Physics with Vernier

4th Edition

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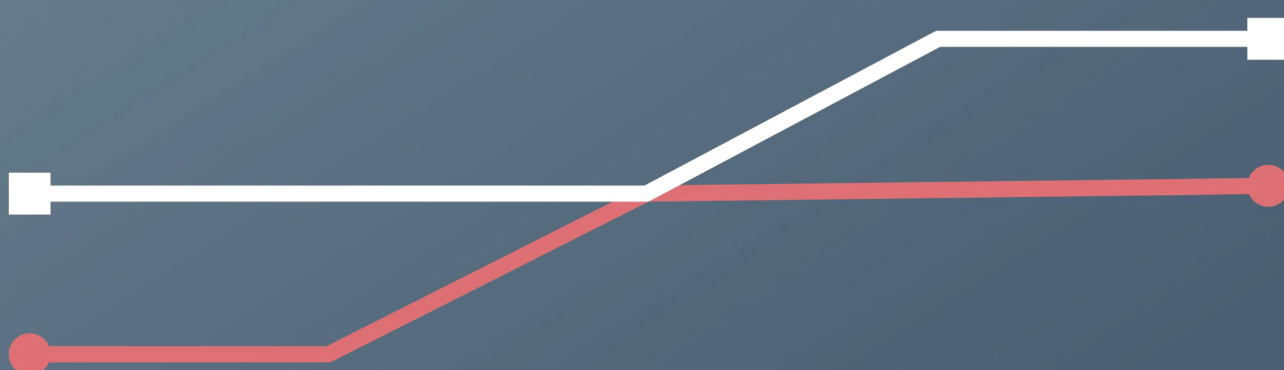

PWV

Vernier

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Appendices

LabQuest Sensors

		Sensors												Accessories									
		Motion Detector	Motion Encoder	Photogate	Accelerometer"	Dual-Range Force"	Current	Differential Voltage	Magnetic Field	Light	Microphone	Temperature	Rotary Motion	Picket Fence	Bumper/Launcher Kit	Extech Power Supply	Optics Expansion Kit	Polarizer/Analyzer Set	Springs Set	Ultra Pulley	Vernier Circuit Board	Dynamics Cart/Track	Projectile Launcher
1	Graph Matching	1																					
2	Back and Forth Motion	1	1																1			1	
3	Cart on a Ramp*	1	1																			1	
4	Determining g on an Incline*	1	1																			1	
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33	Speed of Sound										1	1											
34	Tones, Vowels, and Telephones^^										1												
35	Mathematics of Music^^										1												

* Experiment can be performed with more than one type of sensor. Refer to the Instructor Information for details.

** Optional

^ Logger *Pro*, LabQuest App, and Graphical Analysis 4 app only; not available for Easy Data.

^^ Logger *Pro* and LabQuest App only; not available for Graphical Analysis 4 or Easy Data.

" A Wireless Dynamics Sensor System (WDSS) (discontinued) can be used in place of a Dual-Range Force Sensor and/or an Accelerometer.

Go Direct Sensors

		Sensors												Accessories									
		Motion	Sensor Cart	Photogate	Acceleration	Force and Acceleration	Current	Voltage	3-Axis Magnetic Field	Light and Color	Sound	Temperature	Rotary Motion	Picket Fence	Bumper/Launcher Kit	Extech Power Supply	Optics Expansion Kit	Polarizer/Analyzer Set	Springs Set	Ultra Pulley	Vernier Circuit Board	Dynamics Cart/Track	Projectile Launcher
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** Optional

^ Not supported in Graphical Analysis 4 app.

Cart on a Ramp

(Motion Detector)

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 the questions above.

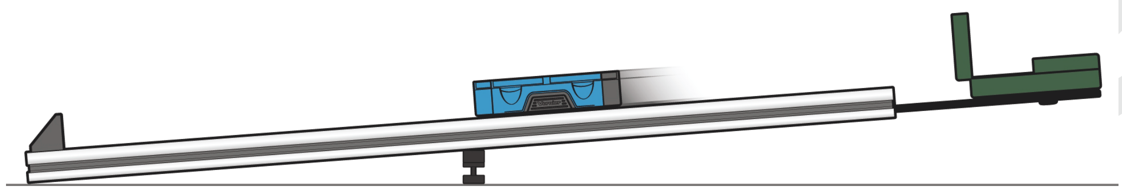


Figure 1

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*
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 Cart.

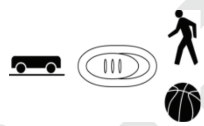


Figure 2

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.

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

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.

   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 $x = \frac{1}{2} at^2 + v_0t + x_0$, 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. 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. For a trigonometric method for determining θ, see the experiment, "Determining *g* on an Incline," in this book.

2. 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?

3. 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.

Accelerations in the Real World

The portability of the data-collection equipment makes it ideal for studying accelerations that occur outside the physics laboratory. Some interesting situations are the automobile and amusement park rides, as well as high-speed elevators, motorcycles, and go-carts.

An accelerometer measures the acceleration in a specific direction. You will need to choose an appropriate time scale and the direction in which to hold the accelerometer to obtain meaningful information. Obtaining acceleration data from independent kinematics measurements can transform an informal study into an empirical evaluation of a mathematical model.

This experiment highlights several situations where you can collect real-world acceleration data. A general procedure is given that you will modify depending on which study is performed. After the general procedure, you will find several suggestions for acceleration investigations. You will need to plan an experiment around the motion to be studied, adjusting data-collection parameters as needed.

OBJECTIVES

- Measure acceleration in a real-world setting.
- Compare the acceleration measured to the value calculated from other data.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Acceleration **or** Go Direct Force and Acceleration

SET UP PROCEDURE

The following steps will guide you through configuring Graphical Analysis to collect acceleration data with an acceleration sensor. You will probably need to modify either the time between samples or the number of points collected for your particular circumstances. Adjust these values as you design your experiment.

1. Launch Graphical Analysis. Connect the Go Direct Force and Acceleration Sensor or the Go Direct Acceleration Sensor to your Chromebook, computer, or mobile device. Click or tap Sensor Channels, and select the appropriate channels for your experiment.

2. Set up the data-collection mode.
   a. Click or tap Mode to open Data-Collection Settings.
   b. Change Rate to 10 samples/s and End Collection to 20 s. You may want to use different values according to your experimental conditions. Click or tap Done.

3. Zero the acceleration sensor in the orientation you plan to collect data. For example, if the acceleration sensor is to be oriented horizontally during data collection, place the sensor on a horizontal surface while zeroing. Or, if you will be collecting data with the sensor oriented vertically, then place the sensor against a vertical surface.
   a. Orient your sensor as appropriate for your experiment. **Note**: If you are collecting data along multiple axes, you will zero the sensor multiple times. Orient the sensor for one of the axes you will use.
   b. Click or tap the appropriate Acceleration meter and choose Zero. When the process is complete, the acceleration values are close to zero.
   c. If collecting data for multiple axes, repeat this process for each axis along which you will collect data.
4. Click or tap Collect to start data collection when you are ready to collect data.
5. When data collection is complete, a graph of acceleration *vs.* time is displayed. Click or tap the graph to examine the data. **Note**: You can also adjust the Examine line by dragging the line.

AUTOMOBILES AND MOTORCYCLES

Part I Linear Acceleration on a Straight Road

The accelerometer can record the acceleration of a motor vehicle. A good motion to study is speeding up from rest, followed by slowing to a stop. Initially, set up data collection for a duration of 30 seconds, although you may find that this time should be shortened or extended. Zero the accelerometer with the relevant arrow held horizontally.

Secure the accelerometer in a horizontal direction with the relevant arrow of the accelerometer aligned with the direction of the motion. Start data collection just before starting the vehicle. Accelerate to a safe speed, and then slow to a stop. Keep the vehicle moving in a straight line and keep it on a level section of roadway for this experiment.

Ask the driver to maintain a constant acceleration while speeding up, as well as a constant acceleration when slowing down. Compare different vehicles; compare acceleration patterns with automatic and manual transmissions. For an independent acceleration measurement, collect velocity *vs.* time data during the trial, either by calling out times and recording the instantaneous velocities, or perhaps by collecting video of the speedometer. Compare the accelerations you obtain with the accelerations that are recorded by the interface.

Part II Centripetal Acceleration in Corners

When a vehicle turns a corner, a centripetal acceleration is present. By securing the relevant axis of the accelerometer horizontally and perpendicular to the forward direction, you can record the accelerations in curvilinear motion. Initially set up data collection for a duration of 30 seconds, although you may find that this time should be shortened or extended. Set up a path that has several curves of measured radii as well as straight sections. A parking lot not used on weekends would be best. Practice until the driver can maneuver through the course while maintaining a steady speed. Orient the relevant arrow of the accelerometer in the horizontal direction so it is stable relative to the vehicle and perpendicular to the vehicle's motion (the relevant arrow should be pointing to the inside of curve). Accelerate to the planned speed and keep the vehicle moving at a constant speed. Start data collection just before entering the test section containing the curves.

For an independent acceleration measurement from kinematics, you will need to know both the radii of the turns and the speed of the vehicle.

ELEVATORS

Investigate a high-speed elevator in a building with six stories or more. Zero the accelerometer with the relevant arrow held vertically. Initially set up data collection for a duration of 90 seconds. You will want to adjust this time depending on the transit time of your elevator.

Enter the elevator and place the accelerometer against the elevator wall or floor with the relevant arrow pointing upward. Do not hold it in your extended hand because the motion of your arm will change the acceleration measurement.

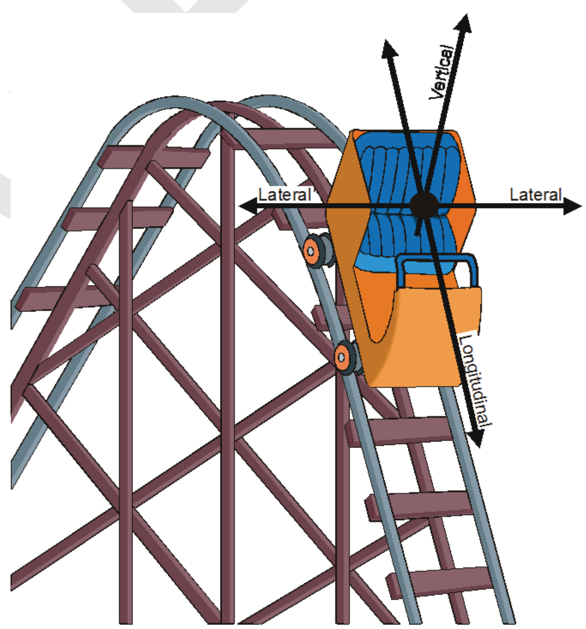
Program the elevator to stop at two floors on the way up, then program it to stop at two floors on the way back down. Start data collection when the doors close on the elevator.

Optional: If you can determine the height of a single story, you can collect data on floor-number *vs.* time to obtain velocities while the elevator is ascending or descending. You can use a video recording to measure this. Compare the velocity you obtain this way with the area under the acceleration *vs.* time graph.

AMUSEMENT PARKS

Many amusement parks feature a Physics Day where students take instruments on the rides and perform calculations. Sensor-based data collection can extend data collection so that the ride characteristics can be studied in more detail than is possible with traditional methods. Several categories of study are suggested below.

For any ride it is essential that you plan your data collection carefully. It is best to concentrate on a single portion of a ride, such as a particular loop or corner of a roller coaster. Decide which part of the ride you want to study, and estimate the length of time you will need to collect data. You may want to measure the time interval while watching others on the ride. The time between samples can then be calculated by dividing the desired time interval by the number of points you want to collect.



Along with planning the data-collection parameters, you must plan the orientation of the accelerometer during the ride. Which axis of the acceleration do you want to record? Hold or fasten the accelerometer so the arrow is parallel to this axis. The direction of the arrow will correspond to positive acceleration.

When describing the directions of accelerations on an amusement park ride, it is convenient to have a common vocabulary. The diagram defines the terms vertical, lateral and longitudinal. These designations are from the frame of reference of the rider.

Note: Depending on the ride, you may need to begin data collection before the ride begins. Extend the suggested data collection duration accordingly. A duration of 60–80 seconds is usually needed to record a complete ride. A decision on which axis to record should be made before getting on the ride.

Part I Dips

Most roller coasters feature a dip following the first major climb, as well as several others during the course of the ride. If you know the speed of the train at the top of the hill and the vertical distance to the bottom, expected speed of the train at the bottom can be calculated using conservation of energy. Knowing the radius of the curve at the bottom, the expected acceleration due to circular motion can be calculated using kinematics.

The acceleration during such a dip can be measured as the train descends into the dip, and the maximum acceleration can be determined by tracing along the graph.

To record a single dip, first zero the accelerometer with the relevant arrow upward. On the ride, secure the accelerometer vertically with the arrow upward relative to the rider. Set the data-collection duration to 15 seconds. Start data collection just before the car starts over the edge of the first drop. Compare the readings obtained at the front of the train as compared to those at the center or at the back of the train. Explain any differences.

Part II Vertical Loops

Many modern roller coasters feature vertical loops. To record acceleration data during loops, first zero the accelerometer with the relevant arrow upward. On the ride, secure the accelerometer with the arrow upward relative to the rider. Set the data collection time to approximately 15 seconds and start data collection just before the car enters the loop.

Part III Corners

Many roller coasters have the cars riding on rails, and so the corners can be nearly horizontal. If the axis of the accelerometer is secured so that it is level and perpendicular to the direction of the motion, the *lateral* acceleration will be recorded. Zero the accelerometer while the relevant axis is horizontal.

Set the data-collection duration for 15–30 seconds, as determined by your study of the ride in advance. Start data collection just before the train enters the horizontal curve.

Part IV Barrels

Some rides at amusement parks and carnivals feature a barrel in which the riders appear to be held to the inside surface by an outward force. In fact, there is no outward force. Instead, the inward normal force from the wall keeps the riders moving in a circular path. To take data in a barrel ride, first zero the accelerometer with the relevant arrow held horizontally. Secure the accelerometer such that the relevant arrow is pointing inward radially toward the center of the circular motion.

Part V Starts and Stops

Many rides feature large accelerations. If the direction is forward or back, the reference is to *longitudinal* acceleration, while if it is up or down, it is *vertical*.

Rapid starts and stops are usually short lived. A data-collection duration of 10–15 seconds is usually enough to capture the entire acceleration, allowing you to start data collection just before the ride begins. If you wish to record the stopping of the car, again a short duration is needed; possibly as short as 10 seconds. Study the ride in advance to choose an appropriate data collection time.

Some parks feature rides that have vertical rises and falls. Recording data on such a ride consists of choosing an appropriate time and holding the relevant arrow of the accelerometer in a vertical direction throughout the ride. Zero the accelerometer while the arrow is vertical.

Part VI Scrambler

Some parks have rides known as scramblers. In the scrambler, the rider's seat rotates about a pivot point with a small radius while that point is being carried around in a larger radius by the overall ride. The axis of the accelerometer directed to the side of the rider will record the lateral acceleration throughout the ride. The axis of the accelerometer that is pointed forward or backward relative to the rider will record the longitudinal acceleration. For these rides, zero the accelerometer twice, while the relevant arrow is held horizontally. Some scramblers may even have vertical accelerations, in which case use all three axes of the accelerometer.

ANALYSIS

Automobiles and Motorcycles

1. For the motion along a straight line, is the acceleration of a motorized vehicle constant? If not, why do you suspect the rate is larger during part of the run than another part? How does the acceleration while speeding up compare to the acceleration while stopping? Why do you suppose this pattern is true? Characterize the ability of your driver to accelerate the vehicle at a constant rate.

2. For the cornering motions, how do the calculated accelerations from kinematics equations compare to the accelerations measured with the interface? How do the measured accelerations compare to the acceleration due to gravity, or g?

Elevators

3. How large is the acceleration when the elevator begins to move? How large is the acceleration when the elevator has been underway for a few seconds? How large is the acceleration when the elevator is slowing to a stop? What does the sign of the acceleration indicate?

4. Use the integral tool to analyze a graph of acceleration *vs.* time. How does the area under the acceleration graph while speeding up compare to the area under the graph while it is slowing down? Why should these two areas be equal magnitude but of opposite signs?

5. Can you determine which direction the elevator is moving (upwards or downwards) by the size or direction of the accelerations? Explain your answer.

6. If you collect data while holding the accelerometer in your hand (arm in front of your body), how does the resulting acceleration compare to that recorded while the accelerometer is held rigidly against the elevator itself?

Amusement Parks

Part II Vertical Loops

7. How does the acceleration at the bottom of the loop compare to the value at the top of the loop? How does the value at the top compare to the acceleration due to gravity? What does the reading you get at the top mean? Is the loop circular in shape? If not, why not?

Part III Corners

8. By measuring the speed of the ride, and estimating the radius of curvature, you can calculate an independent value for the centripetal acceleration using kinematics. Compare this value with the measured value. What aspect of the ride could lead to the two accelerations being different?

Part IV Barrels

9. Because this type of ride is rotating at a constant angular velocity, the physics is that of uniform circular motion. The acceleration is radially inward and should be equal to $4\pi^2R/T^2$. Calculate an acceleration from measurements of the radius R and the period T for comparison to the acceleration measured while on the ride. The changes in this value while the ride is starting up and also while slowing down can be studied using the interface.

Part V Starts and Stops

10. Which is larger, the starting or the stopping acceleration? Why might one be larger than the other? Is the vertical acceleration experienced during the ride ever that of free fall?

Part VI Scrambler

11. How close are the radial accelerations of the scrambler to that of the acceleration of an object in free fall?

EXTENSIONS

1. For any of the applications discussed in this activity, you can use all three axes of the Go Direct Force and Acceleration Sensor or the Go Direct Acceleration Sensor. The vector sum of the three acceleration components can be calculated to give the acceleration magnitude.
2. Collect acceleration data while snow skiing or snowboarding. Make several turns while recording the lateral acceleration. A procedure similar to the one described above could be employed to study the turning accelerations as the rider makes sharp and gradual turns.
3. Have a skier, skateboarder, or a bicyclist go over a vertical jump and record the acceleration in the vertical direction during the jump. Video analysis measurements could be used to compare to the interface measurements.
4. Have a rider on a skateboard, ice skates, or roller blades execute a series of turns while collecting acceleration data. Video analysis measurements could be used to compare to the interface measurements.

5. Other carnival and amusement park rides can be studied using techniques similar to the ones described in this experiment. Most have a preferred direction of acceleration that can be ascertained by studying the motion of the ride.

6. Use the altitude channel of a Go Direct Acceleration to measure changes in elevation during the motion of an elevator or roller coaster ride.