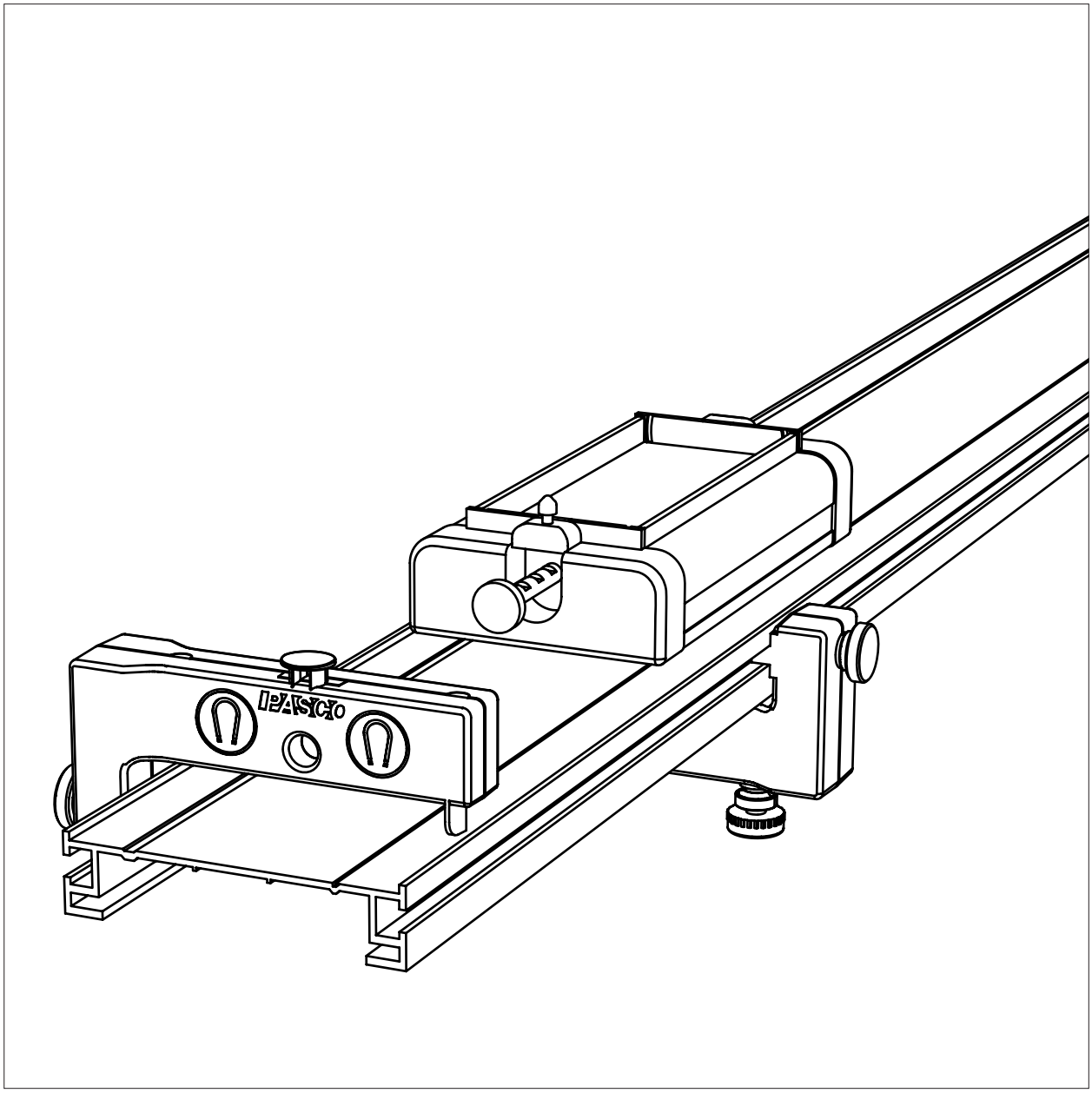
PASCO®

Instruction Manual and
Experiment Guide
012-05024F

2.2 m Classic Dynamics System

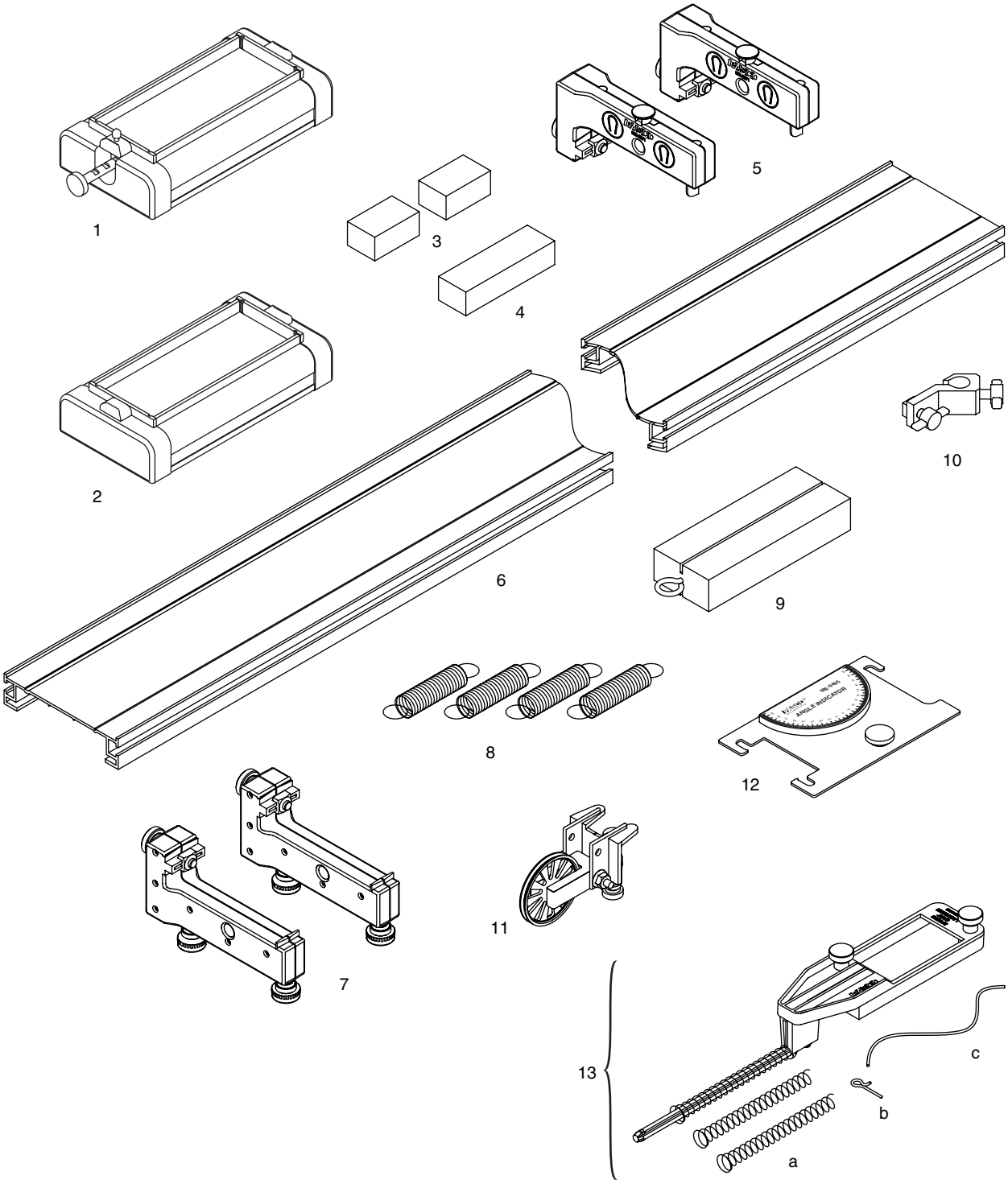
ME-9452



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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

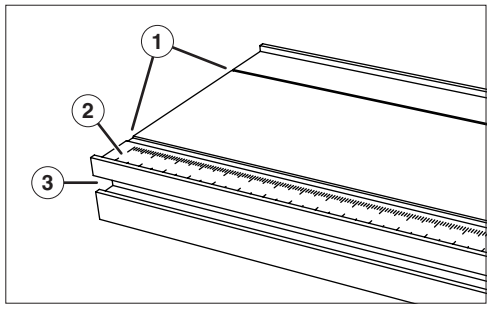
The 2.2 m Classic Dynamics System includes everything you need for a variety of experiments and demonstrations. You can also combine it with many other PASCO produces—both traditional and computer-based—for an even greater range of uses.

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.

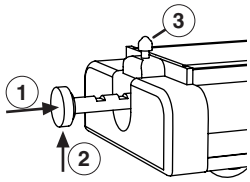
Tip: The track is designed to support the weight of carts and related apparatus. Excess weight will warp it. When you store the track, ensure that no heavy object will be placed on top of it.



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

Plunger Cart 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.

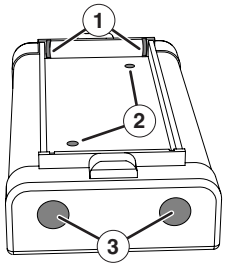


Plunger Cart
1: Push plunger in.
2: Push up to lock.
3: Tap button to trigger.

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.

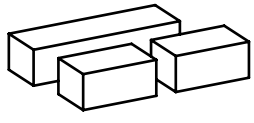
The top or each cart forms a tray designed to hold the included masses. The carts also feature tapped holes for attaching accessories and sensors, and slots for holding a picket fence (such as PASCO part ME-9804) or the included angle indicator.

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



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

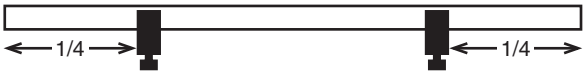
Cart Masses These masses are designed to be placed on the upper tray of a cart.

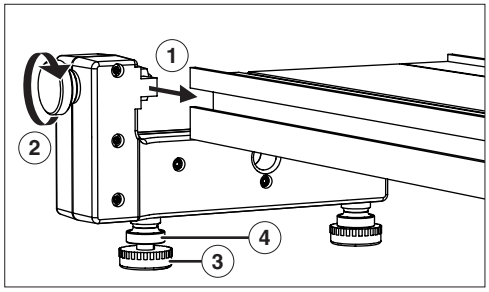


Cart Masses

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.

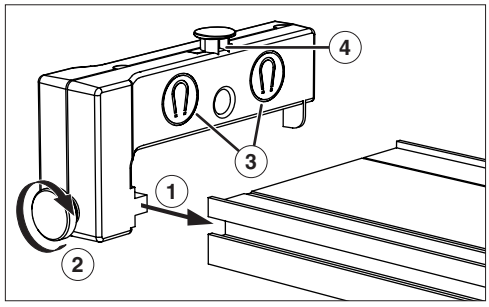
For maximum stability, position the feet about 1/4 of the track length from each end





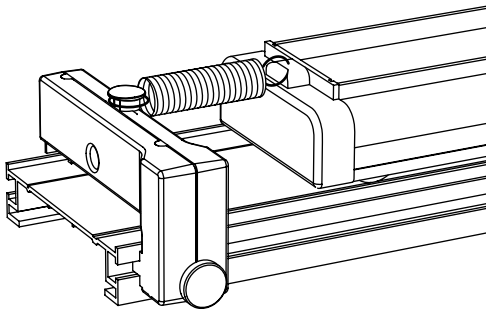
Adjustable Feet
1: Slide tab into T-slot. **2:** Tighten thumbscrew to secure feet set. **3:** Turn feet screws to level track. **4:** Tighten lock nuts to secure feet screws.

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.



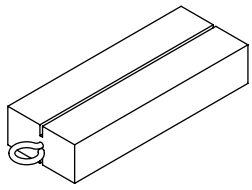
Adjustable End Stop
1: Slide tab into T-slot on side of track. **2:** Tighten thumbscrew to secure end stop. **3:** Magnets repel cart's magnetic bumper **4:** Spring attachment stud

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.



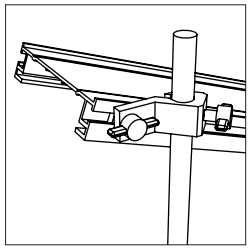
Harmonic Spring

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

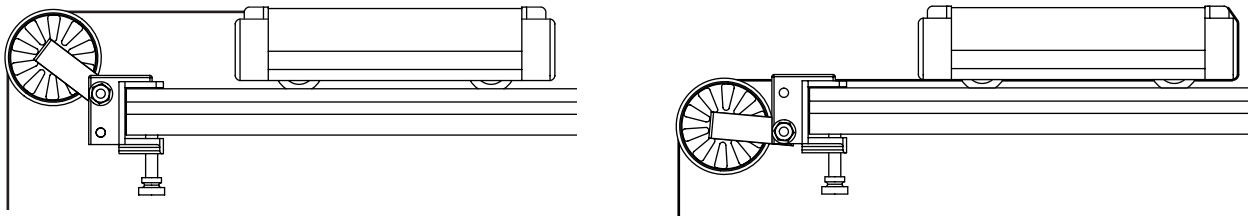
Pivot Clamp Attach the pivot clamp to the T-slot of the track (as illustrated) to elevate one end of the track on a vertical rod.



Pivot Clamp

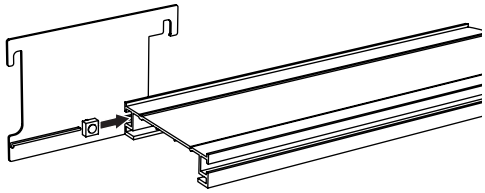
Super Pulley with Clamp This low-friction, low-inertia pulley is designed for clamping onto the end of the track. Tie a string to the hole in the end of the cart an run it over the pulley. Adjust the height of the pulley to make the string parallel to the track.

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.

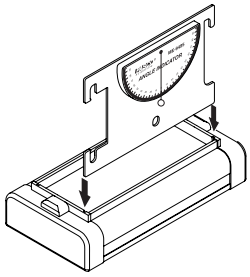


Super Pulley with string in normal position (left) and lower position (right)

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.

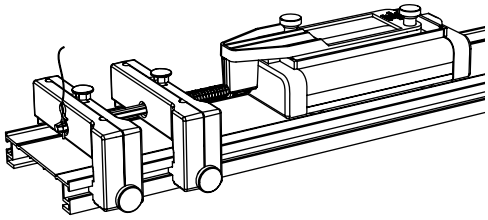


Angle Indicator on track



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.

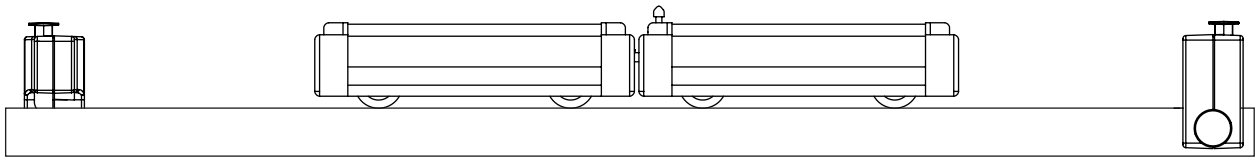


Figure 1.1

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

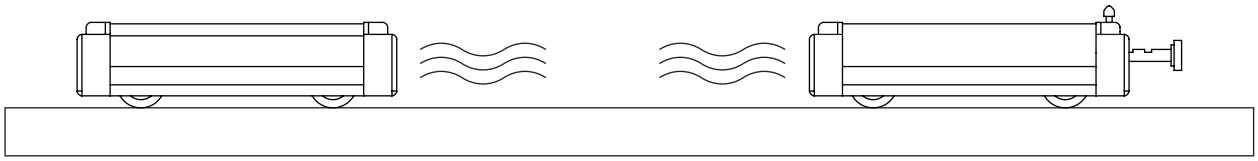


Figure 2.1

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.

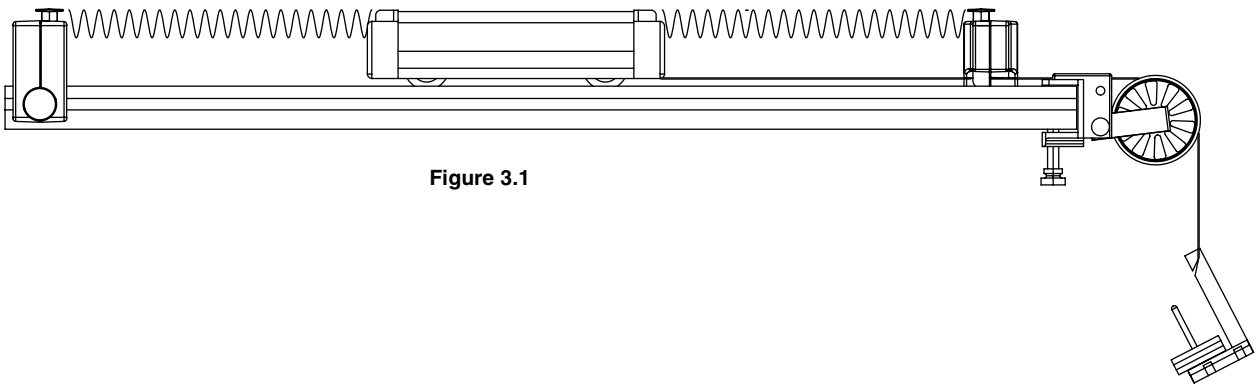


Figure 3.1

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

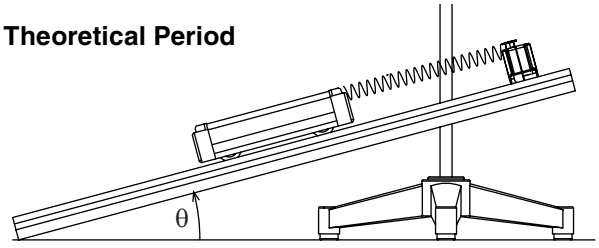


Figure 4.1: Equipment Setup

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.

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.

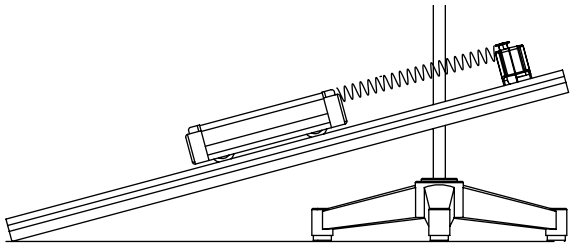


Figure 5.1: Single spring

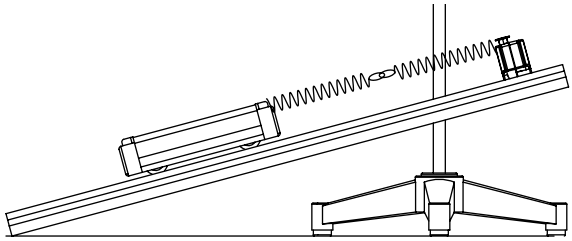


Figure 5.2: Springs in series

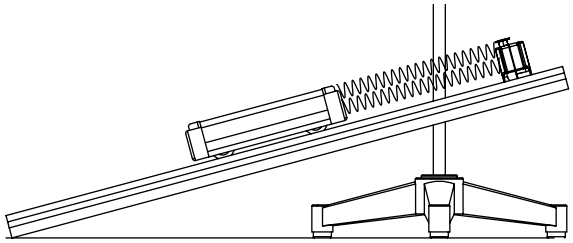


Figure 5.3: Springs in parallel

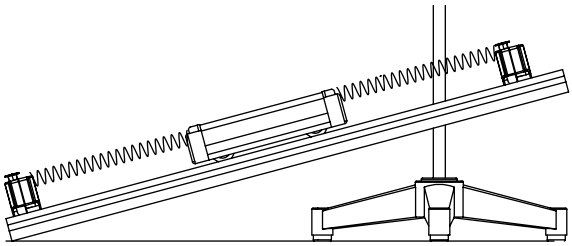


Figure 5.4: Springs on opposite ends

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

Springs	Time for 2 Oscillations					Average	Period
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5		
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, $F = ma$.

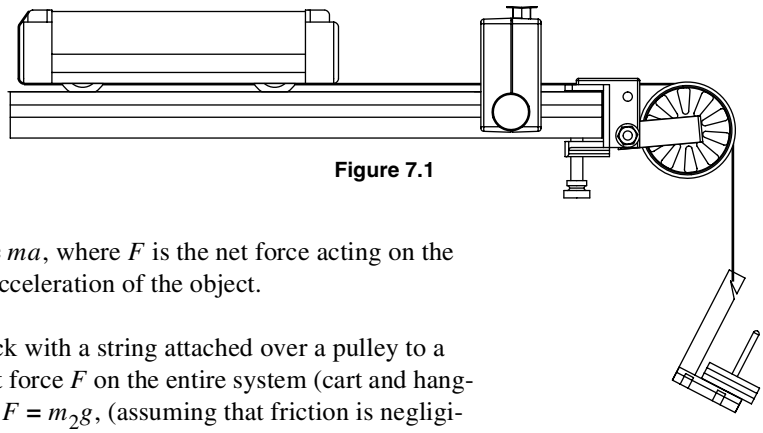


Figure 7.1

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.

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 $mg \sin \theta$.

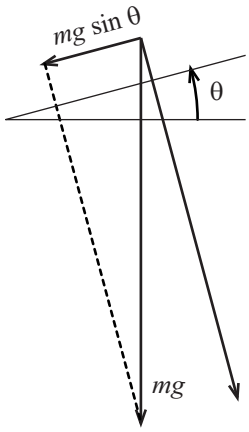


Figure 8.1

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.

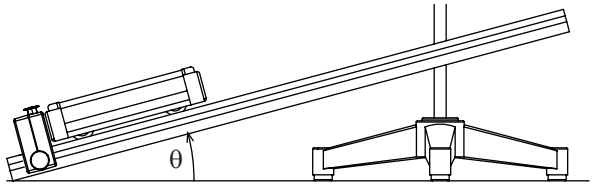


Figure 8.2

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) $$U_{\text{spring}} = \frac{1}{2}kx^2$$ Potential energy stored in a spring

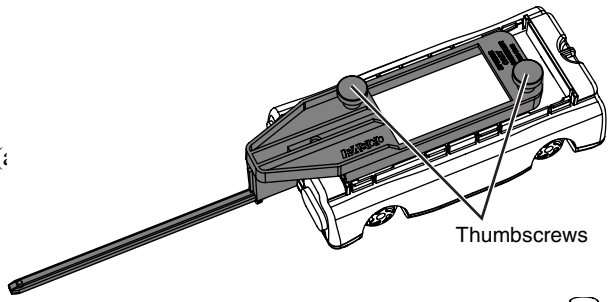
The change in gravitational potential energy of a cart moving up an inclined track is

(eq. 3) $$\Delta U_{\text{gravity}} = mg\Delta s \sin\theta$$ 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.

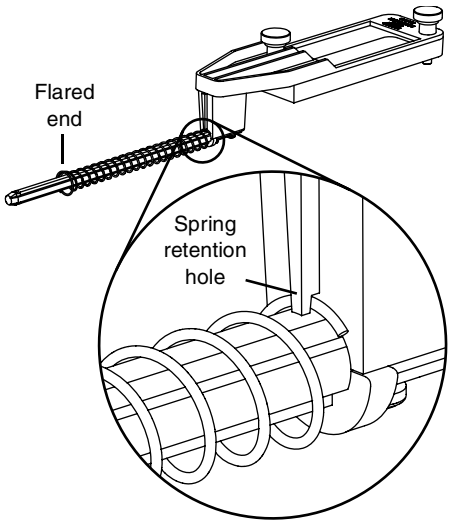
Part I: Spring Constant

Procedure



1. Fit the spring cart launcher onto the top of the cart (a 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.



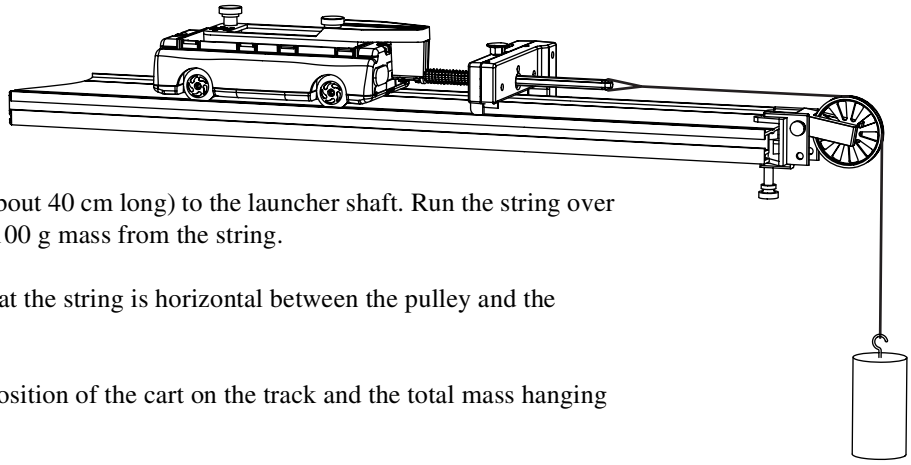
4. Install an end stop about 20 cm from the end of the track.

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 $g = 9.8$ m/s^2.

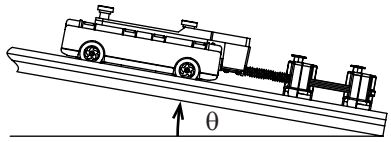
2. Make a graph of F_x versus cart position.

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 collide 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.

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