Comply With FCC Standards

FOR HOME OR OFFICE USE

Note: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/ TV technician for help.

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Instruction Manual and Experiment Guide for the PASCO scientific Model CI-6537

012-05804A
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±50N FORCE SENSOR

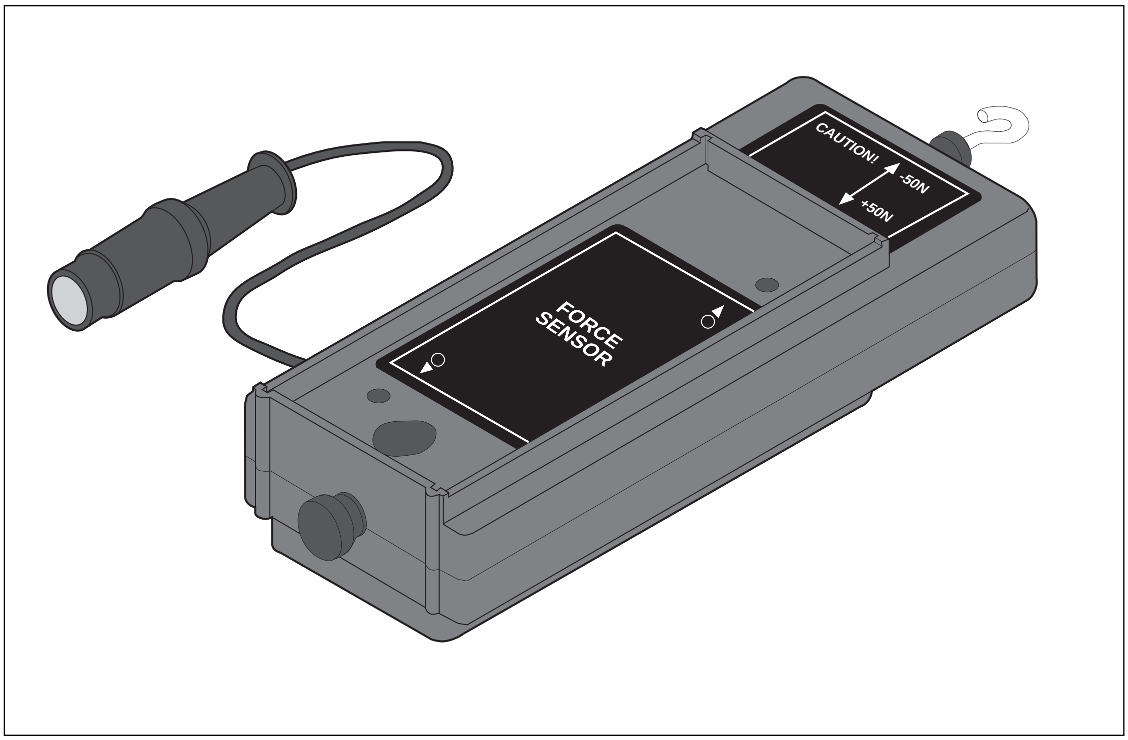

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Table of Contents

Copyright, Warranty and Equipment Return

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Credits

This manual authored by: Dave Griffith

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③ Make certain that the packing material cannot shift in the box or become compressed, allowing the instrument come in contact with the packing carton.

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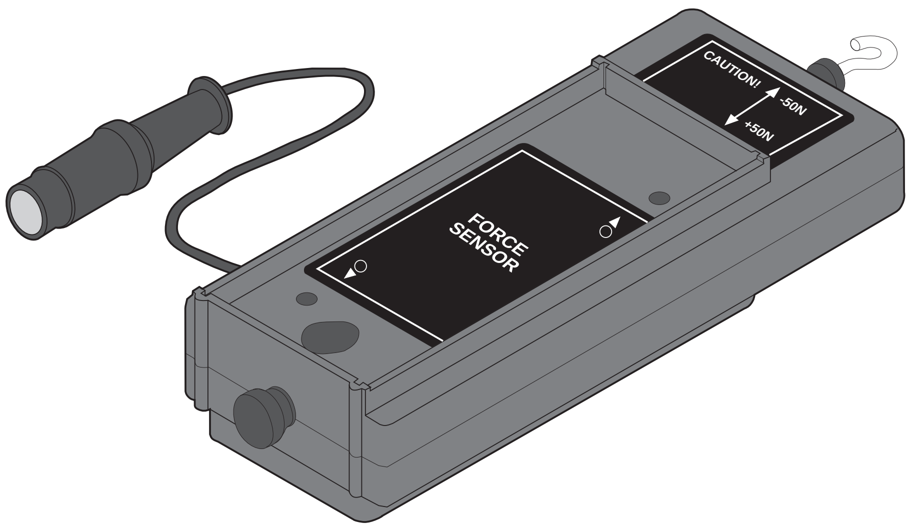
Introduction

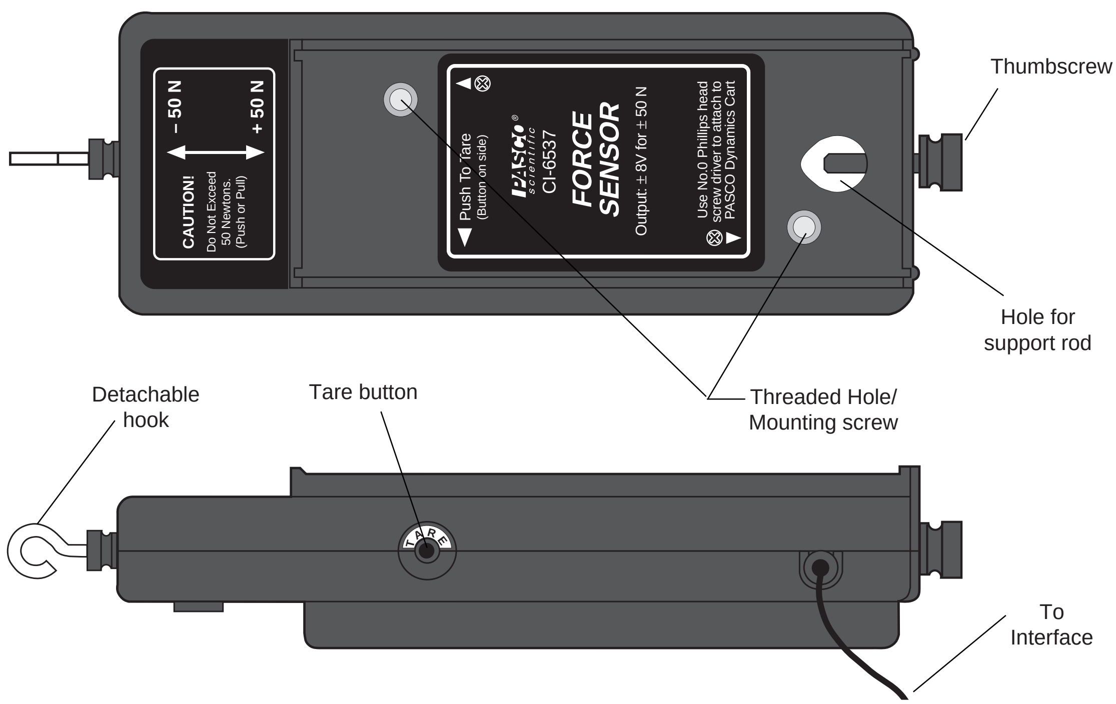


The CI-637 ± 50 Newton Force Sensor is designed to be used with a PASCO Computer interface [such as the CI-6500 (IBM®), AI-6501 (Apple II®), CI-6550 (Macintosh®), or CI-6565 (Windows™)]. This version of the force sensor has an output between -8 Volts and +8 Volts and a range between -50 Newtons and +50 Newtons. In other words, it produces -8 Volts for -50 Newtons, 0 Volts for "zero" force, and +8 Volts for +50 Newtons. (A push is considered to be positive, and a pull is considered to be negative.) The sensor has strain gauges mounted on a specially designed "binocular beam". The beam deflects less than 1 millimeter, and has built-in over-limit protection so it will not be damaged if a force greater than 50 Newtons is applied.

The force sensor consists of the housing for the beam and electronics, a cable with a 8 pin DIN plug for connecting to the computer interface, and a detachable hook. The housing has a tare button (for zeroing the sensor) on the same side of the housing as the cable and a thumbscrew (for mounting on a support rod up to 1/2" diameter) on the end opposite to the detachable hook.

The bottom of the housing fits into the accessory tray of a PASCO Dynamics Cart. The top of the housing has the same dimensions as the Dynamics Cart accessory tray, and includes notches at each end for mounting the IDS "picket fence". The top of the housing has two threaded holes (M5 metric threads). You can mount any accessory that fits on top of the Dynamics Cart into the tray on top of the force sensor. (See the PASCO catalog for more information.)

Equipment



Range and Resolution

The range of the sensor is ±50 Newtons with an output between -8 Volts and +8 Volts, or 160 millivolts per Newton. The resolution of the sensor refers to the smallest change in force that the sensor can measure. An interface with a 12-bit analog-to-digital converter and an input range of ±10 Volts (such as the CI-6500 or CI-6550) gives a resolution of 0.0305 Newtons (or 3.1 grams).

Range: ±50 Newtons

Resolution: 0.0305 Newtons (or 3.1 grams)

Additional Equipment

Needed

- Computer Interface such as the CI-6500 (IBM), AI-6501 (Apple II), or CI-6550 (Macintosh).

Recommended

- Introductory Dynamics System (carts, track, track accessories), such as PASCO Model ME-9429A.
- Force Sensor Bracket and Collision Bumpers (CI-6545)
- Phillips head screwdriver (size #0) for mounting the Force Sensor on a PASCO Dynamics Cart (included with the Force Sensor Bracket).

Operation

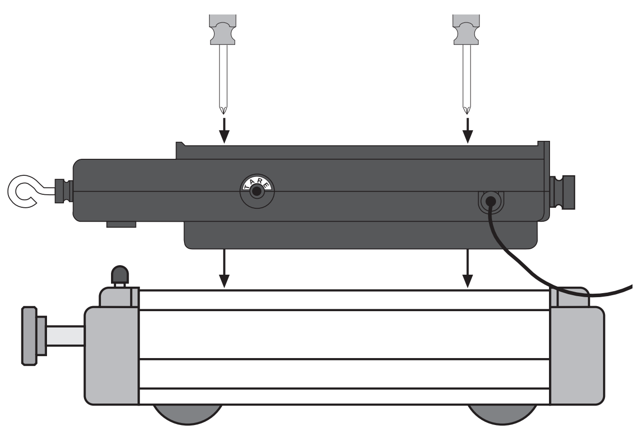
Connecting and Zeroing the Sensor

Connect the 8-pin DIN plug to an analog channel on the computer interface. To “zero” the sensor, press and then release the tare button on the side of the sensor. When the tare button is pressed, the voltage from the sensor will be set to approximately zero Volts. You can also zero the sensor while a force is applied to the sensor. For example, if you want to measure the ***change*** in force during an experiment, set up the experimental equipment as needed, and tare the sensor at the beginning of the experiment before taking data. The sensor can maintain its “zeroed” condition for over thirty minutes.

Mounting the Sensor on a PASCO Dynamics Cart

The Force Sensor has two built-in mounting screws that align with the threaded holes in the accessory tray of a PASCO Dynamics Cart (such as the ME-9430 Plunger Cart or ME-9454 Collision Cart). The screws are spring loaded so they remain in a retracted position when not in use.

To mount the sensor, position it in the accessory tray of the dynamics cart. Insert a size #0 Phillips head screwdriver into the threaded hole in the accessory tray of the force sensor, and align the screwdriver with the Phillips head screw. Press down with the screwdriver until the screw extends into the threaded hole on the dynamics cart. Turn the screwdriver clockwise until the screw is tight. Repeat the process with the other screw.



To mount other accessories (e.g. ME-9481 Bernoulli Cart Accessory) on top of the force sensor, attach the accessory in the force sensor accessory tray in the same way you would attach the accessory to a dynamics cart.

Mounting on a Support Rod

The Force Sensor has a hole and thumbscrew at one end that allows you to mount the sensor on a support rod from 1/4” to 1/2” diameter.

Mounting on the IDS Force Sensor Accessory Bracket

The Force Sensor can be mounted on the CI-6545 Force Sensor Bracket. Place the bracket on top of the sensor so the thumbscrews align with the threaded holes in the top of the sensor accessory tray. Turn each thumbscrew clockwise until it is tight. Mount the Force Sensor Bracket on the T-slot on the side of the IDS Track. (See the Force Sensor Bracket instruction sheet for more information.)

Calibrating the Sensor

The sensor is designed to produce approximately zero Volts when it is “zeroed”. A change in force of one Newton causes a change in output voltage of 160 millivolts (0.160 V). **Therefore, the sensor does not need to be calibrated.** Instead, the voltage can be converted directly into force. For example, after the sensor is “zeroed”, an output voltage of 0.160 Volts equals a force of one Newton, a voltage of 1.60 Volts equals a force of 10 Newtons, and so on. In the same way, a voltage of -1.60 Volts equals a force of -10 Newtons (in other words, a pull of 10 Newtons).

However, you can calibrate the sensor to learn about the process of calibration. All calibrations assume that the sensor produces an output voltage that is linear with respect to the input signal. Calibration is done by setting up two calibration situations (such as “no force” and a known force), measuring the input signal in each situation in comparison to a known standard, and entering the readings.

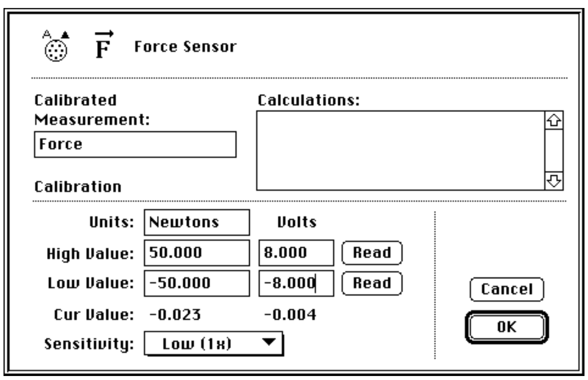
Calibration using *Science Workshop™*

The following calibration procedure assumes that the force sensor is connected to Analog Channel A of the interface. You will need a known mass, such as 1 kilogram, and a support rod for mounting the sensor.

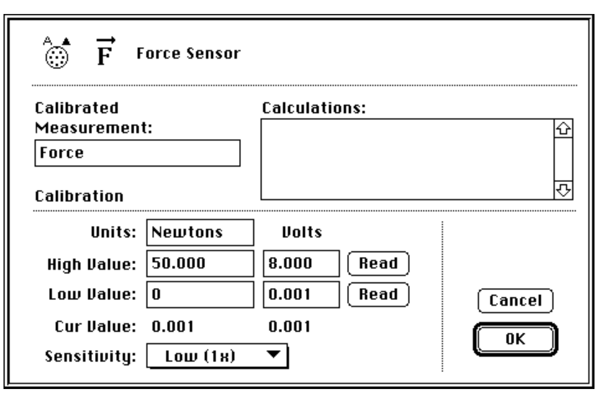
When the *Science Workshop*program begins, click-and-drag the Analog Sensor Plug icon to Analog Channel A. Select “Force Sensor” from the list of analog sensors. The Force Sensor icon will appear below Analog Channel A in the Experiment Setup window.

① Connect the Force Sensor to the interface. Mount the Force Sensor vertically on a support rod so you can hang a known mass from the hook. Don’t put any mass on the hook for this first step.

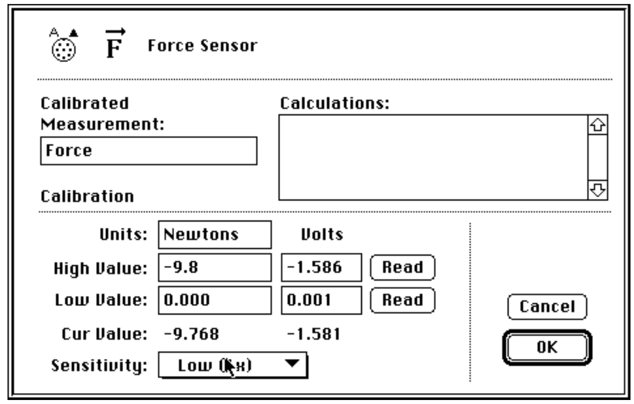
② Double-click on the Force Sensor icon to open the Sensor Setup dialog box. The dialog box shows the default settings for the calibration (i.e., 50.000 Newtons at 8.000 Volts and -50.000 Newtons at -8.000 Volts).



③ Press the tare button to “zero” the sensor. When the reading in the “Cur Value:” row under the “Volts” column settles down, click on the “Read” button in the “Low Value:” row. Enter “0” in the left hand “Low Value:” box.



④ Hang the known mass from the hook. After a few seconds when the reading in the “Cur Value:” row under the “Volts” column settles down, click on the “Read” button in the “High Value:” row. Enter the weight of the mass (e.g.,-9.8 Newtons if you used a 1 kilogram mass). Click OK.



Calibration using the *Data Monitor* Program (MS-DOS) with the CI-6500

Assume for this example that the Force Sensor is connected to Analog Channel A of the interface and that you do not have any other sensors connected to the interface.

① Start the *Data Monitor* program. Select “Other Options” from the Main Menu. Use “Select Channels” to turn off Channels B and C. Return to the Main Menu.

② Select “Calibration” from the Main Menu. Pick “Calibrate Input” from the Calibration Menu. Select “Channel A”. Enter “Force” for the new input label, and “Newtons” for the new input units.

③ **Calibration Point #1:** Zero the sensor by pressing the tare button.. The computer will read a voltage (V1) and will ask you to input the value for the Force in Newtons for reading #1. Type 0 (zero Newtons) for this voltage reading.

④ **Calibration Point #2:** Hang the known mass from the hook. After a few seconds when the voltage reading settles down, press <return> or <enter>. The computer will read a second voltage (V2) and ask you to input the Force in Newtons for reading #2. Enter the weight of the mass (e.g.,-9.8 Newtons if you used a 1 kilogram mass).

⑤ Follow the on-screen instructions to save the calibration on disk as “6537FOR”. The program will automatically add “.CAL” and it will save this file under the name “6537FOR.CAL”.

In the future, the sensor can be calibrated by simply loading the 6537FOR.CAL calibration file using the calibration menu of the *Data Monitor* program.

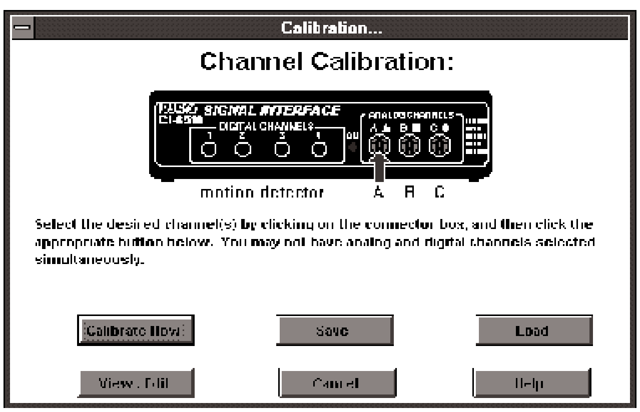
(The procedure for using the *Data Monitor* Program (Apple II) with the AI-6501 is very similar.)

Calibration using the *Data Monitor* Program (Windows™) and the CI-6500

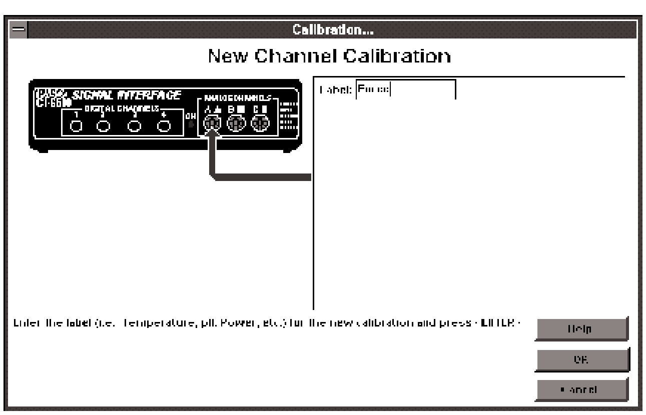
Assume for this example that the force sensor is connected to Analog Channel A of the CI-6500 interface and that you do not have any other sensors connected to the interface.

① Start the *Data Monitor for Windows* program. Pick "Select Channels…" from the Experiment Menu. Turn off Channels B and C.

② In the Toolbar, click on the button for Channel A to open the Channel Calibration window. Click on "Calibrate Now".

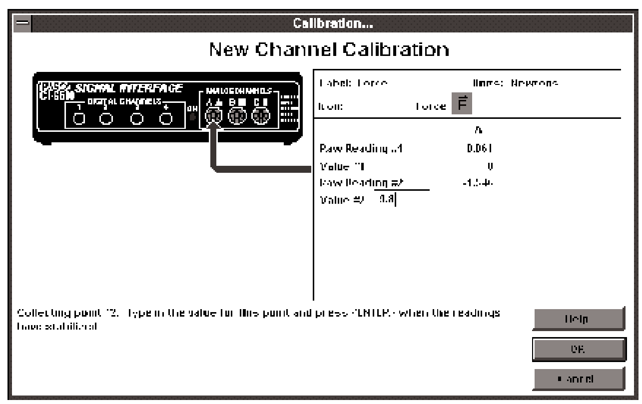


③ The New Channel Calibration window opens when you click on "Calibrate Now" in the Channel Calibration window.

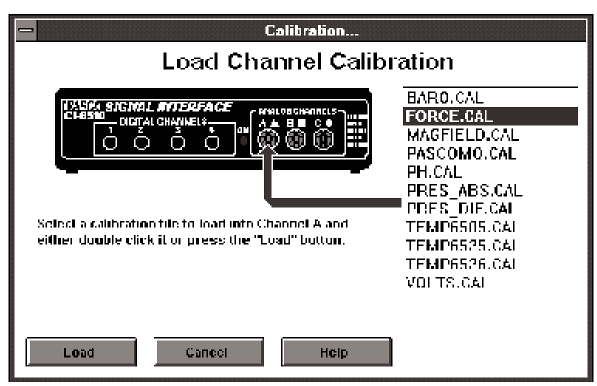


Follow the instructions that appear in the lower left corner of the New Channel Calibration window.

- Enter the label for the parameter being measured ("Force").
- Enter the units ("Newtons").
- Select an appropriate icon from the floating popup menu ("Force")
- Collect data for calibration point #1. When "Raw Reading #1" stabilizes, type in "0" for the value and press <enter>.
- Collect data for calibration point #2. Hang the known mass from the hook. After a few seconds when "Raw Reading #2" stabilizes, type in "9.8" for the value and press <enter>.
- Enter your name and a filename (FORCE) if you want to save the calibration. Press <enter> to end the calibration.



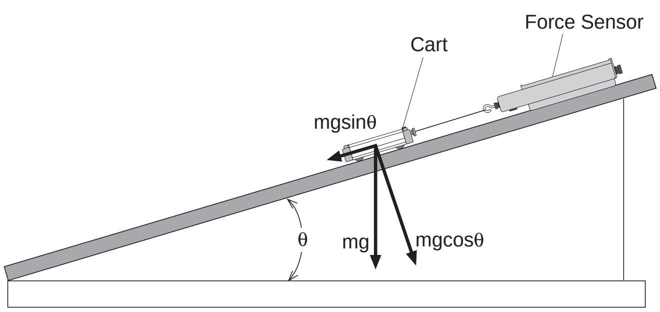
If you choose to save this calibration file, you can use it again later. To use a previously saved calibration file, click on the channel button in the toolbar and select "Load" in the Channel Calibration window. Select "FORCE.CAL" from the list of calibration files in the Load Channel Calibration window.



Suggested Experiments

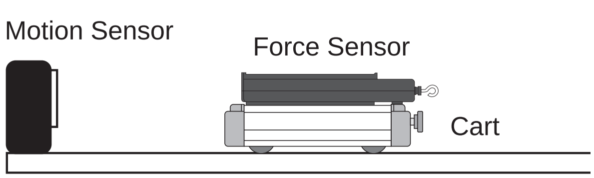
Component of Force on an Inclined Plane

When a cart is at rest on an inclined plane, the component of force acting on the cart that is parallel to the plane is mgsinθ, where mg is the weight of the cart and θ is the angle of the plane. Use the sensor to measure the weight of a dynamics cart. Mount the sensor at the high end of the inclined IDS track and connect it with a string to the dynamics cart on the track. Measure the angle of the track. Measure the tension in the string, and compare this to the theoretical value mgsinθ.



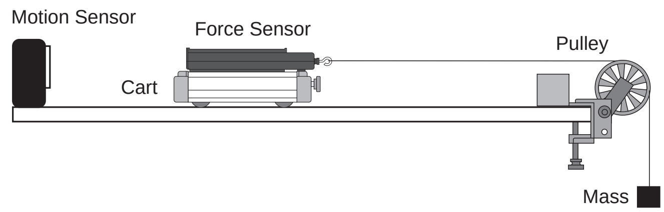
Newton’s Second Law: Pushing and Pulling a Cart

When an object is accelerated by a net force, the acceleration is directly proportional to the net force and inversely proportional to the object’s mass. Mount the force sensor onto a dynamics cart. Use a motion sensor to measure the velocity and acceleration of the cart. Zero the force sensor. Hold the hook on the front of the force sensor, and move the cart gently but irregularly back and forth in front of the motion sensor. Use the computer program to compare the measured force to the measured velocity and acceleration.



Newton’s Second Law: Constant Force

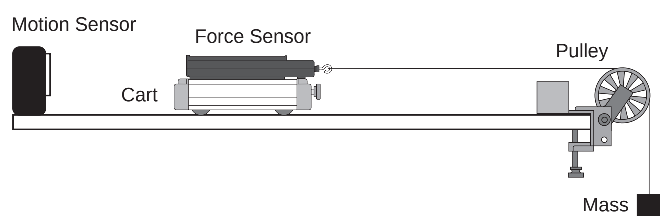
What happens if the cart is pulled by a constant force? Arrange the motion sensor, force sensor, and cart on the track as in the previous suggested experiment. Set up a pulley, string, and hanging mass so that the cart/force sensor will be pulled by the string attached to the hanging mass. Use the motion sensor to measure the velocity and acceleration of the cart as it is pulled by the string. Use the computer program to compare the measured force to the measured velocity and acceleration.



Change the hanging mass and repeat the experiment.

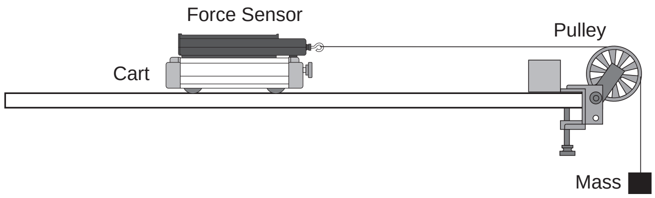
Work-Energy Theorem: W = ∆KE

What happens to the kinetic energy of the cart as it is pulled by a constant force? Arrange the motion sensor, force sensor, and cart on the track as in the previous suggested experiment. Set up a pulley, string, and hanging mass so that the cart/force sensor will be pulled by the string attached to the hanging mass. Use the motion sensor to measure the change in position and the velocity of the cart as it is pulled by the string. Use the computer program to find the integration under the curve of a force versus distance graph. Use the program to calculate the amount of kinetic energy gained by the cart. Compare the calculated value of the work to the calculated value of the final kinetic energy.



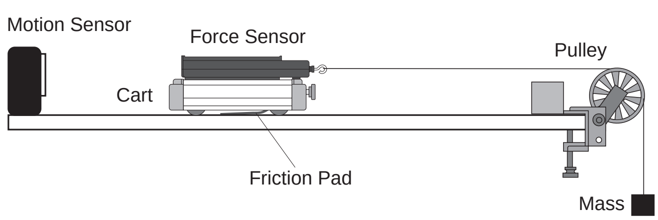
Tension

What is the tension in the string in the previous suggested experiment? Arrange the force sensor and cart on the track as in the previous suggested experiment. Set up a pulley, string, and hanging mass so that the cart/force sensor will be pulled by the string attached to the hanging mass. First, hold the cart at rest so the tension in the string is “mg” (the hanging mass times the acceleration due to gravity). Then, let go of the cart so it accelerates toward the pulley. Use the program to measure the amount of force in the string. The tension should be constant, but less than “mg”.



Newton’s Second Law: Friction

Make observations when a force is applied to the cart/force sensor and compare its acceleration when no friction is present to the acceleration when friction is added. You will need to add the Friction Cart Accessory to the dynamics cart. Arrange the motion sensor, force sensor, and “friction” cart on the track as in the previous suggested experiment. Set up a pulley, string, and hanging mass so that the cart/force sensor will be pulled by the string attached to the hanging mass. Adjust the friction cart accessory so the friction pad is not in contact with the track. Accelerate the cart with a 50 gram mass. Use the motion sensor to measure the velocity and acceleration of the cart as it is pulled by the string. Use the computer program to compare the measured force to the measured velocity and acceleration. Adjust the friction pad on the bottom of the cart until it is rubbing against the track just enough to cause the cart to move with a constant velocity as the 50 gram mass falls. Use the motion sensor and the computer program to analyze the force, velocity, and acceleration. Finally, raise the friction pad so it rubs the track slightly less than before and repeat the measurements.



Newton’s Third Law

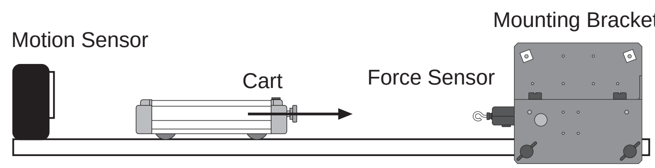
“For every action, there is an opposite but equal reaction.” Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first. Use two force sensors. Set up the computer program so that a push will be negative for one of the sensors. Hook the two sensors together, and use the computer program to measure the force from both force sensors as you pull one force sensor with the second force sensor.

Newton’s Third Law: Impulse/Collision

The impulse during a collision equals the change in momentum during the collision:

$$F\Delta t = \Delta mv$$

Mount the force sensor at one end of the track. Arrange the cart and motion sensor so the motion sensor can measure the motion of the cart as it is pushed toward the force sensor, collides with it, and rebounds. Use the computer program to determine the impulse and the change in momentum during the collision.



Other Suggested Experiments

- Measure the force of a fan cart.
- Measure the centripetal force of a swinging pendulum, and compare the force to the speed, length, and mass of the pendulum.
- Measure the change in mass of liquid nitrogen as it vaporizes versus the energy input to vaporize the liquid nitrogen.
- Measure fluid drag forces on objects of various shapes in a wind tunnel.
- Measure the net force acting on a pair of harmonic oscillators.
- Study damped and undamped harmonic motion using a mass and spring system.

Specifications

Output voltage: +8V for +50 Newtons (pushing)
-8 V for -50 Newtons (pulling)

Output noise: ±2 millivolts

Force slew rate: 25 Newtons/millisecond

Bandwidth limit: 2 kilohertz
(internal low pass filter)

Output drive: 8 meters of cable without instability.

Technical Support

Feedback

If you have any comments about this product or this manual please let us know. If you have any suggestions on alternate experiments or find a problem in the manual please tell us. PASCO appreciates any customer feedback. Your input helps us evaluate and improve our product.

To Reach PASCO

For Technical Support call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

email: techsupp@PASCO.com

Contacting Technical Support

Before you call the PASCO Technical Support staff it would be helpful to prepare the following information:

• If your problem is computer/software related, note:

Title and Revision Date of software.

Type of Computer (Make, Model, Speed).

Type of external Cables/Peripherals.

• If your problem is with the PASCO apparatus, note:

Title and Model number (usually listed on the label).

Approximate age of apparatus.

A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.)

If possible, have the apparatus within reach when calling. This makes descriptions of individual parts much easier.

• If your problem relates to the instruction manual, note:

Part number and Revision (listed by month and year on the front cover).

Have the manual at hand to discuss your questions.

Instruction Manual and Experiment Guide for the PASCO scientific Model CI-6538

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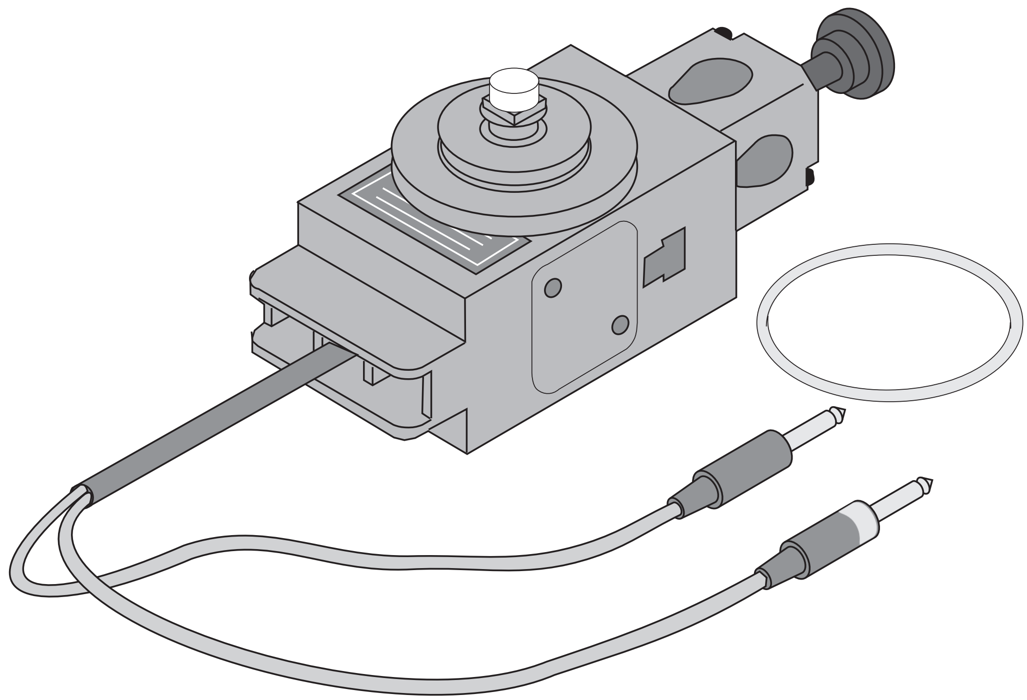
ROTARY MOTION SENSOR



$10.00

PASCO scientific

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better ways to teach science

Table of Contents

Copyright, Warranty and Equipment Return

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Copyright Notice

Limited Warranty

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by PASCO scientific.

Credits

This manual authored by: Jon Hanks

Equipment Return

Should the product have to be returned to PASCO scientific for any reason, notify PASCO scientific by letter, phone, or fax BEFORE returning the product. Upon notification, the return authorization and shipping instructions will be promptly issued.

➤ **NOTE:** NO EQUIPMENT WILL BE ACCEPTED FOR RETURN WITHOUT AN AUTHORIZATION FROM PASCO.

When returning equipment for repair, the units must be packed properly. Carriers will not accept responsibility for damage caused by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

① The packing carton must be strong enough for the item shipped.

② Make certain there are at least two inches of packing material between any point on the apparatus and the inside walls of the carton.

③ Make certain that the packing material cannot shift in the box or become compressed, allowing the instrument come in contact with the packing carton.

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

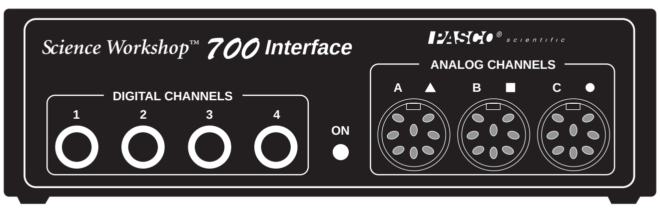
Phone: (916) 786-3800
FAX: (916) 786-3292
email: techsupp@pasco.com
web: www.pasco.com

PASCO® scientific

Introduction

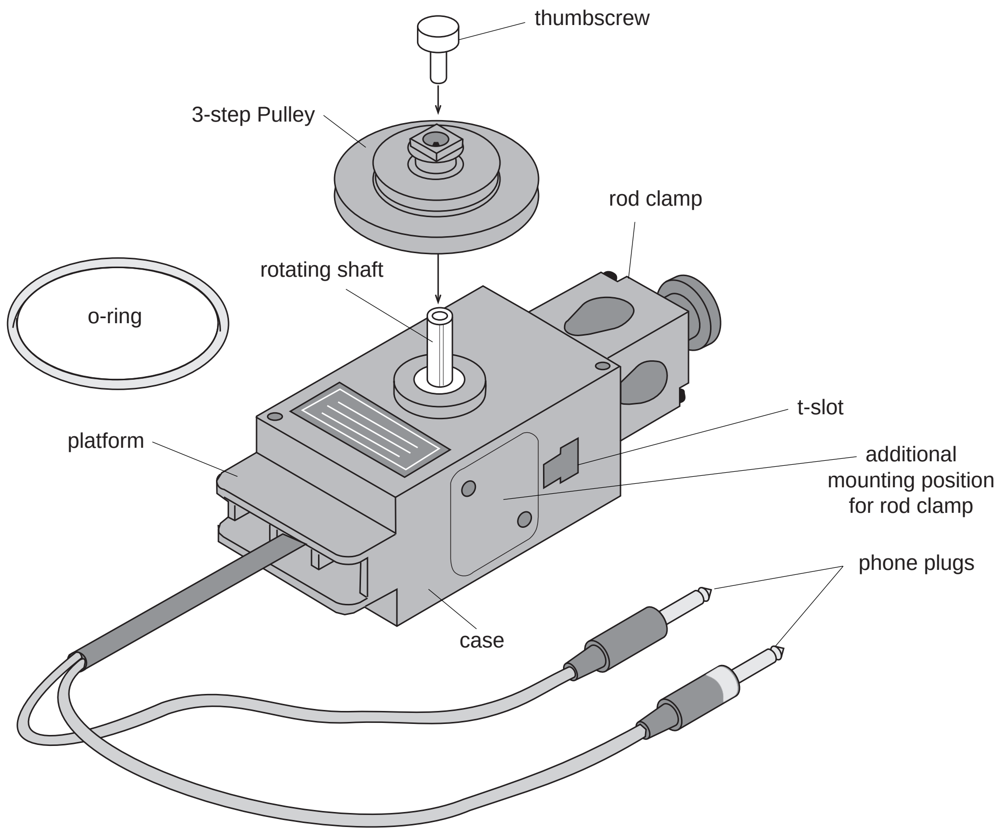
The PASCO CI-6538 Rotary Motion Sensor (RMS) is a bidirectional position sensor designed for use with the PASCO *Science Workshop™ 700 Interface*. It contains an optical encoder which gives a maximum of 1440 counts per revolution (360 degrees) of the Rotary Motion Sensor shaft. The resolution can be set in the *Science Workshop* software to 360 or 1440 times per revolution (1 degree or 1/4 degree). The direction of rotation is also sensed.

The Rotary Motion Sensor has two phone plugs which plug into any two adjacent digital channels on the 700 interface box.



Science Workshop version 2.1 or higher is required.

The rod clamp can be mounted on three sides of the sensor case, allowing the Rotary Motion Sensor to be mounted on a rod stand in many different orientations. The 3-step Pulley keys into the rotating shaft and can be mounted on either end of the shaft. A rubber o-ring is intended to be slipped over the largest pulley step so the RMS can be pressed against a surface to sense the relative motion between the sensor and the surface. The end of the Rotary Motion Sensor where the cord exits the case provides a platform for mounting a clamp-on Super Pulley. The t-slot in either side of the RMS is for inserting the optional Linear Motion Accessory rack. This allows you to measure linear motion over the length of the rack.

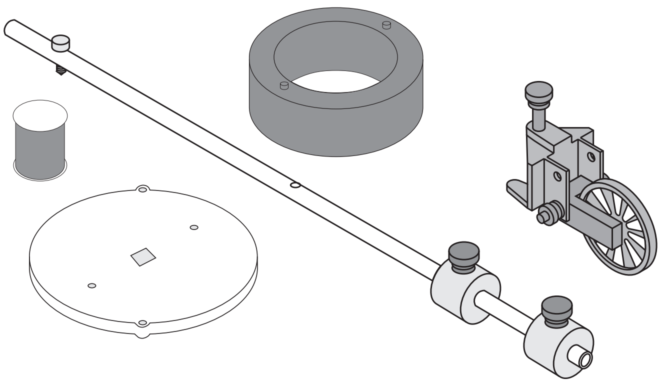


Rotary Motion Sensor Parts

Optional Accessories

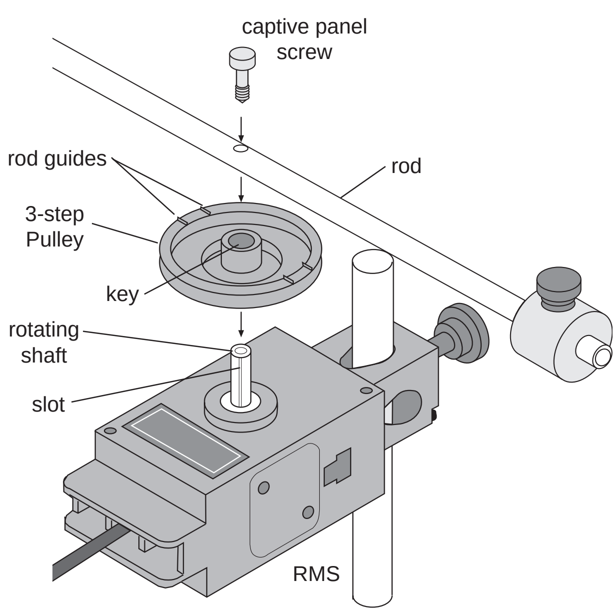
Mini-Rotational Accessory

The PASCO CI-6691 Mini-Rotational Accessory is used to perform rotational inertia experiments, conservation of angular momentum experiments, and pendulum experiments. Included are an aluminum disk, a steel ring, a long thin rod, and two brass masses which can be attached at any point on the thin rod to act as point masses.



Attaching the Rod

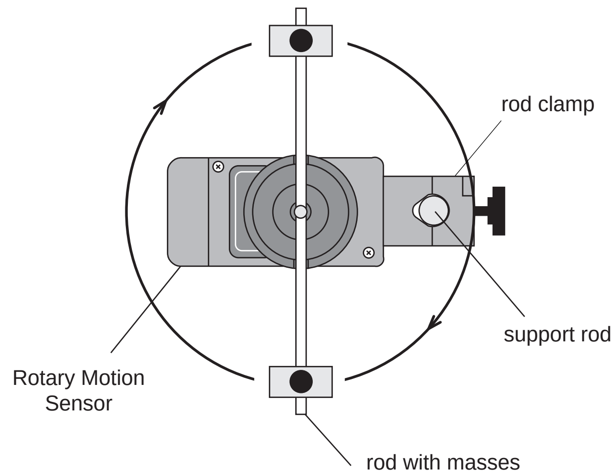
To attach the rod to the RMS, it is necessary to orient the 3-step Pulley so the rod guides on the underside of the pulley face up. The 3-step Pulley and the rotating shaft on the RMS are keyed to assemble only in one position. Assemble the apparatus as illustrated.



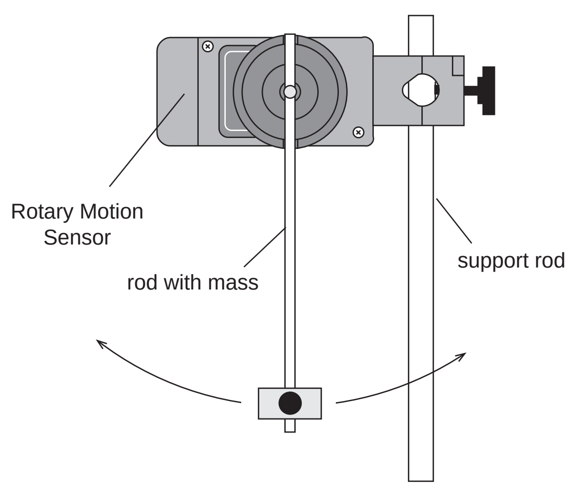
Using the Rod

The rod can be used for two purposes:

- The center of the rod can be attached to the RMS rotating shaft and used with the point masses to find the rotational inertia of point masses.



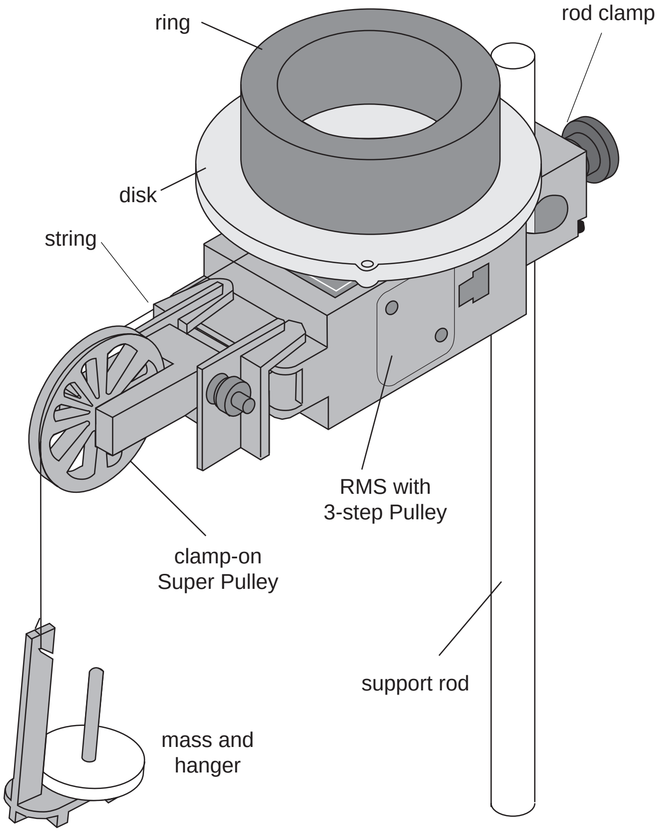
- The end of the rod can be attached to the Rotary Motion Sensor rotating shaft to use it as a pendulum.



Using the Disk and Ring

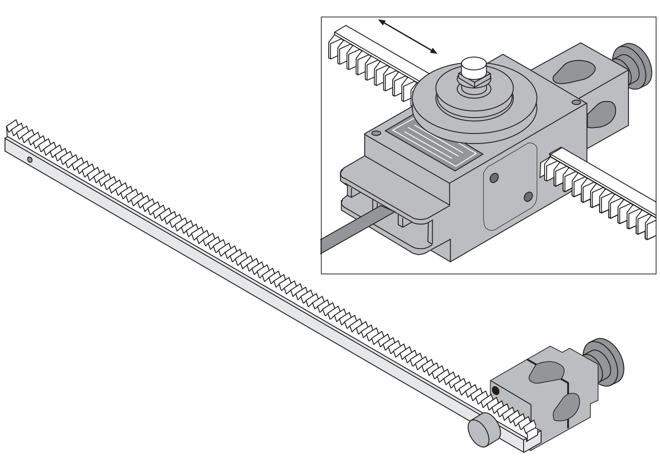
For rotational inertia experiments, wrap a string attached to a mass around the 3-step Pulley included with the Rotary Motion Sensor. Hang the mass over the clamp-on Super Pulley to accelerate the apparatus.

Perform a conservation of angular momentum experiment by dropping the ring onto the rotating disk.



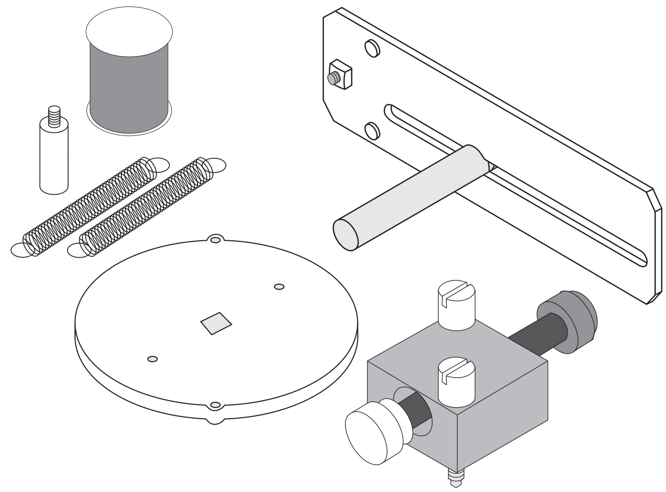
Linear Motion Accessory

The PASCO CI-6688 Linear Motion Accessory is a 21 cm long rack that is inserted into the t-slot in the side of the RMS to convert a linear motion into a rotary motion. The teeth on the rack engage a gear inside the RMS, causing it to rotate as the rack is pushed through the slot. The rack may be inserted into either side of the RMS. Sensors can be mounted to the rack using the rod clamp which can be attached to either end of the Linear Motion Accessory rack.

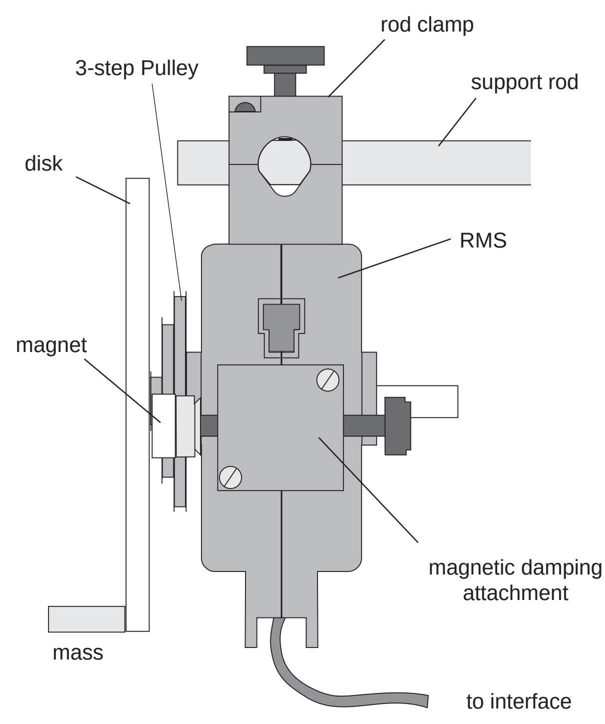


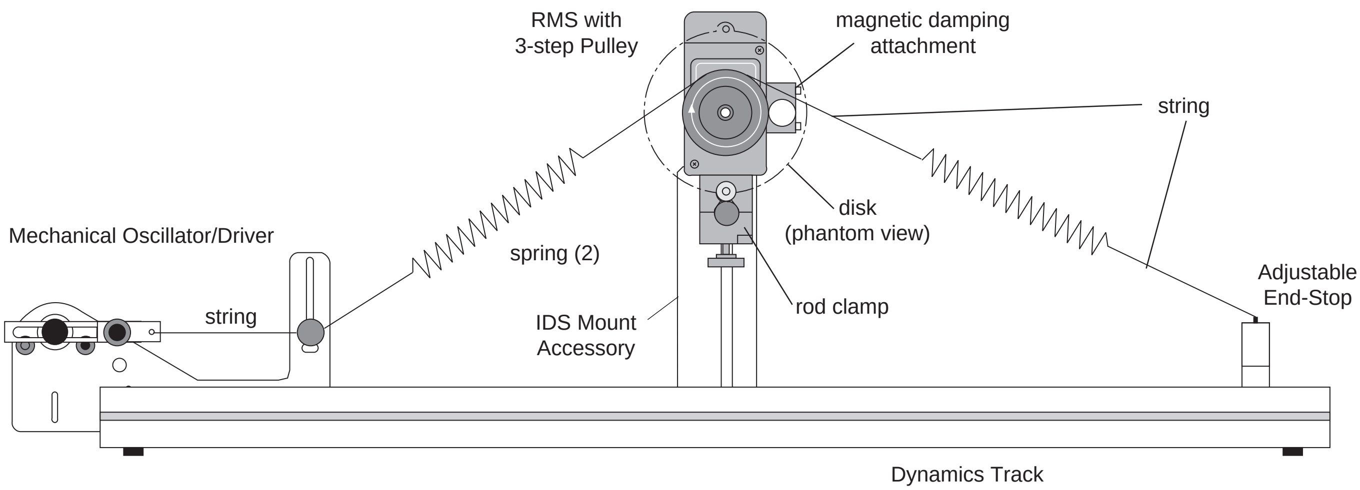
Chaos Accessory

The PASCO CI-6689 Chaos Accessory consists of an aluminum disk (identical to the one provided with the Mini-Rotational Accessory), a mass which attaches to the edge of the disk to form a physical pendulum, two springs for putting tension in the thread, a mounting bracket for mounting the RMS to the PASCO Introductory Dynamics System tracks (1.2 meter ME-9435A or 2.2 meter ME-9458), and an adjustable-gap magnet which attaches to the side of the RMS to provide variable magnetic damping. See the next page for diagram of the equipment setup.



The Chaos Accessory is a driven damped physical pendulum. Various types of phase plots can be made as the driving frequency, driving amplitude, initial conditions, and amount of damping are varied.

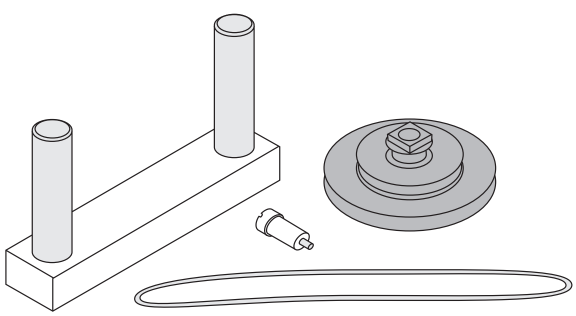




Chaos Accessory with Mechanical Oscillator on a Dynamics Track

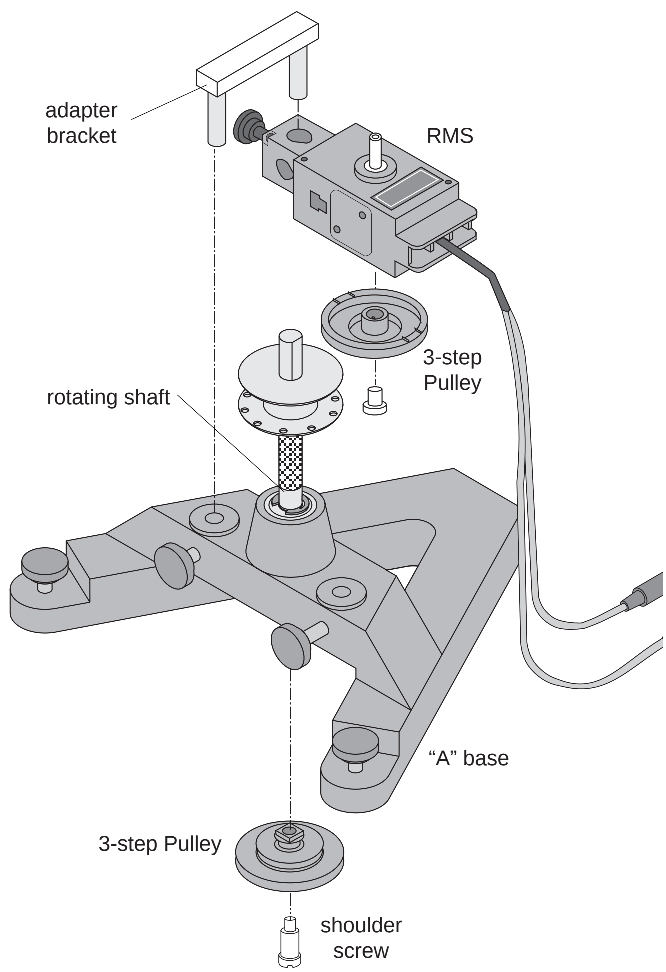
A PASCO ME-8750 Mechanical Oscillator/Driver is also required to drive the Chaos Accessory. The 1.2 m Dynamics Track is used as a convenient way to mount and align all the components. However, it is possible to mount the components on separate rod stands if a Dynamics Track is not available.

“A”-base Rotational Adapter

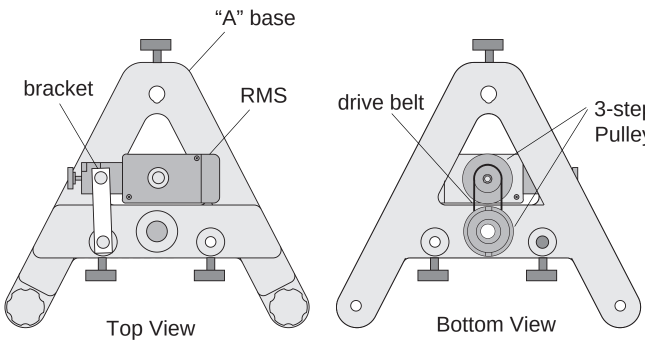


The CI-6690 “A”-base Rotational Adapter is used to mount the Rotary Motion Sensor to the “A” base of the ME-8951 Rotating Platform or the ME-8960 Gyroscope. The RMS provides higher resolution than a Smart Pulley, and precession of the Gyroscope can be plotted since the RMS keeps track of direction of rotation. The adapter includes a mounting bracket, a shoulder screw, a drive belt (o-ring), and a 3-step Pulley. The drive belt links the 3-step Pulley mounted on the “A” base to the 3-step Pulley on the RMS. For a one-to-one correspondence, connect the two pulleys using the o-ring on the middle step of each pulley. Each revolution of the Rotating Platform or Gyroscope corresponds to one revolution of the RMS. If desired, a 5-to-1 ration can be attained by putting the o-ring on the top or bottom steps.

The pulley attaches to the underside of the rotating shaft with the shoulder screw. Please note the pulley orientation illustrated below. The bracket connects to the “A” base of the Rotating Platform or the Gyroscope and to the RMS rod clamp.

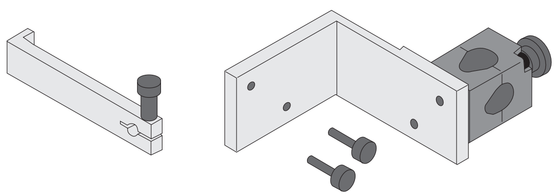


Assembling the RMS to the “A” Base

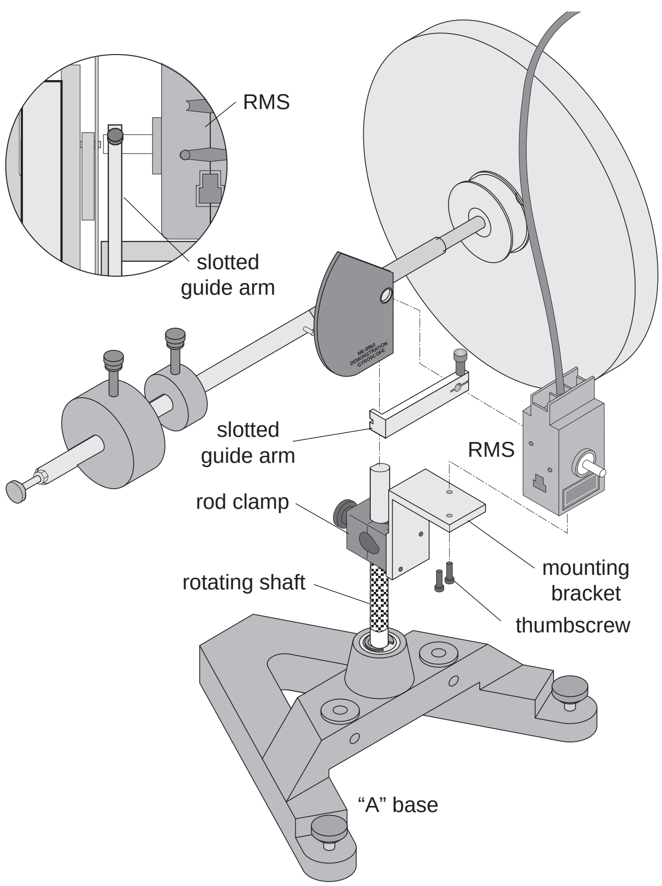


RMS Mounted on "A" Base

RMS/Gyroscope Mounting Bracket

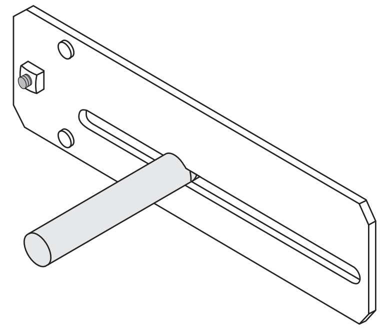


The PASCO ME-8963 RMS/Gyroscope Mounting Bracket attaches the Rotary Motion Sensor to the ME-8960 Gyroscope so the angle of nutation can be detected.

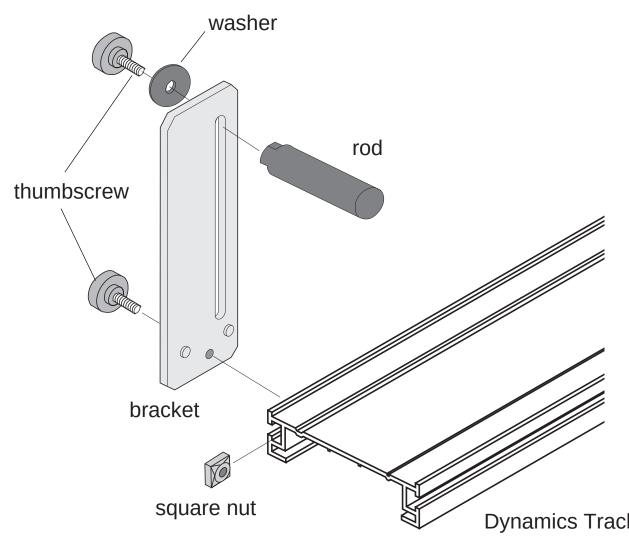


Assembling the RMS to the Gyroscope

IDS Mount Accessory

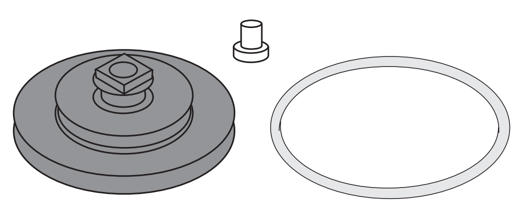


The PASCO CI-6692 IDS Mount Accessory is a bracket that allows the Rotary Motion Sensor to be easily attached to the Introductory Dynamics System tracks.



Attaching IDS Mount Accessory to Dynamics Track

3-step Pulley Accessory



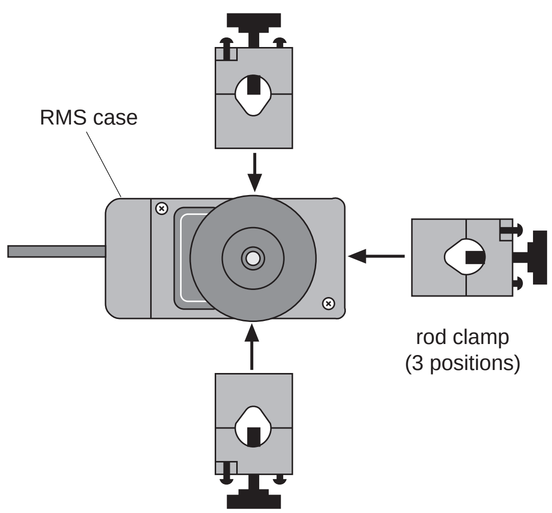
The PASCO CI-6693 3-step Pulley Accessory includes an additional pulley for mounting a 3-step Pulley on each end of the Rotary Motion Sensor rotating shaft. It also includes an o-ring.

General Setup and Operation

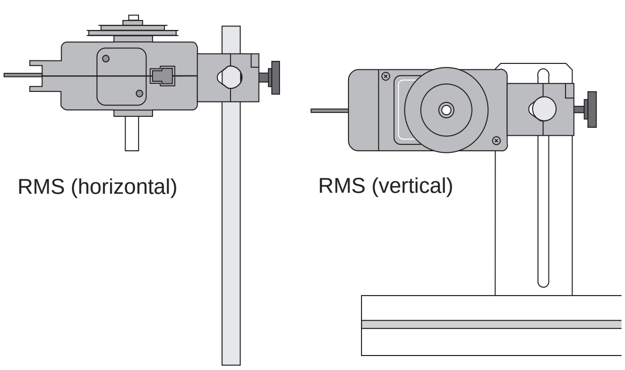
Mounting the RMS

Attaching the RMS to a Support Rod

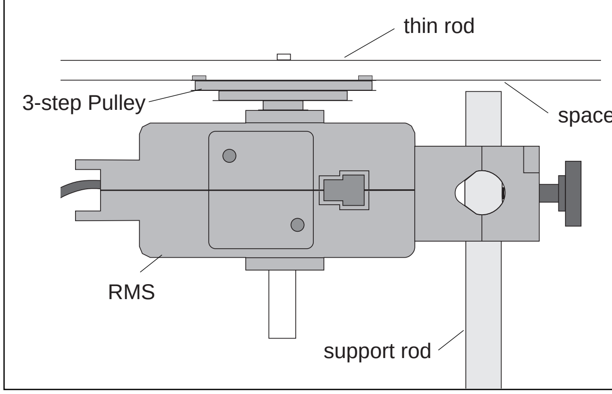
The Rotary Motion Sensor can be mounted on a support rod using the supplied rod clamp. The rod clamp can be mounted in three different locations on the Rotary Motion Sensor: at the end opposite the cable and on either side of the case. A Phillips screwdriver is required to remove the two screws that hold the rod clamp on the Rotary Motion Sensor case.



It is possible to mount the RMS horizontally on a support rod, with the 3-step Pulley facing up or vertically, with the pulley facing forward.

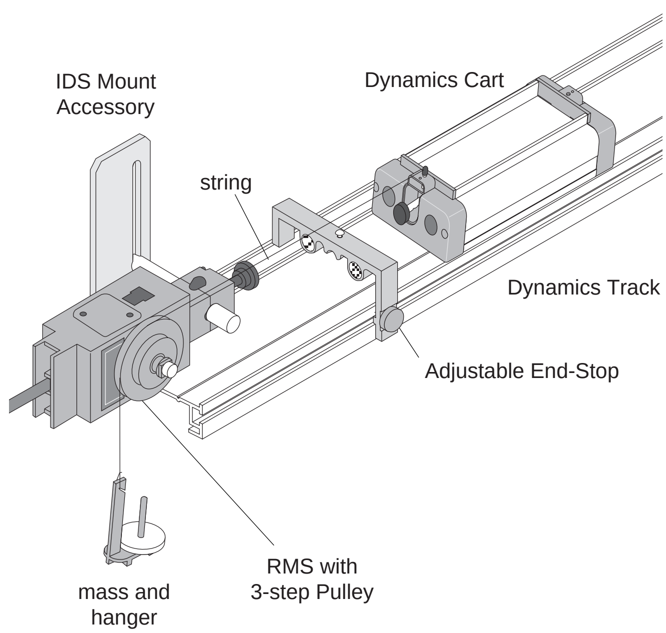


➤ **NOTE:** When setting up the rotational inertia experiment with the thin rod from the Mini-Rotational Accessory, the Rotary Motion Sensor must be mounted at the top of the support rod so the rod does not interfere with the rotation of the thin rod.



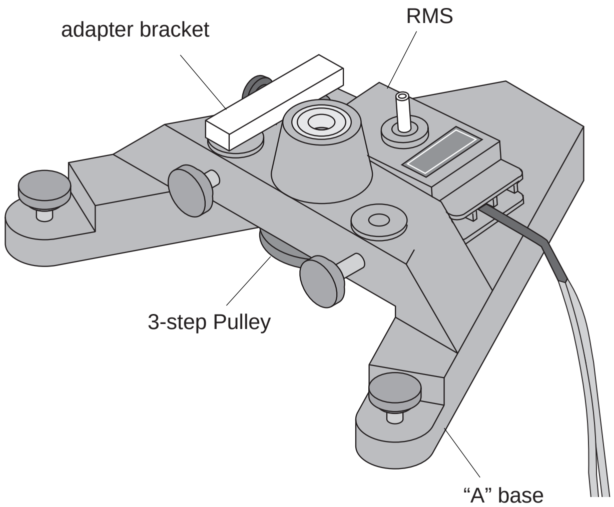
Attaching the RMS to a Dynamics Track

The Rotary Motion Sensor can be mounted to a Dynamics Track using the IDS Mount Accessory. The RMS mounts on the horizontal rod using the RMS rod clamp. The Rotary Motion Sensor can be used as a "Smart Pulley" in this configuration by threading a string over the Rotary Motion Sensor pulley and hanging a mass on the string.



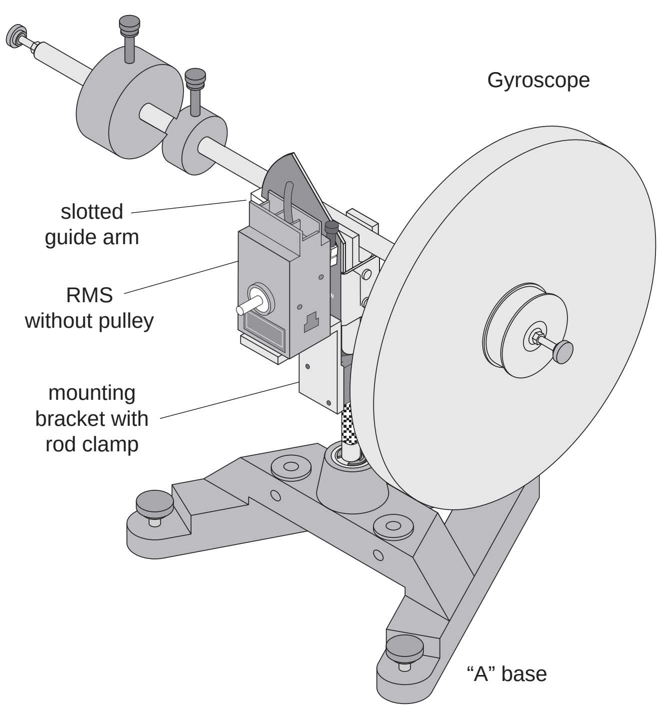
Attaching the RMS to the "A" base

The Rotary Motion Sensor can be mounted to the Rotating Platform or the Gyroscope using the "A"-base Rotational Adapter. This allows the precession angle of the Gyroscope to be detected.



Attaching the RMS to the Gyroscope

The Rotary Motion Sensor can be mounted to the Gyroscope using the RMS/Gyroscope Accessory. This allows the nutation angle of the Gyroscope to be detected.



Plugging the Rotary Motion Sensor Into The Interface

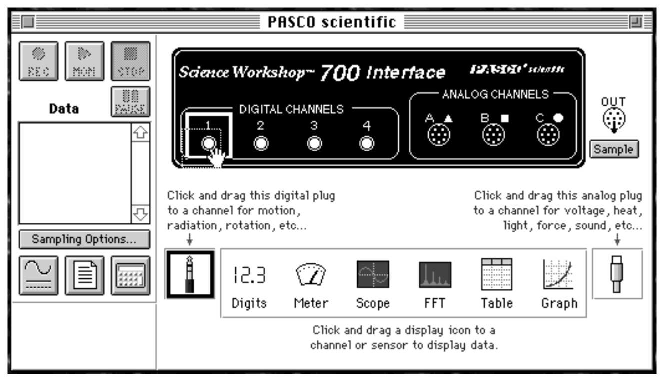
To operate the Rotary Motion Sensor, it must be plugged into the *Science Workshop™ 700 Interface*. The two phone plugs from the Rotary Motion Sensor need to be plugged into any two adjacent digital input channels on the 700 interface box. The order of the plugs is not critical.

> ➤ **NOTE:** If the direction of movement of the Rotary Motion Sensor produces a negative displacement when you desire a positive displacement, simply reverse the order of the plugs.

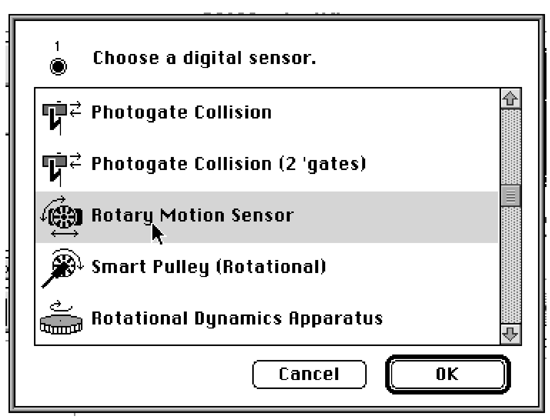
Using the *Science Workshop™* Software with the Rotary Motion Sensor

① Start *Science Workshop*.

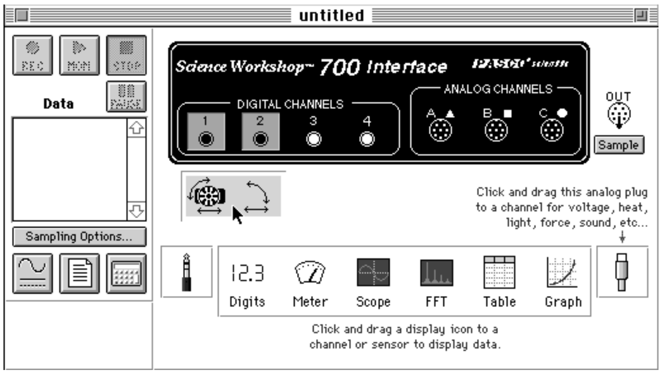
② On the Experiment Setup Window, click on the phone plug icon and drag it to one of the digital channels.



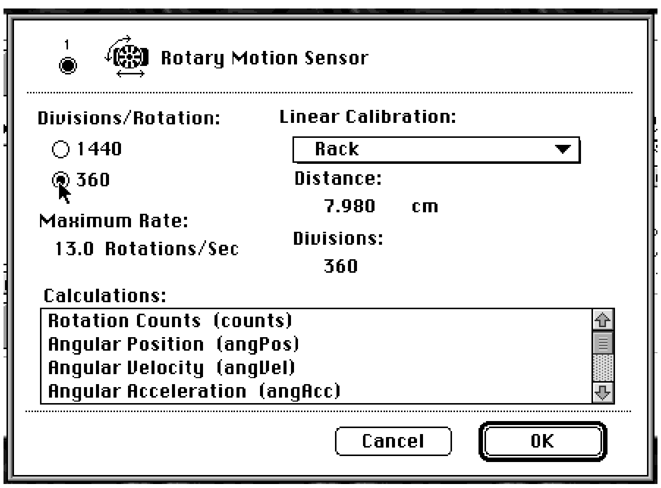
③ Select the Rotary Motion Sensor from the digital sensor menu and click on OK.



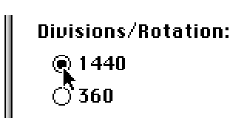
The program will automatically show two phone plugs plugged into two consecutive channels.



④ Double click on the Rotary Motion Sensor icon to activate the sensor setup dialog box for the Rotary Motion Sensor.

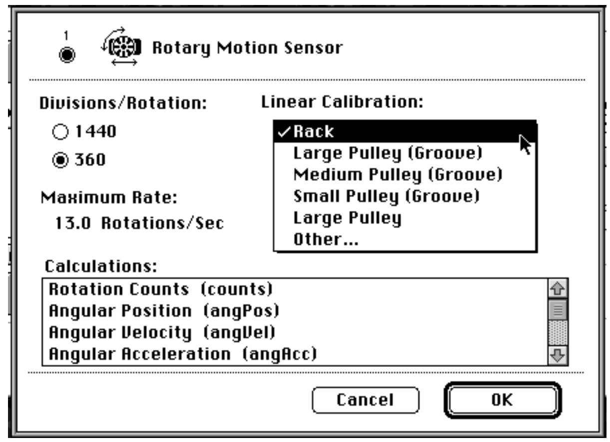


Choose the resolution: 360 divisions per rotation (the default value) or 1440 divisions per rotation.

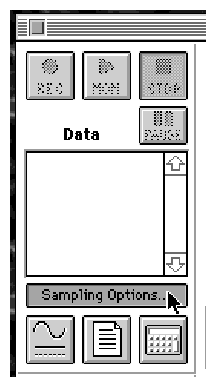


The required resolution depends on the rate at which the Rotary Motion Sensor will rotate during the experiment. See the *Suggested Experiments* section of this manual for suggested resolutions. In general, if the RMS will turn quickly during the experiment, the resolution should be 360 divisions per rotation so the data rate won't be too high. If the RMS will turn slowly and a finer resolution is needed, 1440 should be chosen.

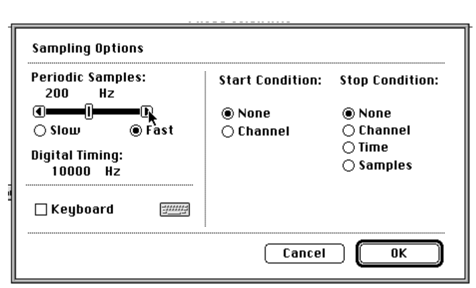
If the RMS is used to take linear measurements, it is necessary to choose the type of linear accessory used. Make the appropriate selection in the Linear Calibration section of the settings menu.



⑤ Click on "Sampling Options" and set the rate at which data will be sampled.



In general, the sampling rate should be as fast as possible. If the sampling rate is too fast, the lines in a graph become chunky.



PASCO® scientific

Experiment 1: Rotational Inertia of a Point Mass

EQUIPMENT REQUIRED

– *Science Workshop™ 700 Interface*
– Mini-Rotational Accessory (CI-6691)
– Base and Support Rod (ME-9355)
– paper clips (for masses < 1 g)
– Rotary Motion Sensor (CI-6538)
– Mass and Hanger Set (ME-9348)
– Triple Beam Balance (SE-8723)
– calipers

Purpose

The purpose of this experiment is to find the rotational inertia of a point mass experimentally and to verify that this value corresponds to the calculated theoretical value.

Theory

Theoretically, the rotational inertia, I, of a point mass is given by $I = MR^2$, where M is the mass, and R is the distance the mass is from the axis of rotation. Since this experiment uses two masses equidistant from the center of rotation, the total rotational inertia will be

$$I_{total} = M_{total}R^2$$

where $M_{total} = M_1 + M_2$, the total mass of both point masses.

To find the rotational inertia experimentally, a known torque is applied to the object and the resulting angular acceleration is measured. Since $\tau = I\alpha$,

$$I = \frac{\tau}{\alpha}$$

where α is the angular acceleration, which is equal to a/r (a = linear acceleration), and τ is the torque caused by the weight hanging from the thread that is wrapped around the 3-step Pulley.

$$\tau = rT$$

where r is the radius of the chosen pulley about which the thread is wound, and T is the tension in the thread when the apparatus is rotating.

Applying Newton's Second Law for the hanging mass, m, gives

$$\Sigma F = mg - T = ma$$

(see Figure 1.1). Solving for the tension in the thread gives:

$$T = m\left(g - a\right)$$

Once the angular acceleration of the mass (m) is measured, the torque and the linear acceleration can be obtained for the calculation of the rotational inertia.

Setup

① Attach a mass on each end of the rod (part of the Mini-Rotational Accessory) equidistant from the rod center. You may choose any radius you wish.

② Tie one end of the string to the Mass Hanger and the other end to one of the levels of the 3-step Pulley on the RMS.

③ Mount the thin rod to the pulley on the Rotary Motion Sensor. Please note the orientation of the 3-step Pulley.

④ Mount the RMS to a support rod and connect it to a computer. Make sure that the support rod does not interfere with the rotation of the accessory rod. See Figure 1.1.

⑤ Mount the clamp-on Super Pulley to the Rotary Motion Sensor.

⑥ Drape the string over the Super Pulley such that the string is in the groove of the pulley and the Mass Hanger hangs freely (see Figure 1.1).

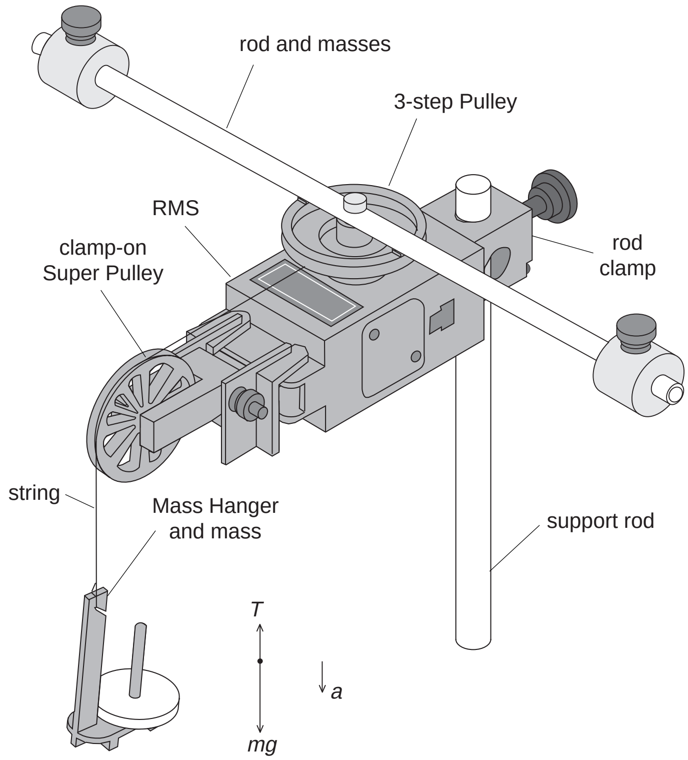
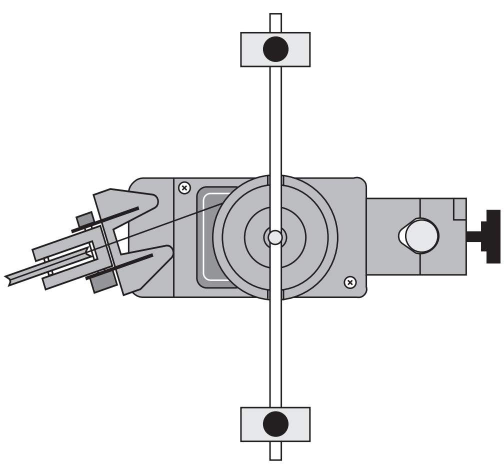


Figure 1.1: Rotary Motion Sensor and Free-Body Diagram

➤ **NOTE:** The clamp-on Super Pulley must be adjusted at an angle so the thread runs in a line tangent to the point where it leaves the 3-step Pulley and straight down the middle of the groove on the clamp-on Super Pulley.



⑦ Adjust the Super Pulley height so the thread is level with the 3-step Pulley.

Procedure

Part I: Measurements For the Theoretical Rotational Inertia

① Weigh the masses to find the total mass M_{total} and record in Table 1.1.

② Measure the distance from the axis of rotation to the center of the masses and record this radius in Table 1.1.

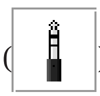
Table 1.1: Theoretical Rotational Inertia Data

Total Mass	
Radius	

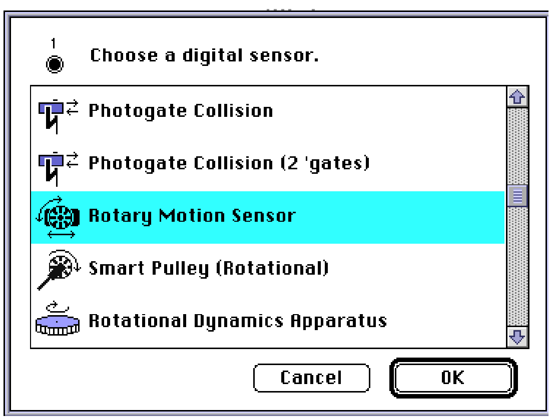
Part II: Measurement For the Experimental Method

Finding the Acceleration of the Point Masses and Apparatus

① Run *Science Workshop*.

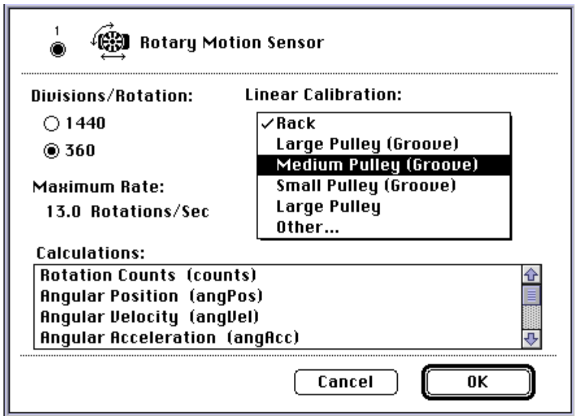
② In the Experiment Setup window, click and drag a digital sensor icon () to the first of the two consecutive digital ports that the RMS is plugged into.

③ Select the RMS from the digital sensor menu and click OK.

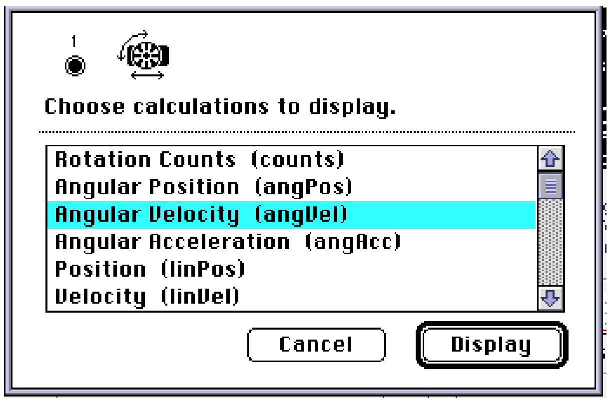


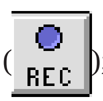
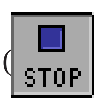
④ Double click the RMS icon in Experiment Setup window to activate the sensor dialog box for the RMS.

⑤ Ensure that the Divisions / Rotation radio button is in the 360 position, and select the appropriate pulley in the Linear Calibration pop-up menu; click OK.

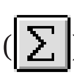


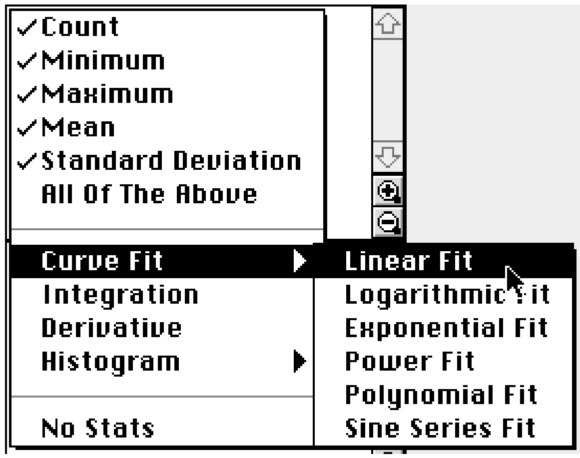
⑥ Click and drag a Graph to the RMS icon and select “Angular Velocity” from the built in calculations window; click OK.



⑦ Put the 50 g mass on the Mass Hanger and wind up the thread. Click on the Record button (); then release the 3-step Pulley, allowing the mass to fall. Click the Stop button () to end the data collection.

➤ **HINT**: Click the stop button before the mass reaches the floor or the end of the thread to avoid erroneous data.

⑧ In the Graph Display window, click on the Statistics button (); then select the linear curve fit from the pop-up menu.



The slope of the linear fit represents the angular acceleration (α) and should be entered in Table 1.2.

Measure the Radius

① Using calipers, measure the diameter of the pulley about which the thread is wrapped and calculate the radius. Record in Table 1.2.

Finding the Acceleration of the Apparatus Alone

In **Finding the Acceleration of the Point Mass and Apparatus,** the apparatus is rotating and contributing to the rotational inertia. It is necessary to determine the acceleration and the rotational inertia of the apparatus by itself so this rotational inertia can be subtracted from the total, leaving only the rotational inertia of the point masses.

① Take the point masses off the rod and repeat **Finding the Acceleration of the Point Mass and Apparatus** for the apparatus alone. It may be necessary to decrease the amount of the hanging mass so the apparatus does not accelerate so fast that the computer cannot keep up with the data collection rate.

② Record the data in Table 1.2.

Calculations

① Calculate the experimental value of the rotational inertia of the point masses and apparatus together and record in Table 1.3.

② Calculate the experimental value of the rotational inertia of the apparatus alone. Record in Table 1.3.

③ Subtract the rotational inertia of the apparatus from the combined rotational inertia of the point masses and apparatus. This will be the rotational inertia of the point masses alone. Record in Table 1.3.

④ Calculate the theoretical value of the rotational inertia of the point masses. Record in Table 1.3.

⑤ Use a percent difference to compare the experimental value to the theoretical value. Record in Table 1.3.

Table 1.2: Experimental Rotational Inertia Data

	Point Mass and Apparatus	Apparatus Alone
Hanging Mass		
Slope		
Radius		

Table 1.3: Results

Rotational Inertia for Point Masses and Apparatus Combined	
Rotational Inertia for Apparatus Alone	
Rotational Inertia for Point Masses (experimental value)	
Rotational Inertia for Point Masses (theoretical value)	
% Difference	

Experiment 2: Rotational Inertia of Disk and Ring

EQUIPMENT REQUIRED

– *Science Workshop™ 700 Interface*
– Mini-Rotational Accessory (CI-6691)
– Base and Support Rod (ME-9355)
– paper clips (for masses < 1 g)
– Rotary Motion Sensor (CI-6538)
– Mass and Hanger Set (ME-9348)
– Triple Beam Balance (SE-8723)
– calipers

Purpose

The purpose of this experiment is to find the rotational inertia of a ring and a disk experimentally and to verify that these values correspond to the calculated theoretical values.

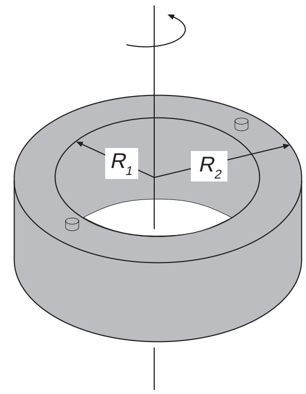


Figure 2.1: Ring

Theory

Theoretically, the rotational inertia, I, of a ring about its center of mass is given by:

$$I = \frac{1}{2}M\left(R_1^{\,2} + R_2^{\,2}\right)$$

where M is the mass of the ring, R_1 is the inner radius of the ring, and R_2 is the outer radius of the ring. See Figure 2.1.

The rotational inertia of a disk about its center of mass is given by:

$$I = \frac{1}{2}MR^2$$

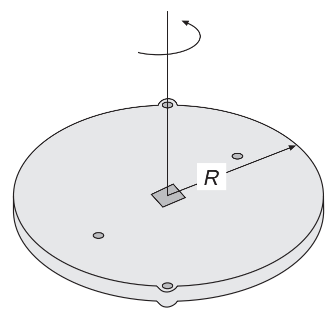


Figure 2.2: Disk about center of Mass

where M is the mass of the disk and R is the radius of the disk. See Figure 2.2.

To find the rotational inertia experimentally, a known torque is applied to the object and the resulting angular acceleration is measured. Since $\tau = I\alpha$,

$$I = \frac{\tau}{\alpha}$$

where α is the angular acceleration, which is equal to a/r (a = acceleration), and τ is the torque caused by the weight hanging from the thread that is wrapped around the base of the apparatus.

$$\tau = rT$$

where r is the radius of the pulley about which the thread is wound, and T is the tension in the thread when the apparatus is rotating.

Applying Newton's Second Law for the hanging mass, m, gives

$$\Sigma F = mg - T = ma$$

(see Figure 2.3). Solving for the tension in the thread gives:

$$T = m(g - a)$$

Once the angular acceleration is measured, the torque and the linear acceleration can be obtained for the calculation of the torque.

Setup

① Mount the RMS to a support rod and connect it to the interface.

② Mount the clamp-on Super Pulley to the Rotational Motion Sensor.

③ Tie one end of the string to the Mass Hanger and the other end to one of the levels of the 3-step Pulley on the RMS.

④ Drape the string over the Super Pulley such that the string is in the groove of the pulley and the Mass Hanger hangs freely (see Figure 2.3).

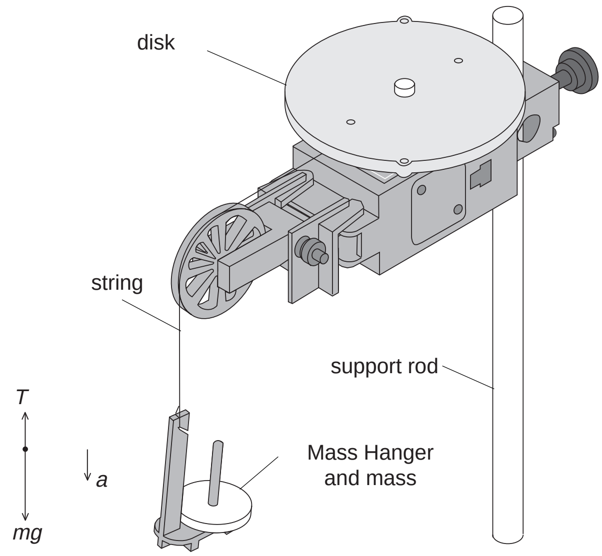
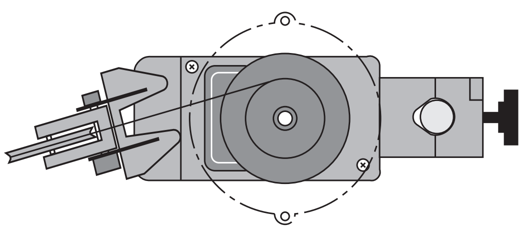


Figure 2.3: Rotary Motion Sensor and Free-Body Diagram

➤ **NOTE:** The clamp-on Super Pulley must be adjusted at an angle so the thread runs in a line tangent to the point where it leaves the 3-step Pulley and straight down the middle of the groove on the clamp-on Super Pulley.



⑤ Place the disk directly on the pulley as shown in Figure 2.3.

⑥ Place the mass ring on the disk, inserting the ring pins into the holes in the disk as shown in Figure 2.4.

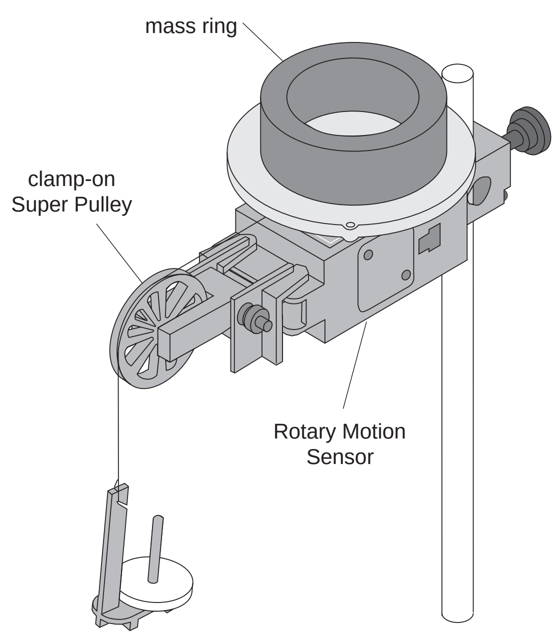


Figure 2.4: Setup for Disk and Ring

Procedure

Measurements for the Theoretical Rotational Inertia

① Weigh the ring and disk to find their masses and record these masses in Table 2.1.

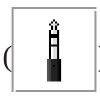
② Measure the inside and outside diameters of the ring and calculate the radii, R_1 and R_2. Record in Table 2.1.

③ Measure the diameter of the disk and calculate the radius, R, and record it in Table 2.1.

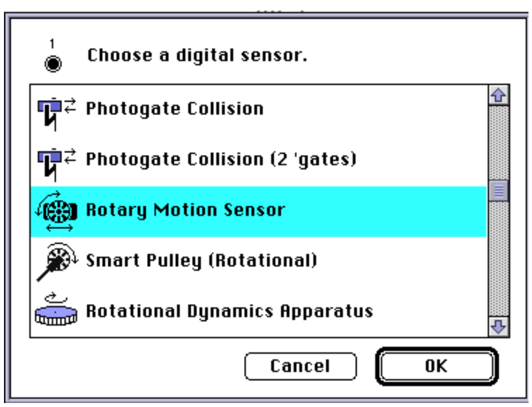
Measurements for the Experimental Method

Finding the Acceleration of Ring and Disk

① Run *Science Workshop*.

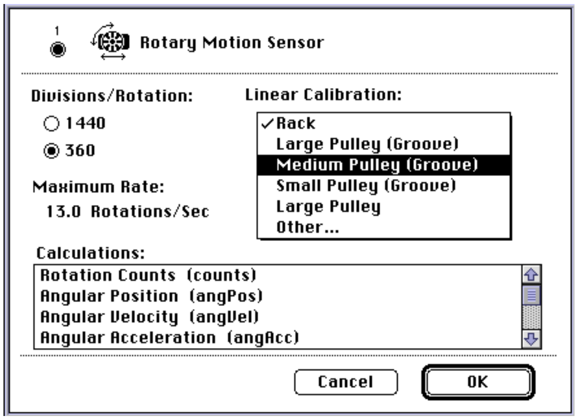
② In the Experiment Setup window, click and drag a digital sensor icon () to the first of the two consecutive digital ports that the RMS is plugged into.

③ Select the RMS from the digital sensor menu and click OK.

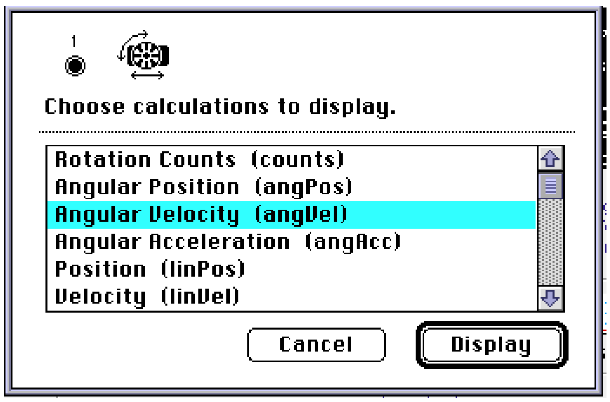


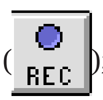
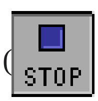
④ Double click the RMS icon in Experiment Setup window to activate the sensor dialog box for the RMS.

⑤ Ensure that the Divisions / Rotation radio button is in the 360 position, and select the appropriate pulley in the Linear Calibration pop-up menu; click OK.

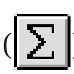


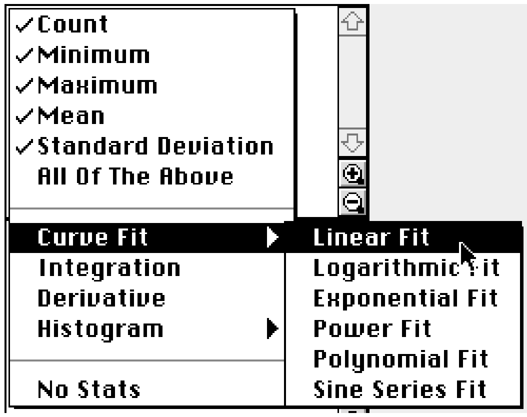
⑥ Click and drag a Graph to the RMS icon and select "Angular Velocity" from the built-in calculations window; click OK.



⑦ Put the 50 g mass on the Mass Hanger and wind up the thread. Click on the Record button (
); then release the 3-step Pulley, allowing the mass to fall. Click the Stop button (
) to end the data collection.

➤ **HINT**: Click the stop button before the mass reaches the floor or the end of the thread to avoid erroneous data.

⑧ In the Graph Display window, click on the Statistics button (); then select the linear curve fit from the pop-up menu.



The slope of the linear fit represents the angular acceleration (α) and should be entered in Table 2.2.

Measure the Radius

① Using calipers, measure the diameter of the pulley about which the thread is wrapped and calculate the radius. Record in Table 2.2.

Finding the Acceleration of the Disk Alone

Since in **Finding the Acceleration of Ring and Disk** both the disk and the ring are rotating, it is necessary to determine the acceleration and the rotational inertia of the disk by itself so this rotational inertia can be subtracted from the total, leaving only the rotational inertia of the ring.

① To do this, take the ring off the rotational apparatus and repeat **Finding the Acceleration of Ring and Disk** for the disk alone.

Calculations

Record the results of the following calculations in Table 2.3.

① Calculate the experimental value of the rotational inertia of the ring and disk together.

② Calculate the experimental value of the rotational inertia of the disk alone.

③ Subtract the rotational inertia of the disk from the total rotational inertia of the ring and disk. This will be the rotational inertia of the ring alone.

④ Use a percent difference to compare the experimental values to the theoretical values.

Table 2.1: Theoretical Rotational Inertia

Mass of Ring	
Mass of Disk	
Inner Radius of Ring	
Outer Radius of Ring	
Radius of Disk	

Table 2.2: Experimental Rotational Inertia Data

	Ring and Disk Combined	Disk Alone
Hanging Mass		
Slope		
Radius of Pulley		

Table 2.3: Results

Rotational Inertia of Ring and Disk	
Rotational Inertia of Disk Alone	
Rotational Inertia of Ring Alone	
% Difference for Disk	
% Difference for Ring	

Experiment 3: Conservation of Angular Momentum

EQUIPMENT REQUIRED

- *Science Workshop™ 700 Interface*
- Mini-Rotational Accessory (CI-6691)
- Base and Support Rod (ME-9355)
- paper clips (for masses < 1 g)
- Rotary Motion Sensor (CI-6538)
- Mass and Hanger Set (ME-9348)
- Triple Beam Balance (SE-8723)
- calipers

Purpose

A non-rotating ring is dropped onto a rotating disk, and the final angular speed of the system is compared with the value predicted using conservation of angular momentum.

Theory

When the ring is dropped onto the rotating disk, there is no net torque on the system since the torque on the ring is equal and opposite to the torque on the disk. Therefore, there is no change in angular momentum; angular momentum (L) is conserved.

$$L = I_i\omega_i = I_f\omega_f$$

where I_i is the initial rotational inertia and ω_i is the initial angular speed. The initial rotational inertia is that of a disk

$$I_i = \left(\frac{1}{2}\right) M_1 R^2$$

and the final rotational inertia of the combined disk and ring is

$$I_f = \frac{1}{2} M_1 R^2 + \frac{1}{2} M_2 \left(r_1^{\ 2} + r_2^{\ 2}\right)$$

where r_1 and r_2 are the inner and outer radii of the ring.

So the final rotational speed is given by

$$\omega_f = \frac{M_1 R^2}{M_1 R^2 + M_2\left(r_1^{\ 2} + r_2^{\ 2}\right)}\,\omega_i$$

Setup

① Mount the RMS to a support rod and connect it to a computer. Place the disk directly on the pulley as shown in Figure 3.1.

② Run *Science Workshop*.

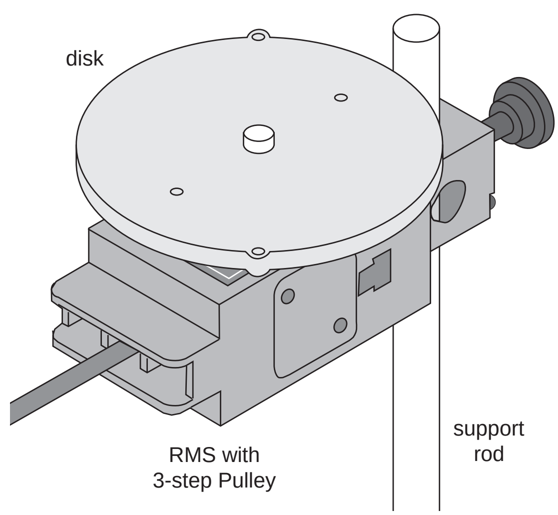
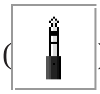
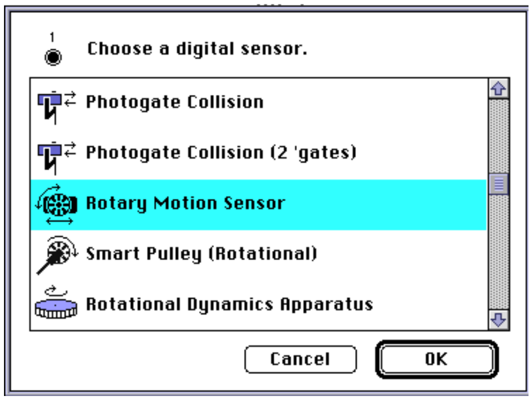


Figure 3.1: Setup for Dropping Ring Onto Disk

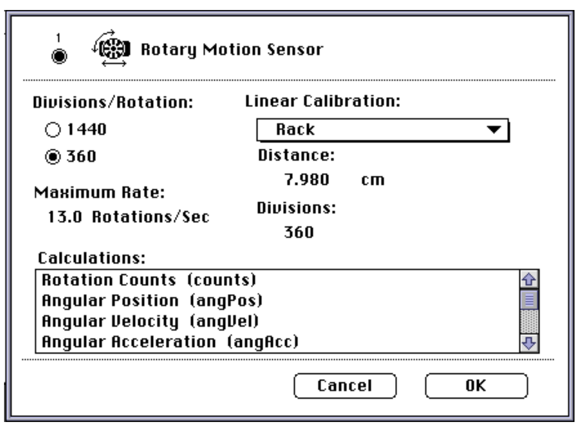
③ In the Experiment Setup window, click and drag a digital sensor icon () to the first of the two consecutive digital ports that the RMS is plugged into.

④ Select the RMS from the digital sensor menu and click OK.

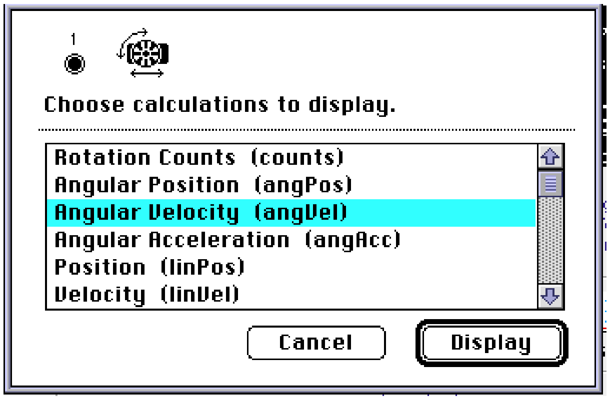


⑤ Double click the RMS icon in Experiment Setup window to activate the sensor dialog box for the RMS.

⑥ Ensure that the Divisions/Rotation radio button is in the 360 position.



⑦ Click and drag a Graph to the RMS icon and select “Angular Velocity” from the built-in calculations window; click OK.



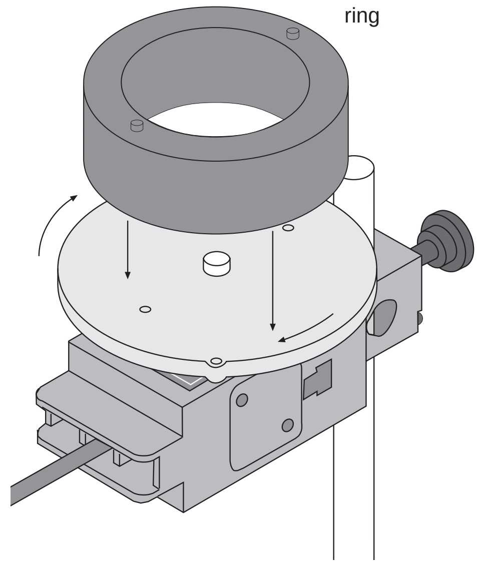
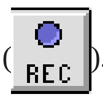
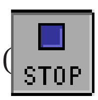
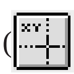


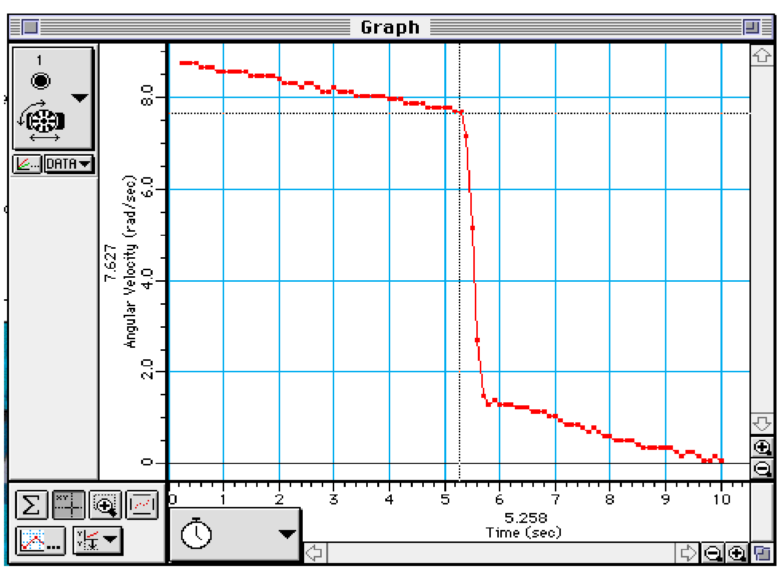
Figure 3.2: Drop Ring on Disk

Procedure

① Hold the ring with the pins up just above the center of the disk. Give the disk a spin using your hand and click the Record button (). After about 25 data points have been taken, drop the ring onto the spinning disk. See Figure 3.2.

② Click on the Stop button () to end the data collection.

③ Click on the Smart Cursor button () and move the cursor to the data point immediately before the collision. Record the Angular Velocity at this point in Table 3.1. Move the cursor to the data point immediately after the collision. Record the Angular Velocity at this point in Table 3.1.



④ Weigh the disk and ring and measure the radii. Record these values in Table 3.1.

Analysis

① Calculate the expected (theoretical) value for the final angular velocity and record this value in Table 3.1.

② Calculate the percent difference between the experimental and the theoretical values of the final angular velocity and record in Table 3.1.

Questions

① Does the experimental result for the angular velocity agree with the theory?

② What percentage of the rotational kinetic energy was lost during the collision? Calculate the energy lost and record the results in Table 3.1.

$$\%KE\ Lost = \frac{\frac{1}{2}I_i\omega_i^2 - \frac{1}{2}I_f\omega_f^2}{\frac{1}{2}I_i\omega_i^2}$$

Table 3.1: Data and Results

Initial Angular Velocity	
Final Angular Velocity (experimental value)	
Mass of Disk (M_1)	
Mass of Ring (M_2)	
Inner Radius of Ring (r_1)	
Outer Radius of Ring (r_2)	
Radius of Disk (R)	
Final Angular Velocity (theoretical value)	
% Difference Between Final Angular Velocities	
% KE lost	

Suggested Experiments

Experiment 4: Force versus Displacement – Collision between Cart and Force Sensor

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– IDS Mount Accessory (CI-6692)
– Dynamics Track (ME-9435A)
– Accessory Bracket with Bumpers (CI-6545)
– paper clips (for masses < 1 g)
– Rotary Motion Sensor (CI-6538)
– Force Sensor (CI-6537)
– Dynamics Cart (ME-9430)
– string

Purpose

The purpose of this experiment is to see the dependence of magnetic and spring forces on distance.

Procedure

① Mount the Force Sensor on one end of the Dynamics Track using the Accessory Bracket. Put the magnetic bumper on the Force Sensor.

② Attach the Rotary Motion Sensor to the other end of the track using the IDS Mount Accessory.

③ Put the cart on the track with its magnetic bumper facing the Force Sensor. Attach one end of a string to the cart and hang a mass (paper clip) on the other end of the string over the Rotary Motion Sensor pulley.

④ Set up *Science Workshop* to make a graph of force versus distance. The resolution of the Rotary Motion Sensor should be set on 1440 divisions per rotation.

⑤ With the cart's magnetic bumper facing the Force Sensor, push the cart against the Force Sensor and begin recording data. Then release the cart and let it move away from the Force Sensor. Is the force linear with distance?

⑥ Replace the magnetic bumper with a spring bumper and repeat the experiment.

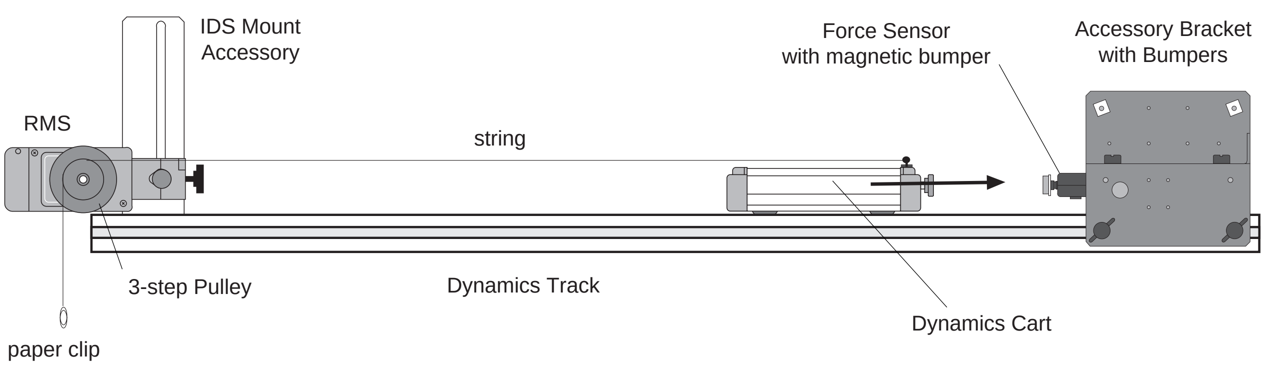


Figure 4.1: Experiment Setup

Experiment 5: Acceleration of Cart with Massive Pulley

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– IDS Mount Accessory (CI-6692)
– Dynamics Track (ME-9435A)
– Mass and Hanger Set (ME-9348)
– Rotary Motion Sensor (CI-6538)
– Mini-Rotational Accessory (CI-6691)
– Dynamics Cart (ME-9430)
– string

Purpose

The disk acts as a massive pulley, the rotational inertia of which cannot be ignored. A cart is accelerated by hanging a weight over the massive pulley and the resulting maximum speed depends on the mass of the cart and the rotational inertia of the pulley. Energy (including rotational kinetic energy) is conserved.

Procedure

① Attach the Rotary Motion Sensor to the Dynamics Track using the IDS Mount Accessory. Mount the disk on the 3-step Pulley on the Rotary Motion Sensor.

② Put the cart on the track and attach one end of a string to the cart and hang a mass on the other end of the string over the Rotary Motion Sensor pulley.

③ Set up *Science Workshop* to make a graph of velocity versus time. The resolution of the Rotary Motion Sensor should be set on 360 divisions per rotation.

④ Start the cart at rest at the end of the track furthest away from the pulley, with the hanging mass a known height above the floor. Begin recording before the cart is released and stop recording after the hanging mass hits the floor.

⑤ From the graph, find the maximum speed. Using Conservation of Energy, this maximum speed can be predicted from the distance the mass fell and the cart mass and rotational inertia of the disk pulley.

⑥ Remove the disk from the 3-step Pulley and repeat the experiment to see how the maximum speed is affected when the pulley is essentially "massless".

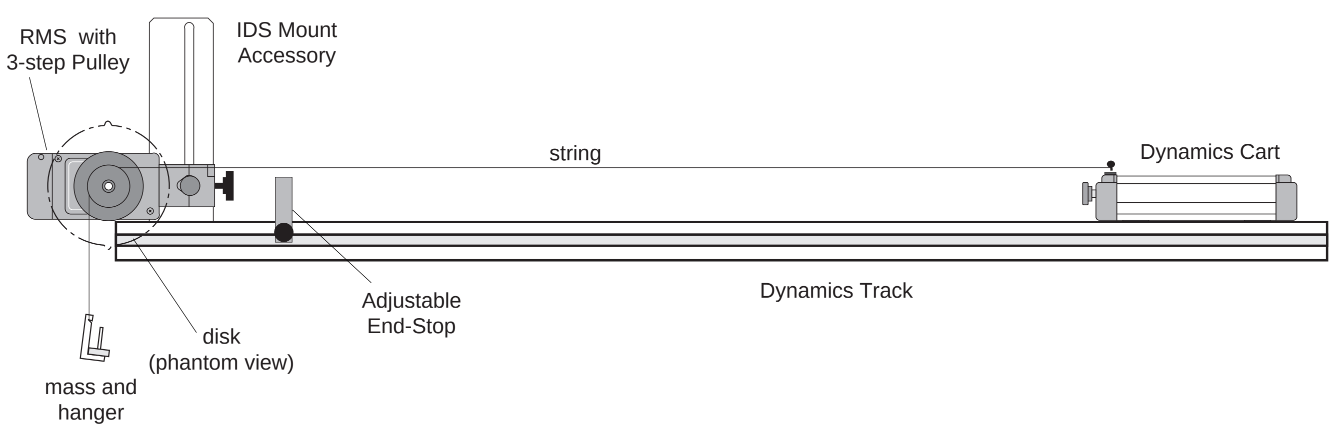


Figure 5.1: Experiment Setup

Experiment 6: Tension versus Angle

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– Force Sensor (CI-6537)
– (2) Pulley Mounting Rod (SA-9242)
– (2) Right Angle Clamp (SE-9444)
– rod for cross piece
– Rotary Motion Sensor (CI-6538)
– (2) Super Pulley (ME-9450)
– (2) Base and Support Rod (ME-9355)
– rod clamp
– string

Purpose

The tension in a string due to a hanging weight is examined as a function of the angle of the string.

Procedure

① Tie a string through the hole in the largest step of the 3-step Pulley on the RMS.

② Thread the string through a Super Pulley and over another Super Pulley and attach the end of the string to the force sensor. Attach a clamp to the hanging Super Pulley rod to add mass. The Super Pulley on the rod stand must be at the same height as the RMS 3-step Pulley.

③ Set up *Science Workshop* to make a graph of force versus angle. The resolution of the RMS should be set on 1440 divisions per rotation.

④ Before clicking on the record button, lift up on the hanging pulley and pull the string horizontal so the initial angle of the RMS will read zero when the string is horizontal. Begin recording in this position and put the hanging pulley back on the string.

⑤ Holding the Force Sensor in your hand, lower the hanging pulley slowly by moving the Force Sensor.

⑥ Use the calculator function in *Science Workshop* to calculate $1/\sin\theta$. Then plot force versus $1/\sin\theta$. The slope of the resulting straight line is related to the weight of the hanging pulley.

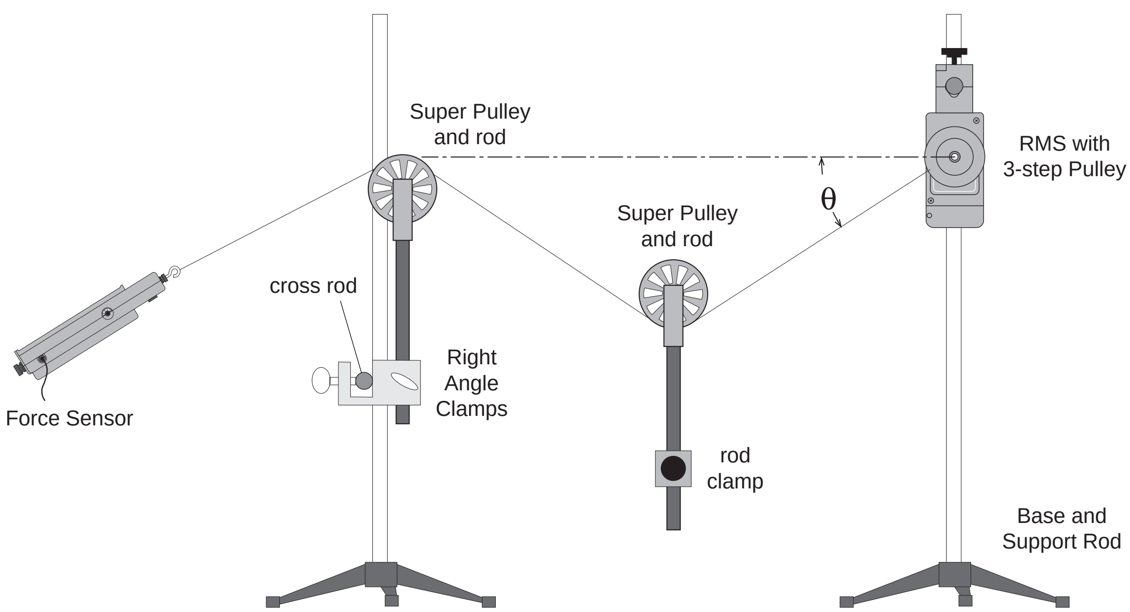


Figure 6.1: Experiment Setup

Experiment 7: Conservation of Angular Momentum – Colliding Disks

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– (2) Rotary Motion Sensor (CI-6538)
– (2) Mini-Rotational Accessory (CI-6691)
– (2) 3-step Pulley Accessory (CI-6693)
– (2) Base and Support Rod (ME-9355)

Purpose

Two rotating disks are pressed against each other to show that angular momentum is conserved.

Procedure

① Mount one RMS on a rod stand with the disk on top and mount the other RMS on the other rod stand with the disk on the bottom.

② Put a rubber o-ring on the large step of each of the 3-step Pulleys that do not have a disk attached to them. Adjust the height of each RMS so the rubber pulley on one matches the height of the other rubber pulley.

③ Set up *Science Workshop* to measure the angular speeds of both disks. The resolution of both Rotary Motion Sensors should be set on 360 divisions per rotation. Make two graphs: angular speed of each disk versus time.

④ Start both disks spinning (in the same direction or opposite directions).

⑤ Start recording and move one rod stand toward the other so rubber pulleys rub against each other.

⑥ Check to see if angular momentum is conserved in the collision.

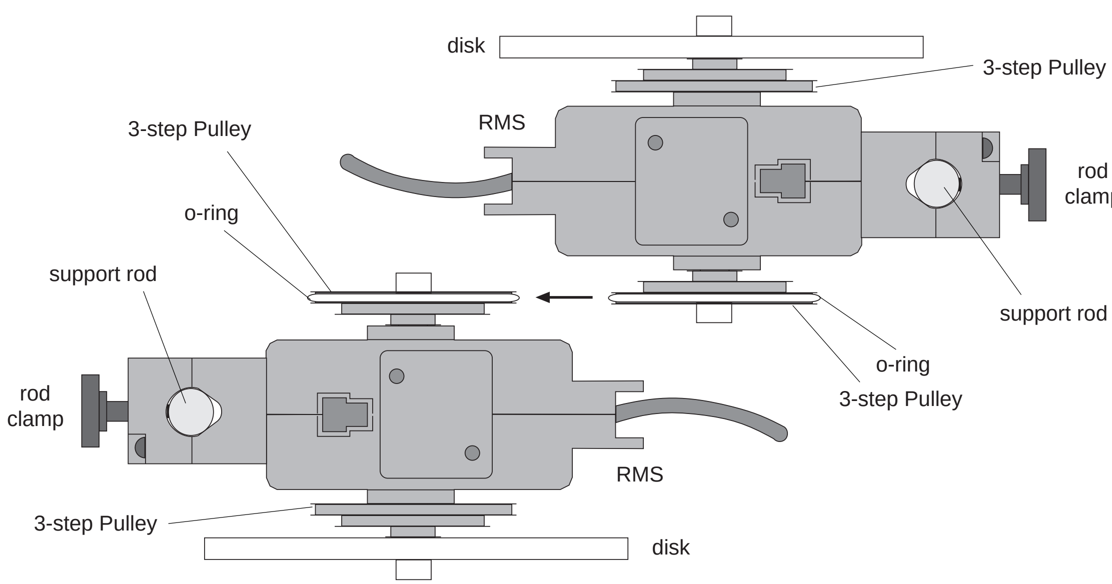


Figure 7.1: Experiment Setup

Experiment 8: Simple Harmonic Motion – Cart and Springs

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– IDS Mount Accessory (CI-6692)
– Dynamics Track (ME-9435A)
– Accessory Bracket with Bumpers (CI-6545)
– (2) spring
– Rotary Motion Sensor (CI-6538)
– Force Sensor (CI-6537)
– Dynamics Cart (ME-9430)
– Adjustable End-Stop
– string

Purpose

The purpose is to examine the relationship between the spring force and the displacement, velocity, and acceleration of an oscillating cart.

Procedure

① Mount the force sensor and the RMS on the Dynamics Track. Tie a string to the Force Sensor hook, wrap it around the RMS pulley and attach the other end of the string to a spring.

② Attach the spring to a Dynamics Cart and attach a second spring to the other end of the cart. Fasten the end of the second spring to the Adjustable End-Stop on the track.

③ Set up *Science Workshop* to graph the force as a function of displacement, velocity, and acceleration. The resolution should be set to 360 divisions per rotation.

④ Start recording with the cart in its equilibrium position. Then pull the cart back and let it go.

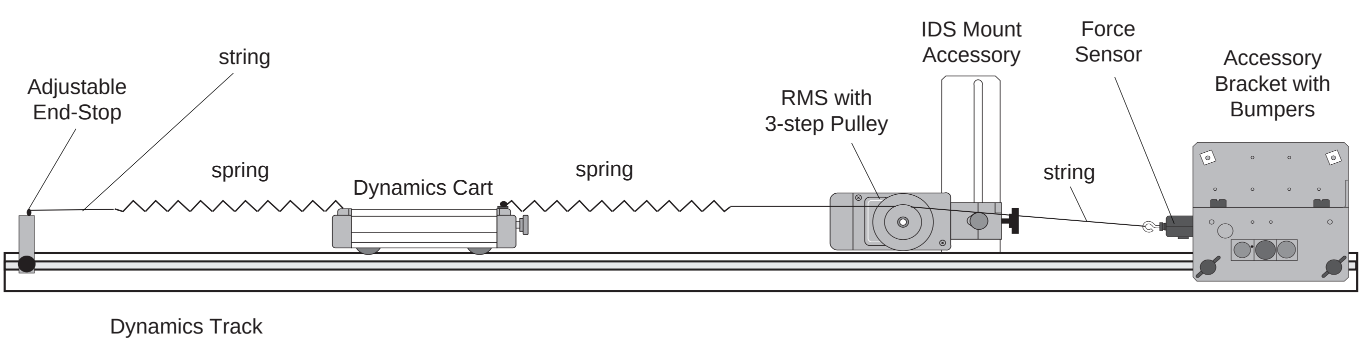


Figure 8.1: Experiment Setup

Experiment 9: Damped Pendulum

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– Rotary Motion Sensor (CI-6538)
– Chaos Accessory (CI-6689)
– Base and Support Rod (ME-9355)

Purpose

The purpose is to show the motion of a magnetically damped physical pendulum.

Procedure

① Mount the RMS on a rod stand and attach the disk with mass to the RMS.

② Mount the magnetic damping attachment on the side of the RMS.

③ Set up *Science Workshop* to plot angle versus time. The resolution should be set on 1440 divisions per rotation.

④ Begin recording with the mass at the bottom. Then pull the mass to the side and let the pendulum oscillate. Try different damping by adjusting the distance of the magnet from the disk. Determine the period and damping coefficient for different amounts of damping.

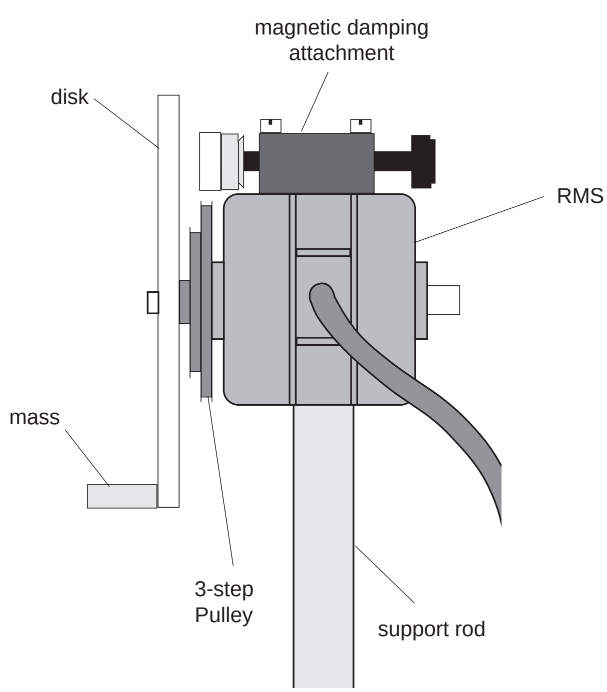


Figure 9.1: Experiment Setup

Experiment 10: Coupled Pendula

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– (2) Rotary Motion Sensor (CI-6538)
– (2) Mini-Rotational Accessory (CI-6691)
– (2) Base and Support Rod (ME-9355) connected by a cross rod
– rubber band for coupling

Purpose

The purpose is to show the energy exchange and the phase difference between two coupled pendula.

Procedure

① Attach two Rotary Motion Sensors to the rod as shown. Each RMS should have a rod mounted to the 3-step Pulley. Adjust the masses on the rods so they are exactly the same distance from the axis of rotation.

② Stretch a rubber band from the top of one RMS rod to the top of the other RMS rod.

③ Set up *Science Workshop* to plot angular speed of each pendulum versus time.

④ Pull back on one of the pendula and let it swing. Monitor the data and compare the velocities of each pendulum as time passes.

⑤ Move the mass up slightly on one pendulum to show that the coupling is not complete when the periods are different.

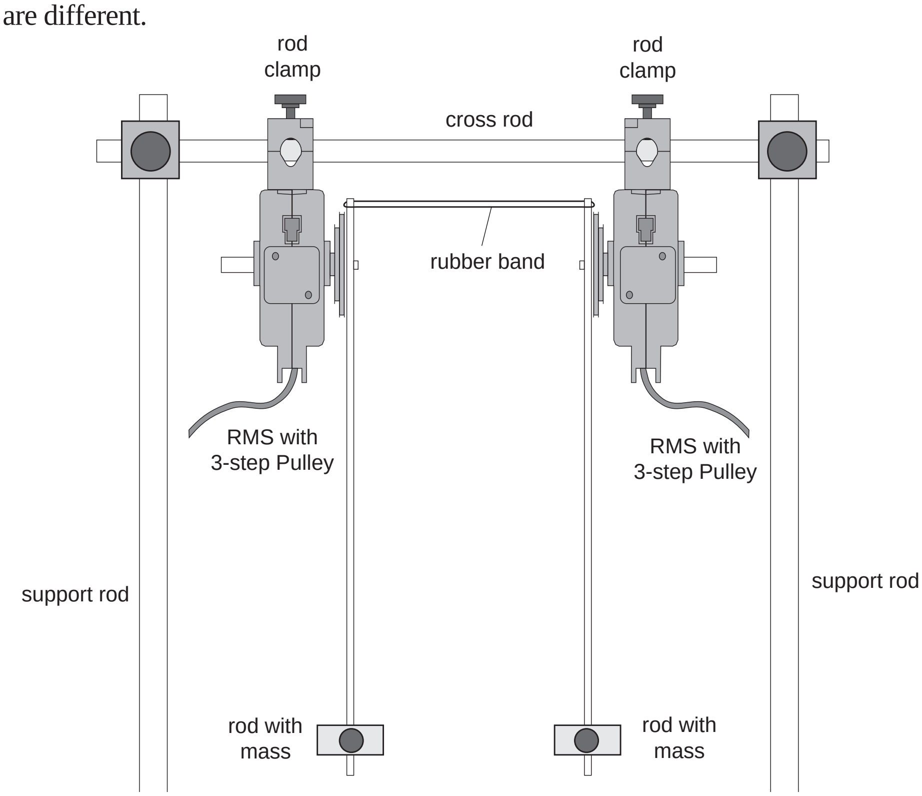


Figure 10.1: Experiment Setup

Experiment 11: Chaos

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– Chaos Accessory (CI-6689)
– 1.2 m Dynamics Track (ME-9435A)
– 0-12 V DC variable power supply
– Rotary Motion Sensor (CI-6538)
– IDS Mount Accessory (CI-6692)
– Mechanical Oscillator/Driver (ME-8750)

Purpose

The purpose is to examine the different modes of oscillation of a damped driven physical pendulum caused by varying the driving amplitude, driving frequency, and magnetic damping.

Procedure

① Set up the equipment as shown below. The string makes one wrap around the largest step on the 3-step Pulley.

② Set up *Science Workshop* to graph angular speed versus angular position. This is a phase plot. The resolution should be set on 1440 divisions per rotation.

③ The magnetic damping can be adjusted to vary the results but begin by varying the driving frequency of the Mechanical Oscillator/Driver. After each change in frequency, observe how the phase plot is affected.

④ Vary the driving amplitude and observe the changes in the phase plot.

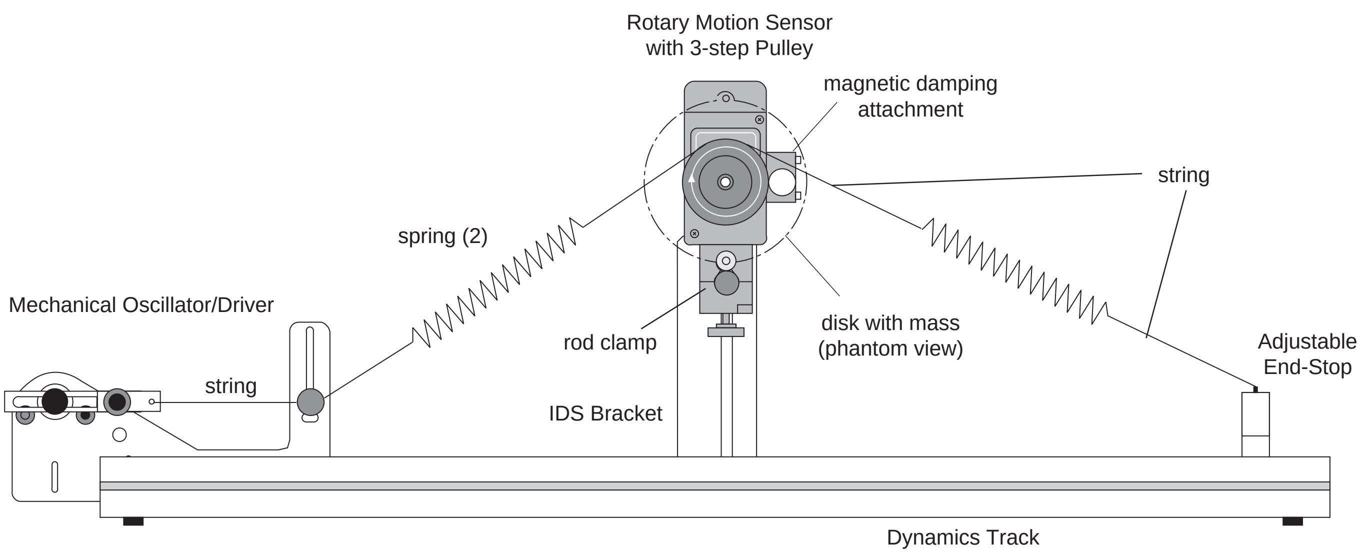


Figure 11.1: Chaos Experiment Setup

Experiment 12: Gyroscope Precession and Nutation

EQUIPMENT NEEDED

– *Science Workshop™ 700 Interface*
– (2) Rotary Motion Sensor (CI-6538)
– “A”-Base Rotational Adapter (CI-6690)
– RMS/Gyroscope Mounting Bracket (ME-8963)
– Gyroscope (ME-8960)

Purpose

The purpose is to plot out the precession and nutation patterns for three different initial conditions.

Procedure

Please refer to the instruction manual supplied with the Gyroscope on how to set up and adjust the Gyroscope.

① Mount one RMS to the “A” base of the Gyroscope and mount the other RMS to the rotating shaft of the Gyroscope.

② Set up *Science Workshop* to graph nutation (tilt) angle versus precession angle. The resolution for both Rotary Motion Sensors should be set on 360 divisions per rotation.

③ Spin the gyroscope disk at various speeds, releasing the Gyroscope from rest at different angles. Also try releasing the Gyroscope with an initial velocity in the direction of the precession and with an initial velocity against the direction of precession.

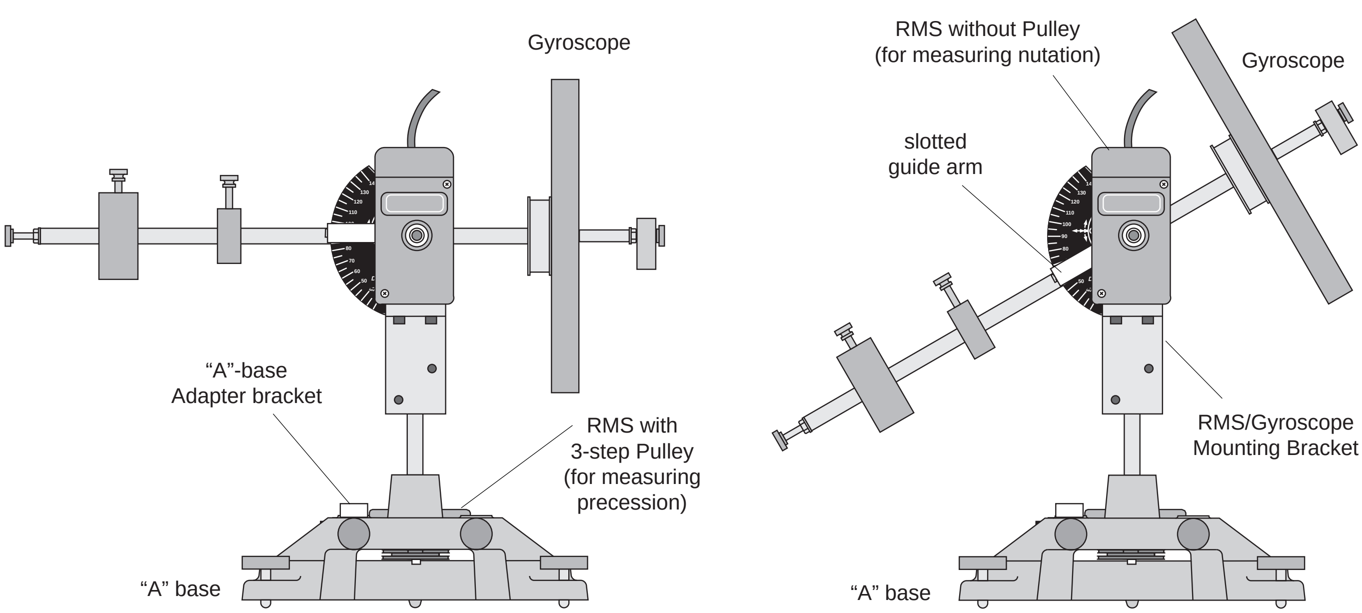


Figure 12.1: Experiment Setup for Precession and Nutation

Experiment 13: Buoyant Force versus Height Submerged

EQUIPMENT NEEDED

– Rotary Motion Sensor (CI-6538)
– Super Pulley (ME-9450)
– (2) Base and Support Rod (ME-9355)
– Force Sensor (CI-6537)
– Pulley Mounting Rod (SA-9242)
– Right Angle Clamp (SE-9444)
– string
– cylindrical object (with density greater than the fluid so it will sink)
– beaker with water or any other fluid (beaker must be big enough to completely submerge the cylindrical object)

Purpose

The relationship between buoyant force and depth in the fluid is determined. Also the density of the fluid can be determined.

Procedure

① Suspend the cylindrical object above the fluid as shown.

② Set up *Science Workshop* to plot force versus distance. The resolution should be set on 1440 divisions per rotation.

③ Hold the Force Sensor so the object is just above the fluid. Start recording and slowly lower the object into the water by moving the Force Sensor.

④ From the slope of the straight-line graph of force versus distance, determine the density of the fluid.

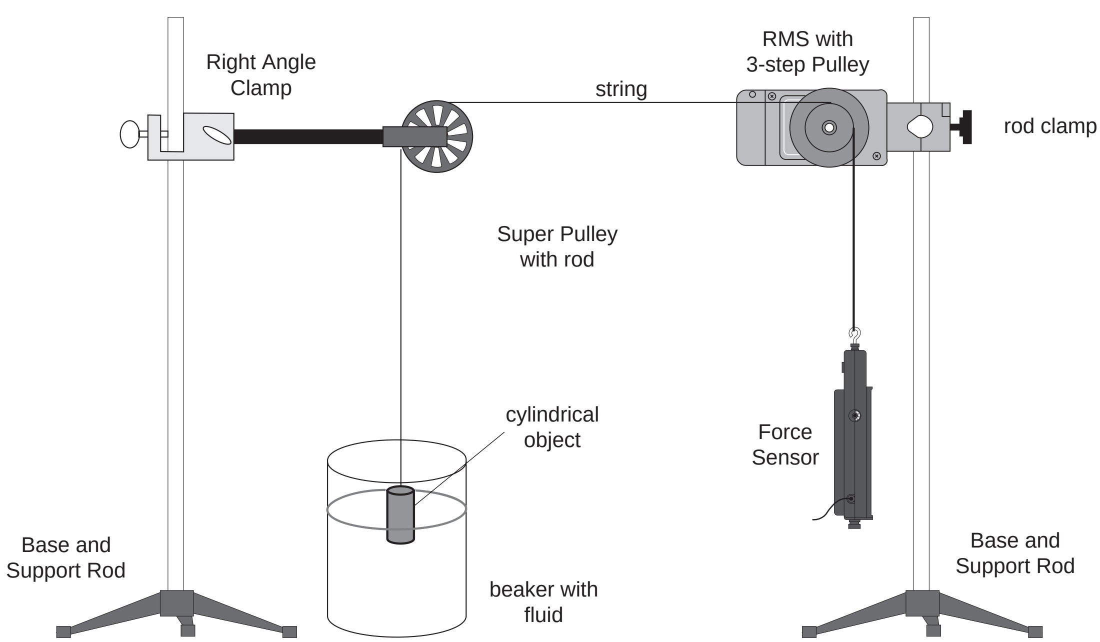


Figure 13.1: Experiment Setup

Experiment 14: Pressure versus Depth in a Fluid

EQUIPMENT NEEDED

– Rotary Motion Sensor (CI-6538)
– Linear Motion Accessory (CI-6688)
– Low Pressure Sensor (CI-6534)
– Base and Support Rod (ME-9355)
– small rubber balloon
– large beaker filled with water or other fluid

Purpose

The relationship between pressure and depth in a fluid is determined. Also the density of the fluid can be determined.

Procedure

① Mount the RMS above the water as shown.

② Insert the end of the pressure sensor tube into the small balloon. The balloon acts as a flexible diaphragm. Gently clamp the tube in the rod clamp at the end of the rack and insert the rack into the RMS.

③ Set up *Science Workshop* to plot pressure versus distance. The resolution should be set on 1440 divisions per rotation.

④ Hold the rack so the balloon is at the top of the water, just barely submerged. Start recording and slowly lower the balloon into the water by moving the rack.

⑤ From the slope of the straight-line graph of pressure versus distance, determine the density of the water.

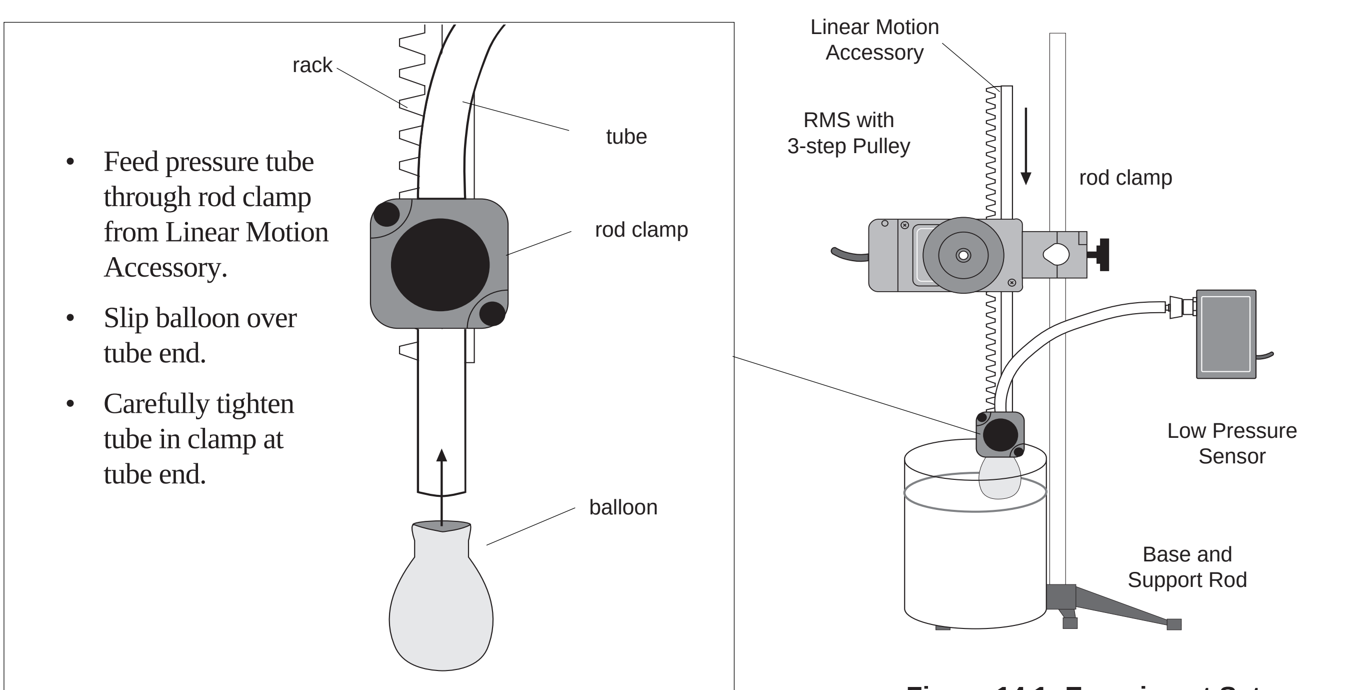


Figure 14.1: Experiment Setup

Experiment 15: Ideal Gas Law: Pressure versus Volume

EQUIPMENT NEEDED

– Rotary Motion Sensor (CI-6538)
– Linear Motion Accessory (CI-6688)
– Low Pressure Sensor (CI-6534)
– Force Sensor (CI-6537)
– Heat Engine/Gas Laws Apparatus (TD-8572)
– Base and Support Rod (ME-9355)

Purpose

A pressure versus volume diagram is obtained for a gas being compressed at constant temperature. The work done is calculated by integrating under the P-V curve. Also a plot of force versus piston displacement is obtained so the work can also be found by integrating under this curve.

Procedure

① Mount the RMS on a rod above the heat engine, with the rack in a vertical position, resting on the platform of the heat engine.

② Attach the Low Pressure Sensor to one of the Heat Engine outlets and clamp the other outlet closed.

③ Set up *Science Workshop* to plot pressure versus displacement. Alternatively, pressure versus volume can be plotted by using the calculator function in *Science Workshop* to multiply the displacement by the area of the piston. Also graph force versus position. The resolution should be set to 1440 divisions per rotation.

④ While recording, push slowly down on the piston by pushing down on the rack with the Force Sensor. This must be done slowly so the temperature does not change.

⑤ Integrate under the pressure versus volume curve and under the force versus distance curve to find the work done.

⑥ The initial volume of the cylinder can be determined using $P_oV_o = PV$, where $V_o = V + \Delta V$.

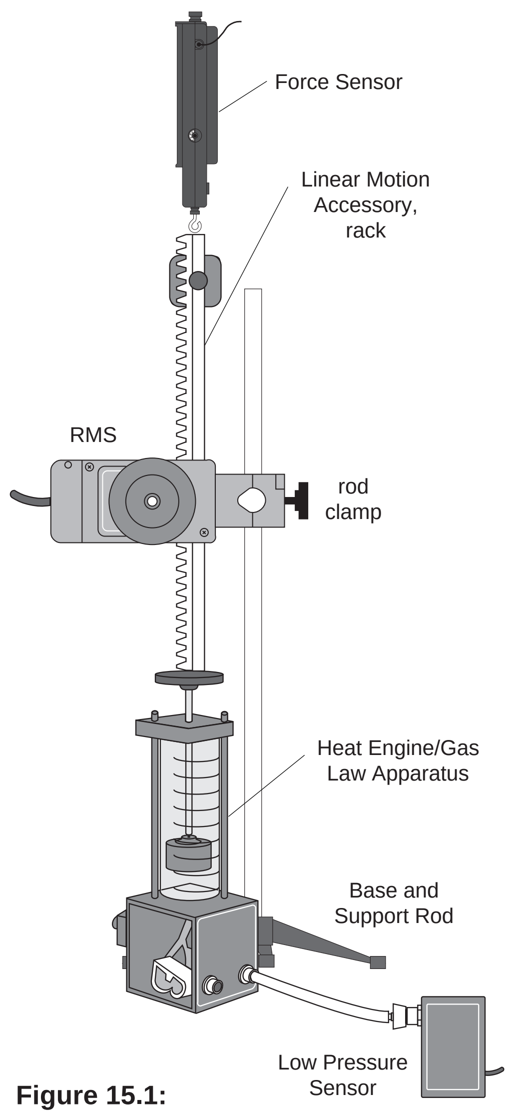


Figure 15.1: Experiment Setup

Experiment 16: Magnetic Field versus Distance

EQUIPMENT NEEDED

– Rotary Motion Sensor (CI-6538)
– Linear Motion Accessory (CI-6688)
– Magnetic Field Sensor (CI-6520)
– Base and Support Rod (ME-9355)
– neodymium magnet

Purpose

The magnetic field of a neodymium magnet is plotted as a function of distance from the magnet.

Procedure

① Mount the Rotary Motion Sensor with rack on a rod stand as shown.

② Gently clamp the rod portion of the Magnetic Field Sensor in the rod clamp on the rack.

③ Place a neodymium magnet on the table directly below the end of the Magnetic Field Sensor.

④ Set up *Science Workshop* to graph magnetic field versus distance. The resolution should be set to 1440 divisions per rotation.

⑥ Start recording with the Magnetic Field Sensor touching the magnet. Slowly pull up on the rack to move the magnetic sensor away from the magnet.

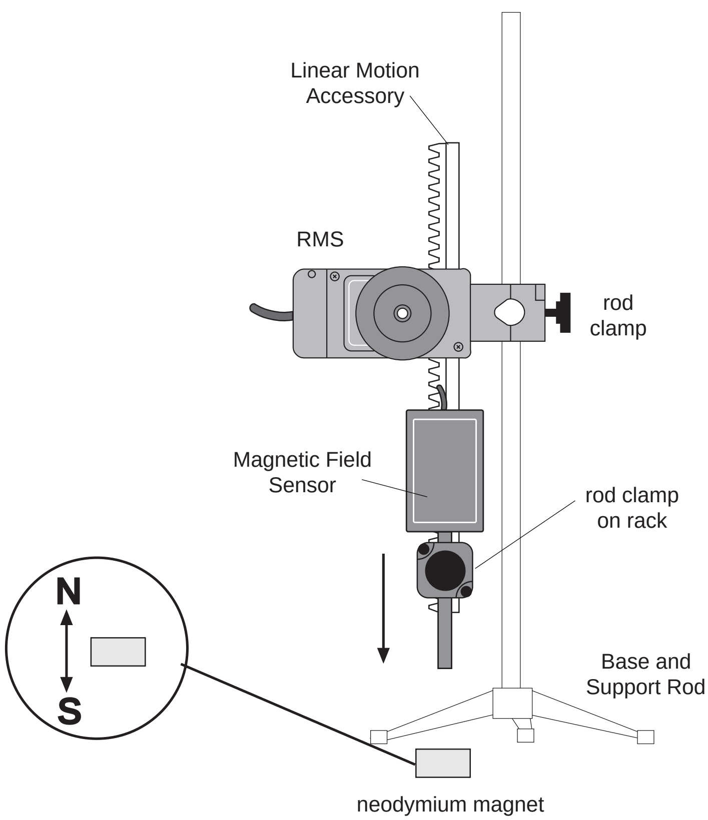


Figure 16.1: Experiment Setup

Experiment 17: Induced Voltage versus Position of Pendulum Coil and Magnet

EQUIPMENT NEEDED

– Rotary Motion Sensor (CI-6538)
– Voltage Sensor (CI-6503)
– 400-turn Detector Coil (EM-6711)
– Variable Gap Magnet (EM-8641)
– Base and Support Rod (ME-9355)

Purpose

The induced voltage in a coil is plotted as a function of angular position as it swings through a magnet.

Procedure

① Mount the Rotary Motion Sensor on a rod stand. Turn the 3-step Pulley so the rod guides face outward.

② Attach the Detector Coil wand to the shaft of the Rotary Motion Sensor and plug the Voltage Sensor into the Detector Coil.

③ Place the Variable Gap Magnet so the coil is able to swing through it.

④ Set up *Science Workshop* to plot voltage versus angular position. The resolution should be set to 1440 divisions per rotation.

⑤ Start recording with the wand hanging straight down. Pull the coil back and let it swing through the pendulum.

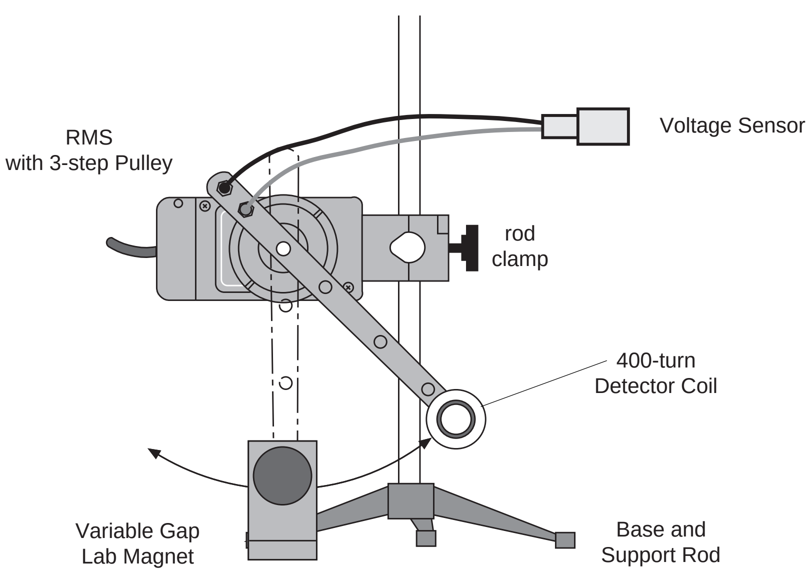


Figure 17.1: Experiment Setup

Experiment 18: Velocity of Aluminum Pendula Swinging through Magnet

EQUIPMENT NEEDED

– Rotary Motion Sensor (CI-6538)
– Variable Gap Magnet (EM-8641)
– Magnetic Force Accessory (EM-8642)
– Base and Support Rod (ME-9355)

Purpose

The angular speed of the paddle is plotted as a function of angular position as it swings through a magnet.

Procedure

① Mount the Rotary Motion Sensor on a rod. Turn the 3-step Pulley so the rod guides face outward.

② Mount the solid paddle on the Rotary Motion Sensor shaft.

③ Place the Variable Gap Magnet so the paddle is able to swing through it.

④ Set up *Science Workshop* to plot angular speed versus angular position. The resolution should be set to 1440 divisions per rotation.

⑤ Start recording with the paddle hanging straight down. Pull the paddle back and let it swing through the magnet.

⑥ Repeat with the other two types of paddles.

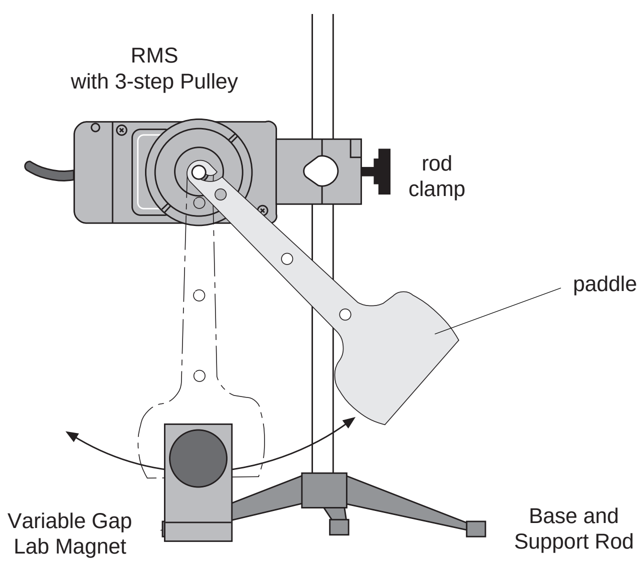


Figure 18.1: Experiment Setup

Experiment 19: Light Intensity versus Distance

EQUIPMENT NEEDED

– Rotary Motion Sensor (CI-6538)
– Dynamics Track (ME-9435A)
– Light Source (OS-8517)
– Mass and Hanger Set (ME-9348)
–block
– IDS Mount Accessory (CI-6692)
– Dynamics Cart (ME-9430)
– Light Sensor (CI-6504)
– string

Purpose

Light intensity is plotted as a function of distance from a point light source.

Procedure

① Attach the Rotary Motion Sensor to one end of the Dynamics Track using the IDS Mount Accessory. Mount the 3-step Pulley on the Rotary Motion Sensor.

② Put the cart on the track and place the Light Sensor, facing away from the RMS, on the cart.

③ Place the Light Source in point source mode at the opposite end of the optics bench. Adjust the Light Source or the Light Sensor so the Light Sensor and the point light source are at the same height.

④ Attach a string to the cart. Then pass the string over the Rotary Motion Sensor pulley and hang a mass (<10 gram) on the end of the string.

⑤ Set up *Science Workshop* to plot light intensity versus distance. The resolution should be set on 360 divisions per rotation.

⑥ Begin recording with the Light Sensor a known distance away from the point light source. As the Light Sensor moves away from the light, the string will rotate the Rotary Motion Sensor pulley.

⑦ The calculator function of *Science Workshop* can be used to add the known initial distance to the recorded distances.

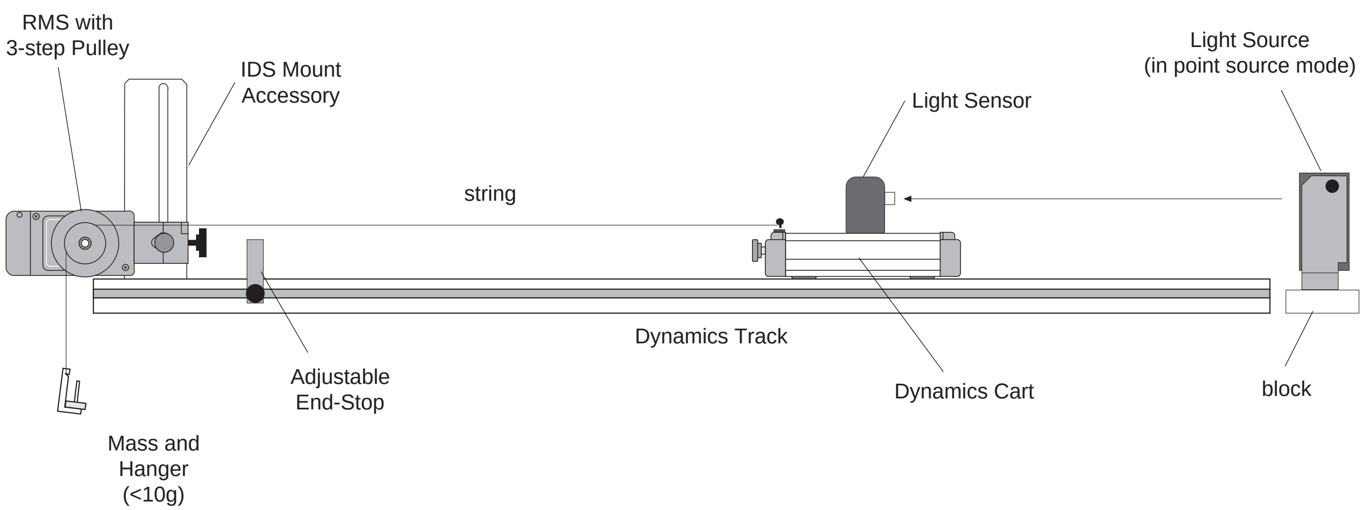


Figure 19.1: Experiment Setup

Technical Support

Feed-Back

If you have any comments about this product or this manual please let us know. If you have any suggestions on alternate experiments or find a problem in the manual please tell us. PASCO appreciates any customer feed-back. Your input helps us evaluate and improve our product.

To Reach PASCO

For Technical Support call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

email: techsupp@PASCO.com

Tech support fax: (916) 786-3292

Web: http://www.pasco.com

Contacting Technical Support

Before you call the PASCO Technical Support staff it would be helpful to prepare the following information:

• If your problem is computer/software related, note:

Title and Revision Date of software.

Type of Computer (Make, Model, Speed).

Type of external Cables/Peripherals.

• If your problem is with the PASCO apparatus, note:

Title and Model number (usually listed on the label).

Approximate age of apparatus.

A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.)

If possible, have the apparatus within reach when calling. This makes descriptions of individual parts much easier.

• If your problem relates to the instruction manual, note:

Part number and Revision (listed by month and year on the front cover).

Have the manual at hand to discuss your questions.