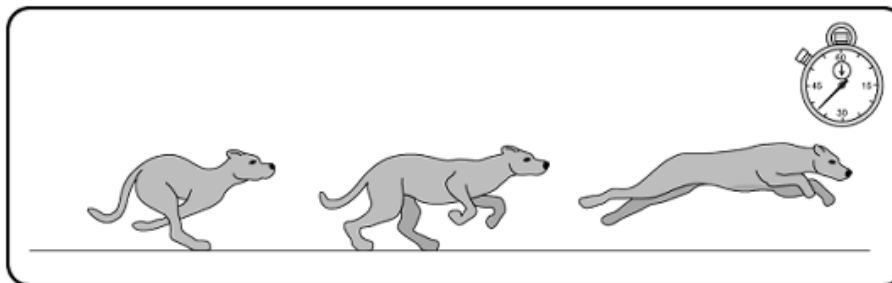


Name _____ Date _____ Partners _____

LAB 3 - VELOCITY AND ACCELERATION



A cheetah can accelerate from 0 to 50 miles per hour in 6.4 seconds.

–Encyclopedia of the Animal World

A Jaguar can accelerate from 0 to 50 miles per hour in 6.1 seconds.

–World Cars

OBJECTIVES

- To understand the meaning of acceleration, its magnitude, and its direction.
- To discover the relationship between velocity and acceleration graphs.
- To learn how to find average acceleration from acceleration graphs, velocity and position graphs.

OVERVIEW

In the previous labs, you looked at position—time and velocity—time graphs of the motion of your body and a cart at a constant velocity. You also looked at the acceleration—time graph of the cart. The data for the graphs were collected using a motion detector. Your goal in this lab is to learn how to describe various kinds of motion in more detail.

You have probably realized that a velocity—time graph is easier to use than a position—time graph when you want to know how fast and in what direction you are moving at each instant in time as you walk (even though you can calculate this information from a position—time graph).

It is not enough when studying motion in physics to simply say that “the object is moving toward the right” or “it is standing still.” When the velocity of an object is changing, it is also important to describe how it is changing. The rate of change of velocity with respect to time is known as the *acceleration*.

To get a feeling for acceleration, it is helpful to create and learn to interpret velocity—time and acceleration—time graphs for simple motions of a cart on a smooth, level ramp. You will be observing the cart with the motion detector as it moves with its velocity changing at a constant rate.

INVESTIGATION 1: VELOCITY AND ACCELERATION GRAPHS

In this investigation you will be asked to predict and observe the shapes of velocity—time and acceleration—time graphs of a cart moving along a smooth, level ramp.

You will need the following materials:

- motion detector
- motion track
- fan unit attachment with batteries and dummy cell
- small screwdriver (to help remove batteries)
- motion cart
- level

Activity 1-1: Moving Away and Speeding Up

In this activity you will look at velocity—time and acceleration—time graphs of the motion of a cart, and you will be able to see how these two representations of the motion are related to each other when the cart is speeding up

This could be done by moving the cart with your hand, but it is difficult to get a smoothly changing velocity in this way. Instead you will use a fan or propeller driven by an electric motor to accelerate the cart.

1. Make sure the fan switch is off, and then place three batteries and the dummy cell in the battery compartment of the fan unit. Place the extra battery in one of the clips on top of the fan unit. [We do this to keep the fan cart mass constant throughout the investigation.]

Note: To preserve the batteries, switch on the fan unit only when you are making measurements.

2. Set the cart on the ramp, with the fan unit and motion detector as shown below. The motion detector should be clipped to the end of the rack, *not* simply resting on its surface. Verify that the ramp is level and that the fan blade does not extend beyond the end of the cart facing the motion detector. [If it does, the motion detector may collect bad data from the rotating blade.]
3. Put the switch on the motion detector to narrow beam.



Note: The software is configured to treat movement away from the detector as being in the positive direction.

4. Open the experiment file called **L03.1-1 Speeding Up**.

5. Start graphing and use the position graph to make sure that the detector can “see” the cart all the way to the end of the ramp. You may need to tilt the detector up or down slightly. Clear all data runs before moving on.
6. With the back of the cart around 20 cm away from the sensor, hold the cart from the side, switch the fan unit on and **begin graphing**. When you hear the clicks of the motion detector, release the cart from rest. *Do not put your hand between the cart and the detector.* **Be sure to stop the cart before it hits the end.** Stop the program from taking data if it has not already shut off. Turn off the fan unit.
7. Repeat, if necessary, until you get a nice set of graphs.
8. Adjust the position and velocity axes if necessary so that the graphs fill the axes.
9. **Print** out one set of graphs for your group report. **Do not erase your data.** Remember what data set this is. Label these graphs “*Speeding Up 1*”.

Question 1-1: What feature of your velocity graph signifies that the motion was away from the motion detector?

Question 1-2: What feature of your velocity graph signifies that the cart was *speeding up*? How would a graph of motion with a constant velocity differ?

Question 1-3: During the time that the cart is speeding up, is the acceleration positive or negative? How does *speeding up* while moving *away* from the detector result in this sign of acceleration? [**Hint:** Remember that acceleration is the *rate of change* of velocity. Look at how the velocity is changing.]

Question 1-4: How does the acceleration change in time as the cart speeds up? Is this what you expect based on the velocity graph? Explain.

Activity 1-2: Speeding Up More

Prediction 1-1: Suppose that you accelerate the cart at a faster rate. How would your velocity and acceleration graphs be different? Sketch your predictions with dashed or different color lines on the graphs you printed out in Activity 1-1.

1. Test your predictions. Make velocity and acceleration graphs with all four of the batteries in the battery compartment. [You may need to use the small screwdriver to pry out the dummy cell.] Place the dummy cell in one of the clips on top of the fan cart. ***Catch the cart before it hits the end stop! Remember to switch the fan unit on only when making measurements.***
2. Repeat as necessary to get nice graphs. When you get a nice set of graphs, **do not erase** them and remember which data set they are for use later.
3. **Print** one set of graphs for your group report. Label these graphs “*Speeding Up 2*”.

Question 1-5: Did the shapes of your velocity and acceleration graphs agree with your predictions? How is the magnitude (size) of acceleration represented on a velocity—time graph?

INVESTIGATION 2: MEASURING ACCELERATION

In this investigation you will examine the motion of a cart accelerated along a level surface by a battery driven fan more quantitatively. This analysis will be quantitative in the sense that your results will consist of numbers. You will determine the cart’s

acceleration from your velocity—time graph and compare it to the acceleration read from the acceleration—time graph.

NOTE: You will need the data you took in Investigation 1.


Activity 2-1: Velocity and Acceleration of a Cart That Is Speeding Up

1. Display the data from Activity 1-1.

Comment: Average acceleration during a particular time interval is defined as the average rate of change of velocity with respect to time—that is, the change in velocity divided by the change in time. By definition, the rate of change of a quantity graphed with respect to time is also the *slope* of the curve. Thus, the (average) slope of an object's velocity-time graph is also the (average) acceleration of the object.

2. We want to find the average acceleration of the cart from your velocity graph. [Do not yet use a fit or any statistical tools.] Look for a reasonably smooth region of the acceleration graph. Only use values from the portion of the graph after the cart was released and before the cart was stopped.

NOTE: Use this same time span for each of the following analysis activities.

3. Click on the velocity graph and use the **Smart Tool**, , to read the velocity and time coordinates for the endpoints of your selected time span.

	Time (s)	Velocity (m/s)
Point 1		
Point 2		

4. Calculate the change in velocity between points 1 and 2. Also calculate the corresponding change in time (time interval). Divide the change in velocity by the change in time. This is the *average* acceleration. Show your calculations below.

Speeding up	
Change in velocity (m/s)	
Time interval (s)	
Average acceleration (m/s ²)	

Question 2-1: Is the acceleration positive or negative? Is this what you expected? Discuss.

Question 2-2: What is your best estimate of the uncertainty (in other words, your probable error) in this determination of the magnitude of the average acceleration? [Consider the following: Have you enough information to give a meaningful answer?] Justify your answer.

Activity 2-2: Using Statistics and Fit to Find the Average Acceleration

In Activity 2-1 you found the value of the average acceleration for a motion with steadily increasing velocity from the slope of the velocity—time graph. The **statistics feature** in the software allows you to find the average (mean) value directly from the acceleration—time graph. The **fit routine** allows you to find the line that best fits your velocity—time graph from Activity 2-1. The equation of this line includes a value for the slope.

1. Use the **statistics feature** to determine the mean value of acceleration. First **select the portion** of the acceleration—time graph for which you want to find the mean value. (Remember to use precisely the same time region that you used in Activity 2-1.)

Average acceleration _____ m/s^2

Standard deviation of acceleration _____ m/s^2

Number of measurements in sample _____

Question 2-3: What is your estimate of the uncertainty and the relative uncertainty in this determination of the magnitude of the average acceleration? Show your work. [Hint: Look in Appendix D for “standard error in the mean”.]

2. Use the **fit routine** to try a linear fit to the velocity—time graph ($y = mx + b$, where y is the velocity and x is the time). **Select** the same portion of the velocity—time graph as before. Record the fit parameters and their associated uncertainties:

m : _____ b : _____

σ_m : _____ σ_b : _____

Question 2-4: What are the physical meanings of the parameters m and b ?

Question 2-5: From this fit, what is the magnitude of the average acceleration?

Question 2-6: What is your estimate of the uncertainty and the relative uncertainty in this determination of the magnitude of the average acceleration? Show your work.

Recall that for uniform linear acceleration a , the position x as a function of time t is given by:

$$x(t) = x_0 + v_0 t + \frac{1}{2} a t^2$$

where x_0 is the initial position and v_0 is the initial velocity.

3. Now use the fit routine to try a quadratic fit to the *position*-time graph ($y = Ax^2 + Bx + C$; here y is the position; x is still the time). Remember to use precisely the same time region that you used in Activity 2-1. Record the fit parameters and their associated uncertainties:

A : _____ B : _____ C : _____

σ_A : _____ σ_B : _____ σ_C : _____

Question 2-7: What are the physical meanings of the parameters A , B and C ? What, then, is the magnitude of the average acceleration?

Question 2-8: What is your estimate of the uncertainty and the relative uncertainty in this determination of the magnitude of the average acceleration? Show your work.

Question 2-9: How do the four values of acceleration that you found here and in Activity 2-1 agree with each other? Which one(s) do you trust the most? Explain.

INVESTIGATION 3: SLOWING DOWN AND SPEEDING UP

In this investigation you will look at a cart moving along a level surface *and slowing down*. A car being driven down a road and brought to rest when the brakes are applied is a good example of this type of motion.

You will also examine the motion of the cart *toward* the motion detector and *speeding up*.

In both cases, we are interested in how velocity and acceleration change over time. That is, we are interested in the shapes of the velocity—time and acceleration—time graphs (and their relationship to each other), as well as the vectors representing velocity and acceleration.

You will need the following materials:

- motion detector
- motion track
- fan unit attachment with batteries
- motion cart
- level

Activity 3-1: Moving Away and Slowing Down

In this activity you will look at the velocity and acceleration graphs of the cart *moving away* from the motion detector and *slowing down*.

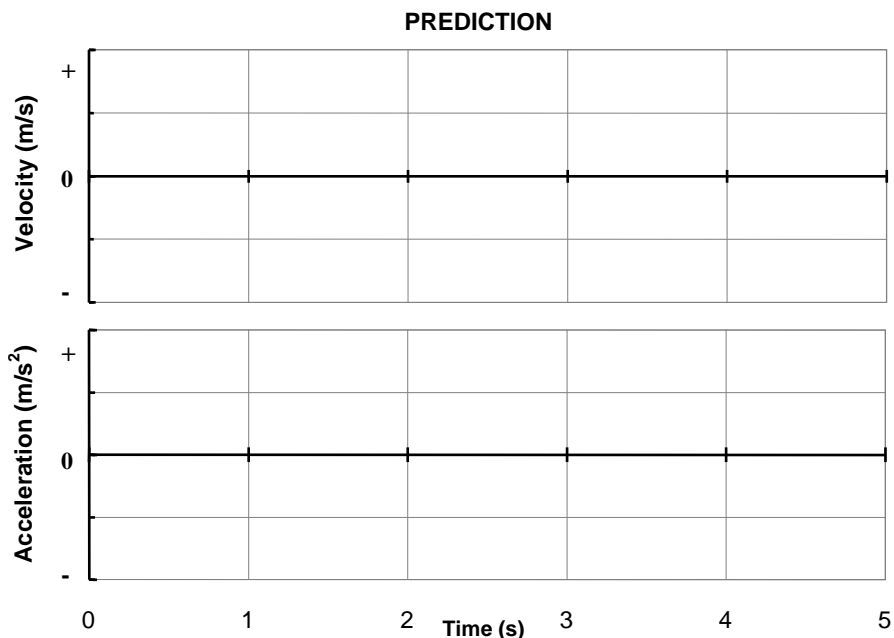
1. The cart, ramp, and motion detector should be set up as in Investigation 1. Use the maximum number of batteries. The fan should be pushing the cart *toward* the motion detector.



Prediction 3-1: If you give the cart a short push *away* from the motion detector and release it, will the acceleration be positive, negative, or zero after it is released? Enter a “+”, “-”, or “0” in the appropriate cell of Table 3-1 below. [We’ll fill in the rest of the table as we go.]

Table 3-1 General rule for sign of Acceleration		
Scenario	Is acceleration + (positive), - (negative) or 0 (zero)?	
	Prediction	Observation
Object is slowing down and moving away.		
Object is speeding up and moving toward.		
Object is slowing down and moving toward.		
Object is speeding up and moving away.		

Prediction 3-2: Sketch your predictions for the velocity—time and acceleration—time graphs on the axes below.



Now we will test your predictions.

- Open the experiment file called **L03.3-1 Slowing Down**.
- Turn the fan unit on. **Begin graphing** with the back of the cart around 20 cm away from the sensor. When you begin to hear the clicks from the motion detector, give the cart a gentle push away from the detector so that it comes to a stop near the end of the ramp. [*Be sure that your hand is not between the cart and the detector.*] Catch the cart before it stops –do not let it return toward the motion detector—and turn the fan unit off immediately to save the batteries.

4. You may have to try a few times to get a good run. Don't forget to **change the axes** if this will make your graphs easier to read.
5. Leave your data so that the graphs are **persistently displayed on the screen**.
6. **Print** out one set of graphs for your group and include them in your report. Label your graphs with
 - A when you started pushing.
 - B when you stopped pushing.
 - C the time span where only the force of the fan is acting on the cart.
 - D when you stopped the cart.

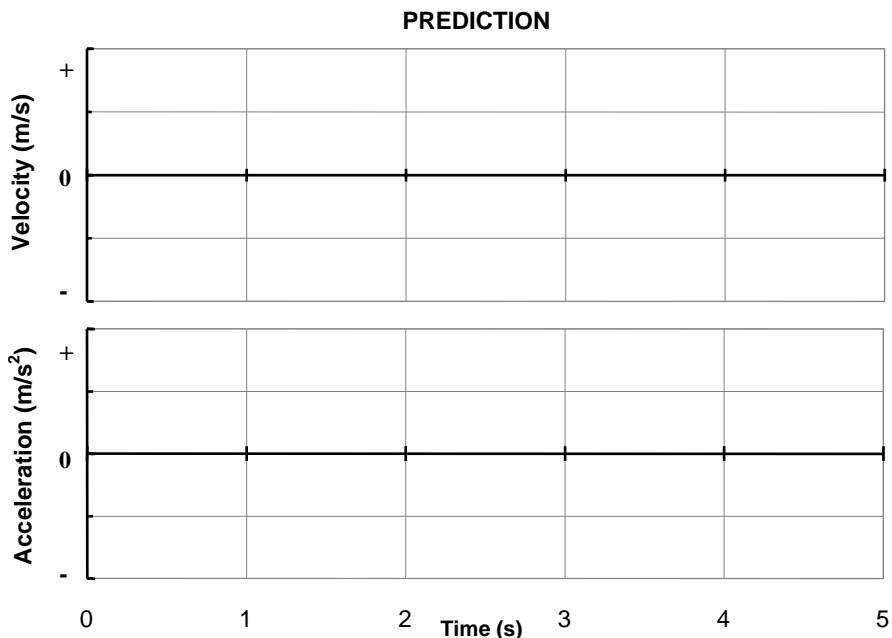
Question 3-1: Did the shapes of your velocity and acceleration graphs agree with your predictions? How can you tell the sign of the acceleration from a velocity—time graph?

Question 3-2: What is the sign of the acceleration (which indicates its direction)? Fill in the corresponding cell in Table 3-1. Is it what you predicted? How does *slowing down* while moving *away* from the detector result in this sign of acceleration? [**Hint:** Remember that acceleration is the *rate of change* of velocity with respect to time. Look at how the velocity is changing.]

Prediction 3-3: Based on your observations so far in this lab, fill in the rest of the *prediction* cells in Table 3-1.

Activity 3-2: Moving Toward and Speeding Up

Prediction 3-4: Suppose now that you start with the cart at the far end of the ramp, and let the fan push it *toward* the motion detector. Sketch your predictions for the velocity—time and acceleration—time graphs on the axes that follow.



Test your predictions.

1. First, **clear** any previous graphs. Graph the cart moving *toward* the detector and *speeding up*: **Do not let the cart hit the motion detector.** Turn the fan unit on, and when you hear the clicks from the motion detector, release the cart from rest from the far end of the ramp. *Be sure that your hand is not between the cart and the detector. Catch the cart when it gets to within about 50 cm of the motion sensor and turn the fan unit off immediately.*
2. **Print** out one set of graphs for your group. Label these graphs as “*Speeding Up Moving Toward*”. Label your graphs with
 - B when you released the cart.
 - C the time span where only the force of the fan is acting on the cart.
 - D when you stopped the cart.

Question 3-3: How does your velocity graph show that the cart was moving *toward* the detector?

Question 3-4: During the time that the cart was speeding up, is the acceleration positive or negative? Fill in the corresponding *observation* cell in Table 3-1. Does this agree with your prediction? Explain how *speeding up* while moving *toward* the detector results in this sign of acceleration. [**Hint:** Look at how the velocity is changing.]

Question 3-5: When an object is speeding up, what must be the direction of the acceleration relative to the direction of object's velocity? [Are they in the same or different directions?] Explain.

Question 3-6: There is one more possible combination of velocity and acceleration directions for the cart: moving *toward* the detector and *slowing down*. Think about your prediction from Table 3-1 to see if you want to change it. Explain why the acceleration should have this direction and this sign in terms of the sign of the velocity and how the velocity is changing.

Activity 3-3: Moving Toward and Slowing Down



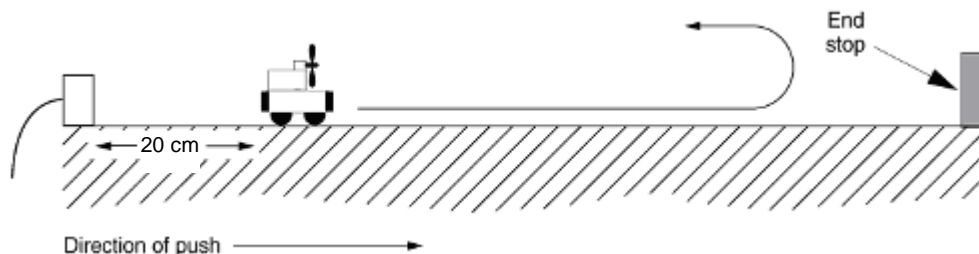
1. Clear any previous graphs. Graph the motion of the cart *moving toward* the detector and *slowing down*: **Do not let the cart hit the motion detector.** Position the cart near the end stop and with the fan again facing the motion sensor. Turn the fan unit on, and when you hear the clicks from the motion detector, give the cart a gentle push away towards the detector so that it travels at least 1 m before stopping. *Catch the cart before it stops and turn the fan unit off immediately.*
2. **Print** out one set for you group. Label as “Slowing Down Moving Toward”. Label your graphs with
 - A when you started pushing.
 - B when you stopped pushing.
 - C the time span where only the force of the fan is acting on the cart.
 - D when the cart stopped moving.
3. Based on your results in this lab, fill in the rest of Table 3-1. [See Investigation 1 for “Moving away and speeding up”.]

INVESTIGATION 4: REVERSING DIRECTION

Activity 4-1: Reversing Direction

In this activity you will look at what happens when the cart slows down, reverses its direction and then speeds up in the opposite direction. How does the velocity change with time? What is the cart’s acceleration?

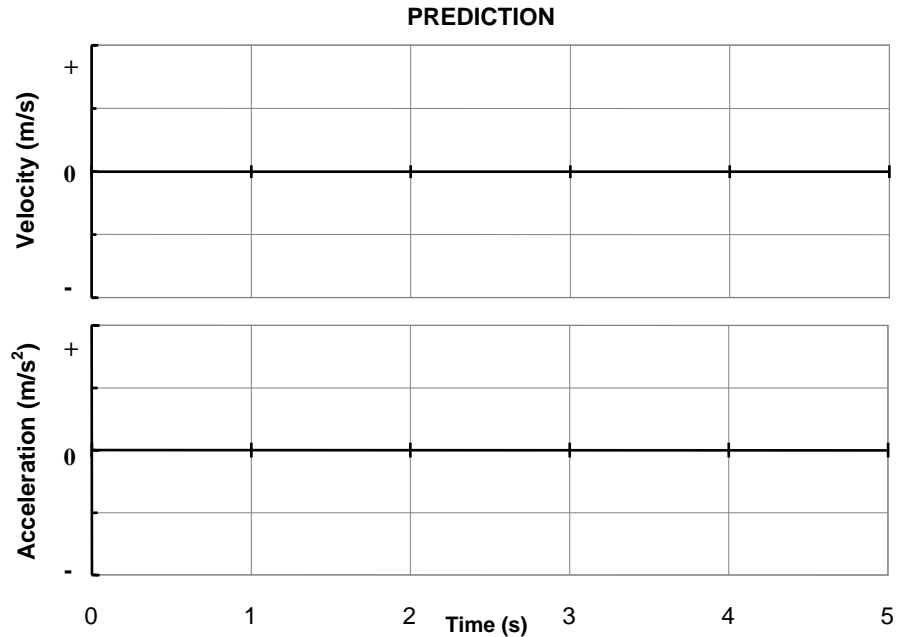
The setup should be as shown below. [The fan unit should have the maximum number of batteries.]



Prediction 4-1: Imagine that you start the fan and give the cart a push *away* from the motion detector. It moves away, slows down, reverses direction, and then moves back toward the detector. For each part of the motion—*away from the detector*, *at the turning point*, and *toward the detector*—indicate in the table below whether the velocity and acceleration will be positive, zero, or negative.

	Moving away	At the turning point	Moving toward
Velocity			
Acceleration			

Prediction 4-2: On the axes that follow sketch your predictions of the velocity—time and acceleration—time graphs of this entire motion.



Test your predictions.

1. Set up to graph velocity and acceleration. [You should still be using the experiment file **L03.3-1 Slowing Down.**]
2. Turn on the fan unit, and **begin graphing** with the back of the cart around 20 cm from the sensor. When you begin to hear the clicks from the motion detector, give the cart a gentle push away from the detector so that it travels at least 1 m, slows down, and then reverses its direction and moves toward the detector. Catch the cart at least 20 cm from the motion detector and then stop taking data. [*Push and stop the cart with your hand on its side. Be sure that your hand is not between the cart and the detector.*] Turn off the fan.
3. You may have to try a few times to get a good round trip. Don't forget to change the scales if this will make your graphs clearer.
4. **Print** one set of graphs for your group after you obtain a good round trip.
5. Label *both* your prediction graph and your final printed graph with
 - A where the cart started being pushed.
 - B where the push ended (where your hand left the cart).
 - C where the cart reached its turning point (and was about to reverse direction).
 - D where you began to stop the cart.
 - E where was once again at rest (fully stopped).

Question 4-1: Did the cart “stop” at its turning point? [**Hint:** Look at the velocity graph. What was the velocity of the cart at its turning point?] Does this agree with

your prediction? How much time did it spend at the turning point velocity before it started back toward the detector?

Question 4-2: According to your acceleration graph, what is the acceleration at the instant the cart reached its turning point? Is it positive, negative, or zero? Is it significantly different from the acceleration during the rest of the motion? Does this agree with your prediction?

Question 4-3: Discuss the difference between the acceleration while the cart is going away from the motion detector and while it is going back towards it.

Activity 4-2: Sign of Push and Stop

Find and mark on your acceleration graphs for Activity 4-1 the time intervals when you pushed the cart to start it moving and when you stopped it.

Question 4-4: What is the sign of the acceleration for each of these intervals? Explain why the acceleration has this sign in each case.

Pushing:

Stopping:

Challenge: You throw a ball up into the air. It moves upward, reaches its highest point, and then moves back down toward your hand. Assuming that upward is the positive direction, indicate in the table that follows whether the velocity and acceleration is positive, zero, or negative during each of the three parts of the motion.



	Moving up <i>after release</i>	At highest point	Moving down
Velocity			
Acceleration			

Question 4-5: In what ways is the motion of the ball similar to the motion of the cart that you just observed? What causes the ball to accelerate?

