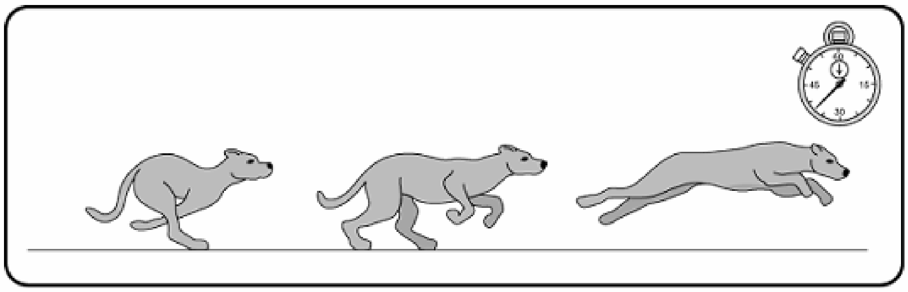
Name____________________________Date___________________Partners____________________________

# 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 discover how and when objects accelerate.
- 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.
- To learn how to calculate average acceleration from 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.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## 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 cart without friction pad
- 2-m motion track
- fan unit attachment with batteries and dummy cells
- level
- small screwdriver (to help remove batteries)

### Activity 1-1: Speeding Up

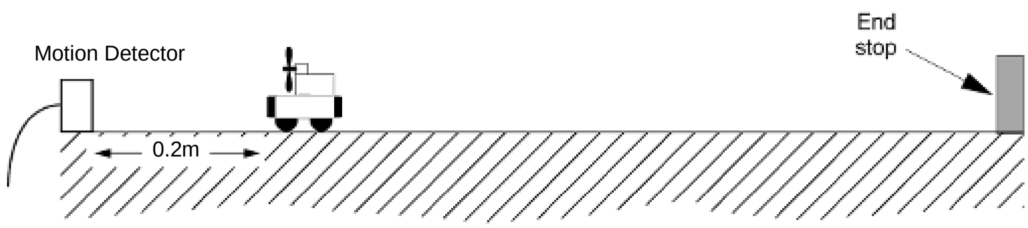
In this activity you will look at velocity—time and acceleration—time graphs of the motion of a cart, and you will be able to see how these two representations of the motion are related to each other when the cart is speeding up.

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, then place two batteries and two dummy cells in the battery compartment of the fan unit. Place the extra two batteries in the clips on top of the fan unit. We want to make sure the fan cart has a constant mass. *To preserve the batteries, switch on the fan unit only when you are making measurements*

**2.** Set up the cart on the ramp, with the fan unit and motion detector as shown below. Tape the fan unit securely to the cart. *Be sure that the ramp is level. Be sure 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.




**4**. Open the experiment file called **Speeding Up L3.1-1**.

**5**. **Begin graphing**. Use a 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. When finished, clear all data runs.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**6.** Hold the cart with your hand on its side, switch the fan unit on, **begin graphing**, and 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.

Repeat, if necessary, until you get a nice set of graphs.

Adjust the position and velocity axes if necessary so that the graphs fill the axes. **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. This time accelerate the cart with the maximum number of batteries in the battery compartment. Place the dummy cells in 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.*

   Repeat if 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.

2. **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 more quantitatively the motion of a cart accelerated along a level surface by a battery driven fan. 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.

You will need the data you took in Investigation 1.

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

1. Display the data *"Speeding Up 1"* for the cart accelerated along the ramp with half batteries and half dummy cells (Investigation 1, 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 use a fit or any statistical tools. Look for a reasonably smooth region of the graph. (We realize the acceleration values jump around a lot.) Only use values from the portion of the graph after the cart was released and before the cart was stopped. Use the **Smart Tool** to read the velocity and time coordinates for two typical points that are several seconds apart. For a more accurate answer, use two points as far apart in time as possible but still during the time the cart was speeding up.


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

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?

## 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.** You must first **select the portion** of the acceleration—time graph for which you want to find the mean value. Use precisely the same time region that you used in Activity 2-1.

Use the **statistics feature** to determine the mean value of acceleration.

Average acceleration _____________$m/s^2$

**2**. *Using **Fit***: You must first **select the portion** of the velocity—time graph that you want to fit. Use the same time region as before.

Next, use the **fit routine** to try a linear fit, $y = mx+b$ (where $y$ is the velocity and $x$ is the time.)

Record the equation of the fit line, and compare the value of the slope ($m$) to the acceleration you found in Activity 2-1.

Fit Parameters: ___________________________________________

**Question 2-2**: What is the physical meaning of the parameters $m$ and $b$?

3. Now use the fit routine to try a quadratic fit to the position-time graph, (here $y$ is the position; $x$ is still the time). ($y = Ax^2 + Bx + C$)

   Fit Parameters: ______________________________________

**Question 2-3**: What is the physical meaning of the parameters $A$, $B$ and $C$?.

**Question 2-4**: 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 why.

## INVESTIGATION 3: SLOWING DOWN AND SPEEDING UP

In this investigation you will look at a cart moving away *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.

Later you will 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 cart
- 2-m motion track
- level
- fan unit attachment with batteries

### Activity 3-1: 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*.


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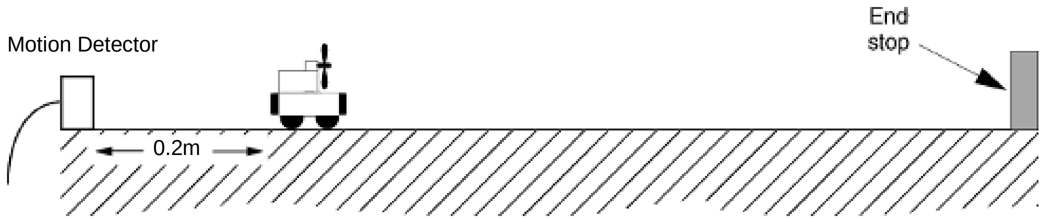
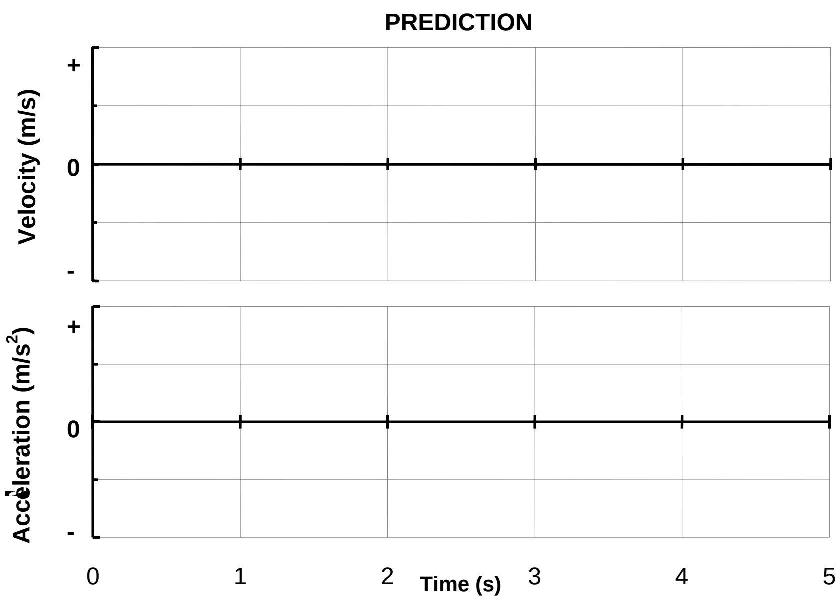
**1.** The cart, ramp, and motion detector should be set up as in Investigation 1. Use the maximum number of batteries. The fan should be pushing the cart *toward* the motion detector.




Now, when you give the cart a quick push away from the motion detector with the fan running, it will slow down after it is released.

**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)?

Sketch your predictions for the velocity—time and acceleration—time graphs on the axes below.




**2**. Open the experiment file called **Slowing Down L3.3-1.** Test your predictions.

**3**. **Begin graphing** with the cart 0.2-m away from the sensor. Turn the fan unit on, and 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*.) *Stop the cart–do not let it return toward the motion detector–and turn the fan unit off immediately to save the batteries*.

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.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Leave your data so that the graphs are **persistently displayed on the screen**.

**4.** **Print** out one set of graphs for your group and include them in your report. Label your graphs with

- A at the spot where you started pushing.
- B at the spot where you stopped pushing.
- C the region where only the force of the fan is acting on the cart.
- D at the spot where the cart stopped moving

**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**: Is the sign of the acceleration (which indicates its direction) 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.)

**Question 3-3**: Based on your observations in this lab, fill in the table below to predict the sign (the direction) of the acceleration if you know the sign of the velocity (i.e., the direction of motion) and whether the object is speeding up or slowing down. Based on this activity, you should know the rule for **moving away** and should be able to predict for **moving toward.**

**Table 3-1. General rule for sign of Acceleration**

| Observation | Is acceleration + (plus) or - (minus)? |
|---|---|
| Object is moving away and speeding up. | |
| Object is moving away and slowing down. | |
| Object is moving toward and speeding up. | |
| Object is moving toward and slowing down. | |

## Activity 3-2: Speeding Up Toward the Motion Detector

**Prediction 3-2**: 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. As the cart moves toward the detector and speeds up, predict the direction of the acceleration. Will the sign (direction) of the acceleration be positive or negative? (Use your general rule from Question 3-3.) Explain.


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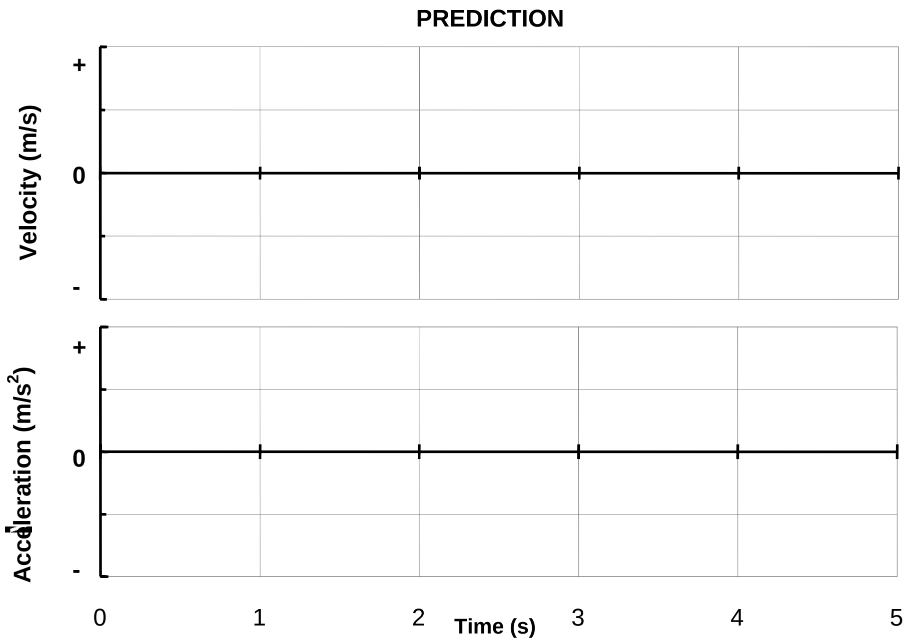
Sketch your predictions for the velocity—time and acceleration—time graphs on the axes that follow.




**1**. Test your predictions. First **clear** any previous graphs. Graph the cart moving *toward* the detector and *speeding up*. 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.) Stop the cart when it reaches the 0.5-m line, 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.*"

**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? Does this agree with your prediction from Table 3-1? 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.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**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.

3. Clear any previous graphs. Graph the motion of the cart moving toward the detector and slowing down.

4. **Print** out one set for you group. Indicate the relevant portions of the data label as "*Slowing Down Moving Toward".*

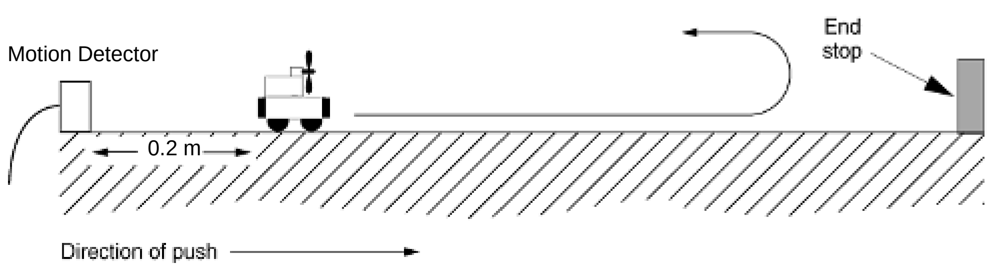
5. We have reproduced Table 3-1 below for your final results. Based on your results in this lab, fill in Table 3-2.

| **Table 3-2. General rule for sign of Acceleration** | |
|---|---|
| **Observation** | **Is acceleration + (plus) or - (minus)?** |
| Object is speeding up and moving away. | |
| Object is speeding up and moving toward. | |
| Object is slowing down and moving away. | |
| Object is slowing down and moving toward. | |

### Activity 3-3: 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 same as before. The fan unit should have the maximum number of batteries and should be taped securely to the cart.




**Prediction 3-3:** 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.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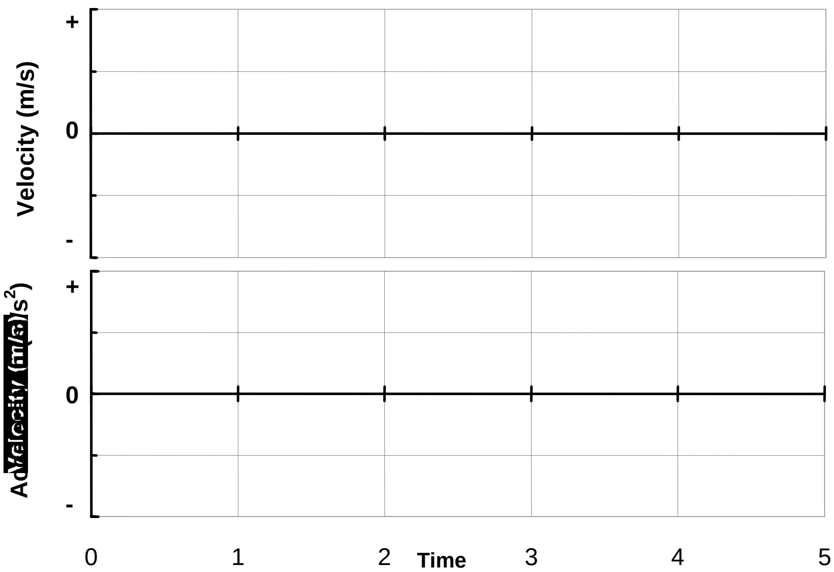
| | Moving away | At the turning point | Moving toward |
|---|---|---|---|
| Velocity | | | |
| Acceleration | | | |

On the axes that follow sketch your predictions of the velocity—time and acceleration—time graphs of this entire motion.

**PREDICTION**




1. **1.** Test your predictions. Set up to graph velocity and acceleration. (You should still be using the experiment file **Slowing Down L3.3-1**)

2. **2**. **Begin graphing** with the back of the cart near the 0.2-m mark. Turn on the fan unit, and 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. (*Push and stop the cart with your hand on its side. Be sure that your hand is not between the cart and the detector.*)

   *Be sure to stop the cart at least 0.2-m from the motion detector and turn off the fan unit immediately.*

   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.

3. **3**. When you obtain a good round trip, **print** one set of graphs for your group.

4. **4.** 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 stopped the cart.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**Question 3-7**: 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 3-8**: According to your acceleration graph, what is the acceleration at the instant the cart reaches 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 3-9**: What is different about the acceleration while the cart is going away from the motion detector and back towards it?

## Activity 3-4: Sign of Push and Stop

Find on your acceleration graphs for Activity 3-3 the time intervals when you pushed the cart to start it moving and when you stopped it.

**Question 3-10**: 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 *after release* | At highest point | Moving down |
|---|---|---|---|
| Velocity | | | |
| Acceleration | | | |

**Question 3-11**: 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?



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