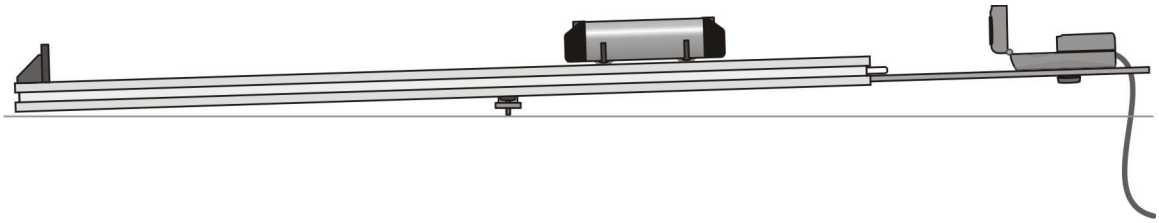
Physics I – Laboratory #2

Part I - Cart on a Ramp

INTRODUCTION

This experiment uses a ramp and a low-friction cart. If you give the cart a gentle push up the ramp, the cart will roll upward, slow and stop, and then roll back down, speeding up. A graph of its velocity *vs.* time would show these changes. Is there a mathematical pattern to the changes in velocity? What is the accompanying pattern to the position *vs.* time graph? What would the acceleration *vs.* time graph look like? Is the acceleration constant?

In this experiment, you will use a Motion Detector to collect position, velocity, and acceleration data for a cart rolling up and down a ramp. Analysis of the graphs of this motion will answer these questions.



OBJECTIVES

- Collect position, velocity, and acceleration data as a cart rolls up and down a ramp.
- Analyze the position *vs.* time, velocity *vs.* time, and acceleration *vs.* time graphs.
- Determine the best fit equations for the position *vs.* time and velocity *vs.* time graphs.
- Determine the mean acceleration from the acceleration *vs.* time graph.

MATERIALS

Computer
Vernier computer interface
Logger *Pro*
Vernier Motion Detector
Vernier Dynamics System

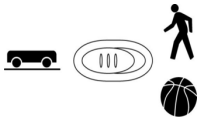
PRELIMINARY QUESTIONS

1. Consider the changes in motion a cart will undergo as it rolls up and down a ramp. Make a sketch of your prediction for the position *vs.* time graph. Describe in words what this graph means.

2. Make a sketch of your prediction for the velocity *vs.* time graph. Describe in words what this graph means.

3. Make a sketch of your prediction for the acceleration *vs.* time graph. Describe in words what this graph means.

PROCEDURE IA



1. Connect the Vernier Motion Detector to the DIG/SONIC 1 channel of the interface. Set the motion detector switch to "Track" (the one with the picture of the cart).

2. Confirm that your ramp, end stop, and Motion Detector bracket are assembled as shown in the figure. Adjust the head of the detector so that it is pointing straight down the track, or angled up just a little (*Note: If you have trouble detecting motion of the cart, you will likely have to tweak the angle of the motion detector head)*.

3. Open the file "03 Cart on a Ramp" from the *Physics with Vernier* folder. **NOTE:** There *may* be an error in the setup file, such that only position and velocity graphs may be shown. If this is the case, in the "Insert" pull-down menu – select "Graph". This should add an acceleration vs. time graph. You can re-position the graphs so that all three are arranged across the screen.

4. Place the cart on the track near the bottom end stop. If your cart has a plunger, face the plunger away from the Motion Detector. Click ▸ Collect to begin data collection[1]. You will notice a clicking sound from the Motion Detector. Wait about a second, then briefly push the cart up the ramp, letting it roll freely up nearly to the top, and then back down. Catch the cart as it nears the end stop.

5. Examine the position *vs.* time graph. Repeat Step 4 if your position *vs.* time graph does not show an area of smoothly changing position. Check with your instructor if you are not sure whether you need to repeat data collection.

ANALYSIS IA

1. Either print or sketch the three motion graphs. The graphs you have recorded are fairly complex and it is important to identify different regions of each graph. Click the Examine button, , and move the mouse across any graph to answer the following questions. Record your answers directly on the printed or sketched graphs.

   a) Identify the region when the cart was being pushed by your hand:

   - Examine the velocity *vs.* time graph and identify this region. Label this on the graph.
   - Examine the acceleration *vs.* time graph and identify the same region. Label the graph.

   b) Identify the region where the cart is rolling freely:

   - Label the region on each graph where the cart was rolling freely and moving up the ramp.
   - Label the region on each graph where the cart was rolling freely and moving down the ramp.

   c) Determine the position, velocity, and acceleration at specific points.

   - On the velocity *vs.* time graph, decide where the cart had its maximum velocity, just as the cart was released. Mark the spot and record the value on the graph.
   - On the position *vs.* time graph, locate the highest point of the cart on the ramp. Note that this point is the closest approach to the Motion Detector. Mark the spot and record the value on the graph.
   - What was the velocity of the cart at the top of its motion?
   - What was the acceleration of the cart at the top of its motion?

2. The motion of an object in constant acceleration modeled by $x = v_0t + \frac{1}{2} at^2$, where x is the position, v_0 is the initial velocity, t is time, and a is the acceleration. This is a quadratic equation whose graph is a parabola. If the cart moved with constant acceleration while it was rolling, your graph of position *vs.* time will be parabolic. To fit a quadratic equation to your data, click and drag the mouse across the

[1] Logger *Pro* tip: if a graph is currently selected, you can start data collection by tapping the Space bar.

portion of the position *vs.* time graph that is parabolic, **highlighting** the free-rolling portion.

3. Click the Curve Fit button, , select Quadratic fit from the list of models and click Try Fit. Examine the fit of the curve to your data and click OK to return to the main graph. Is the cart's acceleration constant during the free-rolling segment?

4. The graph of velocity *vs.* time will be linear if the acceleration is constant. To fit a line to this data, click and drag the mouse across the free rolling region of the motion. Click the Linear Fit button, . How closely does the slope correspond to the acceleration you found in the previous step?

5. The graph of acceleration *vs.* time should appear to be more or less constant during the freely-rolling segment. Click and drag the mouse across the free-rolling portion of the motion and click the Statistics button, . How closely does the mean acceleration value compare to the values of *a* found in Steps 3 and 4?

PROCEDURE IB – BOUNCING CART

1. Your cart can bounce against the track end stop using the plunger and end stop. Practice starting the cart so it bounces at least three times during the ten-second data collection.

2. Collect another set of Motion Detector data showing two or more bounces.

ANALYSIS IB

1. Determine the cart's acceleration *during the free rolling segments* using the velocity graph. How do they compare?

2. Determine the cart's acceleration *during the free rolling segments* using the position graph. How do they compare?

PART II – Measure the Acceleration of Gravity on an Incline

During the early part of the seventeenth century, Galileo experimentally examined the concept of acceleration. One of his goals was to learn more about freely falling objects. Unfortunately, his timing devices were not precise enough to allow him to study free fall directly. Therefore, he decided to limit the acceleration by using fluids, inclined planes, and pendulums. In this lab exercise, you will see how the acceleration of a rolling ball or cart depends on the ramp angle. Then, you will use your data to extrapolate to the acceleration on a vertical "ramp;" that is, the acceleration of a ball in free fall.

If the angle of an incline with the horizontal is small, a cart rolling down the incline moves slowly and can be easily timed. Using time and position data, it is possible to calculate the acceleration of the cart. When the angle of the incline is increased, the acceleration also increases. The acceleration is directly proportional to the sine of the incline angle, (*Θ)*. A graph of acceleration versus sin(*Θ)* can be extrapolated to a point where the value of sin(*Θ)* is 1. When sin *(Θ)* is 1, the angle of the incline is 90°. This is equivalent to free fall. The acceleration during free fall can then be determined from the graph.

Galileo was able to measure acceleration only for small angles. You will collect similar data. Can these data be used in extrapolation to determine a useful value of *g*, the acceleration of free fall? We will see how valid this extrapolation can be. Rather than measuring time, as Galileo did, you will use a Motion Detector to determine the acceleration. You will make quantitative measurements of the motion of a cart rolling down inclines of various small angles. From these measurements, you should be able to decide for yourself whether an extrapolation to large angles is valid.

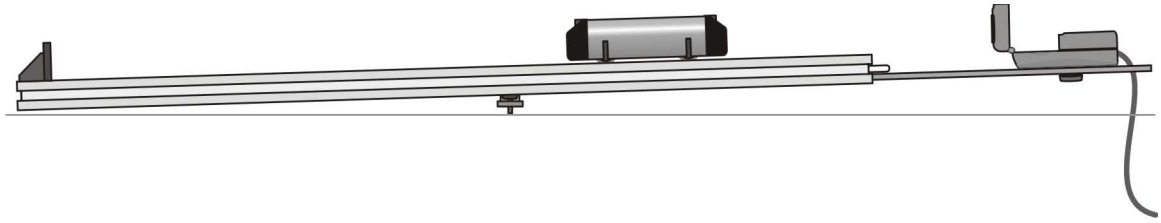
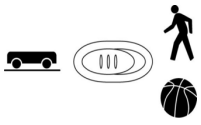


Figure 1

OBJECTIVES

* Use a Motion Detector to measure the speed and acceleration of a cart rolling down an incline.
* Determine the mathematical relationship between the angle of an incline and the acceleration of a cart rolling down the ramp.
* Determine the value of free fall acceleration, *g*, by extrapolating the acceleration *vs*. sine of track angle graph.
* Determine if an extrapolation of the acceleration *vs*. sine of track angle is valid.

PROCEDURE II



1. Connect the Motion Detector to the DIG/SONIC 1 channel of the interface. If the Motion Detector has a switch, set it to Track.
2. Place a single book under one end of the track so that it forms a small angle with the horizontal.
3. Place the Motion Detector at the top of an incline.
4. Open the file "04 g On An Incline" from the *Physics with Vernier* folder.
5. Hold the cart on the incline about 0.15 m from the Motion Detector.

6. Click ▸ Collect to begin collecting data; release the cart after the Motion Detector starts to click. Get your hand out of the Motion Detector path quickly. You may have to adjust the position and aim of the Motion Detector several times before you get it right. Adjust and repeat this step until you get a good run showing approximately constant slope on the velocity *vs.* time graph during the rolling of the cart.

7. Logger *Pro* can fit a straight line to a portion of your data. First indicate which portion is to be used by dragging across the graph to indicate the starting and ending times. Then click on the Linear Fit button, , to perform a linear regression of the selected data. Use this tool to determine the slope of the velocity *vs*. time graph, using only the portion of the data for times when the cart was freely rolling. From the fitted line, find the acceleration of the cart. Record the value in your data table.

8. Repeat Steps 5–7 two more times.

9. Measure the length of the incline, *x*, which is the ***distance between the two contact points of the ramp***. See Figure 1.

10. Measure the height, *h*, the height of the book(s). These last two measurements will be used to determine the angle of the incline.

11. Raise the incline by placing a second book under the end. Adjust the books so that the distance, *x*, is the same as the previous reading.

12. Repeat Steps 5–10 for the new incline.

13. Repeat Steps 5–11 for 3, 4, and 5 books.

DATA TABLE

Data using cart							
Number of books	Height of books, *h* (m)	Length of incline, *x* (m)	sin(*Θ*)	Acceleration			Average acceleration (m/s^2)
				trial 1 (m/s^2)	trial 2 (m/s^2)	trial 3 (m/s^2)	
1							
2							
3							
4							
5							

ANALYSIS II

1. Using trigonometry and your values of *x* and *h* in the data table, calculate the sine of the incline angle for each height. Note that *x* is the hypotenuse of a right triangle.

2. Calculate the average acceleration for each height. Plot a graph of the average acceleration (*y* axis) *vs*. sin(*Θ)*. Use either Page 3 of the experiment file or graph paper. When setting up your axes, make sure to carry the sin(*Θ)* axis out to 1 (one) to leave room for extrapolation.

3. Draw a best-fit line by hand or use the linear fit feature of Logger *Pro*, and determine the slope. The slope can be used to determine the acceleration of the ball on an incline of any angle.

4. On the graph, carry the fitted line out to sin(90°) = 1 on the horizontal axis, and read the value of the acceleration.[2]

5. How well does the extrapolated value agree with the accepted value of free-fall acceleration (g = 9.8 m/s^2)?

6. Discuss the validity of extrapolating the acceleration value to an angle of 90°.

7. What potential sources of error are present in this experiment? Would these errors tend to cause you to overestimate or underestimate the actual value of g?

[2] Notice that extrapolating to the y value at the x = 1 point is equivalent to using the slope of the fitted line.