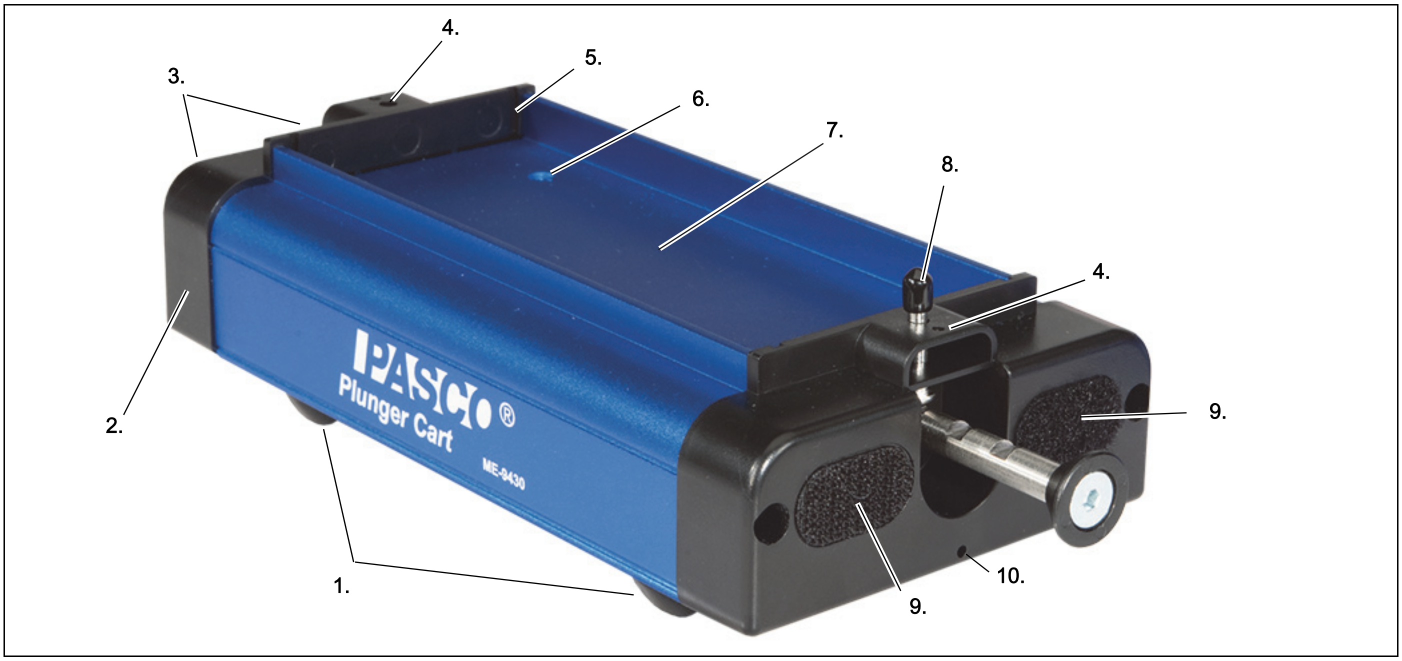
Instruction Manual
012-14781A

Plunger Cart

ME-9430



Features

1	Low-friction Retractable Ball-Bearing Wheels	6	Two Mounting Holes
2	ABS End Caps	7	Accessory Tray
3	Magnets in non-plunger end cap (not shown)	8	Plunger Trigger
4	Upper Tie Point (each end cap)	9	Hook and Loop (Velcro®) Tabs
5	Slot for Cart Picket Fence (ME-9804)	10	Lower Tie Point (each end cap)

Accessories

Please see the PASCO catalog or the PASCO web site at

www.pasco.com

for information about accessories such as tracks, springs, bumpers, pulleys, masses, and special attachments that are designed to be used with the Plunger Cart.

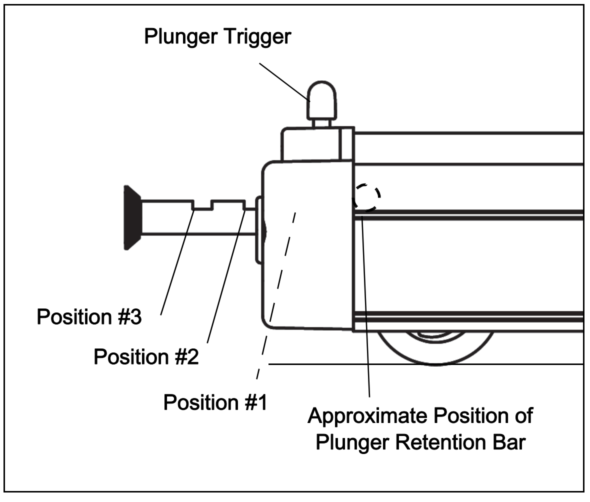
Introduction

The Plunger Cart is a 500 gram cart with an aluminum body and ABS (acrylonitrile butadiene styrene) end caps. It has a spring plunger in one end and magnets in the other. It has “hook-and-loop” (Velcro®) tabs on the plunger end for inelastic collision studies. The magnets can be used for elastic collisions studies. The spring plunger has three setting positions and is released by a plunger trigger on the top of the plunger end of the Plunger Cart. Both ends of the Plunger Cart have convenient tie points at the top and the bottom. On the top of the Plunger Cart is an accessory tray that can hold extra masses. The tray has threaded holes for attaching PASCO accessories such as a Cart Adapter that can be used to mount a Motion Sensor, and slots for holding a Cart Picket Fence.

Other Features

The Plunger Cart has ball-bearing wheels that are designed with narrow edges to minimize friction. The cart has a spring suspension system that prevents damage to the wheels and internal components if the cart is dropped or stepped on. Plunger Carts can be stacked for easy storage.

Plunger Operation



The plunger has three indentations on the top side that you can see when the plunger is fully extended. Inside the cart is a Retention Bar located above the plunger. When the plunger is pushed in far enough so that an indentation lines up with the Retention Bar, the plunger will be held in that position until the Plunger Trigger is pushed down. If the end of the plunger is next to an object such as a heavy book, the Plunger Cart will accelerate away from the object when the Plunger Trigger is pushed down and the plunger applies a force.

Positions #1 and #2

Apply a slight upward force on the end of the plunger, Push the plunger into the Plunger Cart until you hear or feel the first “click” (Position #1) as the indentation on the plunger lines up with the Retention Bar. Lower the end of the plunger slightly to disengage it from the Retention Bar, and push the plunger a little farther into the Plunger Cart. Slightly raise the end of the plunger and push the plunger until you hear or feel the second “click” (Position #2). To release the plunger, push down on the Plunger Trigger.

CAUTION: The plunger comes out rapidly, so be prepared. For example, do not hold the plunger end of the Plunger Cart against your eye (or anything else that would be harmed) if the plunger is released.

Position #3

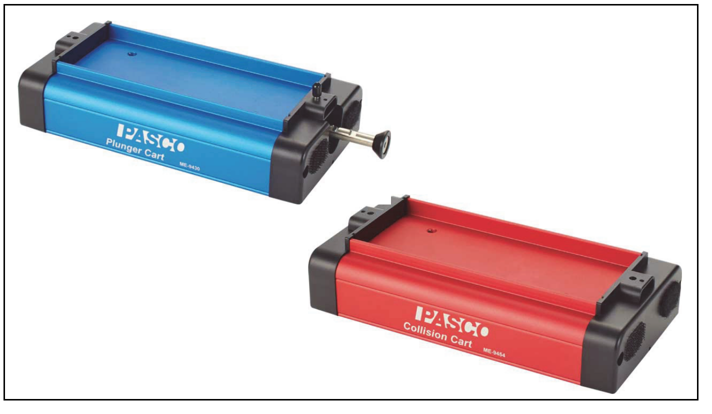
Apply a slight upward force on the end of the plunger. Push the plunger all the way into the Plunger Cart until the Position #3 indentation catches on the Retention Bar. The end of the plunger will be flush with the end cap of the Plunger Cart. The plunger pushes outward with maximum force when it is released from Position #3. This is also the position used when doing inelastic collisions with the Velcro bumpers.

Usage

The following illustrations show a few of the ways that the Plunger Cart is used. See the PASCO web site at www.pasco.com for more information.

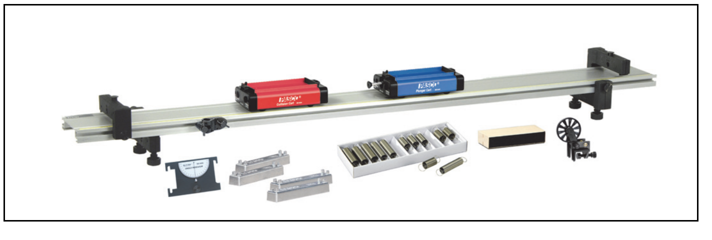
Collision Cart

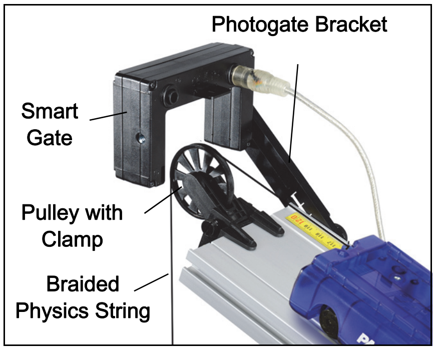
The PASCO ME-9454 Collision Cart is a “twin” of the Plunger Cart but it is red and does not have a spring plunger. The different colors make it easier to keep track of the carts in collisions studies.



Plunger Cart Dynamics Systems

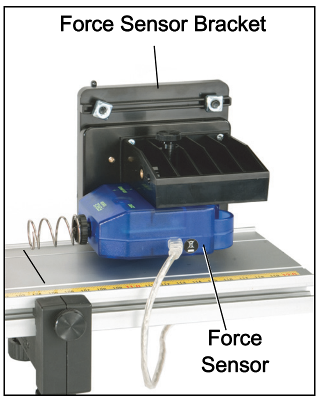
Plunger Carts are included in bundles with tracks, adjustable feet, end stops, a track pivot clamp a friction block, and other accessories such as mass bars, springs, photogate brackets, “cart picket fences”, and a pulley with clamp.

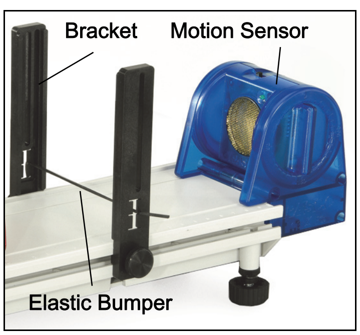




Brackets and Bumpers

There are a variety of accessories that fit onto a Plunger Cart or onto a track for use with a Plunger Cart.





Experiments

The included Plunger Cart experiments rely on the measurement of time, distance, and mass. The basic equipment required is: stopwatch, metric tape measure (2 m or more), and a mass balance.

Equipment Suggested	Model Number
Cart Masses, 250 g (2)	ME-6567A
Friction Block	ME-9807
Stopwatch	ME-1234
Pulley with Clamp	ME-9448B
Hooked Mass Set	SE-8959
Physics String	SE-8050
Triple-Beam Balance	SE-8723
Meter Stick	SE-8827
30 Meter Measuring Tape	SE-8712A

For information about the suggested equipment and other items for use with the Plunger Cart, see the PASCO catalog or the PASCO web site at

www.pasco.com

Technical Support

For assistance with any PASCO product, contact PASCO at:

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

Phone: 916-462-8384 (worldwide)
800-772-8700 (U.S.)

Web: www.pasco.com

Email: support@pasco.com

More Information

For more information about the latest revision of this Instruction Manual, visit:

www.pasco.com/manuals

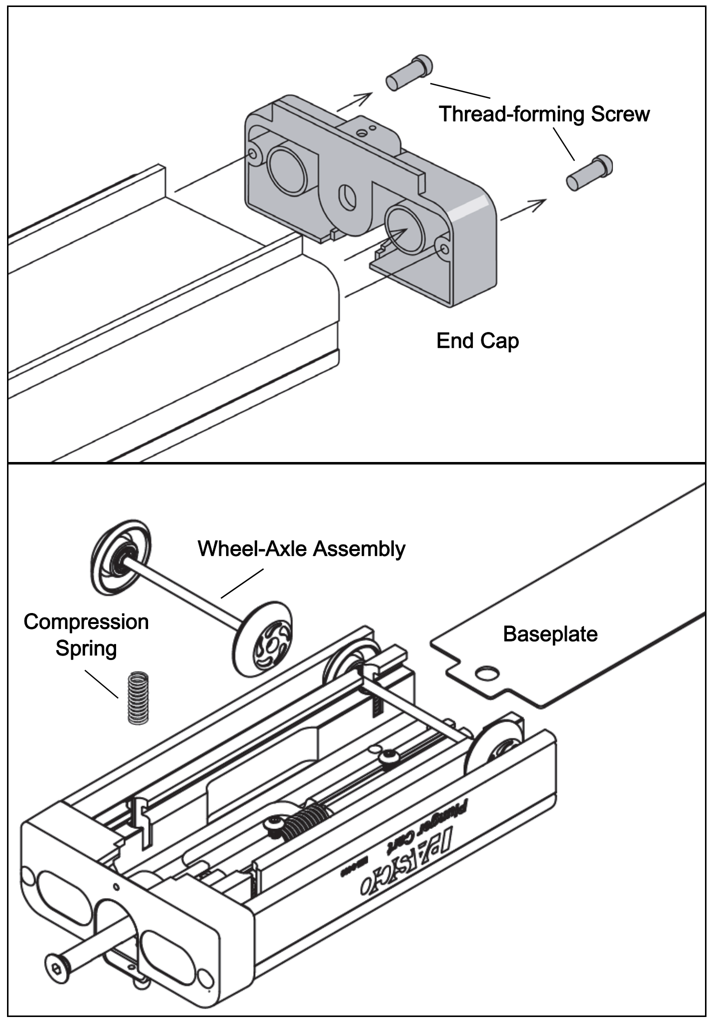
and enter the Product Number.

For information about the Plunger Carts or any PASCO product, what software to use, and what other accessories are available, check the PASCO web site.

Appendix

Replacing the Wheel-Axle Assemblies (PASCO ME-6957A - set of four)

Warning! When the baseplate is removed, the wheel-axle assemblies may pop upward because they are supported on compressed springs. Pull the baseplate with one hand and cover the wheel-axle area with the other hand. This will help keep the wheel-axle assembly from popping out.



1. Using a Phillips screwdriver, remove the screws from the non-plunger end cap.

NOTE: The screws that connect the end cap to the body of the Plunger Cart are thread-forming screws and may require substantial force to remove and reinstall. A #1 Phillips point screwdriver is recommended.

2. Position the Plunger Cart with the baseplate facing upward.
3. Begin to slide the baseplate out of the cart. Be careful to “catch” each wheel-axle assembly as it is uncovered.
4. With the car in a stable position, lift the wheel-axle assemblies from the grooves.

NOTE: Be sure to keep the components such as springs, plunger, and magnets in their proper orientation. Rearranging or moving any items could change the operational capability of the Plunger Cart.

5. Place the new wheel-axle assemblies over the suspension springs.
6. Push the rear axle down against the springs first, and slide the baseplate back into a position that covers the wheel-axle assembly.
7. Push the front axle down second, and slide the baseplate all the way back into its original position.
8. Replace the non-plunger end cap with the two screws.

Experment 1: Kinematics (Average vs. Instantaneous Velocities)

Equipment Needed
Plunger Cart
Metric Tape Measure
Stopwatch

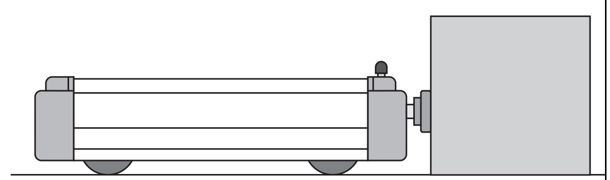


Figure 1.1

Purpose

In this lab, the Plunger Cart will be used to investigate one dimensional accelerated motion. The Plunger Cart will be launched over the floor using the built-in spring plunger. The Plunger 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 Plunger 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 **D** covered and the total elapsed time **T** from launch to stop will be measured and recorded. The average velocity over this interval is given by the following equation:

$$v_{av} = \frac{D}{T} \qquad \text{Eqn. 1}$$

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

$$v_0 = 2v_{av} = \frac{2D}{T} \qquad \text{Eqn. 2}$$

And the value of the acceleration would be given by the following equation:

$$a = \frac{\Delta v}{t} = \frac{0 - v_0}{T} = -\frac{2D}{T^2} \qquad \text{Eqn. 3}$$

If the acceleration and v_o 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 the following equation:

$$d = v_0 t_1 + \frac{1}{2} a t_1^2 \qquad \text{Eqn. 4}$$

Calculated values of 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 Plunger Cart, clearly mark a distance **d** that is about half way out from the start. Measure this distance and record it at the top of Table 1.1.
2. Using a stopwatch with a lap timer and metric tape, it is possible to determine $\mathbf{t_1}$, **T** and **D** for each launch. Practice this step a few times before you start recording data.

   NOTE: To eliminate reaction time errors, it is very important to have the person who launches the Plunger 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. (Don’t count the trials in which the timer feels that a distraction interfered with the measurement.) Record your best trials in Table 1.1.
4. Using the equations described in the theory section and the data recorded in the table, do the calculations needed to complete the table.

Data Analysis

d= _________ cm

Table 1.1

Trial	Experiment					Theory	% Diff.
	t_1 (s)	T (s)	D (cm)	v_0 (cm/s)	a (cm/s^2)	t_1 (s)	
1							
2							
3							
4							
5							
6							

Questions

1. Is there a systematic difference between the experimental and calculated values of $\mathbf{t_1}$? If so, suggest possible factors that would account for this difference.
2. Can you think of a simple follow up experiment that would allow you to determine how much the cart’s “deceleration” was affected by floor slope?

Experiment 2: Coefficient of Friction

Equipment Needed
Plunger Cart
Metric Tape Measure
Stopwatch

Purpose

In this lab, the Plunger 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.)

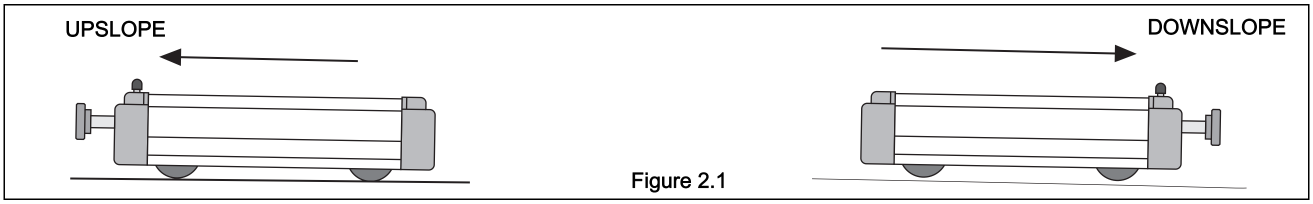


Figure 2.1

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 downslope, the acceleration of the Plunger Cart is given by the following equation:

$$a_1 = +g\sin\theta - \mu_r g \qquad \text{Eqn. 1}$$

And the acceleration in the direction that is slightly upslope 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 the following equation:

$$a = \frac{2d}{t^2} \qquad \text{Eqn. 3}$$

Having obtained numerical values for a_1 and a_2, Eqn. 1 and Eqn. 2 can be simultaneously solved for μ_r and θ.

Procedure

1. Place the Plunger Cart in its starting position and then launch it. To cock the spring plunger, push the plunger in, and then push the plunger slight upward to allow one of the notches on the plunger bar to "catch" on the bar inside the cart. 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 algebraically solving for the two unknowns.

Table 2.1

	First Direction		
Trial	d (cm)	t (s)	a (cm/s^2)
1			
2			
3			
4			
5			
6			

Average Acceleration = __________ cm/s^2

	Second Direction		
Trial	d (cm)	t (s)	a (cm/s^2)
1			
2			
3			
4			
5			
6			

Average Acceleration = __________ 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 Plunger 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	
Plunger Cart	Pulley and Pulley Clamp
Mass Set	Balance
Stopwatch	String
Paper clips	Block (to act as bumper)

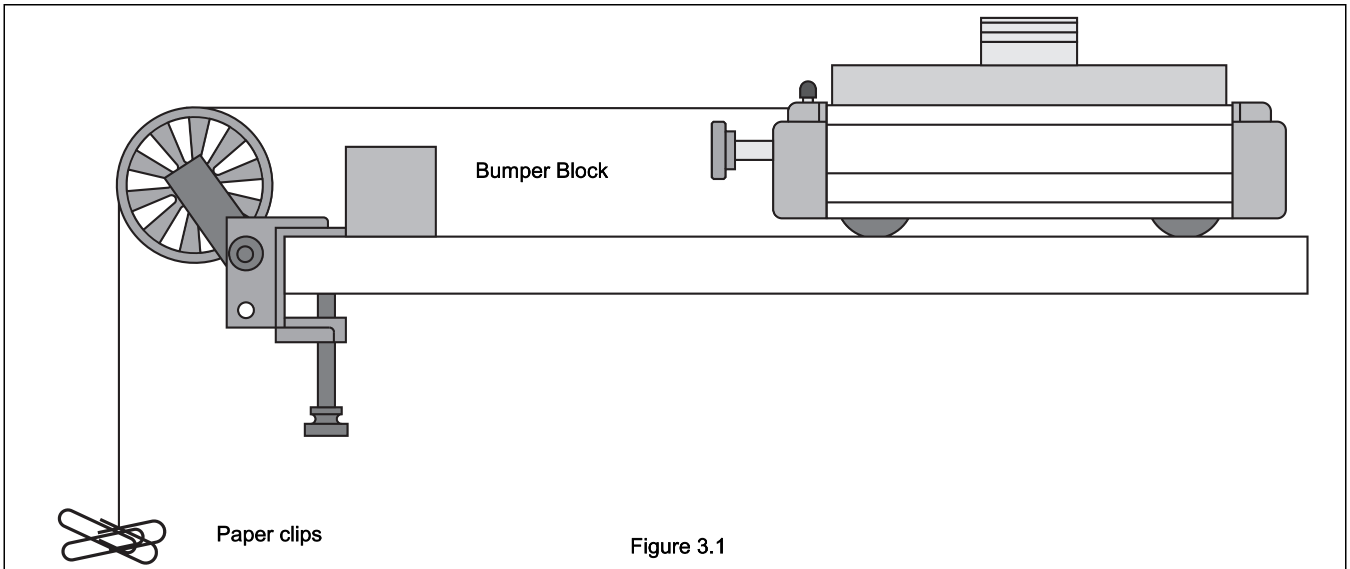


Figure 3.1

Purpose

In this lab, a small mass **m** will be connected to the 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 Plunger Cart will have the same acceleration. The resulting acceleration of this system will be experimentally determined and this value will be compared to the acceleration predicted by Newton's Second Law.

Theory

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

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

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:

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

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 accessory tray of the Plunger Cart: 10-g, 50-g, 500-g, and two 20-g masses.
2. Carefully level the table until the cart has no particular tendency to drift or accelerate in either direction along its run.
3. Tie one end of the string to the tie point on the top of one end of the Plunger Cart. Drape the string over the pulley. Adjust the pulley up-or-down 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 Plunger 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 Plunger Cart to the hanging loop and pull the cart back to a clearly marked starting point. Determine the distance d that the Plunger 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 Plunger 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 Plunger Cart arrives at the bumper. To eliminate reaction time errors, it is best that the person who releases the cart also does the timing!
8. Determine the average time for the cart to move through the distance d, having been released from rest. Record the average of the four time trials in which you have the most confidence in Table 3.1. Repeat for all of the masses given in the data table.
9. Excluding the pulley, determine the total mass of your system, M_{total} (Plunger Cart, added masses, string) and record at the top of Table 3.1. (It will be close to 1100 grams, but you should 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} = ________________ gram

Table 3.1

Trial	m (g)	Average time (s)	a_{exp} (cm/s^2)	a_{th} (cm/s^2)	% Diff.
1	10				
2	20				
3	30				
4	40				
5	50				
6	60				
7	70				
8	80				

Question

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	
Plunger Cart	Stopwatch
Mass Set	Balance
Pan for holding masses	Metric Ruler
Metric Measuring Tape	

Purpose

The Plunger Cart has a spring plunger, which can be used for producing relatively elastic collisions and providing a reproducible launch velocity.

Theory

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

$$k = \frac{\Delta F}{\Delta x} \qquad \text{Eqn. 1}$$

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

$$\frac{1}{2}mv_0^2 = \frac{1}{2}kx_0^2 \qquad \text{Eqn. 2}$$

which leads to:

$$v_0 = x_0\sqrt{\frac{k}{m}} \qquad \text{Eqn. 3}$$

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

$$v_0 = 2\frac{d}{t} \qquad \text{Eqn. 4}$$

It is assumed that the acceleration of the Plunger 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.

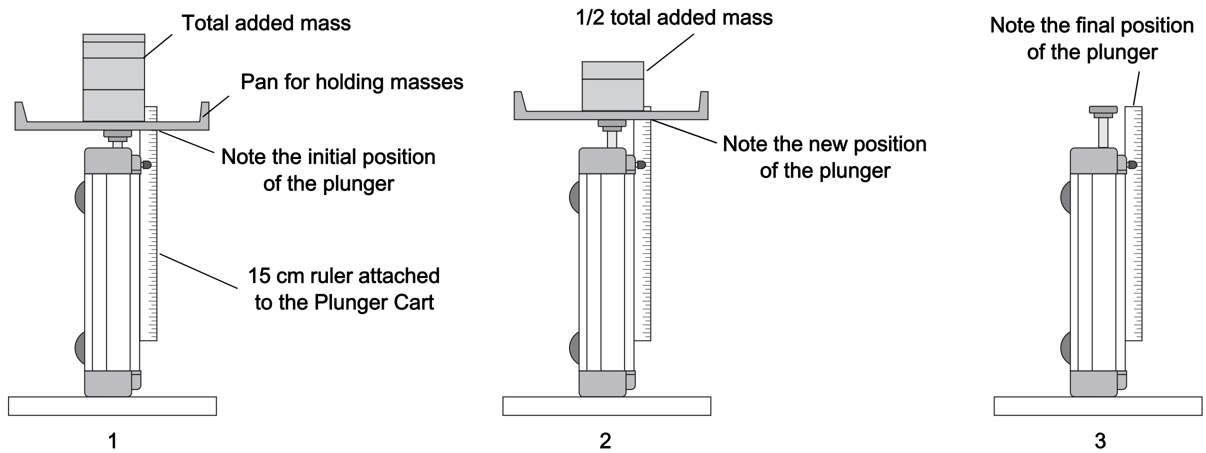


Figure 4.1

Procedure

1. Stand the Plunger 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 car 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 car. 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**, x_o (i.e. the compression of the cocked spring) and **k**, predict the launch velocity of your cart and record this below.
8. Cock the spring plunger to the value of x_o 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 v_o and compare it with the predicted value.

Data and Analysis

mass of cart = _______________ kg

k = _______________ N/m $\mathbf{x_o}$ = ______________ m

Predicted value of launch velocity $\mathbf{v_0}$ = ______________ m/s

Average **d** = ___________________m Average **t** = _______________ s

Observed value of the launch velocity $\mathbf{v_0}$ = ________________ m/s

Percent difference (% Diff) between observed and expected values of $\mathbf{v_0}$ = ________

Table 4.1

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

NOTES

Experiment 5: Rackets, Bats, and "Sweet Spots"

Equipment Needed	
Plunger Cart	Metric Measuring Tape
Meter Stick or Long Rod	Mass Set

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 "sweetspot". We will call this maximum energy sweetspot SS1.

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

Theory

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

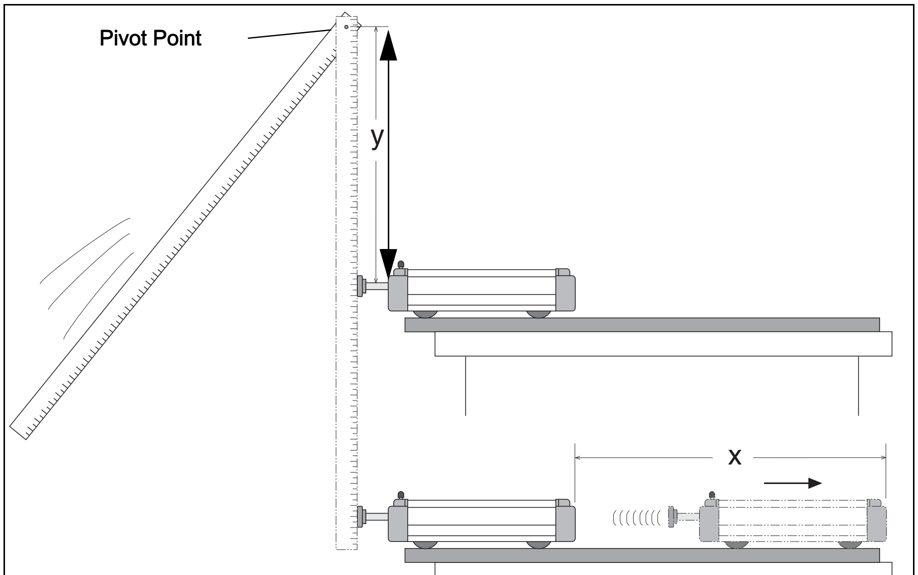


Figure 5.1

$$y_{SS2} = \frac{I}{my_{cm}} \qquad \text{Eqn. 1}$$

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 endpoint, 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 20 for details). The position of SS2 can be found experimentally using the PASCO Force Sensor 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.

If you have already done the experiment to determine the coefficient of rolling friction for your cart for the same surface that you are using in this experiment, you can determine the kinetic energy of the cart at the moment after impact as shown in Eqn. 2.

$$\frac{1}{2}mv^2 = \mu mgx \qquad \text{Eqn. 2}$$

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 pullback angle for the hanging meter stick.
3. Pull the meter stick or rod back to the pullback 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 repositioning 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!

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 "Superbat" 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 SweetSpot 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, Sacrament, CA, using Quickbasic 4.5.

```
REM Program: SWEET SPOTS and PER-CUSSION POINTS (Fixed Pivot)
REM (Version: 15DEC91)
CLS
LOCATE 1, 1
INPUT “What pullback angle will you be using for this experiment (deg.)”; theta
INPUT “What is the mass of your meter-stick ’bat’ (kg); Ms
g = 9.8:  Mc = .5:  L = 1:  theta = theta / 57.3
COLOR 15
Begin:
CLS
LOCATE 1, 1
INPUT “How far from the center-of-mass is the pivot located (m)”; S
INPUT “How large is the load mass (kg)”; m
IF m = 0 GOTO Skip
INPUT “ How far is the load mass from the pivot (m)”; y
Skip:
I = (1 / 12) ∗ Ms ∗ L ^ 2 + Ms ∗ S ^ 2 + m ∗ y ^ 2
PE = (Ms ∗ S + m ∗ y) ∗ (1 – COS(theta)) ∗ g
Wo = SQR(2 ∗ PE / I)
h = (1 + 2 ∗ (y / L) ∗ (m / Ms)) ∗ (1 – COS(theta)) ∗ L / 2
PRINT: PRINT
COLOR 14
PRINT “Y-Impact (m)”; TAB(16); “Cart-Speed (m/s)”;  TAB(35);  “Omega (rad/sec)”; TAB(54);  “Impulse at Pivot (N∗sec)”
COLOR 15
PRINT
FOR k = 1 TO 9
r = k / 10
a = Mc / 2 + (Mc ∗ r) ^ 2 / (2 ∗ I)
b = –Mc ∗ Wo ∗ r
c = –PE + (1 / 2) ∗ I ∗ Wo ^ 2
v = (–b + SQR(b ^ 2 – 4 ∗ a ∗ c)) / (2 ∗ a)
w = (I ∗ Wo – Mc ∗ r ∗ v) / I
DeltaP = Mc ∗ v + Ms ∗ w ∗ L / 2 – Ms ∗ Wo ∗ L / 2
v = INT(1000 ∗ v + .5) / 1000
w = INT(1000 ∗ w + .5) / 1000
DeltaP = INT(100 ∗ DeltaP + .5) / 100
PRINT TAB(5);  r;  TAB(20);  v;  TAB(39);  w; TAB(60);  DeltaP
NEXT
PRINT: PRINT
INPUT “Would you like to input different values ”; a$
IF a$ < > “N” and a$ < > “n” GOTO Begin
END
```

NOTES

Experiment 6: Sliding Friction and Conservation of Energy

Equipment Needed	
Plunger Cart	Stopwatch
Metric Measuring Tape	Brick or Block
Long Board (ramp)	Friction Block
Protractor	

Purpose

In this lab, the Plunger 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 car are converted to thermal energy as the car slides to a stop. The thermal energy generated on the surfaces is the same as the work done against sliding friction.

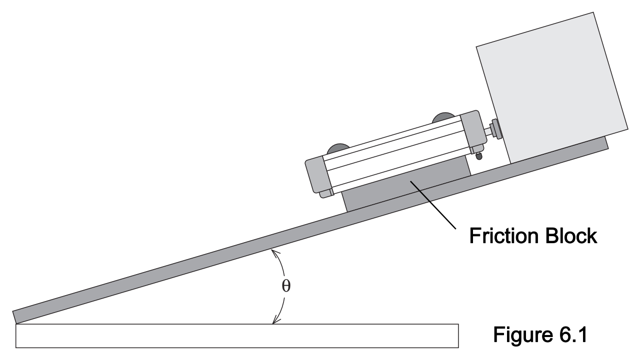


Figure 6.1

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:

$$\frac{1}{2}kx^2 + mgD\sin\theta = \mu_k mgD\cos\theta \qquad \text{Eqn. 1}$$

(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 (-μkmgcosø) 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:

$$a = mg\sin\phi - \mu_k\cos\phi \qquad \text{Eqn. 2}$$

The average acceleration down the ramp is given by:

$$a = \frac{2d}{t^2} \qquad \text{Eqn. 3}$$

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 the 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 begins 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 data in Table 6.1. Repeat the measurements four times. Use Eqn. 3 to compute the accelerations of the block and enter the values in data Table 6.1. Determine the average value of acceleration and enter it below data Table 6.1.

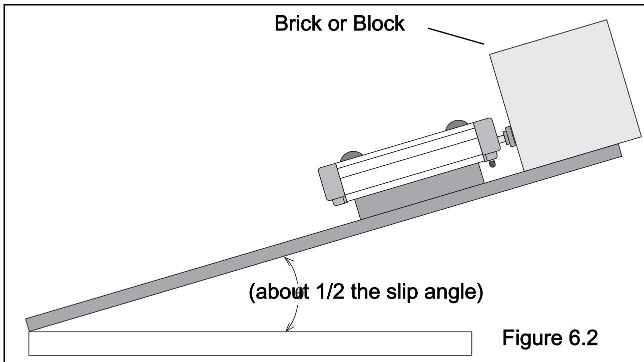


Figure 6.2

4. Use Eqn. 2 to calculate the coefficient of kinetic or “sliding” friction. Enter it below the data table.

Prediction of D and Measurement of D:

5. Now slightly reduce the angle of the ramp 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 car 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 Plunger Trigger with a rod or stick using a flat edge.

   NOTE: This will help to insure that you do not give the car an initial velocity other than that supplied by the spring plunger.
8. For six trials, measure the distance **D** that the car slides and record these in Table 6.2.

NOTE: Sometimes the car will twist a bit as it descends, so use the midpoint of the back edge of your car 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 (cm/s^2)
1			
2			
3			
4			

average acceleration = _______________ cm/s^2 coefficient of sliding friction = ______________

$\theta =$ _________________ 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 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