Inclined Plane Dynamics Set

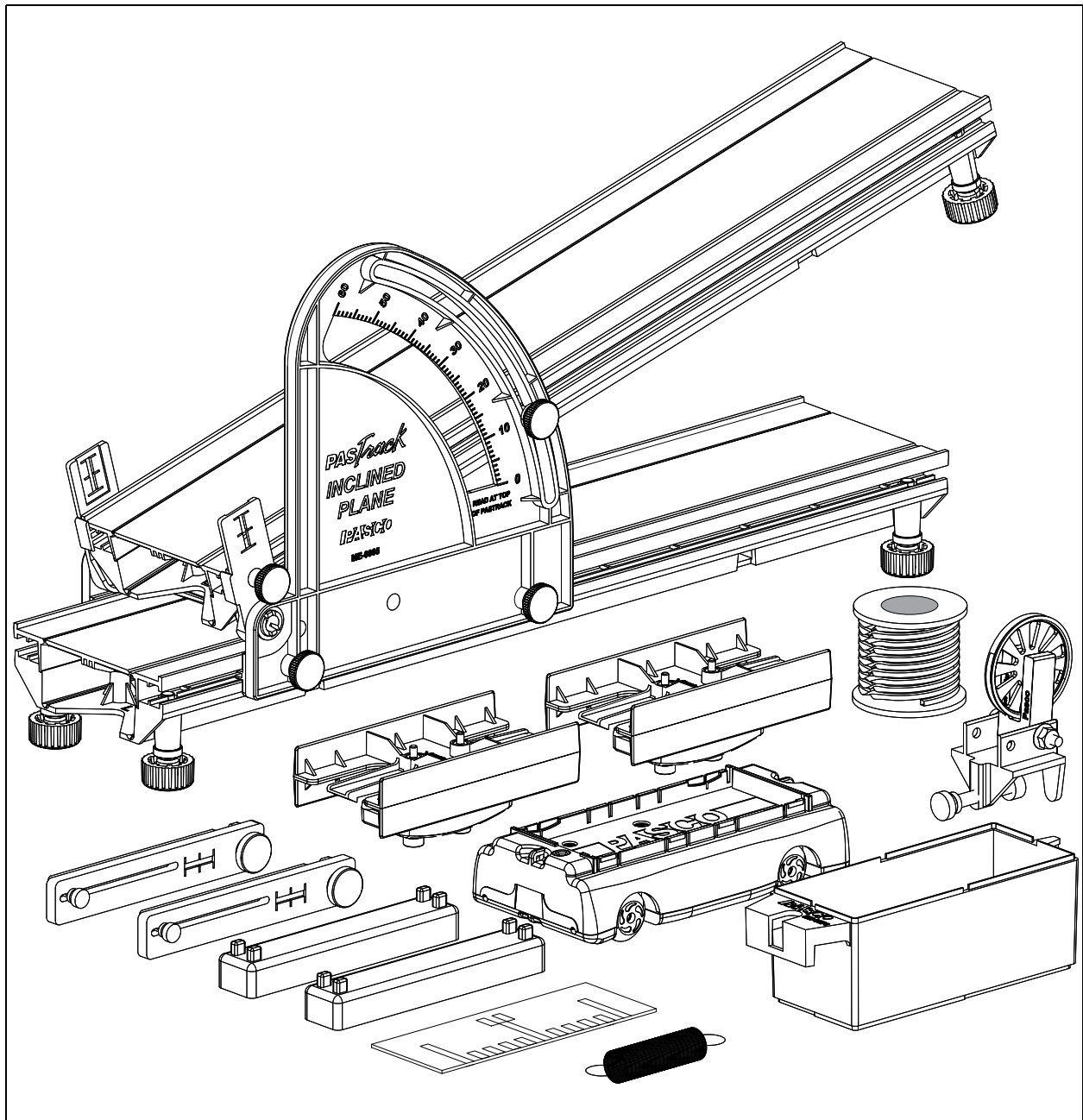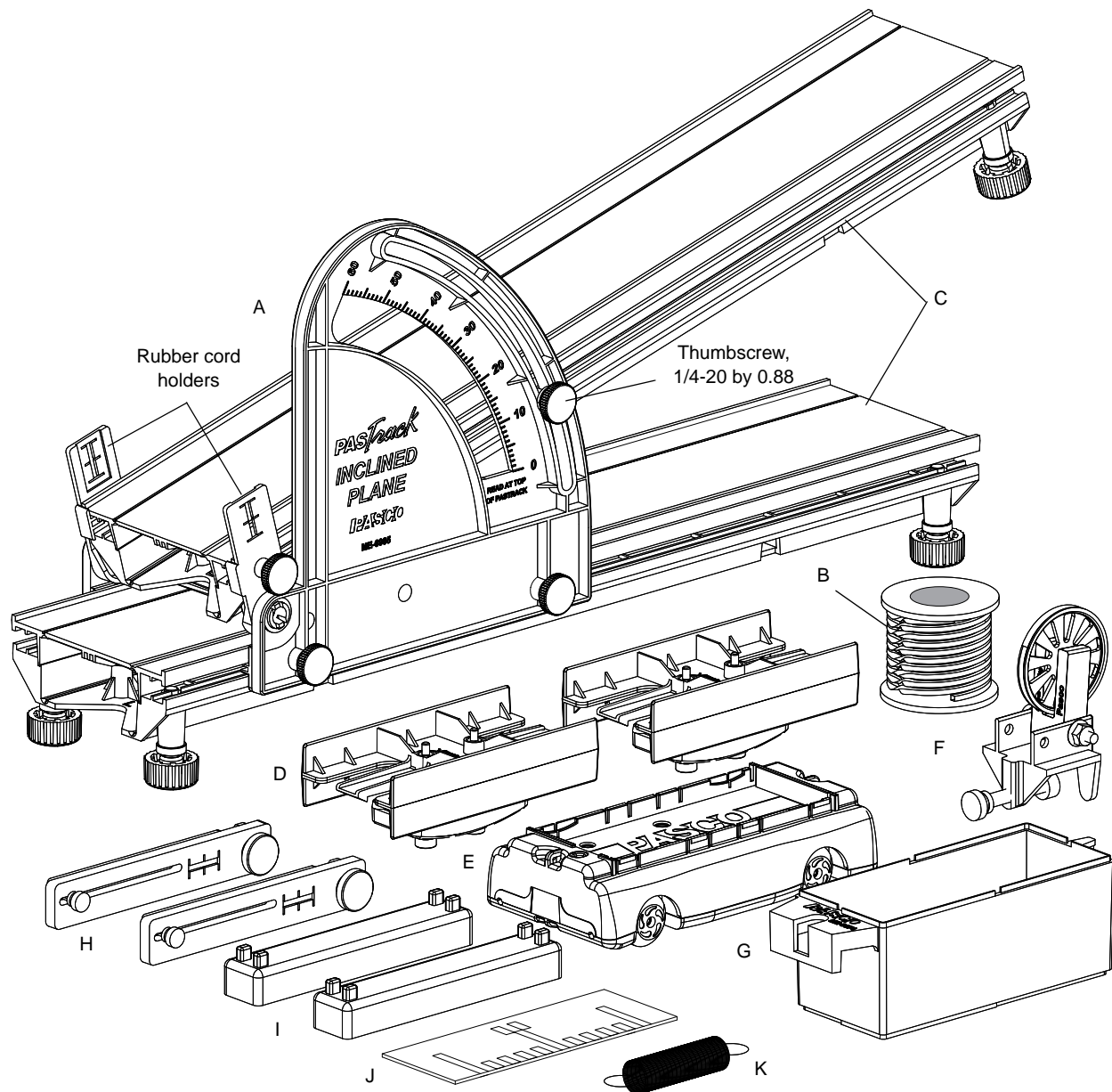## ME-6966

Table of Contents

ME-6966 Inclined Plane Dynamics Set

ME-6966

A

Rubber cord
holders

C

Thumbscrew,
1/4-20 by 0.88

B

F

D

E

G

H

I

J

K

Included Equipment			Part Number
ME-6966	ME-6967	ME-6965 A. PAStrack Inclined Plane Accessory	ME-6965
		B. Rubber Cord, 1.5 mm square, 30 m	ME-8986
		C. PAStrack, 1 meter	ME-6960
		D. PAStrack Connectors (2)	648-10127
	E. GOcar		ME-6951
	F. Super Pulley with Clamp		ME-9448A
	G. Discover Friction Accessory (1 of 4 trays shown)		ME-8574
	H. Photogate Brackets (2)		ME-9806
	I. PAScar Masses (2)		ME-6956
	J. Picket Fence - Smart Timer (2) (1 of 2 shown)		648-06817
	K. Dynamics Track Spring Set (1 of 12 shown)		ME-8999
	Nylon Thread (not shown)		699-011

Related Equipment*	Related Equipment*
Mass and Hanger Set (ME-8979)	Photogate Head (ME-9498A)
Motion Sensor (PS-2103 or CI-6742A)	Stopwatch (ME-1234)
Force Sensor (PS-2104 or CI-6746)	PASCO Interfaces

(*See the PASCO Catalog or the PASCO web site at www.pasco.com for more information.)

Introduction

The ME-6966 Inclined Plane Dynamics Set consists of the following: 1 m PAStrack, Inclined Plane Accessory, GOcar, Discover Friction Accessory, Super Pulley with Clamp, Photogate Brackets (2), PAScar Masses (2), Smart Timer Picket Fence (2), and a Dynamics Track Spring Set (12 springs).

Together they provide many opportunities for experiments on Newton's Laws, velocity, acceleration, friction, and vectors.

About the Components

The **PAStrack** consists of two 50 cm sections that can be joined together with the included connector and split apart for storage. Each section has a millimeter scale along one edge. Together the two sections form a 1 meter track. An extra connector is included allowing any number of tracks to be joined together.

The **PAStrack Inclined Plane Accessory** holds both sections of the PAStrack. It can tilt the top section up to 60 degrees above horizontal. The Accessory has two Rubber Cord Holders that allow a piece of rubber cord (included) to be mounted at the bottom end of the tilted section of the PAStrack.

NOTE: The PAStrack Connector is not needed when the PAStrack is used with the Inclined Plane Accessory.
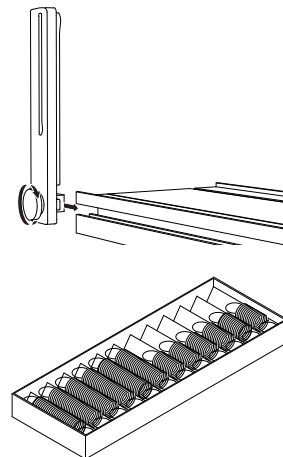
PASCO ®

The **GOcar** is a rugged dynamics car for the study of motion and its causes. It features spring-loaded wheels to prevent damage from drops and precision ball bearings that reduce friction. The GOcar has a molded polycarbonate body that can endure tough classroom use. Each end of the car has two hooks, one on the top and bottom, for the attachment of strings or springs. Three threaded holes in the bed of the car enable the attachment of accessories.

The **Discover Friction Accessory** consists of four molded polycarbonate trays that have three different surfaces on the bottom: one with felt, one with cork, and two with smooth plastic. The trays can hold extra mass and have attachment points at each end. They can be stacked for easy storage.

The **Super Pulley with Clamp** attaches to the end of a PASCO track, or to the edge of a table up to 2.0 cm (13/16 in) thick. The Super Pulley can be connected to the Clamp at two positions and is adjustable.

The **Photogate Brackets** are designed for mounting photogates to a PASCO track. There are two ways to attach a bracket to the T-slot on a PASCO track: one way keeps the bracket at right angles to the track, and the other way allows the bracket to pivot to other angles.
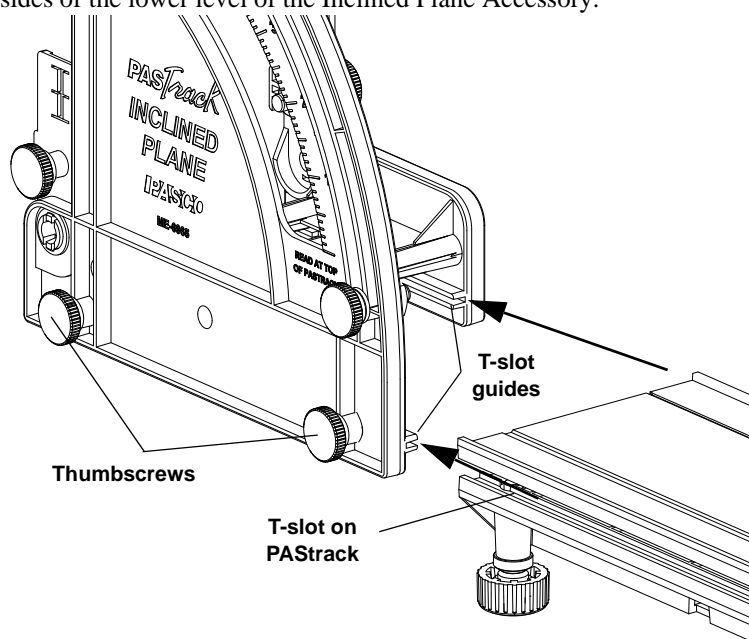
The **Spring Set** contains twelve springs (1.6 cm diameter) of two different lengths and spring constants. Three of the short and three of the long springs have a spring constant of approximately 3.4 N/m. The other six springs have a spring constant of approximately 6.8 N/m.
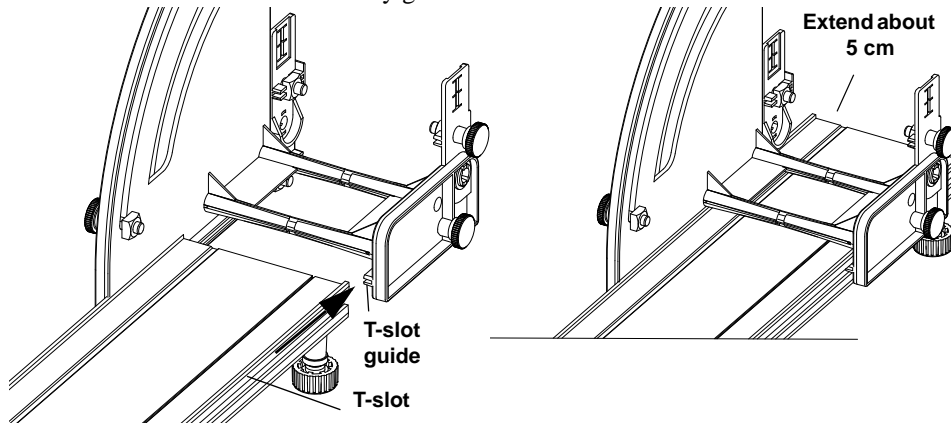
Assembly

The Inclined Plane Accessory has six thumbscrews, front and back. Loosen the thumbscrews.

Align the T-slots on both sides of one section of PAStrack with the T-slot guides on both sides of the lower level of the Inclined Plane Accessory.
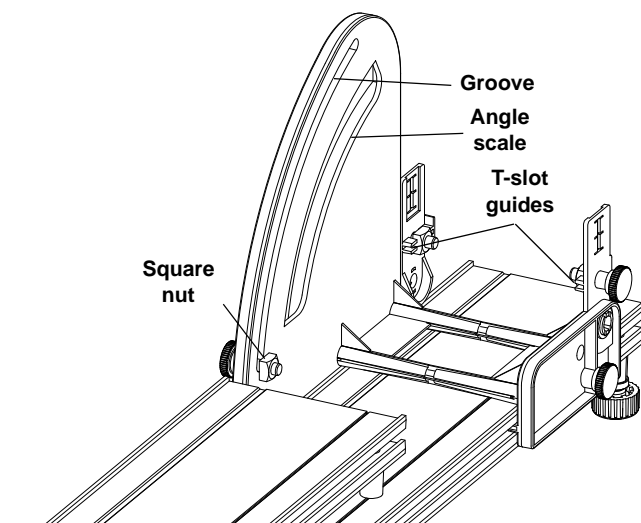

Thumbscrews

T-slot guides

T-slot on PAStrack

Slide the PAStrack onto the T-slot guides so that the square nuts on the thumbscrews of the Inclined Plane Accessory go into the T-slots of the PAStrack.

Slide the PAStrack along the T-slot guides until about 5 cm of the PAStrack extends beyond the end of the Inclined Place Accessory. Tighten the thumbscrews to hold the section of PAStrack in place.

For the second section of PAStrack, remove the feet from one end of the track section. Align this end of the section of PAStrack with the Inclined Plane Accessory.

Align the T-slot of the second section of the PAStrack with the square nut that is connected to the thumbscrew that is in the groove next to the angle scale.

Slide the PAStrack's T-slot onto the square nut. Continue to slide the PAStrack forward until its undercarriage bumps into the cross-beam supports of the Inclined Plane Accessory.

Tilt the PAStrack up so that it makes an angle of about 30 degrees and the forward end of the PAStrack can get over the cross-beam supports of the accessory.

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Continue to slide the track until the T-slots mate with the T-slot guides on the pivot parts of the accessory. The pivot parts have a stop on one side that the end of the track section should rest against.
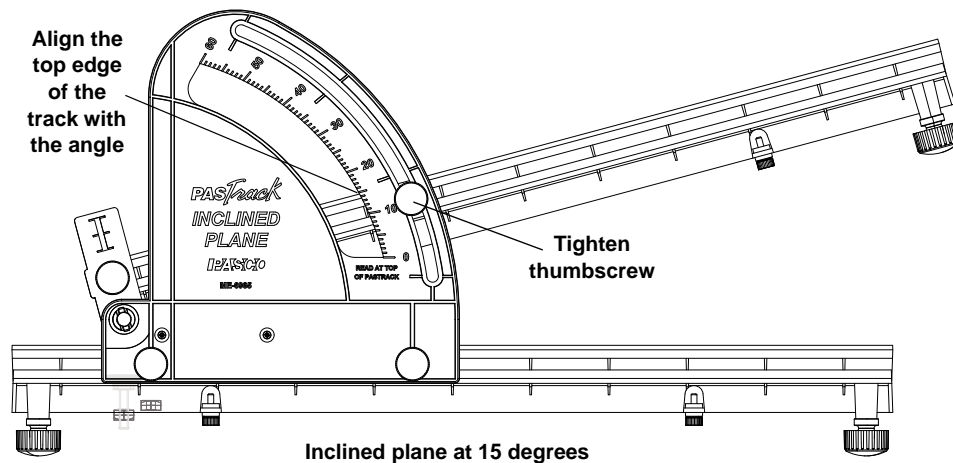

Tighten the thumbscrews attached to each pivot part. You do not need to tighten the thumbscrew that is in the groove next to the angle scale until the section of track is adjusted to the desired angle.

Adjusting the Angle

Lift the end of the top section of PAStrack until the top edge of the PAStrack is aligned with the desired angle on the angle scale. When the PAStrack is at the proper angle, tighten the thumbscrew that is in the groove next to the angle scale.
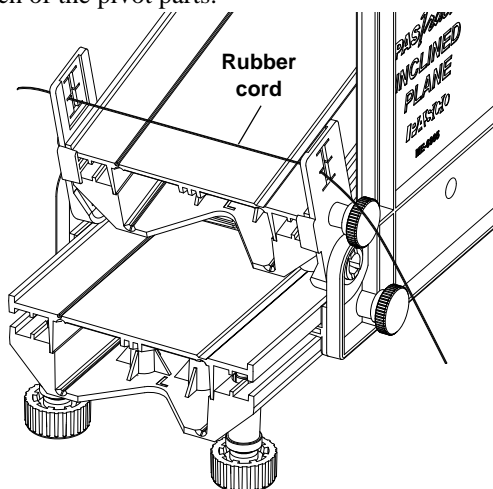

Inclined plane at 15 degrees

Caution!

The PAStrack Inclined Plane Accessory is designed to work with two sections of one PAStrack (ME-6960). Do not use the accessory with more than two PAStrack sections or with aluminum tracks.
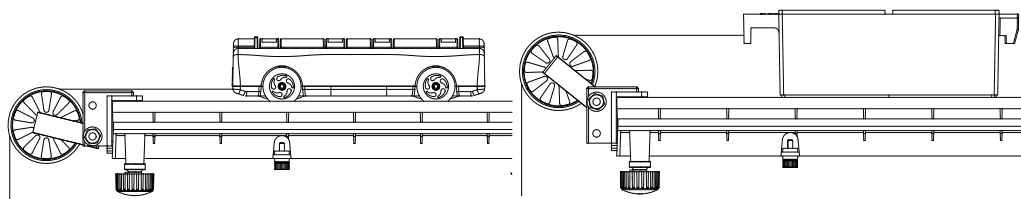
Rubber Cord Bumper

Each pivot part has six notches for holding a piece of rubber cord (included) at the lower end of the inclined plane. Cut a piece of rubber cord about 20 cm long. Thread it through the vertical gap between the notches, and then squeeze the rubber cord into the notches on each of the pivot parts.
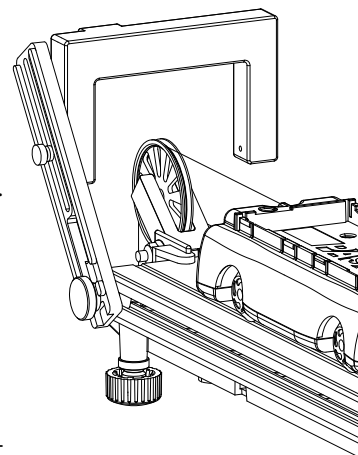
Super Pulley with Clamp

This low-friction, low-inertia pulley is designed for clamping onto the end of the track. Tie a string to one of the holes in the end of the GOcar, or attach a string to one of the Discover Friction trays. Place the string over the pulley. Adjust the pulley so that the string is parallel to the track.
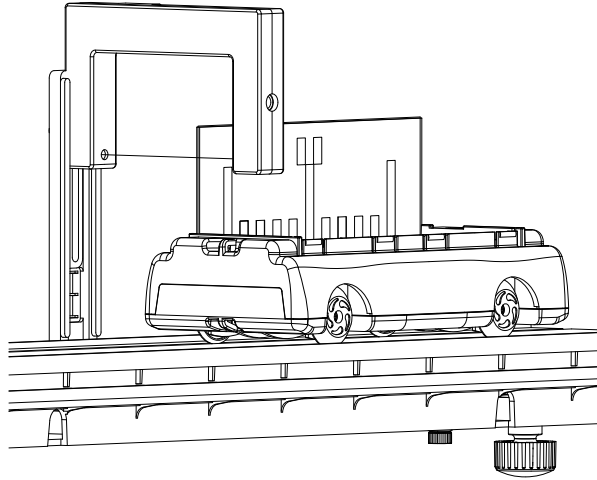
Using a Photogate with the Super Pulley

One way to measure the motion of a GOcar or one of the Discover Friction trays as it moves up or down the inclined plane is to use a Photogate (such as the ME-9489A) and the Super Pulley with Clamp. Use a Photogate Bracket (ME-9806) to mount a photogate to the T-slot on the side of the PAStrack, and then adjust the position of the photogate so that the spokes of the Super Pulley will interrupt the photogate's infrared beam as the pulley turns. Connect the photogate to a timer or interface that can translate the signals from the photogate into time, position, velocity, and acceleration data.

One side of the Photogate Bracket is smooth and the other side has ridges to help hold a photogate in place and to align the bracket at right angles to the T-slot on a PAStrack. To be able to adjust the bracket and the photogate to some other angle, reverse the large thumbscrew and square nut and mount the bracket on the track with the smooth side next to the track. Adjust the bracket to the desired angle and tighten the large thumbscrew. Use the small thumbscrew to attach the photogate to the bracket. Adjust the angle and position of the photogate as needed and tighten the small thumbscrew.

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Using a Photogate with the Picket Fence

Fit the Smart Timer Picket Fence into the accessory tray of the GOcar (or tape it to the side of a Friction Tray). The fence has three different patterns: 1 cm gate, 5 cm gates, and 1 cm picket fence. Adjust the photogate and bracket so that the desired pattern on the picket fence interrupts the infrared beam of the photogate.

To cause a different pattern to interrupt the photogate's beam, raise or lower the photogate, or turn the picket fence upside down and re-attach it to the cart. Adjust the photogate so that the desired pattern interrupts the photogate's beam.

Experiments

These five 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. Oscillations on an inclined plane.

2. Acceleration of a cart down an inclined plane.

3. Springs in Series and Parallel.

4. Friction and the inclined plane.

5. Newton's Second Law on an inclined plane.

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

For more information about the ME-6966 Inclined Plane Dynamics Set and the latest revision of this Instruction Manual, visit:

www.pasco.com/go?ME-6966

Oscillations on an Inclined Plane

Equipment from Inclined Plane Dynamics Set

PAStrack	ME-6960
PAStrack Inclined Plane Accessory	ME-6965
GOcar	ME-6951
Super Pulley with Clamp	ME-9448A
Dynamics Track Spring Set	ME-8999
Other Required Equipment	**Suggested Model Number**
Mass and Hanger Set	ME-8979
PASCO Stopwatch	ME-1234
Ohaus Triple-Beam 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

1. Measure the mass of the cart and record it in Table 1.1.

2. Install the Super Pulley with Clamp on one end of a section of the PAStrack. Assemble the PAStrack in the Inclined Plane Accessory.

3. Set the GOcar on the PAStrack and attach a spring to one end. Attach the other end of the spring to the Super Pulley (see the figure).

4. Incline the PAStrack. 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
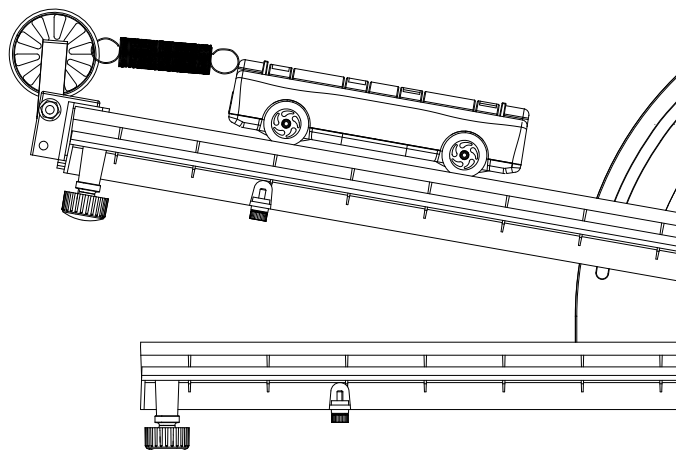

Figure 1.1: Equipment Setup

not stretched more than about a few centimeters. Measure the angle and record it in Table 1.1.

5. Let the GOcar hang freely and come to rest. Record the equilibrium position in Table 1.1.

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 1.1: 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. Use the stop-watch to time 3 oscillations and record the time in Table 1.2.

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 1.1, 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 1.2, calculate the average time for 3 oscillations.

2. Calculate the period by dividing these average values by 3 and record the periods in Table 1.2.

Table 1.2: 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°?

Acceleration Down an Incline

Required Equipment from Inclined Plane Dynamics Set

PAStrack	ME-6960
PAStrack Inclined Plane Accessory	ME-6965
GOcar	ME-6951
Photogate Bracket	ME-9806
PAScar Mass	ME-6956
Picket Fence - Smart Timer	648-06817
Other Required Equipment	**Suggested Model Number**
Photogate Head	ME-9498A
PASCO Interface or Timer	(see catalog or PASCO web site)
PASCO Data Recording Software	(see catalog or PASCO web site)

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 your data, you will be able to calculate 'g', 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 the figure. The component of the force of gravity that is parallel to the inclined surface is $mg \sin \theta$.

To determine the acceleration, you will release a cart from rest and use a photogate and picket fence to measure the velocity (v) as it travels down the inclined plane. The acceleration can be calculated from the slope of a velocity versus time graph.

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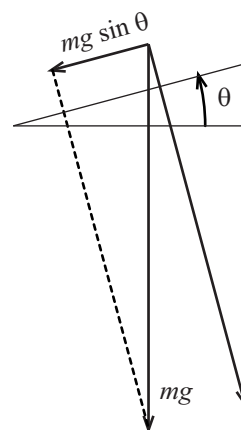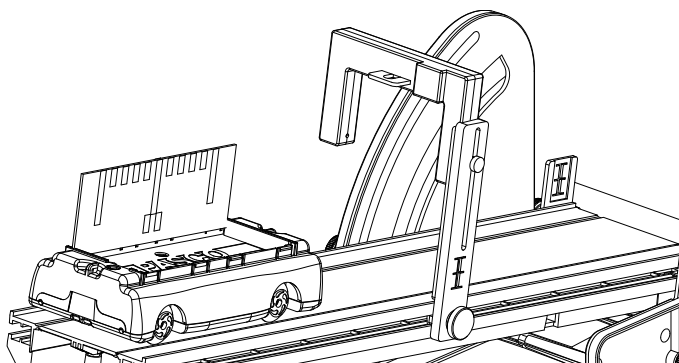

Figure 2.1

Figure 2.2

Procedure

1. Set up the PAStrack and Inclined Plane Accessory as shown in Figure 2.2 with a Photogate Head and Photogate Bracket. Elevate the PAStrack to an angle of 14 degrees.

2. Put the Smart Timer Picket Fence on the GOcar so that the 1 cm 'picket fence' pattern is at the top.

If you are using a PASCO Smart Timer, set the photo-gate so the 5 cm pattern on the Smart Timer Picket Fence will interrupt the photogate beam.

3. Set the GOcar on the PAStrack and adjust the Photogate Head so that the 1 cm 'picket fence' pattern of the Smart Timer Picket Fence will interrupt the photogate beam as the GOcar moves through the photogate. Put the GOcar at the top of the track where it will be released from rest.

4. Set up the Photogate Head, PASCO Interface and Data Recording Software (or PASCO Timer) so that the motion of the GOcar through the photogate will be recorded as the 'picket fence' pattern interrupts the photogate beam.

The procedure is easier if one person handles the Interface or Timer and another person handles the GOcar.

5. Start recording data. Release the GOcar from rest. Catch the GOcar when it reaches the rubber cord bumper at the bottom of the PAStrack. Stop recording data.

6. Complete three trials of the data recording procedure for the angle.

7. Lower the end of the track by 2 degrees and repeat the data recording procedure. Use the same release position each time.

8. Repeat the data recording for a total of 6 angles, lowering the end of the track by 2 degrees for each trial..

Table 2.1: Data

		Angle of Track						
		14 deg	12 deg	10 deg	8 deg	6 deg	4 deg	2 deg
Acceleration	Trial 1							
	Trial 2							
	Trial 3							
	Average							
	sin θ							

Data Analysis

1. Determine the acceleration for each trial at each angle and record it in Table 2.1.

2. Calculate the average acceleration and the sine for each angle and record the results in Table 2.1

For the Smart Timer, use "Acceleration, One Gate".

3. 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.

For PASCO interfaces, find the slope of the graph of velocity versus time and record the slope as the acceleration.

slope = _____

% difference = _____

Questions

1. How does your experimental value for the acceleration due to gravity compare to the accepted value?

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

Springs in Series and Parallel

Equipment from Inclined Plane Dynamics Set

PAStrack	ME-6960
PAStrack Inclined Plane Accessory	ME-6965
GOcar	ME-6951
Super Pulley with Clamp	ME-9448A
Dynamics Track Spring Set	ME-8999
Other Required Equipment	**Suggested Model Number**
Mass and Hanger Set	ME-8979
PASCO Stopwatch	ME-1234
Ohaus Triple-Beam Balance	SE-8723
Nylon Thread	699-011

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 GOcar. Record this value at the top of Table 3.1.

2. Mount the Super Pulley with Clamp at the end of a section of PAStrack. Assemble the PAStrack with
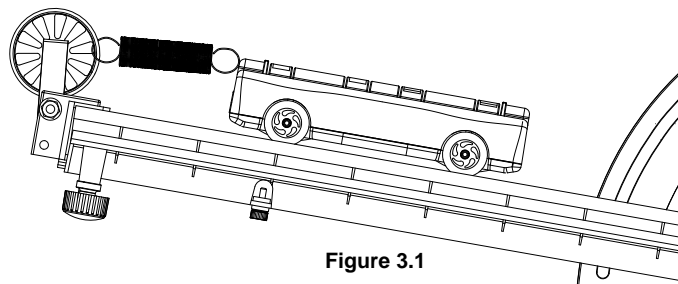

Figure 3.1

the Inclined Plane Accessory.Set the cart on the track and attach a spring to one end. Attach the other end of the spring to the Super Pulley (see Figure 3.1).

3. Incline the PAStrack. 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 one-third of the length of the section of PAStrack.

4. Displace the GOcar from equilibrium and let it go. Time two oscillations and record the time in Table 3.1. Repeat this measurement at least 5 times, using the same initial displacement.

Measuring the Effective Spring Constant of Spring Combinations

5. Add a second spring in series as shown in Figure 3.2 and repeat step 5

6. Put the two springs in parallel as shown in Figure 3.3 and repeat step 5.

7. Tie a loop of thread to the rubber cord holders at the end of the inclined PAStrack. Arrange the GOcar with one spring at each end as shown in Figure 3.4 and repeat step 5.
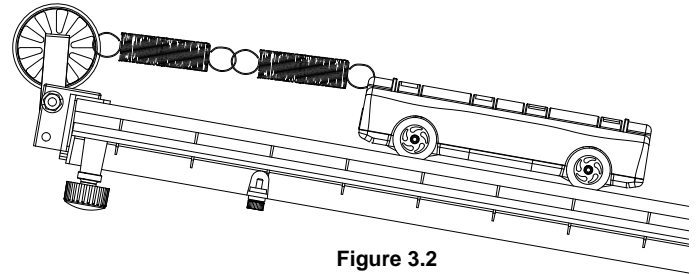

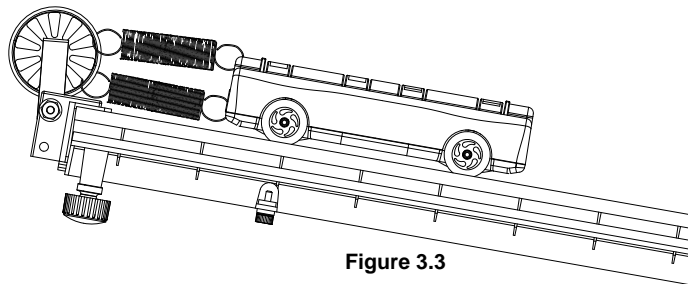**Figure 3.2**

Figure 3.3

Calculations

1. Using the data in Table 3.1, calculate the average time for 2 oscillations.

2. Calculate the period by dividing these times by 2 and record the periods in Table 3.1.

Figure 3.4

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

.

Table 3.1: Experimental Period

Mass of GOcar = _____

Springs	Time for 2 Oscillations					Average	Period	*k*
	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?

Friction and the Inclined Plane

Equipment from Inclined Plane Dynamics Set

PAStrack	ME-6960
PAStrack Inclined Plane Accessory	ME-6965
GOcar	ME-6951
Discover Friction Accessory	ME-8574
Photogate Bracket	ME-9806
Picket Fence - Smart Timer	648-06817
Other Required Equipment	**Suggested Model Number**
Photogate Head	ME-9498A
Sticky tape	

Purpose

In this experiment, you will measure the coefficient of kinetic (sliding) friction for several combinations of materials using the inclined plane.

Theory

When a block accelerates down an inclined plane, the force of kinetic friction pulls against the component of the force of gravity that is parallel to the surface of the plane, $mg \sin \theta$, where m is the mass of the block, g is the acceleration due to gravity, and θ is the angle of the plane. The net force on the block is the difference of the two.

$$F_{net} = ma = mg\sin\theta - \mu_k mg\cos\theta$$

The kinetic friction force is the coefficient of kinetic friction multiplied by the normal force between the block and the plane, $\mu_k\, mg \cos \theta$, where μ_k is the coefficient of kinetic friction.

Solving for the coefficient of kinetic friction gives the following:

$$\mu_k = \frac{g\sin\theta}{g\cos\theta} - \frac{a}{g\cos\theta}$$

$$\mu_k = \tan\theta - \frac{a}{g\cos\theta}$$

Figure 4.1

You will determine the acceleration of a friction tray sliding down the inclined plane and calculate the coefficient of kinetic friction.

Procedure

1. Set up the PAStrack and Inclined Plane Accessory as shown in Figure 4.1 with a Photogate Head and Photogate Bracket. Elevate the PAStrack to a shallow angle.

2. Select a Friction Tray and record its bottom material in Table 4.1. Tape the Smart Timer Picket Fence to the Friction Tray so that the 1 cm 'picket fence' pattern is at the top.
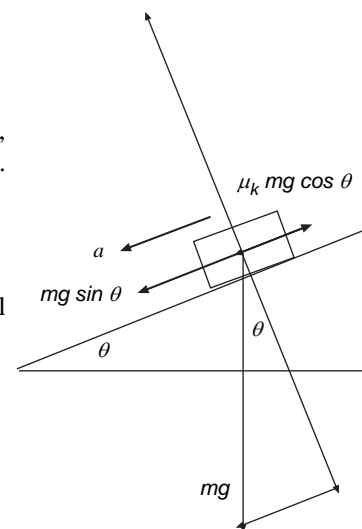
If you are using a PASCO Smart Timer, set the photogate so the 5 cm pattern on the Smart Timer Picket Fence will interrupt the photogate beam.

3. Set the Friction Tray on the PAStrack and adjust the Photogate Head so that the 1 cm 'picket fence' pattern of the Smart Timer Picket Fence will interrupt the photogate beam as the Friction Tray moves through the photogate. Put the Friction Tray at the top of the track where it will be released from rest.

4. Raise the angle of the PAStrack so that when the Friction Tray is released from the top, it accelerates down the plane. Record the angle in Table 4.1.

Figure 4.1

5. Set up the Photogate Head, PASCO Interface and Data Recording Software (or PASCO Timer) so that the motion of the Friction Tray through the photogate will be recorded as the 'picket fence' pattern interrupts the photogate beam.

6. Start recording data. Release the Friction Tray from rest. Stop recording data.

The procedure is easier if one person handles the Interface or Timer and another person handles the GOcar.

7. Complete three trials of the data recording procedure for the first Friction Tray. Use the same release position each time.

8. Move the Smart Timer Picket Fence to the second Friction Tray. Record the kind of material that's on the bottom of the tray. Adjust the angle of the PAStrack so that when the Friction Tray is released from the top, it accelerates down the plane. Record the angle.

9. Complete three trials of the data recording procedure for the second Friction Tray.
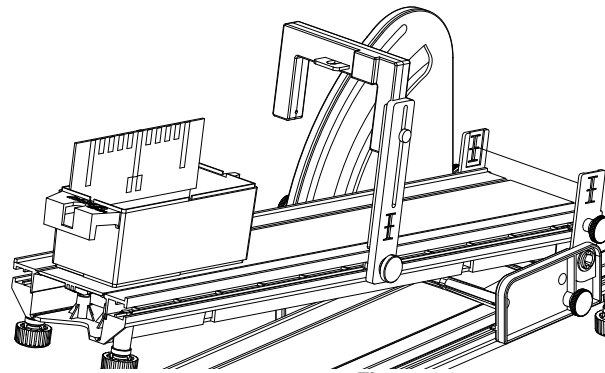
10. Repeat the procedure for the third Friction Tray..

Table 4.1: Data

	Material			
	Angle	____deg	____ deg	____deg
Acceleration	Trial 1			
	Trial 2			
	Trial 3			
	Average			
	μ_k			

For the Smart Timer, use "Acceleration, One Gate".

For PASCO interfaces, find the slope of the graph of velocity versus time and record the slope as the acceleration.

Data Analysis

1. Determine the acceleration for each trial at each angle and record it in Table 4.1.

2. Calculate the average acceleration for each Friction Tray and use the average acceleration and the angle to determine the coefficient of kinetic friction.

Questions

1. Which material has the highest coefficient of kinetic friction?

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

Newton's Second Law on an Inclined Plane

Equipment from Inclined Plane Dynamics Set

PAStrack	ME-6960
PAStrack Inclined Plane Accessory	ME-6965
GOcar	ME-6951
Discover Friction Accessory	ME-8574
Photogate Bracket	ME-9806
Super Pulley with Clamp	ME-9448A
Nylon Thread	699-011
Other Required Equipment	**Suggested Model Number**
Photogate Head	ME-9498A
Mass and Hanger Set	ME-8979
Balance	SE-8707

Purpose

In the first part of this experiment you will measure the acceleration of a low-friction cart as it is pulled up an inclined plane by a descending mass connected to the cart by a thread over a pulley at the edge of the inclined plane. Compare the measured acceleration to the theoretical acceleration.

In the second part of the experiment you will measure the acceleration of a friction tray as it is pulled up the inclined plane by a descending mass connected to the tray by a thread over a pulley at the edge of the inclined plane. Use the measured acceleration to calculate the coefficient of kinetic friction of the friction tray.

Theory

When a frictionless cart is pulled up an inclined plane by the tension in a string attached to a descending mass, the forces on the cart are the tension in the string, T, the component of gravity that is parallel to the inclined plane, $m_1 g \sin \theta$, where m_1 is the mass of the cart, g is the acceleration due to gravity, and θ is the angle of the plane, the normal force, F_N, and the component of gravity that is perpendicular to the inclined plane, $m_1 g \cos \theta$.

The net force on the cart is the difference of the tension and the component of gravity that is parallel to the inclined plane.
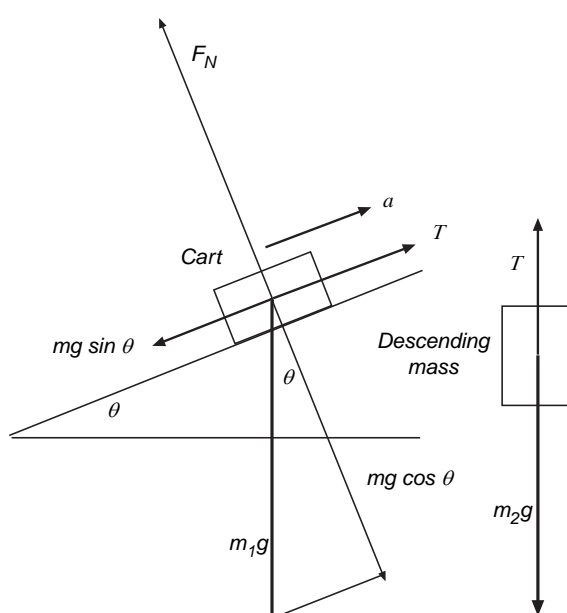

F_N

a

T

Cart

T

$mg \sin \theta$

Descending mass

θ

θ

$mg \cos \theta$

$m_2 g$

$m_1 g$

Figure 5.1

$$F_{net} = m_1 a = T - m_1 g \sin \theta$$

The net force on the descending mass is the difference between the weight of the descending mass, $m_2 g$, and the tension in the string, T, where m_2 is the descending mass.

$$F_{net} = m_2 a = m_2 g - T$$

Solving for T in the second equation, substituting the new expression into the first equation, and solving for a gives the following:

$$a = \frac{m_2 - m_1 \sin \theta}{m_1 + m_2} g$$

When a friction tray is pulled up an inclined plane by the tension in a string attached to a descending mass, the forces on the tray are the tension in the string, T, the component of gravity that is parallel to the inclined plane, $m_1 g \sin \theta$, the kinetic (sliding) friction, f_k, where f_k is $\mu_k m_1 g \cos \theta$, the normal force, F_N, and the component of gravity that is perpendicular to the inclined plane, $m_1 g \cos \theta$.
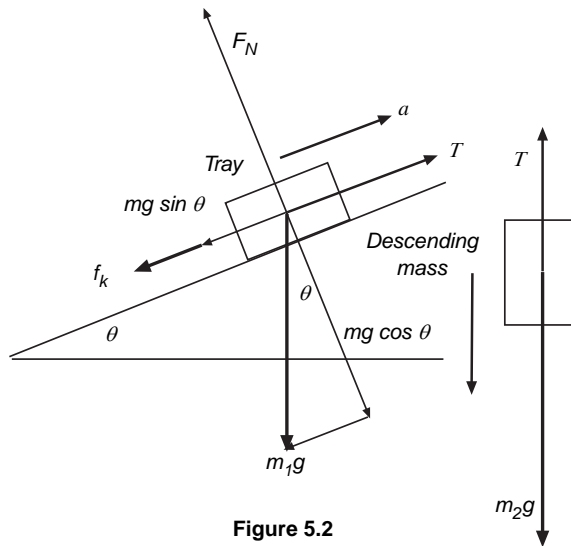

Figure 5.2

The net force on the tray is the difference of the tension in the string, which pulls up the incline, and the combination of the force of kinetic friction and the component of gravity that is parallel to the incline, both of which are against the upward motion of the tray.

$$F_{net} = m_1 a = T - m_1 g \sin \theta - \mu_k m_1 g \cos \theta$$

The net force on the descending mass is the difference between the weight of the descending mass, $m_2 g$, and the tension in the string, T, where m_2 is the descending mass.

$$F_{net} = m_2 a = m_2 g - T$$

Solving for T in the second equation, substituting the new expression into the first equation, and solving for μ_k gives the following:

$$\mu_k = \frac{a(m_1 + m_2) + g(m_1 \sin \theta - m_2)}{m_1 g \cos \theta}$$

Use the acceleration of a friction tray sliding up the inclined plane to calculate the coefficient of kinetic friction.

Procedure: GOcar

1. Set up the PAStrack and Inclined Plane Accessory as shown in Figure 5.3 with a Super Pulley with Clamp, Photogate Head, and Photogate Bracket. Elevate the PAStrack to an angle less than 30 degrees. Adjust the Photogate Head and Photo-

gate Bracket so that the infrared beam of the photogate will be interrupted by the spokes of the Super Pulley as it turns.
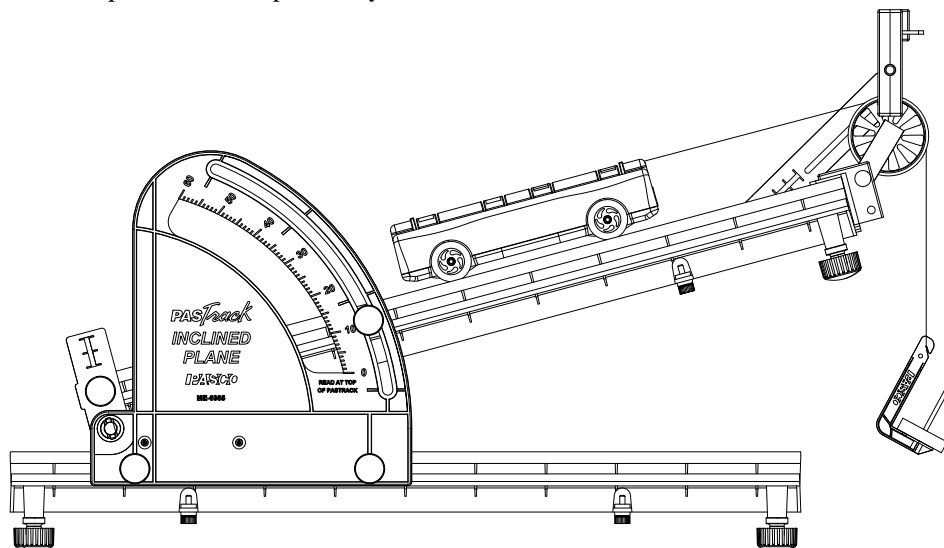

Figure 5.3

2. Measure and record the mass of the GOcar.

3. Attach a thread to one end of the GOcar, and place the GOcar on the inclined PAStrack at the bottom of the track. Drape the thread over the Super Pulley and attach a mass hanger to the end of the thread. Adjust the Super Pulley so that the thread is parallel to the PAStrack. Re-adjust the photogate head if necessary.

4. Put enough mass on the mass hanger so that the GOcar accelerates up the PAStrack when the mass hanger is allowed to drop (about 50 to 60 grams).

5. Measure and record the total mass of the masses and hanger. Remember that the hanger by itself is 5 g.

The data collection may be easier if one person handles the interface and computer while another person handles the GOcar

6. Set up the Photogate Head, PASCO Interface and Data Recording Software (or PASCO Timer) so that the motion of the GOcar up the inclined PAStrack will be recorded as the spokes of the Super Pulley interrupt the photogate beam.

7. Hold the GOcar at the bottom of the PAStrack. Start recording data and release the GOcar so that it accelerates up the incline. Stop recording data before the GOcar reaches the Super Pulley.

8. Complete three trials of the data recording procedure for the GOcar. Use the same release position each time.

Table 5.1: Data

	GOcar mass		Hanging mass	
Acceleration	Trial 1			
	Trial 2			
	Trial 3			
	Average			
	Theoretical			

Data Analysis: GOcar

1. Determine the acceleration for each trial and record it in Table 5.1. Calculate the average experimental acceleration.

2. Calculate the theoretical acceleration for the system. Compare it to the average experimental acceleration.

Questions: GOcar

1. How did the experimental acceleration compare to the theoretical acceleration?

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

Procedure: Friction Tray

1. Set up the PAStrack and Inclined Plane Accessory as shown in Figure 5.4 with a Super Pulley with Clamp, Photogate Head, and Photogate Bracket. Elevate the PAStrack to an angle less than 30 degrees. Adjust the Photogate Head and Photogate Bracket so that the infrared beam of the photogate will be interrupted by the spokes of the Super Pulley as it turns.
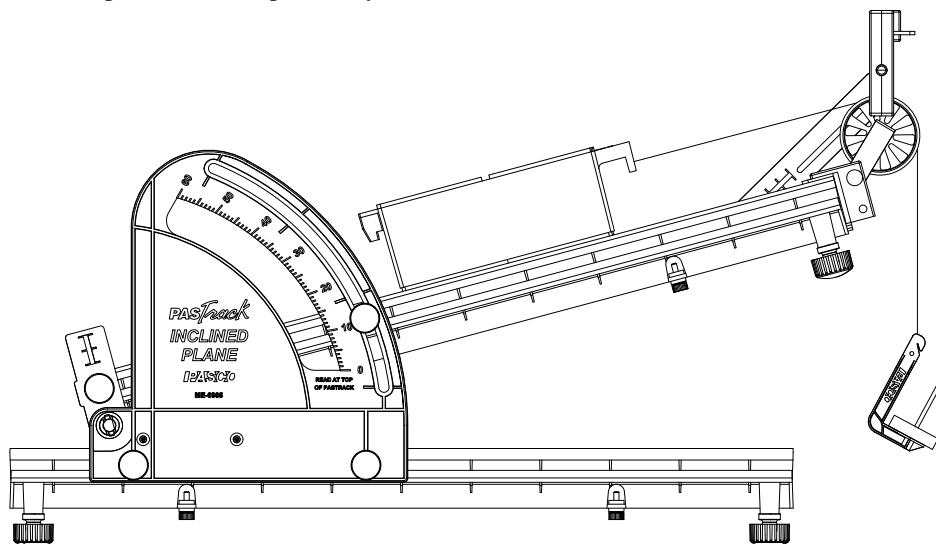

Figure 5.4

1. Select a Friction Tray and record its bottom material in Table 5.2. Measure and record the mass of the Friction Tray.

2. Attach a thread to one end of the Friction Tray, and place the tray on the inclined PAStrack at the bottom of the track. Drape the thread over the Super Pulley and attach a mass hanger to the end of the thread. Adjust the Super Pulley so that the thread is parallel to the PAStrack. Re-adjust the photogate head if necessary.

3. Put enough mass on the mass hanger so that the Friction Tray accelerates up the PAStrack when the mass hanger is allowed to drop.

4. Measure and record the total mass of the masses and hanger. Remember that the hanger by itself is 5 g.

The data collection may be easier if one person handles the interface and computer while another person handles the GOcar

5. Set up the Photogate Head, PASCO Interface and Data Recording Software (or PASCO Timer) so that the motion of the Friction Tray up the inclined PAStrack will be recorded as the spokes of the Super Pulley interrupt the photogate beam.

PASCO ®

6. Hold the Friction Tray at the bottom of the PAStrack. Start recording data and release the tray so that it accelerates up the incline. Stop recording data before the tray reaches the Super Pulley.

7. Complete three trials of the data recording procedure for the Friction Tray. Use the same release position each time

8. Complete three trials of the data recording procedure for the second Friction Tray.

9. Repeat the procedure for the third Friction Tray

Table 5.2: Data.

	Tray material			
	Tray mass			
	Hanging mass			
Acceleration	Trial 1			
	Trial 2			
	Trial 3			
	Average			
	μ_k			

Data Analysis: Friction Tray

1. Determine the acceleration for each trial and record it in Table 5.1. Calculate the average experimental acceleration.

2. Use the data to calculate the coefficient of kinetic friction for each tray.

Questions: Friction Tray

1. How did your calculated coefficients for kinetic friction compare to your results from a previous experiment?

2. How will doubling the mass of each Friction Tray affect the results? Try it.

Suggested Experiments

1. **Conservation of Potential Energy and Kinetic Energy**: Set up the PAStrack at a shallow angle. Measure the mass of the GOcar with the Smart Timer Picket Fence. Place the GOcar at the top of the track and mark the starting position. Mount a Photogate Bracket and Photogate Head near the bottom of the inclined plane so that it can measure the motion of the GOcar. Use a PASCO Interface or Timer to find the velocity of the GOcar as it reaches the bottom of the plane. Determine the difference in height of the GOcar from the beginning point to the final point. Calculate kinetic energy and gravitational potential energy and compare them.

2. **Coefficient of Static Friction**: Set up the PAStrack at a shallow angle. Measure the mass of a Friction Tray. Place the tray near the top of the PAStrack. Tap the track slightly. If the tray does not begin to slide, then raise the PAStrack to a higher angle and try again. When the tray will start sliding as the PAStrack is tapped and continue to slide with increasing speed, record the angle of the PAStrack. Use the data to calculate the coefficient of static friction.