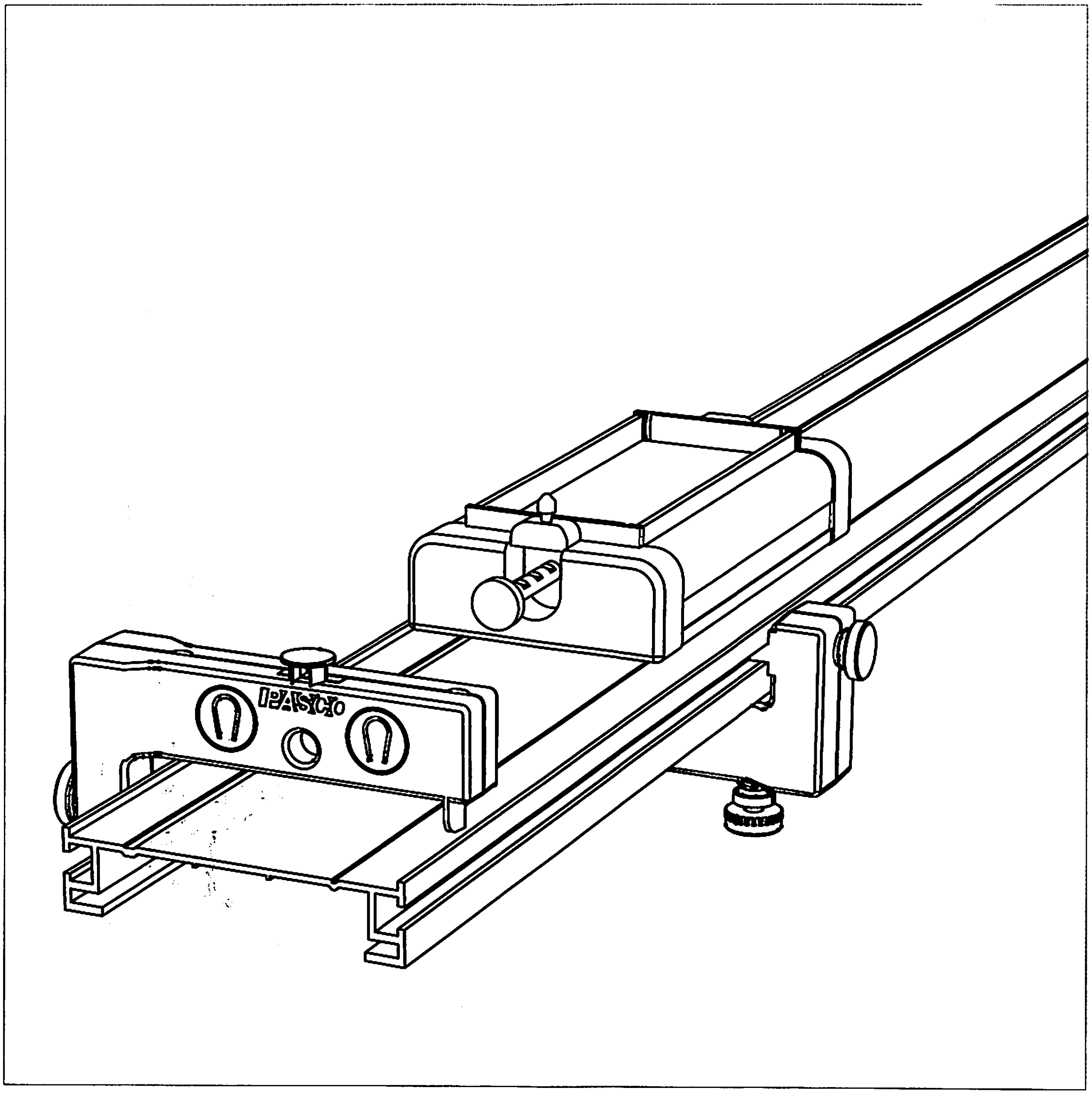
PASCO®

Instruction Manual and
Experiment Guide
012-05024F

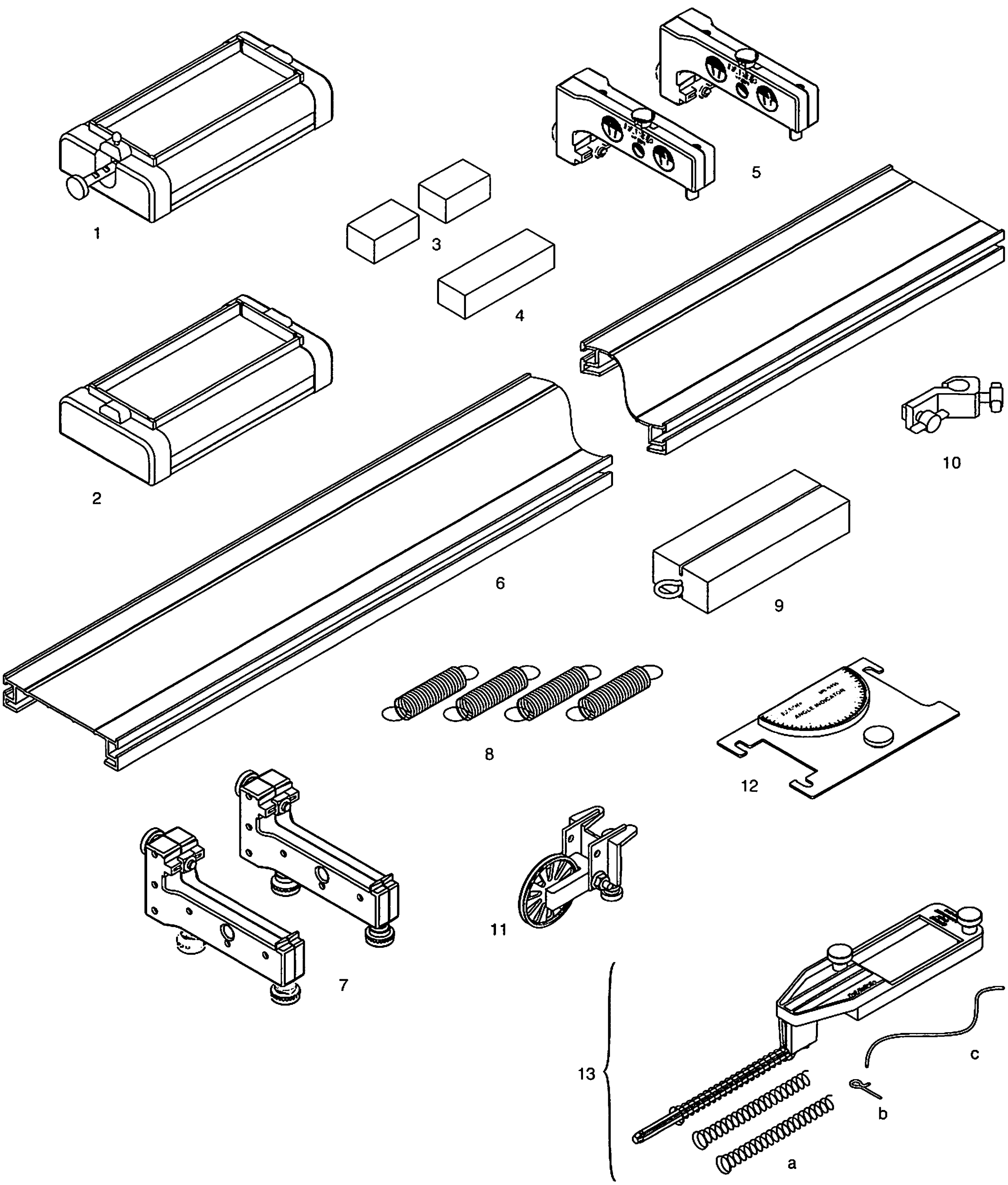
2.2 m Classic Dy ~~~stem

ME-9



2.2 m Classic Dynamics System

ME-9452



Included Equipment	Quantity	Replacement Part Number
1. Plunger Cart	1	ME-9340
2. Collision Cart	1	ME-9454
3. 250 g Compact Cart Masses	2	ME-6755
4. 500 g Cart Mass	1	ME-6757
5. Adjustable End Stops	2	ME-8971 (2-pack)
6. 2.2 m Dynamics Track	1	ME-9779
7. Adjustable Feet	2	ME-8972 (2-pack)
8. Harmonic Springs	4	ME-9803 (3-pack)
9. Friction Block	1	ME-9807
10. Pivot Clamp	1	ME-9810
11. Super Pulley with Clamp	1	ME-9448A
12. Angle Indicator	1	ME-9495
13. Spring Cart Launcher with:		ME-6843
a. Compression Springs	3	ME-6847 (6 springs, 4 release pins)
b. Release Pin	2	
c. String	1 m	

Introduction

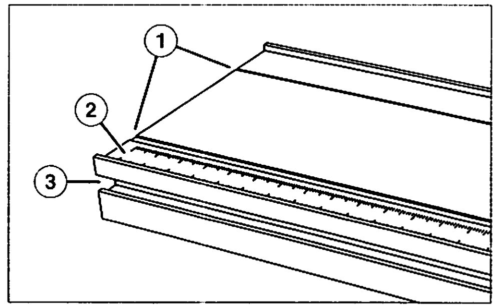
The 2.2 m Classic Dynamics System includes everything you need for a variety of experiments and demonstrations. You can also combine it with many other PASCO produces—both traditional and computer-based—for an even greater range of uses.

This manual contains descriptions of the included equipment, complete instructions for nine experiments, and ten additional experiment suggestions.

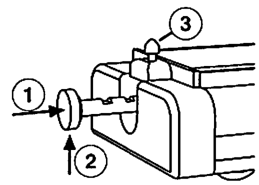
About the Equipment

Track The 2.2 m aluminum track has two groves to guide the wheels of carts, a metric scale for measuring cart positions, and T-slots on both sides for attaching end stops, leveling feet and other accessories.

Tip: The track is designed to support the weight of carts and related apparatus. Excess weight will warp it. When you store the track, ensure that no heavy object will be placed on top of it.



Track Features
1: Grooves **2:** Metric scale **3:** T-slot



Plunger Cart
1: Push plunger in.
2: Push up to lock.
3: Tap button to trigger.

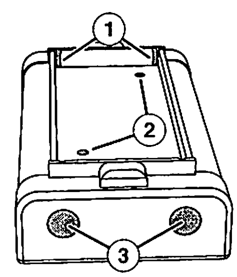
Plunger Cart and Collision Cart These carts run along the track on low-friction wheels.

The plunger cart includes a spring-loaded plunger that launches the cart off of an end stop or another cart. Push the plunger in to the first, second, or third "click" (for a slow, medium, or fast launch); then push up to make the trigger catch. To make the plunger pop out, tap the trigger button with a hard object (such the included 500 g mass). When the plunger is not in use, push it all the way in to the third position.

For elastic and inelastic collisions, both carts have hook-and-loop bumpers on one end and magnetic bumpers on the other end. When the hook-and-loop bumpers collide, the carts stick to each other. When the magnetic bumpers collide, the carts repel each other without touching. The magnetic bumpers also repel the magnets in the end stops.

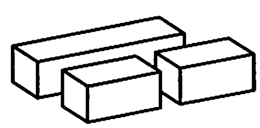
The top or each cart forms a tray designed to hold the included masses. The carts also feature tapped holes for attaching accessories and sensors, and slots for holding a picket fence (such as PASCO part ME-9804) or the included angle indicator.

For more information, see the manuals packaged with both carts.



Cart Features
1: Slots **2:** Tapped holes
3: Bumpers

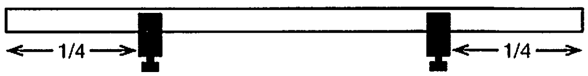
Cart Masses These masses are designed to be placed on the upper tray of a cart.

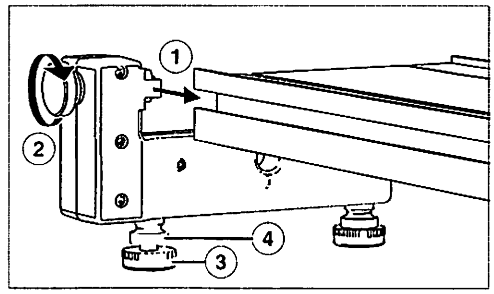


Cart Masses

Adjustable Feet Attach the feet to the track as illustrated. Turn the feet screws to level the track then tighten the lock nuts to secure them.

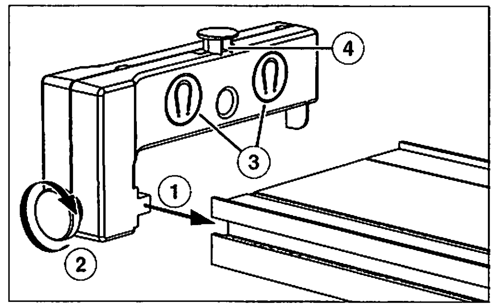
For maximum stability, position the feet about 1/4 of the track length from each end





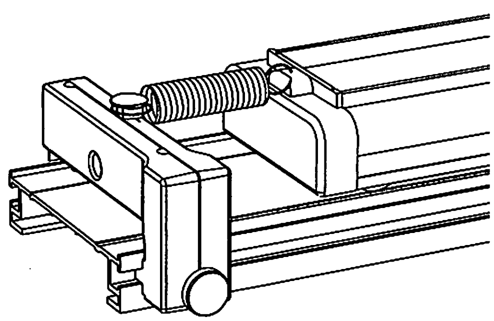
Adjustable Feet
1: Slide tab into T-slot. **2:** Tighten thumbscrew to secure feet set. **3:** Turn feet screws to level track. **4:** Tighten lock nuts to secure feet screws.

Adjustable End Stops Attach the end stops to the track as illustrated. The end stops contain magnets to repel the magnetic bumper of a cart. A stud is provided as an attachment point for a spring.



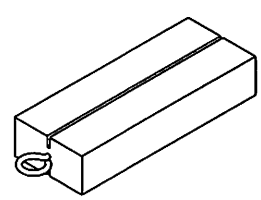
Adjustable End Stop
1: Slide tab into T-slot on side of track. **2:** Tighten thumbscrew to secure end stop. **3:** Magnets repel cart's magnetic bumper **4:** Spring attachment stud

Harmonic Springs Ideal for studying harmonic oscillation of carts on a flat or inclined track, these spring hook onto holes at the ends of the carts and to studs on top of the end stops. The springs are packed in storage tubes, which include adhesive tape so that they may be permanently attached to the underside of the track.



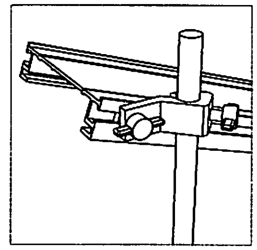
Harmonic Spring

Friction Block The friction block has two different surfaces (wood and felt) and two different surface areas for studying friction. It includes an eye screw for attaching a string and slots on both broad surfaces for holding a picket fence (such as PASCO part ME-9804) or the included angle indicator.



Friction Block

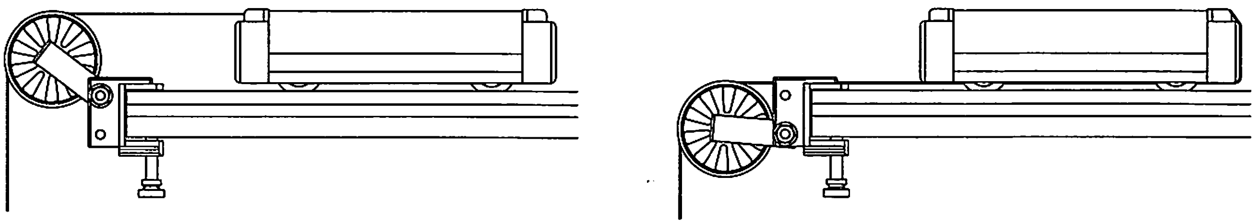
Pivot Clamp Attach the pivot clamp to the T-slot of the track (as illustrated) to elevate one end of the track on a vertical rod.



Pivot Clamp

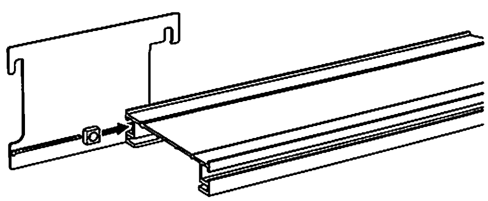
Super Pulley with Clamp This low-friction, low-inertia pulley is designed for clamping onto the end of the track. Tie a string to the hole in the end of the cart an run it over the pulley. Adjust the height of the pulley to make the string parallel to the track.

The pulley can also be mounted in the lower position as illustrated. Tie the string to the opposite end of the cart and wrap it underneath the cart. In the lower position, the string can be run under an end stop, another cart, or a motion sensor.

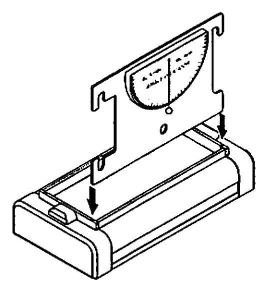


Super Pulley with string in normal position (left) and lower position (right)

Angle Indicator Attach the angle indicator to the track as illustrated, or remove the attachment screw and slip it into the slots of a cart or friction block. The hanging thread indicates the angle or incline.

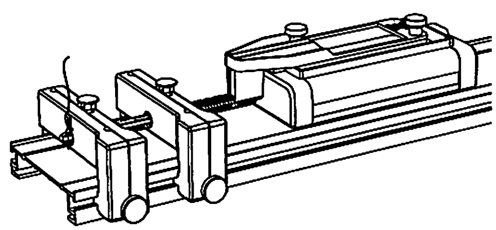


Angle Indicator on track



Angle Indicator on cart

Spring Cart Launcher This accessory is designed for the study of force and motion, potential energy, conservation of energy, the work-energy theorem, Hooke's Law, and spring constants. Use it to launch either cart by compressing and releasing one of three interchangeable springs. The included release pin, in combination with two end stops, allows you to use precisely the same spring compression for multiple launches.



Spring Cart Launcher

For more information, see Experiment 9 on page 29 and the manual packaged with with the launcher.

Spare Parts

You can order any of the major components of the system using the part numbers listed in the table on page 5. For an assortment of smaller parts, the following kits are available.

IDS Spares Kit (ME-9823) This kit includes assorted thumbscrews, square nuts, and harmonic springs.

Cart Launcher Springs Kit (ME-6847) This kit includes four compression springs and four release pins for the Spring Cart Launcher.

For help identifying a part, contact PASCO technical support (see page 34).

About the Experiments

These nine experiments can be done with the equipment included in the system and other equipment commonly found in introductory physics labs. See each experiment for a specific equipment list.

1. **Conservation of Momentum in Explosions** (page 11): Demonstrate conservation of momentum when two carts push off from each other.

2. **Conservation of Momentum in Collisions** (page 13): Demonstrate conservation of momentum in elastic and inelastic collisions.

3. **Simple Harmonic Oscillator** (page 15): Study how the period of oscillation of a system varies with its mass.

4. **Oscillations on an Incline** (page 18): Study the oscillation of a cart attached to a spring on an inclined track.

5. **Springs in Series and Parallel** (page 21): Examine how springs combined in different ways affect the period of oscillation of a cart.

6. **Launch Speed** (page 23): Show qualitatively how the final speed of the plunger cart depends on its mass and the initial compression of the plunger spring.

7. **Newton's Second Law** (page 24): Show quantitatively how the acceleration of a cart is related its mass and net force.

8. **Acceleration Down an Incline** (page 26): Determine the strength of earth's gravity (g) by measuring the acceleration of a cart on an inclined track.

9. **Conservation of Energy** (page 29): Use the spring cart launcher to launch a cart up an incline. Compare the potential energy initially stored in the spring to the maximum gravitational potential energy achieved by the cart.

Additional Experiment Suggestions (page 32): Many of these suggestions are variations on the above experiments. Some require additional carts.

Experiment 1: Conservation of Momentum in Explosions

Required Equipment from Dynamics System	
Track with Feet and End Stops	
Plunger Cart	
Collision Cart	
Cart Masses	

Other Required Equipment	Suggested Model Number
Mass set	ME-9348

Purpose

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

Theory

When two carts push away from each other (and there is no net force on the system), the total momentum is conserved. If the system is initially at rest, the final momentum of the two carts must be equal in magnitude and opposite in direction to each other so the resulting total momentum of the system is 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.

$$\frac{v_1}{v_2} = \frac{m_1}{m_2}$$

To simplify this experiment, the starting point for the carts at rest is chosen so that the two carts will reach the ends 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.

$$\frac{v_1}{v_2} = \frac{\left(\frac{\Delta x_1}{\Delta t}\right)}{\left(\frac{\Delta x_2}{\Delta t}\right)} = \frac{\Delta x_1}{\Delta x_2}$$

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

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

Procedure

1. Instal the feet on the track and level it. Install one end stop at each end with the magnetic sides facing *away* from the carts.

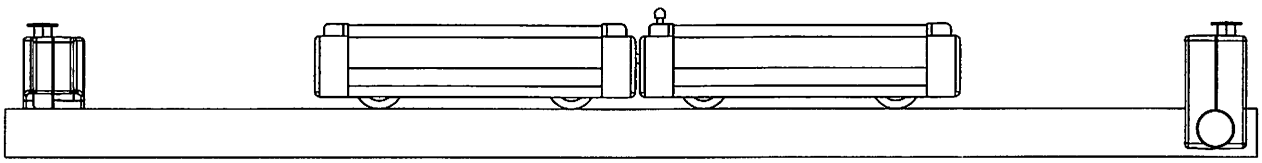


Figure 1.1

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

3. Tap 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 the ends of the track at the same time. Measure the masses of the carts. Record the masses and the starting position in Table 1.1.

Table 1.1: Results

Additional Mass on Cart 1	Additional Mass on Cart 2	m_1	m_2	Starting Position	x_1	x_2	x_1/x_2	m_2/m_1
0	0							
500 g	0							
1000 g	0							
500	250							

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 the plunger? Why?

Experiment 2: Conservation of Momentum in Collisions

Required Equipment from Dynamics System

Track with Feet

Plunger Cart

Collision Cart

Other Required Equipment

Paper (for drawing diagrams)

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 of both carts is conserved regardless of the type of collision.

An elastic collision is one in which the 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 carts hit and stick to each other. In this experiment, this is accomplished with the hook-and-loop bumpers on the carts.

Part I: Elastic Collisions

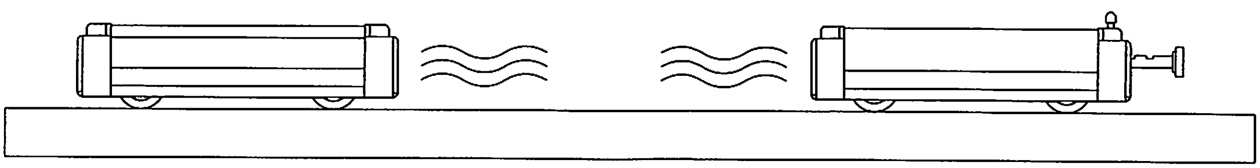


Figure 2.1

1. Instal the feet on the track and level it.
2. Orient the two carts on the track so their magnetic bumpers are toward each other.
3. Test cases A1 through A3 and B1 through B3 described below. Draw two diagrams (one for before the collision and one for after the collision) for each case. In every diagram, show a velocity vector for each cart with a length that approximately represents the relative speed of the cart.

A. Carts with Equal Mass

Case A1: Place one cart at rest in the middle of the track. Give the other cart an initial velocity toward the cart at rest.

Case A2: Start the carts with one at each end of the track. Give each cart approximately the same velocity toward each other.

Case A3: 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 B1: 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 B2: 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 B3: Start the carts with one at each end of the track. Give each cart approximately the same velocity toward each other.

Case B4: 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

1. Orient the two carts so their hook-and-loop bumpers are toward each other. Push the plunger in all the way so it will not interfere with the collision.

2. Repeat test cases A1 through A3 and B1 through B3 and draw diagrams for each case.

Questions

1. When two carts having the same mass and the same speed collide and stick together, they stop. 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

Required Equipment from Dynamics System	
Track with Feet and End Stops	
Cart	
Super Pulley with Clamp	
Harmonic Springs (2)	
500 g Cart Mass	

Other Required Equipment	Suggested Model Number
Mass hanger and mass set	ME-9348
Stopwatch	ME-1234
Mass balance	SE-8723
String (about 2 m)	
Graph paper	

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, F, exerted by the spring is proportional to the distance, x, by which the spring is compressed or stretched: $F = kx$, where k is the spring constant. Thus the spring constant can be experimentally determined by applying different forces to stretch the spring different distances. If force is plotted versus distance, the slope of the resulting straight line is equal to k.

Procedure

Measurements to Find the Spring Constant and Theoretical Period

1. Measure the mass of the cart and record it in Table 3.1.
2. Instal the feet on the track and level it.
3. Instal the end stops about 1 m apart.
4. Clamp the pulley at one end of the track.
5. Set the cart on the track and attach a spring to each end. Attach the other ends of the springs to the end stops (see Figure 3.1).

6. Tie a string to the end of the cart farther from the pulley. Wrap the string under the cart; then run it under one end stop and over the pulley as shown in Figure 3.1. Attach the mass hanger to the other end of the string. Adjust the pulley so that the string runs parallel to the track.

7. Let the mass hang freely and wait for the cart to come to rest. Record the mass of the hanger and the resting equilibrium position of the cart in Table 3.1.

8. Add mass to the hanger. Record the hanging mass and the new equilibrium position of the cart in Table 3.1. Repeat this for a total of 5 different masses, being careful not to over-stretch the springs.

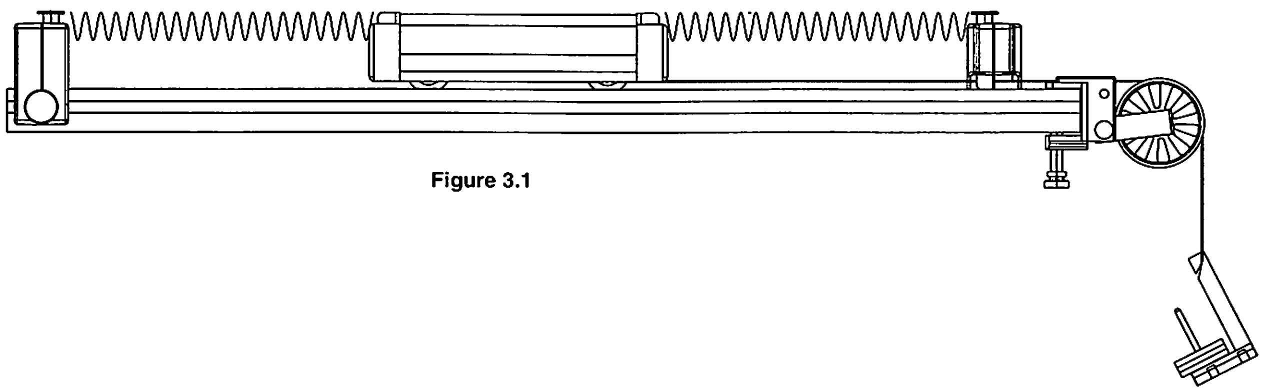


Figure 3.1

Table 3.1: Data and Analysis

Mass of cart = ________		
Hanging Mass	**Position**	**Force**

Measuring the Experimental Period

9. Displace the cart from equilibrium and let it go. Time 5 oscillations and record the time in Table 3.2.

10. Repeat this measurement at 5 times, using the same initial displacement.

11. Add a 500 g mass to the cart and repeat steps 9 and 10.

Calculations

Spring Constant and Theoretical Period

1. Calculate the forces applied by the hanging mass and write them in Table 3.1.

2. Using the data in Table 3.1, plot force versus position. 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.

$k =$ ____________

3. Using the mass of the cart and the spring constant, calculate the theoretical period of the cart alone and with added mass.

   theoretical period of cart alone _______________

   theoretical period of cart with added mass _______________

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 average times by 5 and record the periods in Table 3.2.

Table 3.2: Experimental Data

Trial	Time for 5 Oscillations	Period
1		period of cart without added mass
2		
3		
4		
5		
Average		
1		period of cart with 500 g added mass
2		
3		
4		
5		
Average		

Comparison

Calculate the percent difference between the measured and theoretical values:

cart alone percent difference = _______________

cart with added mass percent difference = _______________

Questions

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

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

Experiment 4: Oscillations on an Incline

Required Equipment from Dynamics System	
Track with End Stop	
Cart	
Pivot Clamp	
Harmonic Spring	
Other Required Equipment	**Suggested Model Number**
Base and support rod	ME-9355
Mass hanger and mass set	ME-9348
Stopwatch	ME-1234
Mass balance	SE-8723

Purpose

In this experiment, you will 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 cycle, 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, x, by which 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 Spring Constant and Theoretical Period

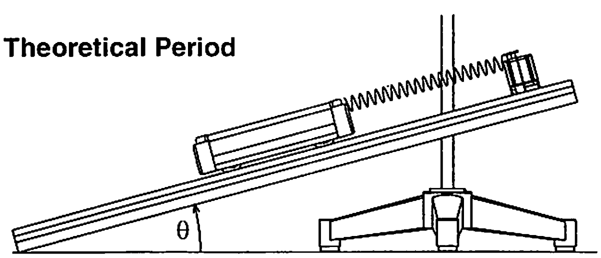


Figure 4.1: Equipment Setup

1. Measure the mass of the cart and record it in Table 4.1.
2. Instal the end stop on the track near one end.
3. Set the cart on the track and attach a spring to one end. Attach the other end of the spring to an the end stop (see Figure 4.1).
4. Incline the track by raising the end of the track where 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 about 50 cm. Use

the pivot clamp and support stand to hold the track at this angle. Measure this angle and record it in Table 4.1.

5. Let the cart hang freely and come to rest. Record the equilibrium position in Table 4.1.

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

Table 4.1: Measurements to Find Theoretical Period

Original Position (without added mass) = _________ Mass of Cart = _________ Angle of Incline = _________		
Added Mass	**Position**	**Force**

Measuring the Experimental Period

7. Remove all of the added mass from the cart.

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

9. Repeat this measurement at least 5 times, using the same initial displacement.

10. Change the angle of the incline and repeat steps 8 and 9. Follow steps 8 and 9 for a total of three different angles.

Calculations

Spring Constant and Theoretical Period

1. Using the data in Table 4.1, calculate the force caused by the mass of the cart: $F = mg \sin \theta$, where θ is the angle of incline.

2. Plot force versus position. 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.

   $k =$ _____________

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

   $T =$ _____________

Experimental Period

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

2. Calculate the period by dividing these average values by 3 and record the periods in Table 4.2.

Table 4.2: Experimental Period

Angle	Time for 3 Oscillations					Average	Period
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5		

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°?

Experiment 5: Springs in Series and Parallel

Required Equipment from Dynamics System	
Track with End Stops	
Cart	
Pivot Clamp	
Harmonic Springs (2)	

Other Required Equipment	Suggested Model Number
Base and support rod	ME-9355
Stopwatch	ME-1234
Mass balance	SE-8723

Purpose

In this experiment, you will measure and compare the periods of oscillation of a cart attached to various combinations of springs.

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 cycle, 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 by

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

You will determine spring constant of a spring by measuring the period of oscillation and mass of a cart attached to the spring. You will use the same method to determine the effective spring constant of two identical springs combined in series and in parallel. For each type of combination, you will discover the relationship between the spring constant of the single spring and the effective spring constant of the combination.

Procedure

Measuring the Spring Constant of a Single Spring

1. Measure the mass of the cart. Record this value at the top of Table 5.1.

2. Install the end stop on the track near one end.

3. Set the cart on the track and attach a spring to one end. Attach the other end of the spring to the end stop (see Figure 5.1).

4. Incline the track by raising the end where the spring is attached. As the end of the track is raised the spring will stretch. Incline the track by raising the end of the track where 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 about 50 cm. Use the pivot clamp and support stand to hold the track at this angle.

5. Displace the cart from equilibrium 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.

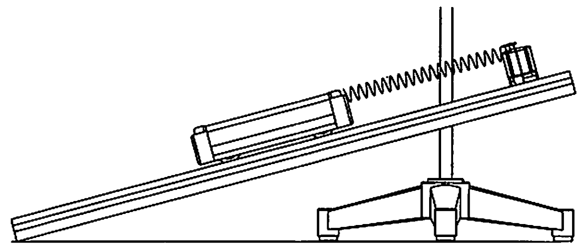


Figure 5.1: Single spring

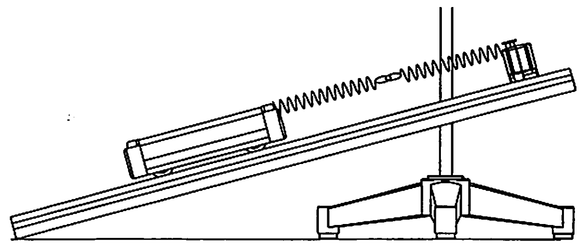


Figure 5.2: Springs in series

Measuring the Effective Spring Constant of Spring Combinations

6. Add a second spring in series as shown in Figure 5.2 and repeat step 5.

7. Put the two springs in parallel as shown in Figure 5.3 and repeat step 5.

8. Arrange the springs as shown in Figure 5.4 and repeat step 5.

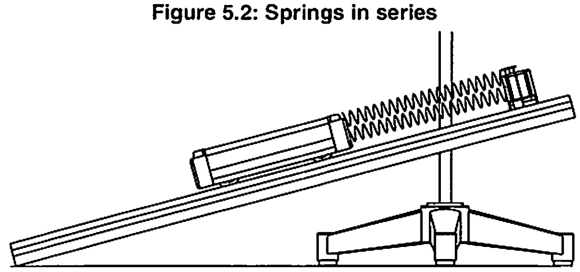


Figure 5.3: Springs in parallel

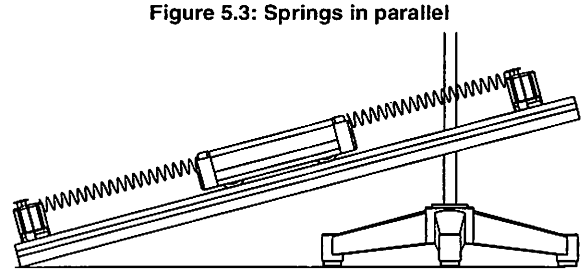


Figure 5.4: Springs on opposite ends

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: Experimental Period

	Time for 2 Oscillations						
Springs	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Average**	**Period**
Single							
Series							
Parallel							
Opposite ends							

Questions

1. For which type of combination (series of parallel) is the effective spring constant equal to $2k$?

2. For which type of combination (series of parallel) is the effective spring constant equal to $k/2$?

3. Is the arrangement with springs at opposite ends a series or parallel combination?

Experiment 6: Launch Speed

Required Equipment from Dynamics System

Track with Feet and End Stops

Plunger Cart

Pivot Clamp

Cart Masses

Purpose

In this experiment, you will qualitatively demonstrate how the final speed of the plunger cart depends on its mass and the initial compression of the plunger spring.

Procedure

1. Install the feet on the track and level it.

2. Install and end stop at each end of the track.

3. Push the plunger of the cart into the first, second, or third position. Place the cart on the track with the plunger against one end stop. Tap the trigger button to launch the cart.

4. **Varying Spring Compression:** Repeat step 3 three times. 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.

5. **Varying Mass:** For these trials, always cock the spring plunger to the maximum. Observe the relative accelerations of the cart alone and with 250 g, 500g, 750 g, and 1000 g of added mass.

Questions

1. When does the spring apply force to the cart? When is the net force on the cart (ignoring friction) zero?

2. Does the final speed of the cart increase or decrease with increasing initial spring compression?

3. Does the final speed of the cart increase or decrease with increasing cart mass?

Experiment 7: Newton's Second Law

Required Equipment from Dynamics System	
Track with Feet and End Stop	
Cart	
Super Pulley with Clamp	
500 g Cart Mass	

Other Required Equipment	Suggested Model Number
Stopwatch	ME-1234
Mass hanger and mass set	ME-9348
Mass balance	SE-8723
String (about 2 m)	

Purpose

In this experiment, you will verify Newton's Second Law, $F = ma$.

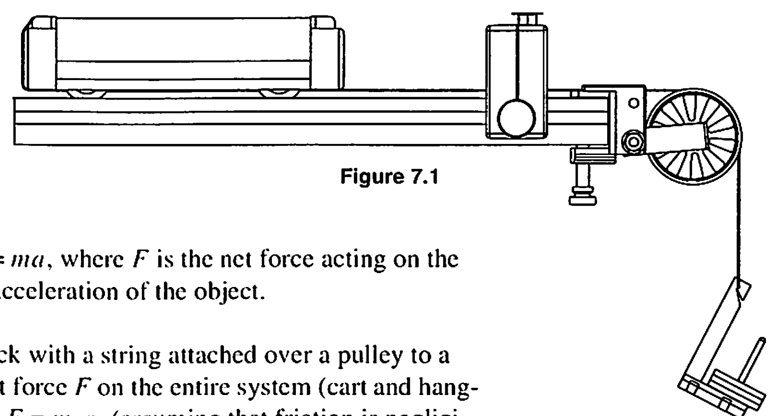


Figure 7.1

Theory

According to Newton's Second Law, $F = ma$, where 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 m_1 on a horizontal track with a string attached over a pulley to a hanging mass m_2 (see Figure 7.1), the net force F on the entire system (cart and hanging mass) is the weight of hanging mass, $F = m_2 g$, (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 $m_1 + m_2$. You will check to see if $m_1 g = (m_1 + m_2)a$ as predicted by theory.

To determine the acceleration, you will release the cart from rest and measure the time (t) for it to travel a certain distance (d). Since $d = (1/2)at^2$, the acceleration can be calculated using $a = 2d/t^2$.

Procedure

1. Install the feet on the track and level it.
2. Install the end stop on the track near one end with the magnets facing away from the track.
3. Measure the mass of the cart and record it in Table 7.1.
4. Attach the pulley and end stop to the track as shown in Figure 7.1. Place the cart on the track. Tie a string to the end of the cart farther from the pulley. Wrap the string under the cart. Tie a mass hanger on the other end of the string. Run the string under the end stop and over the pulley. Adjust the pulley so that the string runs parallel to the track. The string must be just long enough so the cart reaches the end stop before the mass hanger reaches the floor.

5. Pull the cart back until the mass hanger reaches the pulley. Record this initial release position in 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 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.

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

7. Pull the cart back to the initial release position. Release it and time how long it takes to reach the end stop. Record the time in Table 7.1.

8. Measure the time at least 5 times with the same mass and record these values in Table 7.1.

Table 7.1: Experimental Period

Initial release position = __________
Final position = __________
Distance traveled (d) = __________

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

9. Add a 500 g mass to the cart and repeat the procedure.

Data Analysis

1. Calculate the average times and record them in Table 7.1.

2. Record the distance traveled (from initial to final position) in Table 7.1.

3. Calculate the accelerations and record them Table 7.2.

4. For each case, calculate $(m_1 + m_2)a$ and record in Table 7.2.

5. For each case, calculate the net force, F_{NET}, and record in Table 7.2.

6. For each case, calculate the percent difference between F_{NET} and $(m_1 + m_2)a$ and record in Table 7.2.

Table 7.2:

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

Questions

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

2. Why must the mass in $F = ma$ include the hanging mass as well as the mass of the cart?

Experiment 8: Acceleration Down an Incline

Required Equipment from Dynamics System	
Track with End Stop	
Cart	
Pivot Clamp	
Other Required Equipment	**Suggested Model Number**
Base and support rod	ME-9355
Stopwatch	ME-1234
Graph paper	

Purpose

In this experiment, you will investigate how the acceleration of a cart rolling down an inclined track depends on the angle of incline. From you data, you will calculate the acceleration of an object in free-fall.

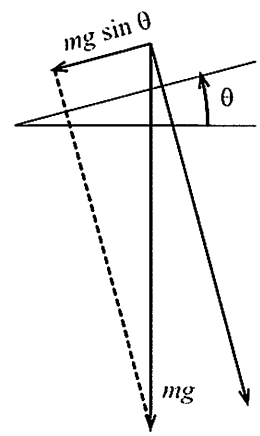


Figure 8.1

Theory

A cart of mass m on an incline will roll down the incline as it is pulled by gravity. The force of gravity (mg) is straight down as shown in Figure 8.1. The component of that is parallel to the inclined surface is $mg \sin \theta$.

To determine the acceleration, you will release the cart from rest and measure the time (t) for it to travel a certain distance (d). Since $d = (1/2)at^2$, the acceleration can be calculated using $a = 2d/t^2$.

A plot of a versus $\sin \theta$ will be a straight line with a slope equal to the acceleration of an object in free-fall, g.

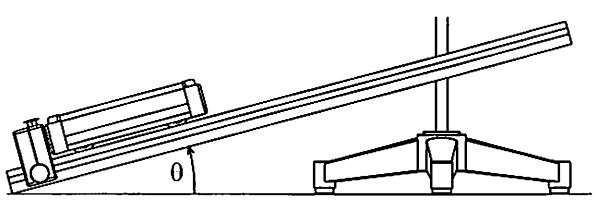


Figure 8.2

Procedure

1. Set up the track as shown in Figure 8.2 with a pivot clamp and support stand. Elevate the end of the track by about 10 cm.

2. Set the cart on the track against the end stop and record this final position in Table 8.1. (Use the non-magnetic end of the cart so it touches the end stop.)

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 reach 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 repeat step 4. Use the same release position.

6. Repeat step 4 for a total of 7 angles, lowering the end of the track by 1 cm for each new angle.

Table 8.1: Data

Initial release position = ________
Final position = ________
Distance traveled (d) = ________

		Height of Track						
		10 cm	9 cm	8 cm	7 cm	6 cm	5 cm	4 cm
Time	Trial 1							
	Trial 2							
	Trial 3							
	Trial 4							
	Trial 5							
	Trial 6							
	Trial 7							
	Trial 8							
	Trial 9							
	Trial 10							
	Average							

Data Analysis

1. Calculate the average time for each angle and record it in Table 8.1.

2. Calculate the distance traveled, d, from the initial to the final position.

3. Use the distance traveled and average time to calculate the acceleration for each angle and record it in in Table 8.2.

Table 8.2: Analysis

Height	Acceleration	$\sin\theta$
10 cm		
9 cm		
8 cm		
7 cm		
6 cm		
5 cm		
4 cm		

4. Measure the hypotenuse of the triangle formed by the track and use this to calculate sin θ for each angle.

   Hypotenuse = __________

5. Plot acceleration versus sin θ. Draw the best-fit straight line and calculate its slope. Calculate the percent difference between the slope and $g = 9.8$ m/s^2.

   slope = ______________________

   % difference = _______________

Questions

1. Does your reaction time in operating the stopwatch cause a greater percentage error at higher or lower track angles?

2. How will doubling the mass of the cart affect the results? Try it.

Experiment 9: Conservation of Energy

Required Equipment from Dynamics System	
Track with Feet and End Stops	
Cart	
Pivot Clamp	
Spring Cart Launcher (with a spring and release pin)	
Super Pulley with Clamp	

Other Required Equipment	Suggested Model Number
Base and support rod	ME-9355
Mass hanger and mass set	ME-9348
Graph paper	
String (40 cm)	

Purpose

In this experiment, you will determine the spring constant of a compression spring and use the spring to launch a cart up an incline. You will compare the potential energy initially stored in the spring to the maximum gravitational potential energy achieved by the cart.

Theory

The spring constant of a spring is

(eq. 1)
$$k = \frac{F_x}{x}$$
Spring constant

where F_x is the force applied to the spring and x is the distance by with it is compressed.

The potential energy stored in a spring is

(eq. 2)
$$U_{\mathrm{spring}} = \frac{1}{2}kx^2$$
Potential energy stored in a spring

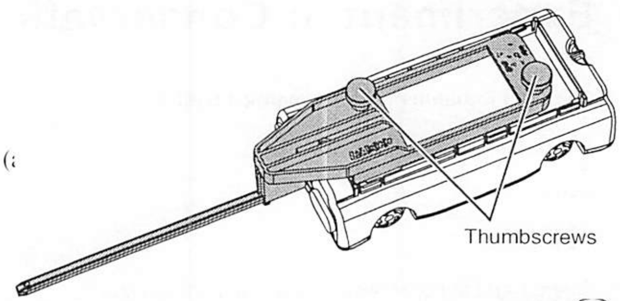
The change in gravitational potential energy of a cart moving up an inclined track is

(eq. 3)
$$\Delta U_{\mathrm{gravity}} = mg\Delta s\sin\theta$$
Potential energy of a cart on an inclined track

where m is the mass of the cart, $g = 9.8$ m/s^2, Δs is the distance traveled along the track (in the uphill direction), and θ is the track's angle of incline.

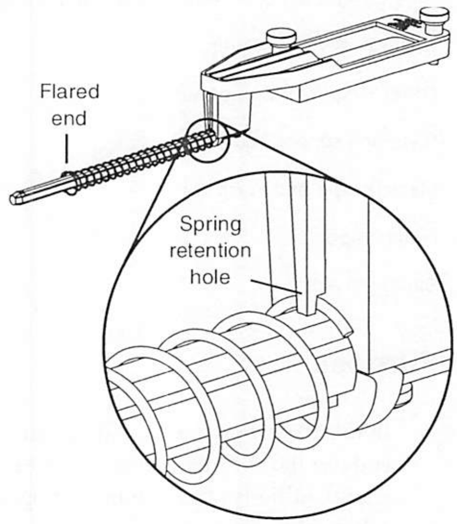
Part I: Spring Constant

Procedure

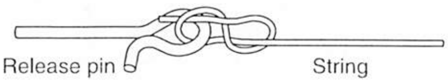


1. Fit the spring cart launcher onto the top of the cart (
Tighten the thumbscrews to secure it.

2. Select one of the included springs. Slide it onto the launcher shaft with the flared end out. Turn the spring to secure the end in the spring retention hole as illustrated.



3. Tie the string to the release pin.



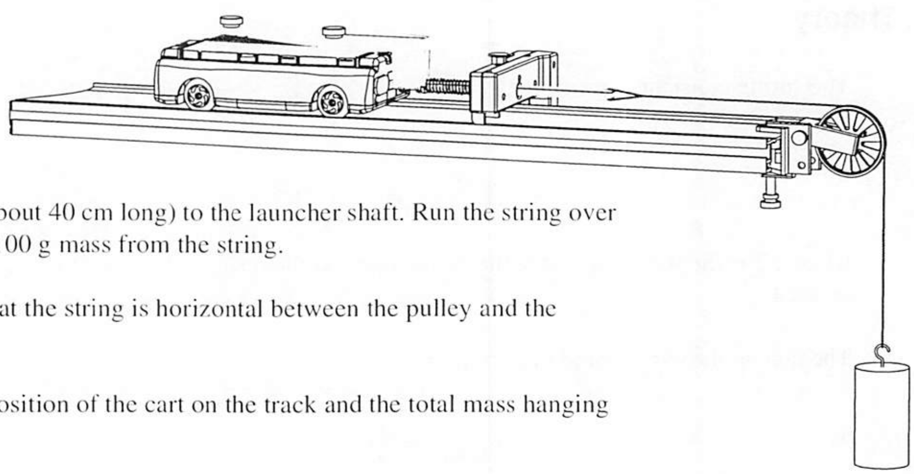
4. Install an end stop about 20 cm from the end of the track.

5. Clamp a pulley to the same end of the track.

6. Position the track so that a mass hanging from the pulley is free to hang over the edge of your lab bench.

7. Level the track so that the cart does not roll when release from a standstill.

8. Place the cart on the track with the launcher shaft through the hole in the end stop.



9. Tie a piece of string (about 40 cm long) to the launcher shaft. Run the string over the pulley and hang a 100 g mass from the string.

10. Adjust the pulley so that the string is horizontal between the pulley and the launcher shaft.

11. In a table, record the position of the cart on the track and the total mass hanging from the string.

12. Add 100 g to the hanging mass.

13. Repeat steps 11 and 12 up to about 500 g.

Data Analysis

1. Calculate the force applied to the spring at each step: $F_x = m_h g$, where m_h is the hanging mass and $g = 9.8\ \text{m/s}^2$.

2. Make a graph of F_x versus cart position.

3. Draw a best-fit line on your graph. The slope of that line equals the spring constant, k.

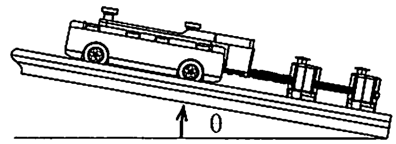
Untie the string from the launcher shaft and remove the pulley for the next part.

Part II: Spring Potential Energy and Kinetic Energy

Procedure

1. Place a second end stop on the track about 8 cm behind the first end stop.

2. Elevate one end of the track by about 20 cm.



3. Hold the cart on the track with the launcher shaft through the hole in the first end stop, and with the spring just touching the end stop, but not compressed. Record this position of the cart as x_1.

4. Push the shaft through both and stops and put the release pin into the shaft. Let the pin rest against the second end stop. Record this position of the cart as x_2.

5. Pull out the release pin with a quick jerk.

6. Watch the cart carefully as it ascends the track. Observe the highest position achieved. Try to read it to the nearest centimeter. Record this position as x_3.

Data Analysis

1. Calculate the spring compression: $x = x_1 - x_2$

2. Use x, the value of k that you found in the previous part, and Equation 2 to calculate the initial potential energy of the spring.

3. Calculate the distance traveled by cart: $\Delta s = x_3 - x_2$

4. Measure the mass, m, of the cart with the cart launcher and spring attached.

5. Measure the angle, θ, of the track.

6. Use Equation 3 to calculate the change in gravitational potential energy of the cart.

7. Compare the initial potential energy of the spring to the maximum gravitational potential energy of the cart. Are they equal? If not, what might account for the difference?

Additional Experiment Suggestions

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 a 500 g 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. Trigger the 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 remains balanced. Repeat this procedure using carts of unequal mass.

Oscillation Modes of Two Carts and Three Springs

Place two carts of equal mass on the track. Attach a spring between the 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.

Newton's Second Law: Uphill Acceleration

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

Damped Motion

Incline the track with the end stop at the bottom. Release the cart from a measured distance up the track. Use the magnetic bumpers in the cart and end stop so the cart rebounds. On each rebound, when the cart reaches its peak, record the time and position. Make a graph of amplitude versus time.

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.

Oscillation modes of Three Carts and Four Springs

Place three carts of equal mass on the track. Attach springs between the carts and connect the end carts to the 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.

Multiple Elastic Collisions

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.

Multiple Inelastic Collisions

Use three carts with the magnets removed from the middle cart. Push the left cart into the middle cart, which in turn will collidé with the right cart. The carts will all stick together. Note the resulting final velocity of the carts.

Rocket Staging

Use three or more plunger carts to simulate a rocket expelling fuel. Push the plungers in on each cart and attach the carts together in a line. Use tape to lightly attach the carts to each other. 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.

Longitudinal Wave

Use six or more carts with magnetic bumpers installed on both ends. Install end stops on the track with the magnetic side 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.

Technical Support

For assistance with any PASCO product, contact PASCO at:

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

Phone: 916-786-3800 (worldwide)
800-772-8700 (U.S.)

Fax: (916) 786-7565

Web: www.pasco.com

Email: support@pasco.com

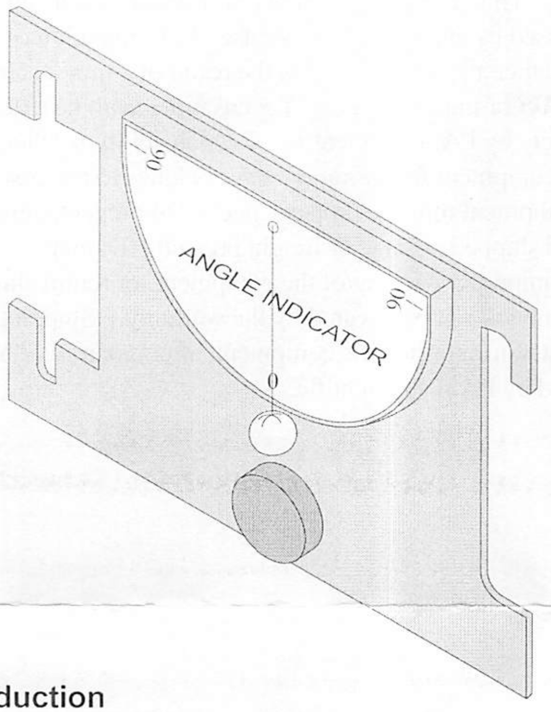
Limited Warranty
For a description of the product warranty, see the PASCO catalog.

Authors: Ann Hanks
Jon Hanks
Eric Ayars
Alec Ogston

012-06262A
11/96
$1.00

Instruction Sheet for the PASCO Model ME-9495

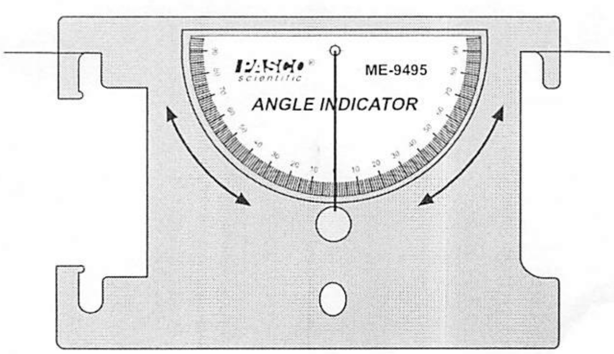
ANGLE INDICATOR



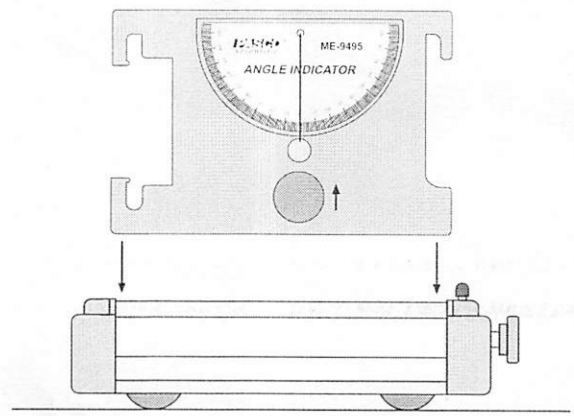
Introduction

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.

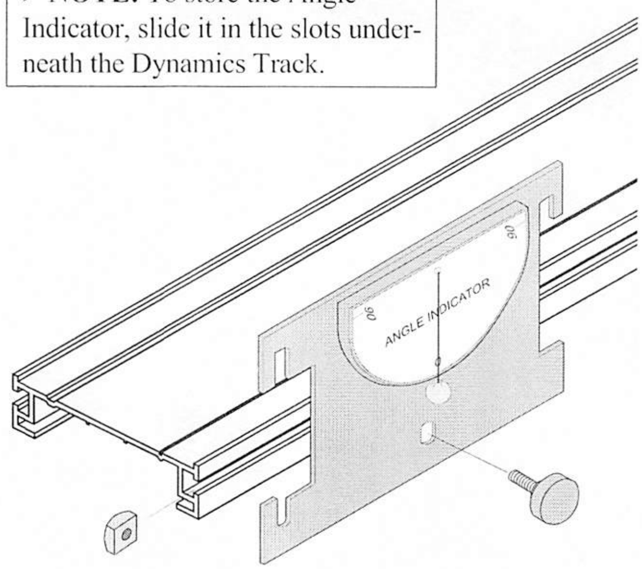


- attached to a PASCO Dynamics Cart, by sliding the device into the slots on the top of the cart. It is necessary to adjust the thumbscrew and square nut as far up as possible on the Angle Indicator.



- 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:

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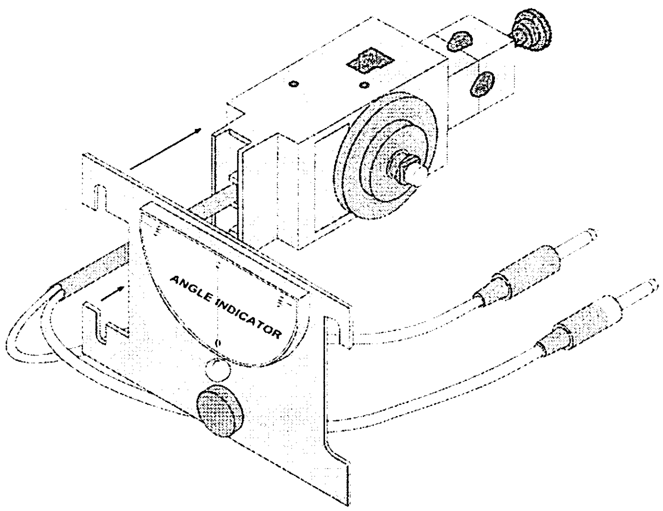
Phone (916) 786-3800 • FAX (916) 786-8905 • email: techsupp@PASCO.com
better ways to teach science

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



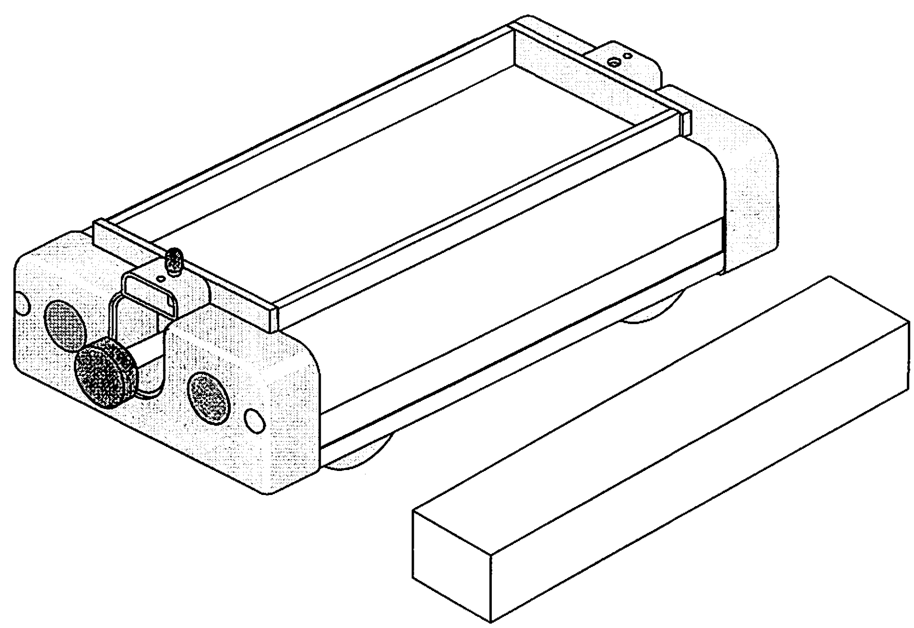
Limited Warranty

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.

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

012-04840E

Dynamics Cart with Mass



Copyright, Warranty and Equipment Return

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Credits

This manual authored by: Scott K. Perry

This manual edited by: Dave Griffith

Equipment Return

If this product requires return 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 properly packed. 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.

Address: PASCO scientific
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Web: www.pasco.com

Table of Contents

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:

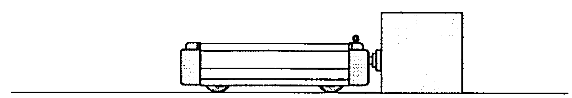
- An extremely low friction ball-bearing design provides smooth motion.
- A built-in spring plunger, activated by a convenient trigger (button) located on the front end cap, with three positions of launching amplitude, enables the cart to be launched without using additional apparatus.
- A unique suspension 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 ensure 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.

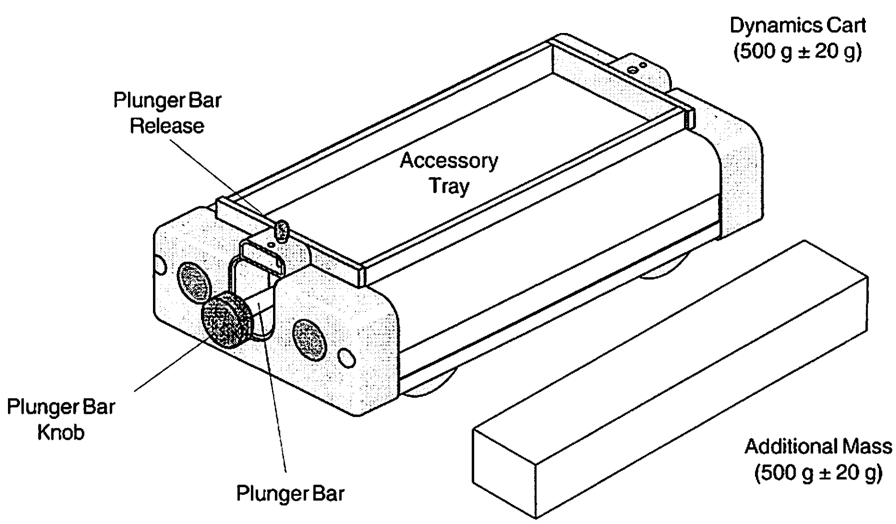
Equipment

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 PASCO's Slotted Mass Set (SE-8704)
- A pulley and clamp, such as PASCO's 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 PASCO's Metric Measuring Tape (SE-8712) and 30cm/12in. Ruler (SE-8731)
- Stopwatch, such as PASCO's Digital Stopwatch (SE-8702)
- Mass balance, such as PASCO's Triple-Beam Balance (SE-8723)
- A friction block that can fit in the cart's accessory tray (i.e. 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)

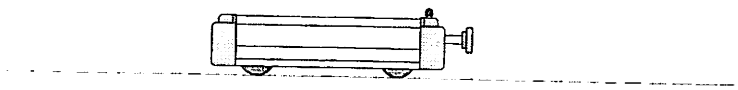


Figure 1.1

Purpose

In this lab, the Dynamics Cart will be used to investigate one dimensional accelerated motion. You will launch the cart 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:

$$v_{av} = \frac{D}{T} \quad \text{(EQN-1)}$$

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:

$$v_0 = 2v_{av} = \frac{2D}{T} \quad \text{(EQN-2)}$$

And the value of the acceleration would be given by:

$$a = \frac{\Delta v}{\Delta t} = \frac{0 - v_0}{T} = -\frac{2D}{T^2} \quad \text{(EQN-3)}$$

If the acceleration and v_0 are known, then the time, 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:

$$d = v_0 t_1 + 1/2 a t_1^2 \quad \text{(EQN-4)}$$

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, you can determine t_1, T and D for each launch. Practice this step a few times before you start recording data.

> **NOTE:** To eliminate reaction time errors, 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 slightly upward 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. (NOTE: If the timer feels that a distraction interfered with the measurement, don't count that trial.) Record your best trials in Table 1.1.

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

Data Analysis

d = _______cm

Table 1.1

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							

Questions

1. Is there a systematic difference between the experimental and calculated values of 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. To determine both the coefficient of rolling friction μ_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:

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

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

$$a_2 = - g\sin\theta - \mu_r g \qquad \text{(EQN-2)}$$

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:

$$a = \frac{2d}{t^2} \qquad \text{(EQN-3)}$$

Having obtained numerical values for a_1 and a_2, **EQN-1** and **EQN-2** can be solved simultaneously for μ_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.

Table 2.1

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			

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.)

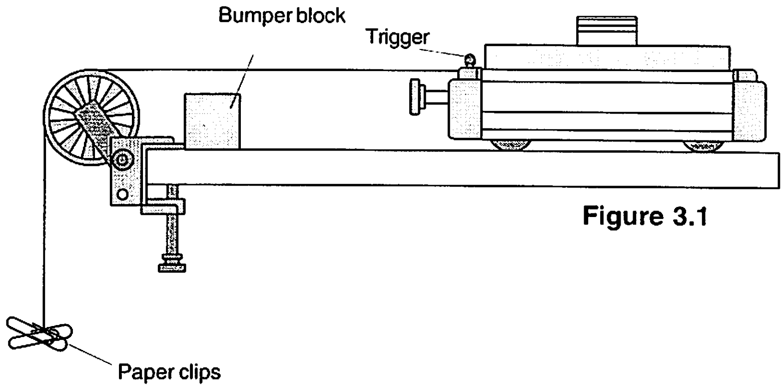


Figure 3.1

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 stop-watch, 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, have the person who releases the cart also do 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

Table 3.1

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				

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.)
- 500 g mass
- Stopwatch (SE-8702)
- 15 cm/6 in ruler (SE-8730)

Purpose

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

Theory

For this and following experiments, you will 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** vs. **x** is plotted on graph paper, the spring constant is given by the slope of the graph as:

$$k = \Delta F/\Delta x \qquad \textbf{(EQN-1)}$$

Once **k** is known, you can predict the launch velocity v_0 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:

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

which leads to:

$$v_0 = x_0 \sqrt{\frac{k}{m}} \qquad \textbf{(EQN-3)}$$

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:

$$v_0 = 2\frac{d}{t} \qquad \textbf{(EQN-4)}$$

(Here 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.

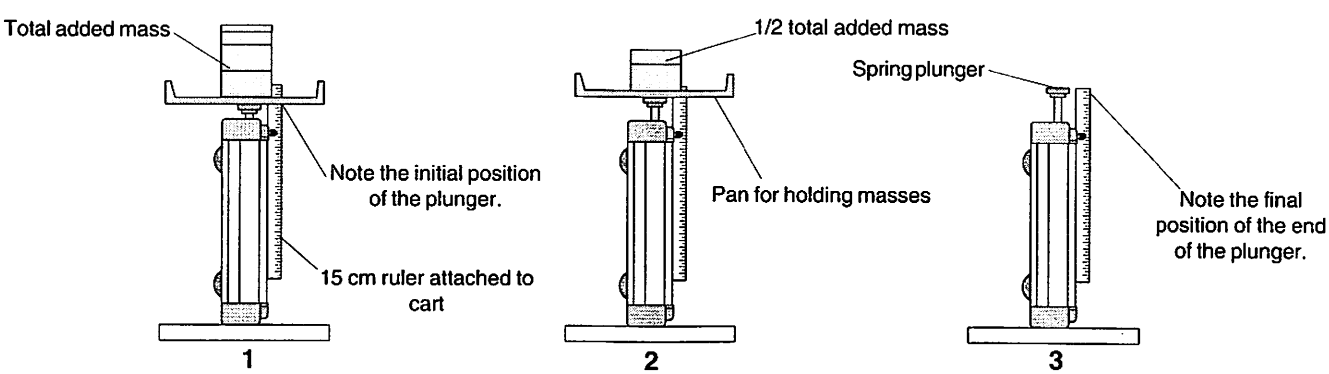


Figure 4.1

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. 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**, $\mathbf{x_0}$ (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 $\mathbf{x_0}$ that you have chosen; then place the cart in its 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 $\mathbf{v_0}$ and compare it with the predicted value.

Data and Analysis

Mass of cart = _________ kg

k = _________ $\frac{N}{m}$ **x_0 = _________ m**

Predicted value of launch velocity v_0 = _________ $\frac{m}{s}$

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

Observed value of the launch velocity v_0 = _________ $\frac{m}{s}$

Percent (%) difference between observed and expected values of v_0 = _________

Table 4.1

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

Notes:

Experiment 5: Rackets, Bats and "Sweet Spots"

EQUIPMENT NEEDED:

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

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 the sweet-spot (**SS1**).

NOTE: For simplicity, it is assumed that the collisions are perfectly elastic.

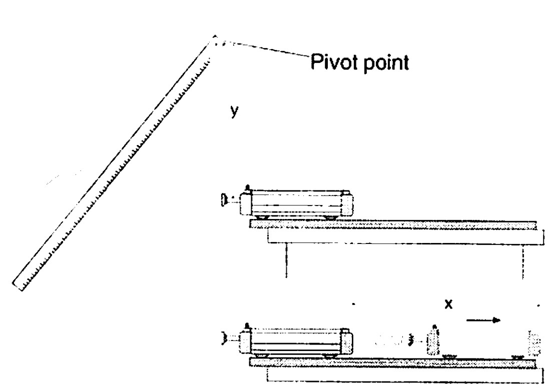


Figure 5.1

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:

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

where **I** is the rotational inertia of the bat for the corresponding pivot, **m** is the total mass of the bat, and 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

Table 5.1

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			

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 affect 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); "Im-
pulse 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.

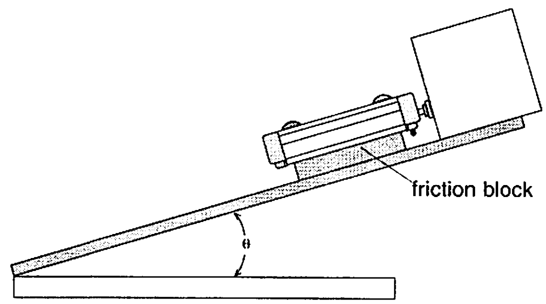


Figure 6.1

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:

$$1/2kx^2 + mgD\sin\theta = \mu_k mgD\cos\theta \qquad \text{(EQN-1)}$$

(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 μ_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 μ_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 ($-\mu_k mg\cos ø$) 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:

$$a = g\sin ø - \mu_k g\cos ø \qquad \text{(EQN-2)}$$

The average acceleration down the ramp is given by:

$$a = 2d/t^2 \qquad \text{(EQN-3)}$$

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

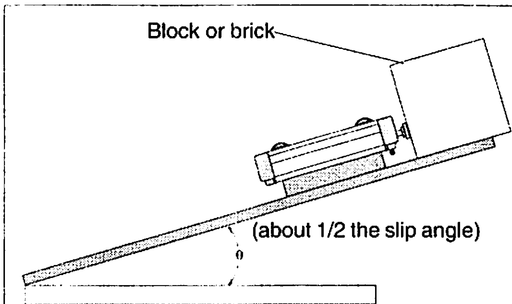


Figure 6.2

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)

Table 6.1

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

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

θ = _________ Predicted value of D = _________ cm

Table 6.2

Trial	D (cm)
1	
2	
3	
4	
5	
6	

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:

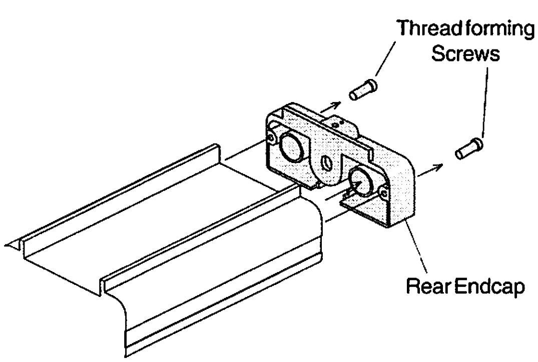
Appendix

> **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.

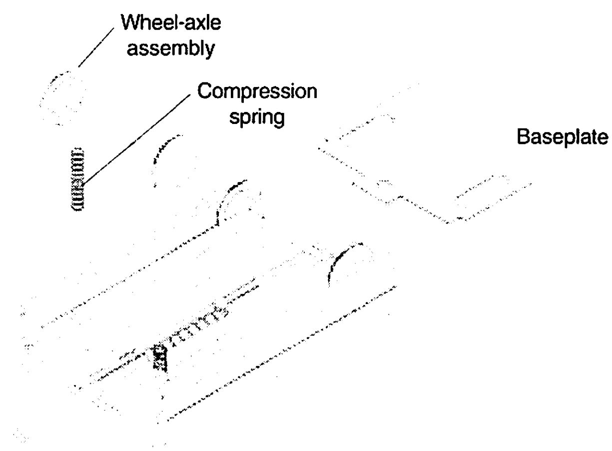
Replacing the Wheel-Axles Assemblies

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.



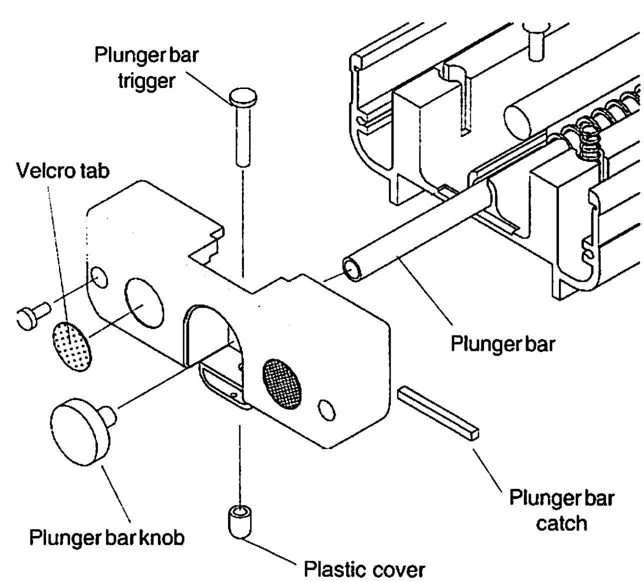
2. Push the wheels into the recessed area and slide the base plate over the wheels.
3. Replace the wheel-axle assembly and springs in reverse order.



4. Slide the 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 the new cover.
- If the plunger bar becomes defective, please contact PASCO scientific for technical support.



Replacement Parts

Description	Part No.	Qty
Wheel-axle assembly	ME-6957	4
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

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,

Phone: 1-800-772-8700 (toll-free within the U.S.)

or (916) 786-3800.

Email: techsupp@PASCO.com

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 the 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)

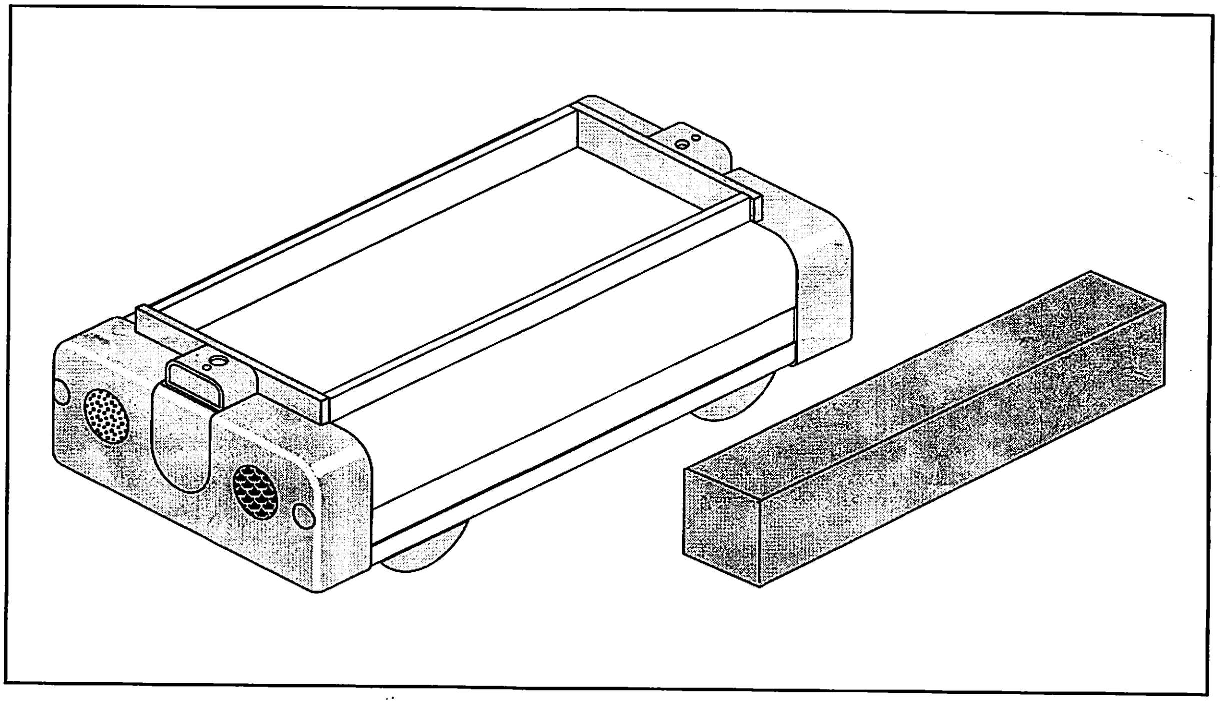
-Have the manual at hand to discuss your questions.

Instruction Manual

Manual No. 012-04966D

Collision Cart

Model No. ME-9454



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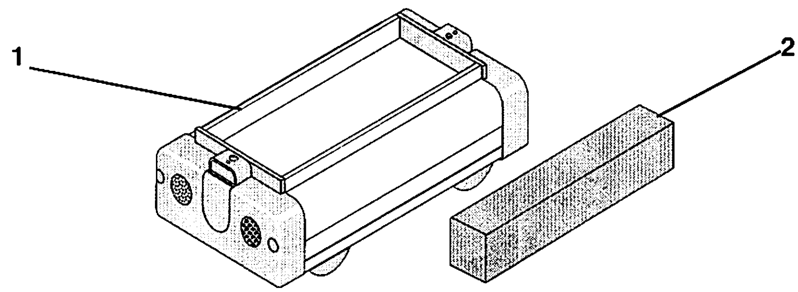
better ways to teach science

Collision Cart

Model No. ME-9454

Equipment List



Included Equipment	Replacement Model Number*
1. Collision Cart (1)	ME-9454
2. 500 g Mass (1)	648-0636

*Use Replacement Model Numbers to expedite replacement orders.

Additional Equipment Required	
Dynamics Cart Track, 1.2 meters or 2.2 meters	ME-9435A or ME-9458

Replacement Parts	
Wheel-Axle Assembly (2)	003-05311
End cap (2)	648-04969
End cap plug (2)	648-04694
Suspension spring (4)	632-034
Base Plate (1)	648-04651
1/2" Velcro® loop (2)	616-074
1/2" Velcro® hook (2)	616-075
Magnet (4)	634-022
Foam Retainer (4)	648-04702

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 Classic Plunger Cart in two ways:

1. The Collision Cart has no spring plunger.

2. The Collision Cart has magnets and Velcro® pads installed on both ends of the cart.

Like the Plunger Cart, the Collision Cart has a mass of approximately 500 g and holes in each end-cap for attaching string or springs. An additional mass of approximately 500 g is included with the cart and fits into the mass tray on top of the cart.

Tip: For best results, measure the mass of the cart and any added mass with an accurate balance or scale.

Advantages of the Collision Cart

- The cart comes supplied with Velcro® pads attached, so a Collision Cart will stick to a Plunger Cart during an inelastic collision. (Note: The end of the ME-9430 Plunger Cart used in the inelastic collision must not have magnets attached, or the two carts will not stick together due to the repulsive properties of the magnet assemblies.)
- The Collision Cart has magnets attached, so the cart will bounce off any other cart's magnetic bumpers in an elastic collision, with very little frictional loss. (Note: If you place magnets on the end of the ME-9430 Plunger Cart, the magnets must be placed 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 Plunger Cart to perform explosions.
- Multiple inelastic and elastic collisions may be performed using three or more carts.

Note: Experiments using the Collision Cart are described in the Experiment Guide for the ME-9458 and ME-9435 Dynamics Track Accessory Sets.

Removing the Magnet Bumpers

1. Detach each end cap by removing the two screws from the rear of the end cap (See Figure 1).

Note: The screws that secure the end caps to each end of the Collision 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.

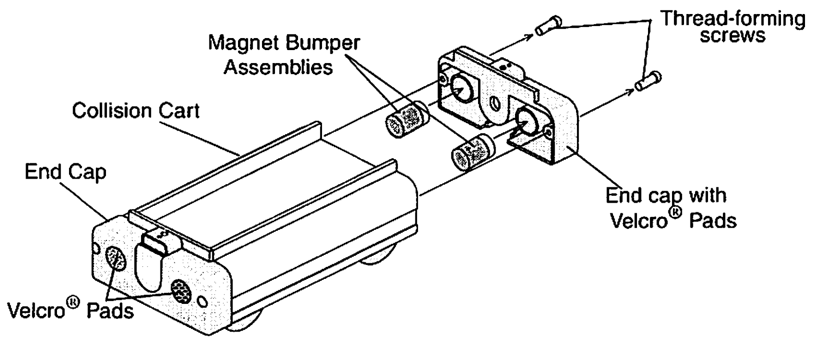


Figure 1: Removing the Magnetic Bumper Assemblies

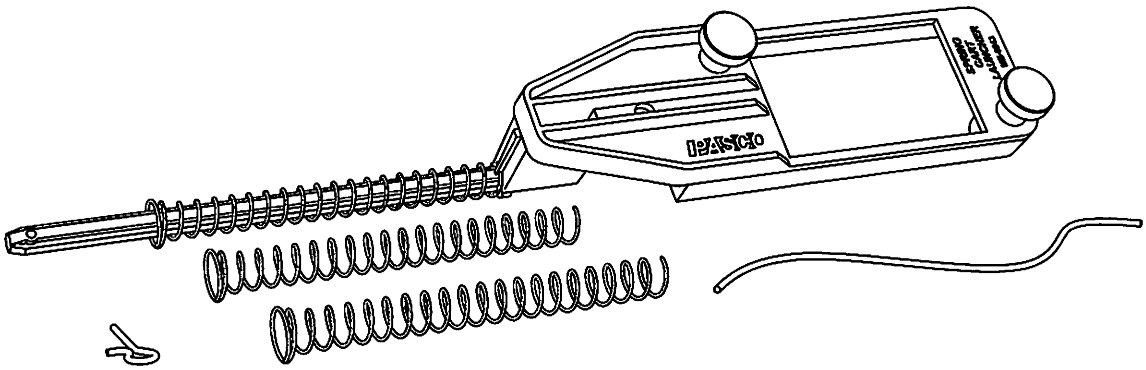
Note: When attaching the magnet assemblies, first slide the magnets into the end cap cavities.

3. Replace the rear end cap with the two screws.

CAUTION!: Each magnet assembly consists of a foam pad attached to a neodymium magnet. The neodymium magnets are extremely strong. Although 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.

Spring Cart Launcher

ME-6843



Included Equipment	Quantity	Replacement Part Number
Spring Cart Launcher	1	ME-6843
Firm Spring (black)	1	ME-6847[1]
Medium Spring (blue)	1	ME-6847[1]
Soft Spring (red)	1	ME-6847[1]
Release Pin	2	ME-6847[1]
String	1 m	ME-6847[1]
Required Equipment		**Part Number**
Cart[2]	1	ME-6951, ME-6950, ME-9430, or ME-9454
Track[2]	1	ME-6953 or similar
End Stops[3]	2	ME-9469 (2-pack)
Recommended Equipment		
250 g Compact Cart Mass	2	ME-6755
For sensor-based method:		
Motion Sensor[4]	1	PS-2103
Force Sensor[4]	1	PS-2104
For traditional method:		
Super Pulley with Clamp	1	ME-9448A
Hooked Mass Set	1	SE-8759 or similar

[1]ME-6847 replacement kit includes (2) of each spring and (4) release pins
[2]This part is included in many of the PASCO dynamics systems. See PASCO catalog or www.pasco.com for details.
[3]New-style plastic end stops required. These are included with PASCO dynamics systems starting in 2007.
[4]PASPORT sensors require a PASPORT interface. See PASCO catalog or www.pasco.com for details.

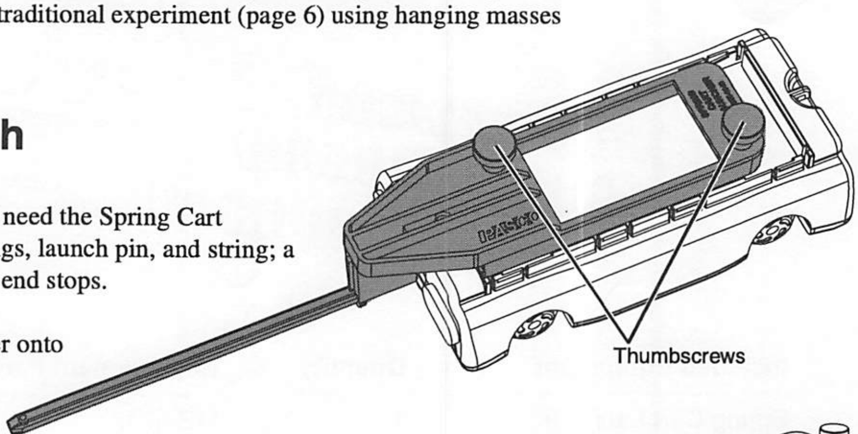
Introduction

The Spring Cart Launcher is designed for the study of force and motion, potential energy, conservation of energy, the work-energy theorem, Hooke's Law, and spring constants. Use it to launch any PASCO dynamics cart by compressing and releasing one of three interchangeable springs. The included release pin, in combination with two end stops, allows you to use precisely the same spring compression for multiple launches.

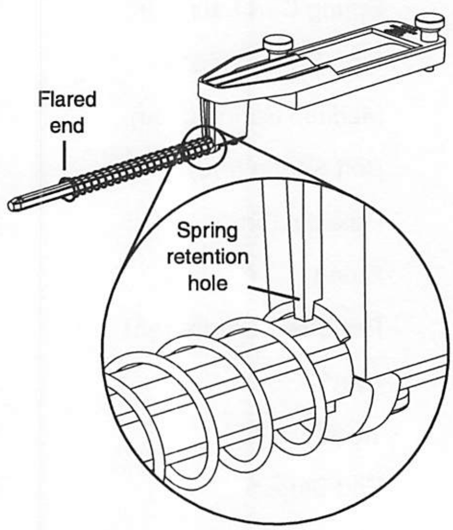
This manual includes instructions for a sensor-based experiment (page 4) using motion and force sensors, and a traditional experiment (page 6) using hanging masses and an inclined track.

Set-up and Launch

For this general set-up, you will need the Spring Cart Launcher with its included springs, launch pin, and string; a cart; a track, and two adjustable end stops.

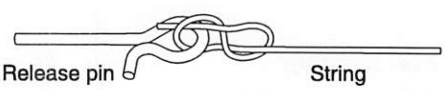


1. Fit the Spring Cart Launcher onto the top of the cart (as illustrated). Tighten the thumbscrews to secure it.



2. Select one of the included springs. Slide it onto the launcher shaft with the flared end out. Turn the spring to secure the end in the spring retention hole as illustrated.

3. Tie the string to the release pin.

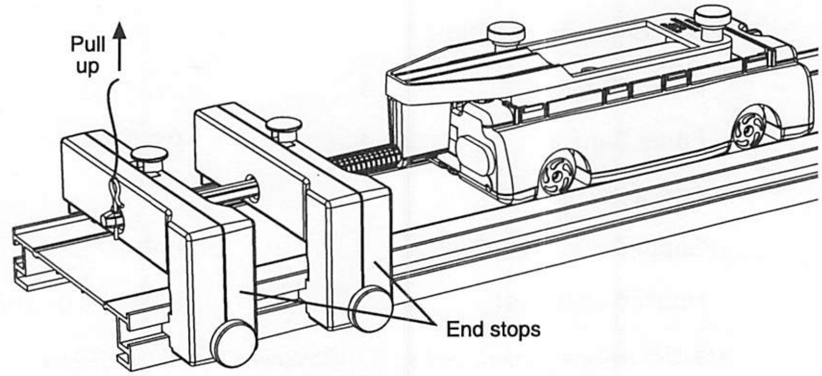


4. Install two end stops near one end of a dynamics track between 3 cm and 10 cm apart, measured center-to-center.

5. Place the cart on the track. Push the launcher shaft through the holes in both end stops.

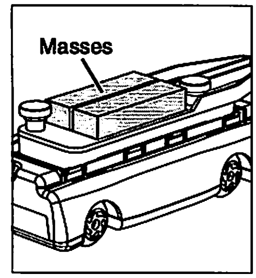
6. Insert the release pin through the hole in the end of the launcher shaft. Allow the launch pin to rest against the end stop.

7. To launch the cart, jerk the launch pin out by pulling sharply up on the string.



As a simpler, but less repeatable, alternative to the above set-up, use only one end stop and do not use the launch pin. Pull the shaft through the end stop and release it from your hand.

Cart Mass



For varying the mass of the cart, the Spring Cart Launcher is designed to hold one or two Compact Cart Masses (PASCO part ME-6755). The launcher prevents these masses from shifting or sliding. Place the masses as illustrated.

Theory

The spring constant of a spring is

(eq. 1) Spring constant

$$k = \frac{F_x}{x}$$

where F_x is the force applied to the spring and x is the displacement of the end of the spring from its equilibrium position.

As you push the end of a spring (or anything else) from position x_1 to x_2, the work that you do is equal to the area under the F_x versus x graph, or

(eq. 2) Work done on a spring

$$W = \int_{x_1}^{x_2} F_x dx$$

The potential energy stored in a spring is

(eq. 3) Potential energy stored in a spring

$$U_{spring} = \frac{1}{2}kx^2$$

The kinetic energy of a cart moving on a track is

(eq. 4) Kinetic energy

$$K = \frac{1}{2}mv^2$$

where m is the mass of the cart, and v is the magnitude of velocity.

The change in gravitational potential energy of a cart moving up an inclined track is

(eq. 5) Potential energy of a cart on an inclined track

$$\Delta U_{gravity} = mg\Delta s \sin\theta$$

where $g = 9.8$ m/s^2, Δs is the distance traveled along the track (in the uphill direction), and θ is the track's angle of incline.

Sensor-based Experiment

Note About Sensors and Interfaces

In this experiment, a force sensor measures the force that you apply to the spring; a motion sensor measures the displacement of the end of the spring as it is compressed, the position of the cart, and the velocity of the cart.

You can use the PASPORT sensors recommended on page 1 with a multiple-port interface (such as an Xplorer GLX or Power Link) or two single-port interfaces (such as USB Links). Most of the measurements described below can also be done with just one single-port interface using one sensor at a time. *ScienceWorkshop* sensors and interfaces would also work.

The instructions below refer to operations in DataStudio software such as connecting sensors, setting sampling rates, and setting up graphs. For information about these tasks, press F1 to open DataStudio Help. This experiment can also be done on the Xplorer GLX in standalone mode (without a computer).

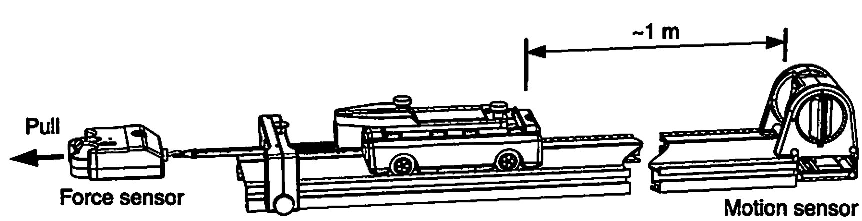
Additional Set-up

1. Follow set-up steps 1 through 3 on page 2.
2. Install one end stop on the track. If you are using a 1.2 m track, place the end stop near one end. If you are using a 2.2 m track, place the end stop in the middle.
3. Level the track so that the cart does not roll when release from a standstill.
4. Clip the motion sensor to the end of the track opposite from the end stop. Aim the sensor along the track. Set the range switch to the NEAR or cart setting.
5. Connect the motion sensor and a force sensor to your PAPORT interface (or interfaces). If you are using a computer, connect the interfaces to it and start DataStudio.
6. Set the sampling rate of both sensors to 20 Hz.
7. Prepare the following graphs: Position versus Time, Velocity versus Time, Position versus Force (Pull Positive).

Spring Constant, Work, and Spring Potential Energy

In this part you will use Equation 1 to determine k for your spring. The force sensor measures F_x, and the motion measures x. The slope of the F_x versus x graph equals k.

1. Place the cart on the track with the launcher shaft through the hole in the end stop.
2. Use a piece of string to tie the hook of the force sensor to the launcher shaft.



3. Pull back with the force sensor so that the end of the spring just touches the end stop, but do not compress the spring yet.

4. Press the ZERO or TARE button on the force sensor.

5. Start data recording.

6. Slowly pull back with the force sensor until the spring is *almost* completely compressed.

Note: Have your partner hold the track to prevent it from slipping, but be careful not to block the motion sensor.

7. Stop data recording.

8. Determine k from the slope of the F_x versus x graph.

9. Measure the area under graph. This area equals the work, W, that you did on the spring.

10. From the graph, determine the displacement (or *change* in position) of the end of the spring.

11. Use Equation 3 to calculate U_{spring}, the potential energy stored in the spring after you compressed it.

12. Compare W to U_{spring}. Do both values have the same (or equivalent) units? What is the percent difference?

13. Repeat steps 1 through 8 to determine the spring constants of all three springs.

Untie the string from the launcher shaft for the next part.

Spring Potential Energy and Kinetic Energy

In this part, you will study the relationship between the potential energy initially stored in the spring and the kinetic energy of the cart just after launch.

1. Place a second end stop on the track about 8 cm behind the first end stop.

2. Place the cart on the track with the launcher shaft through the hole in the first end stop. Position the cart so that the spring is touching the end stop but not compressed.

3. Start data recording.

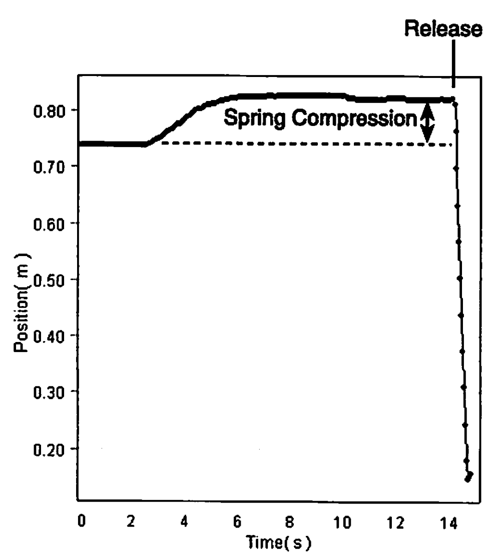
4. Wait a few seconds (to let the sensor measure the uncompressed position). Push the shaft through both and stops and put the release pin into the shaft. Let the pin rest against the second end stop and wait a few more seconds (to let the sensor measure the compressed position).

Important: In the next step, have your partner catch the cart before it hits the motion sensor.

5. Pull out the release pin with a quick jerk to launch the cart

6. Stop data recording.

7. Determine the spring compression from the graph of position versus time.



8. Use the value of k that you found in the previous part and Equation 3 to calculate U_{spring}.

9. Look at the graph of velocity versus time to find the velocity of the cart just after the launch.

10. Measure the mass of the cart with the launcher and spring attached.

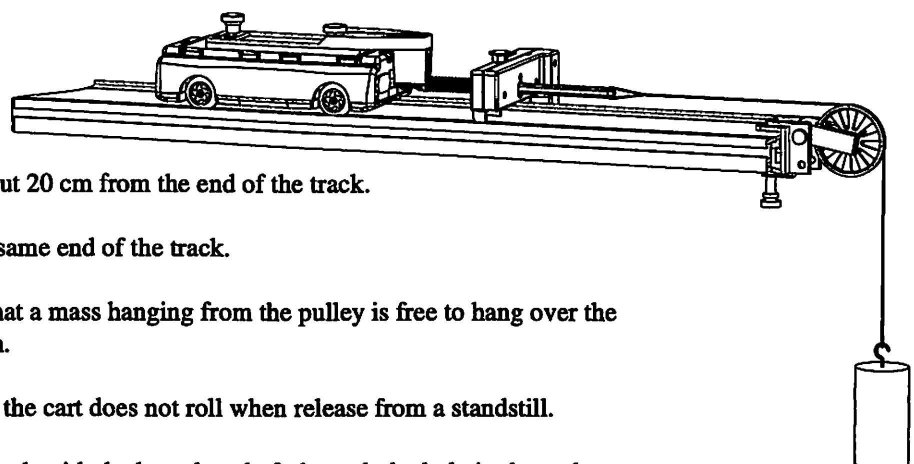
11. Use Equation 4 to calculate the kinetic energy of the cart.

12. Compare the initial potential energy of the spring to the kinetic energy of the cart. Are they equal? If not, what might account for the difference?

Traditional Experiment

In this experiment (which does not require sensors), you will determine the spring constant by using a hanging mass to apply a known force. To determine the energy transferred to the cart, you will observe the maximum height that the cart reaches as it runs up an inclined track.

Spring Constant



1. Follow set-up steps 1 through 3 on page 2.

2. Install an end stop about 20 cm from the end of the track.

3. Clamp a pulley to the same end of the track.

4. Position the track so that a mass hanging from the pulley is free to hang over the edge of your lab bench.

5. Level the track so that the cart does not roll when release from a standstill.

6. Place the cart on the track with the launcher shaft through the hole in the end stop.

7. Tie a piece of string (about 40 cm long) to the launcher shaft. Run the string over the pulley and hang a 100 g mass from the string.

8. Adjust the pulley so that the string is horizontal between the pulley and the launcher shaft.

9. In a table, record the position of the cart on the track and the total mass hanging from the string.

10. Add 100 g to the hanging mass.

11. Repeat steps 9 and 10 up to about 500 g.

12. Calculate the force applied to the spring at each step: $F_x = m_h g$, where m_h is the hanging mass and $g = 9.8$ m/s^2.

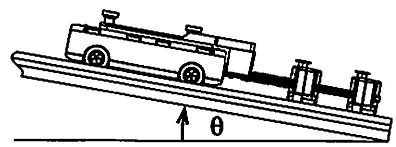
13. Make a graph of F_x versus cart position.

14. Draw a best-fit line on your graph. The slope of that line equals the spring constant, k.

Untie the string from the launcher shaft and remove the pulley for the next part.

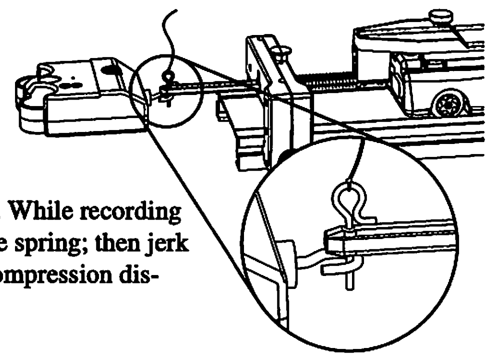
Spring Potential Energy and Kinetic Energy

1. Place a second end stop on the track about 8 cm behind the first end stop.
2. Elevate one end of the track by about 20 cm.



3. Hold the cart on the track with the launcher shaft through the hole in the first end stop, and with the spring just touching the end stop, but not compressed. Record this position of the cart as x_1.
4. Push the shaft through both and stops and put the release pin into the shaft. Let the pin rest against the second end stop. Record this position of the cart as x_2.
5. Pull out the release pin with a quick jerk.
6. Watch the cart carefully as it ascends the track. Observe the highest position achieved. Try to read it to the nearest centimeter. Record this position as x_3.
7. Calculate the spring compression: $x = x_1 - x_2$
8. Use x, the value of k that you found in the previous part, and Equation 3 to calculate the initial potential energy of the spring.
9. Calculate the distance traveled by cart: $\Delta s = x_3 - x_2$
10. Measure the mass, m, of the cart with the cart launcher and spring attached.
11. Measure the angle, θ, of the track.
12. Use Equation 5 to calculate the change in gravitational potential energy of the cart.
13. Compare the initial potential energy of the spring to the maximum gravitational potential energy of the cart. Are they equal? If not, what might account for the difference?

Other Suggested Experiments



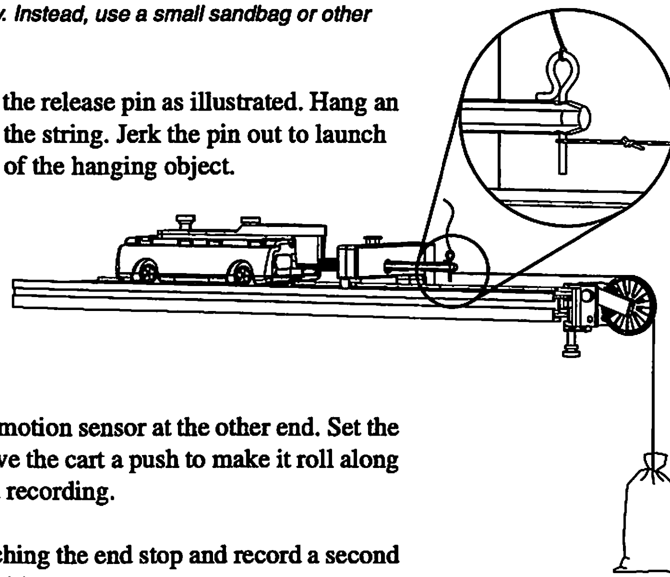
Launch from a Force Sensor

Set up an end stop, a force sensor, and the release pin as illustrated. While recording motion- and force-sensor data, pull the force sensor to compress the spring; then jerk out the release pin to launch the cart. In this way, you can record compression distance, spring force, and launch velocity in a single data run.

Launch from a Hanging Mass

Important: Do not use precision masses in this activity. Instead, use a small sandbag or other object that will not be damaged when dropped.

Set up an end stop, a Super Pulley, a string, and the release pin as illustrated. Hang an object of known mass (up to about 500 g) from the string. Jerk the pin out to launch the cart. The spring force is equal to the weight of the hanging object.



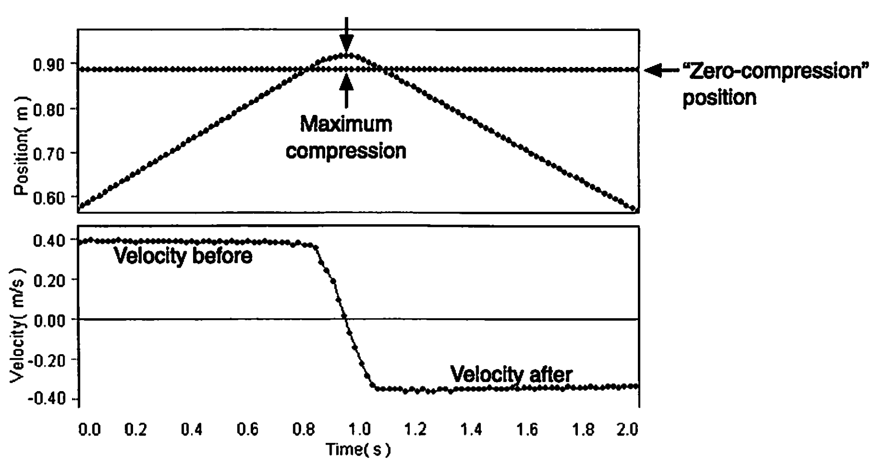
Collision with a Fixed Object

Set up a track with an end stop at one end and a motion sensor at the other end. Set the sampling rate to 50 Hz. Start data recording. Give the cart a push to make it roll along the track and bounce off the end stop. Stop data recording.

Hold the cart stationary with the spring just touching the end stop and record a second data run to measure the "zero-compression" position.

Use the velocity data to determine the kinetic energy of the cart before and after the collision. Use the position data to determine the maximum spring compression (that is, the maximum position measured during the collision minus the position measured when the spring was just touching the end stop). From the compression distance, calculate the maximum potential energy stored in the spring.

In this collision, energy is transferred from kinetic energy to potential energy and back to kinetic energy. At each step, how much energy is "lost?" Where does it go?



Specifications

Launcher dimensions	31 cm x 5 cm x 4 cm
Shaft length	14 cm
Spring length	10 cm
Spring diameter	1 cm
Spring constants	142 ± 14 N/m (black) 112 ± 11 N/m (blue) 84 ± 8 N/m (red)

Technical Support

For assistance with any PASCO product, contact PASCO at:

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

Phone: 916-786-3800 (worldwide)
800-772-8700 (U.S.)

Fax: (916) 786-7565

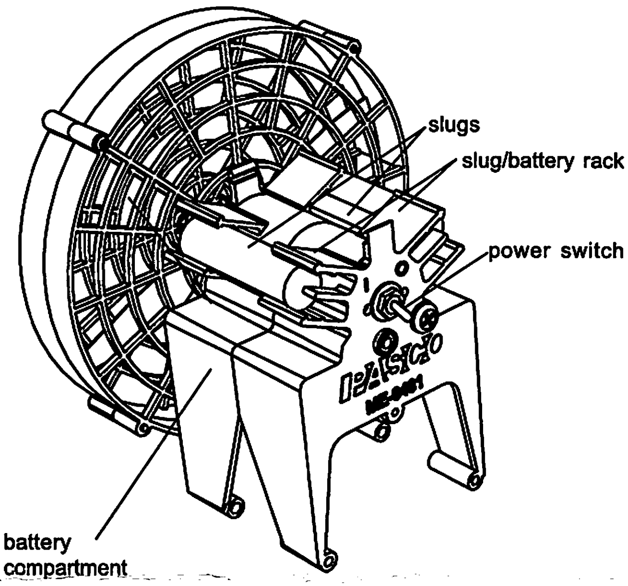
Web: www.pasco.com

Email: support@pasco.com

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

Instruction Sheet for the PASCO Model ME-9491

FAN ACCESSORY



Introduction

The PASCO ME-9491 Fan Accessory mounts on any PASCO Cart for use with a Dynamics Track (ME-9429A or ME-9452) to demonstrate principles of motion. The self-propelled Fan Accessory facilitates students' understanding of Newton's Second Law of Motion because the fan produces the applied force, and all the mass of the system is in one place. The mass and force can be adjusted for a variety of force experiments, and optional accessory wheels can be added for experiments that do not use the Dynamics Track and Cart.

Equipment

Included equipment
- Fan Accessory
- aluminum slugs (2)
- rubber bands

Additional required equipment
- 4 AA batteries
- Dynamics Cart (ME-9430 or ME-9454) *or* PAScar (ME-6950) *or* GOcar (ME-6951)

Additional equipment suggested
- Dynamics Track (ME-9429A or ME-9452)
- Fan Accessory Wheel Set (ME-9492)
- Tape Timer (ME-9283) *or*
- Motion Sensor (CI-6529) and a *Science Workshop™* computer interface *or*
- Motion Sensor (CI-6742) and a 750 interface (CI-7500) *or*
- PASport Motion Sensor (PS-2103), USB Link (PS-2100) and a USB enabled computer
- Smart Pulley (ME-9387) and computer interface
- Friction Cart Accessory (ME-9457)

Assembly

Assembly on the Dynamics Cart

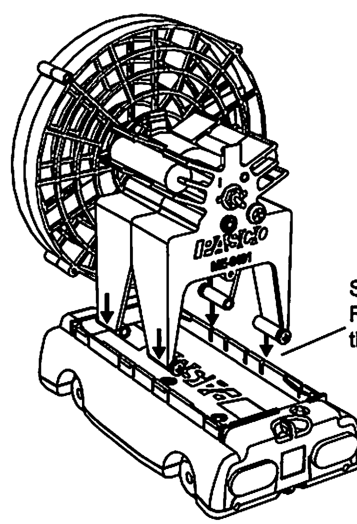


Figure 1. Attaching the Fan Accessory to the Cart

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Attaching the Fan Accessory Wheel Set (ME-9492, ordered separately) to the Fan Accessory

To operate the Fan Accessory directly on the floor or tabletop without using the Dynamics Cart or Dynamics Track, attach the Fan Accessory Wheel Set (ME-9492, ordered separately) to each side of the Fan Accessory as follows (Figure 2):

① Attach the wheel bracket to the Fan Accessory with two screws.

② Turn two screws and washers into the wheel bracket, leaving about 5 mm of thread exposed.

③ Slide the axle into the slots under the screw shafts and behind the washers and turn the screws until the washers lightly secure the axle in place.

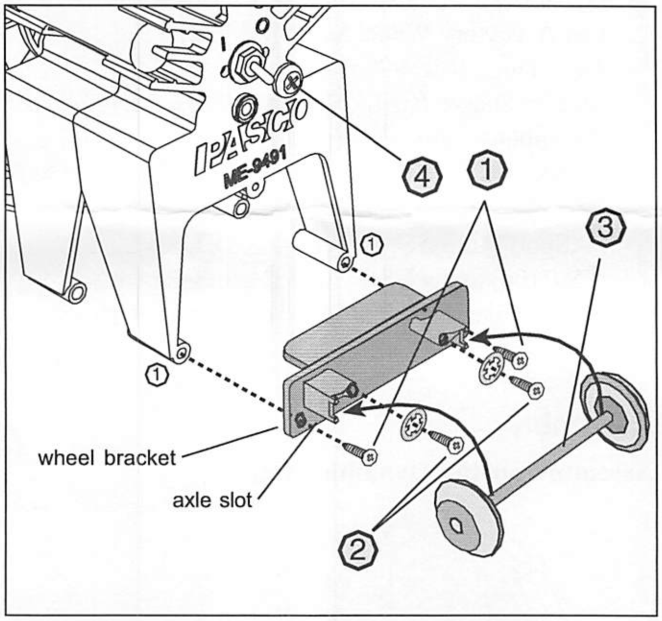

Figure 2. Attaching the Fan Accessory Wheel Set (ME-9492, not included) to the Fan Accessory.

④ If the wheels are not coplanar, *slightly* loosen the screw (4) on each side of the Fan Accessory, and place it on a flat surface. Wiggle the two halves of the Fan Accessory until all four wheels touch the flat surface, and tighten the screws.

> ➤ Note: To prevent a runaway cart when using the Fan Accessory with the Fan Accessory Wheel Set, attach the cart to a fixed object with a safety tether.

Operation

① Change the speed of the Fan Accessory by using two, three, or four batteries. When using less than four batteries, insert the slugs as necessary to complete the circuit (Figure 3).

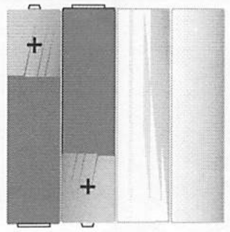

Figure 3. Supplying three different voltages by installing two, three or four batteries.

② Store unused batteries or slugs in the storage rack on the top of the Fan Accessory.

③ Vary the mass of the Fan Accessory by placing or removing the slugs or batteries in the storage rack.

> **CAUTION**
>
> **The propeller blade rotates at a high velocity with considerable force and can cause injury.**
>
> **➤ Keep fingers and other objects away from the moving fan blade!**
>
> **➤ Keep the Fan Accessory away from the face, hair, and eyes.**
>
> **➤ The Fan Accessory should be operated only in a supervised classroom setting.**

Specifications

Mass of Fan Accessory (with 4 AA Energizer™ batteries and mass slugs)[1]: approximately 310 g

Mass of aluminum slug: approximately 20 g

[1]Note: The masses of batteries of different brands vary slightly.

Suggested Experiments[1]

Experiment #1: *Measure the acceleration of the cart* using the Motion Sensor, Smart Pulley or Tape Timer. Vary the mass of the Fan Accessory or the speed of the propeller and repeat (Figure 4).

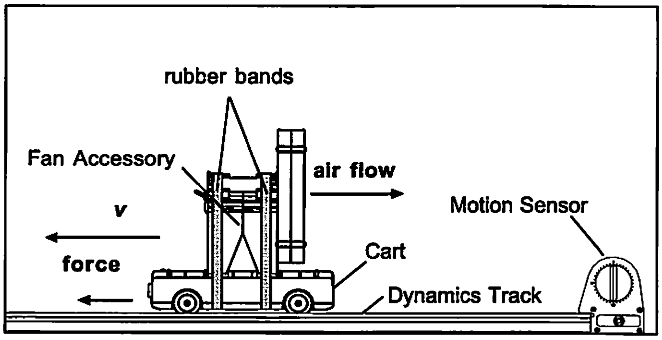

Figure 4. Measuring the acceleration of the cart.

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. Vary the fan speed and repeat (Figure 5).

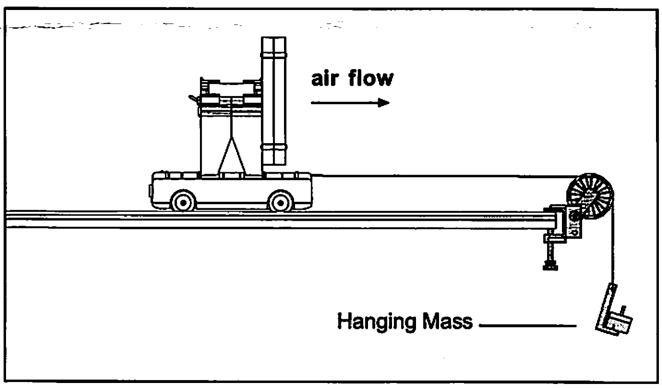

Figure 5. Determining the fan's force (method 1).

Alternative method: Use a spring scale to determine the fan's force at three different propeller speeds (Figure 6).

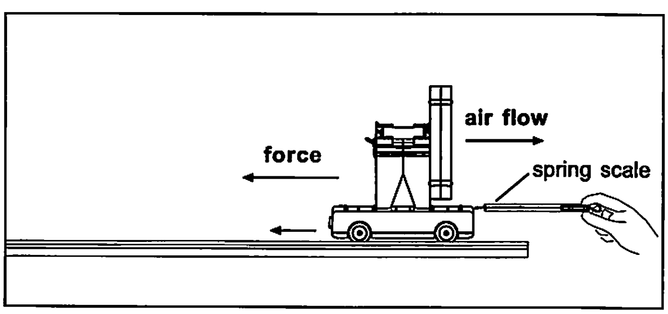

Figure 6. Determining the fan's force (method 2).

Experiment #3: *Counteract the fan's force with the force of gravity* by inclining the track until the cart cannot climb it. Vary the fan speed and repeat (Figure 7).

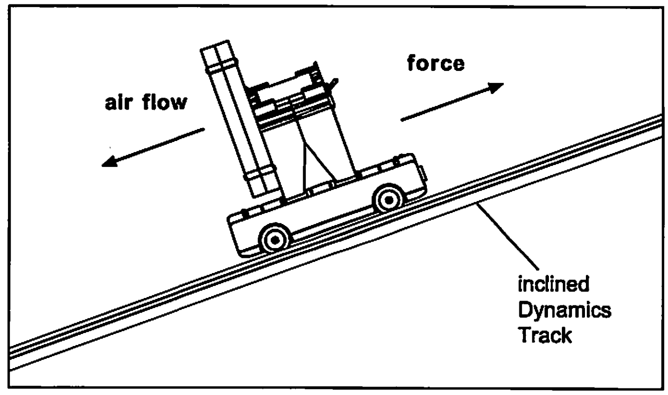

Figure 7. Counteracting the fan's force with gravity.

Experiment #4: *Counteract the acceleration due to the fan's force with friction* by attaching a Friction Cart Accessory to the Dynamics Cart and adjusting the friction until the cart moves at constant speed. Vary the fan speed and repeat (Figure 8).

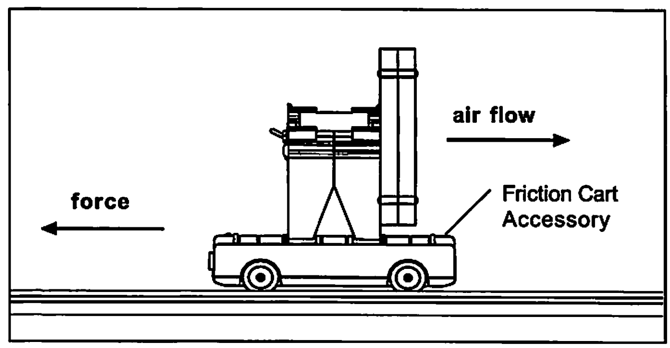

Figure 8. Counteracting the acceleration of the cart with friction.

> ➤ Note: To prevent the Fan Accessory from popping off the cart during a collision with a wall or End Stop, secure it to the cart with the included rubber bands as shown in Figure 4.

[1] For a discussion of fan cart experiments, refer to Robert A. Morse, "Constant Acceleration Experiments with a Fan-Driven Dynamics Cart," *The Physics Teacher*, October, 1993, pp. 436-438.

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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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