Cart on a Ramp

This experiment uses an incline and a low-friction cart. If you give the cart a gentle push up the incline, 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 does 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 an incline. Analysis of the graphs of this motion will answer these questions.

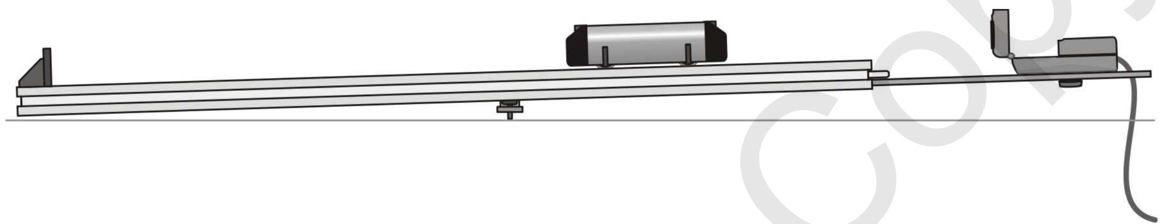


Figure 1

OBJECTIVES

- Collect position, velocity, and acceleration data as a cart rolls freely up and down an incline.
- Analyze 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 Track
Adjustable End Stop
Motion Detector Bracket
Vernier Dynamics Cart with plunger

PRELIMINARY QUESTIONS

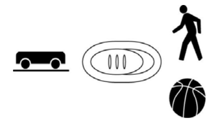
1. Consider the changes in motion a Dynamics Cart will undergo as it rolls up and down an incline. Make a sketch of your prediction for the position *vs.* time graph. Describe in words what this graph means.

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

Part I



1. Connect the Motion Detector to the digital (DIG) port of the interface. Set the Motion Detector sensitivity switch to Track.

2. Confirm that your Dynamics Track, Adjustable End Stop, and Motion Detector Bracket are assembled as shown in Figure 1. Adjust the head of the Motion Detector so that it is pointing straight down the track, or angled up just a little.

3. Open the file "03 Cart on a Ramp" from the *Physics with Vernier* folder.

4. Place the cart on the track near the end stop. 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 incline, 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.

6. Answer the Analysis questions for Part I before proceeding to Part II.

Part II

7. Your cart can bounce against the end stop with its plunger. Practice starting the cart so it bounces at least twice during data collection.

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

9. Proceed to the Analysis questions for Part II.

ANALYSIS

Part I

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 Examine, , 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 was rolling freely:
      - Label the region on each graph where the cart was rolling freely and moving up the incline.
      - Label the region on each graph where the cart was rolling freely and moving down the incline.

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

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 incline. 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 is modeled by $x = ½ at^2 + v_0t + x_0$, where x is the position, a is the acceleration, t is time, and v_0 is the initial velocity. 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. Fit a quadratic equation to your data.

   a. Click and drag the mouse across the portion of the position *vs.* time graph that is parabolic, highlighting the free-rolling portion.
   b. Click Curve Fit, , select Quadratic fit from the list of models and click Try Fit.
   c. 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?

3. The graph of velocity *vs.* time is 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 Linear Fit, . How closely does the slope correspond to the acceleration you found in the previous step?

4. The graph of acceleration *vs.* time should appear approximately constant during the freely-rolling segment. Click and drag the mouse across the free-rolling portion of the motion and click Statistics, . How closely does the mean acceleration value compare to the values of a found in Steps 2 and 3?

Part II

5. Determine the cart's acceleration during the free-rolling segments using the velocity graph. Are they the same?

6. Determine the cart's acceleration during the free-rolling segments using the position graph. Are they the same?

EXTENSIONS

1. Adjust the angle of the incline to change the acceleration and measure the new value. How closely does the coefficient of the t^2 term in the curve fit compare to $½\, g \sin \theta$, where θ is the angle of the track with respect to horizontal? For a trigonometric method for determining θ, see the experiment, *Determining* g *on an Incline*, in this book.

2. Compare your results in this experiment with other measurements of g. For example, use the experiment, *Picket Fence Free Fall*, in this book.

3. Use a free-body diagram to analyze the forces on a rolling cart. Predict the acceleration as a function of incline angle and compare your prediction to your experimental results.

4. Even though the cart has very low friction, the friction is not zero. From your velocity graph, devise a way to measure the difference in acceleration between the roll up and the roll down. Can you use this information to determine the friction force in newtons?

5. Use the modeling feature of Logger *Pro* to superimpose a linear model on the velocity graph. To insert a model, choose Model from the Analyze menu. Select the linear function and click OK. On the Model window, click the slope or intercept label and adjust using the cursor keys or by typing in new values until you get a good fit. Interpret the slope you obtain. Interpret the y-intercept.

Vernier Lab Safety Instructions Disclaimer

THIS IS AN EVALUATION COPY OF THE VERNIER STUDENT LAB.

This copy does not include:

- **Safety information**
- **Essential instructor background information**
- **Directions for preparing solutions**
- **Important tips for successfully doing these labs**

The complete *Physics with Vernier* lab manual includes 35 labs and essential teacher information. The full lab book is available for purchase at: www.vernier.com/pwv

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