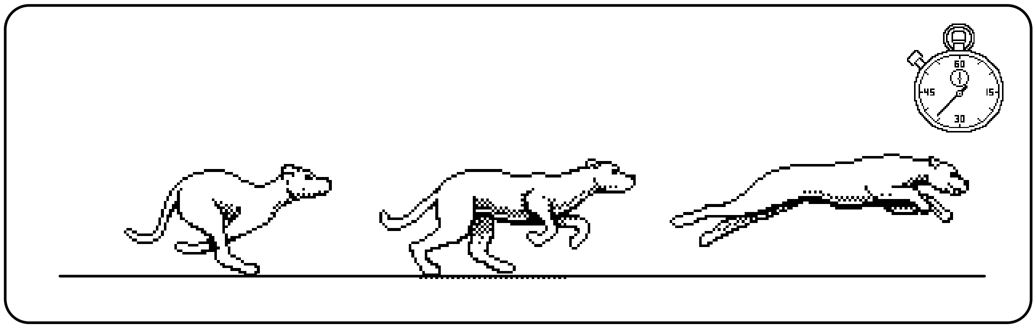
LAB 2: CHANGING MOTION



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 direction
- To discover the relationship between velocity and acceleration graphs
- To learn how to represent velocity and acceleration using vectors
- To learn how to find average acceleration from acceleration graphs
- To learn how to calculate average acceleration from velocity graphs

OVERVIEW

In the previous lab, you have looked at position-time and velocity-time graphs of the motion of your body and of a cart moving 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 better 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. When the velocity of an object is changing, it is also important to know how it is changing. The rate of change of velocity with respect to time is known as the *acceleration*.

In order to get a feeling for acceleration, it is helpful to create and learn to interpret velocity-time and acceleration-time graphs for some relatively simple motions of a cart on a smooth track or other level surface. 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 track. You will focus on cart motions with a steadily changing velocity.

You will need the following materials:

- Laptop computer with power supply
- RTP Lab 2 files
- Motion Detector
- LabPro Interface
- Track with leveling feet
- Two-way level
- Battery-operated fan cart
  To preserve the batteries, only switch on the fan when you are collecting data.

Set up the lab equipment as follows.

- Plug in the laptop computer using the provided power supply and turn it on.
- Plug in and connect the LabPro interface to the computer using the USB cable.
- Connect the Motion Detector to the DIG/SONIC 2 input using its cable. Set the switch on the motion detector to cart.
- Level your track as described by your instructor.
- Place the motion detector at one end of the track as in the picture on the following page.

Always catch the cart by hand before it reaches the end of the track and collides with the endstop or falls off! The cart should always be on a leveled track or in a lab equipment box. Never place the cart on the table! It may roll off and break!!!

Be careful of the fan blades while the cart is in operation. Hair can get caught in fan blades! Fingers can be injured!!

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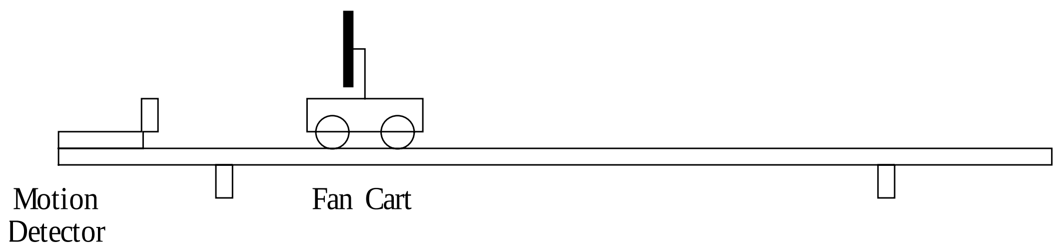
Activity 1-1: Speeding Up

In this activity you will look at velocity and acceleration graphs of the motion of a cart when its velocity is changing. 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 continuously changing velocity in this way. Instead you will use a fan or propeller driven by an electric motor to accelerate the cart.

1. Set the cart on the track, with the fan and motion detector as shown. The fan support post will need to be rotated relative to the cart to match the picture. The air flow direction should be toward the motion detector and the on/off switch should point away from the motion detector.



2. Open the experiment **L2A1-1 (Speeding Up)** to display a two graph layout with **Position** from **0** to **2.0** m, **Velocity** from **-1.0** to **1.0** m/s, and **Acceleration** from **-2.0** to **2.0** m/s^2 for a time interval of **3.0** s, as shown on the next page.

   Make sure that the detector can "see" the cart all the way to the end of the track. To do this, leave the fan off and move the cart by hand slowly to the far end while collecting data. If the detector cannot "see" the cart all the way to the end of the track, you may need to adjust the detector slightly.

3. Hold the cart about 40 cm from the detector. Press "Collect" to begin graphing. When you hear the clicks of the motion detector, switch the fan unit on **LOW** and 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. Turn off the fan.**

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

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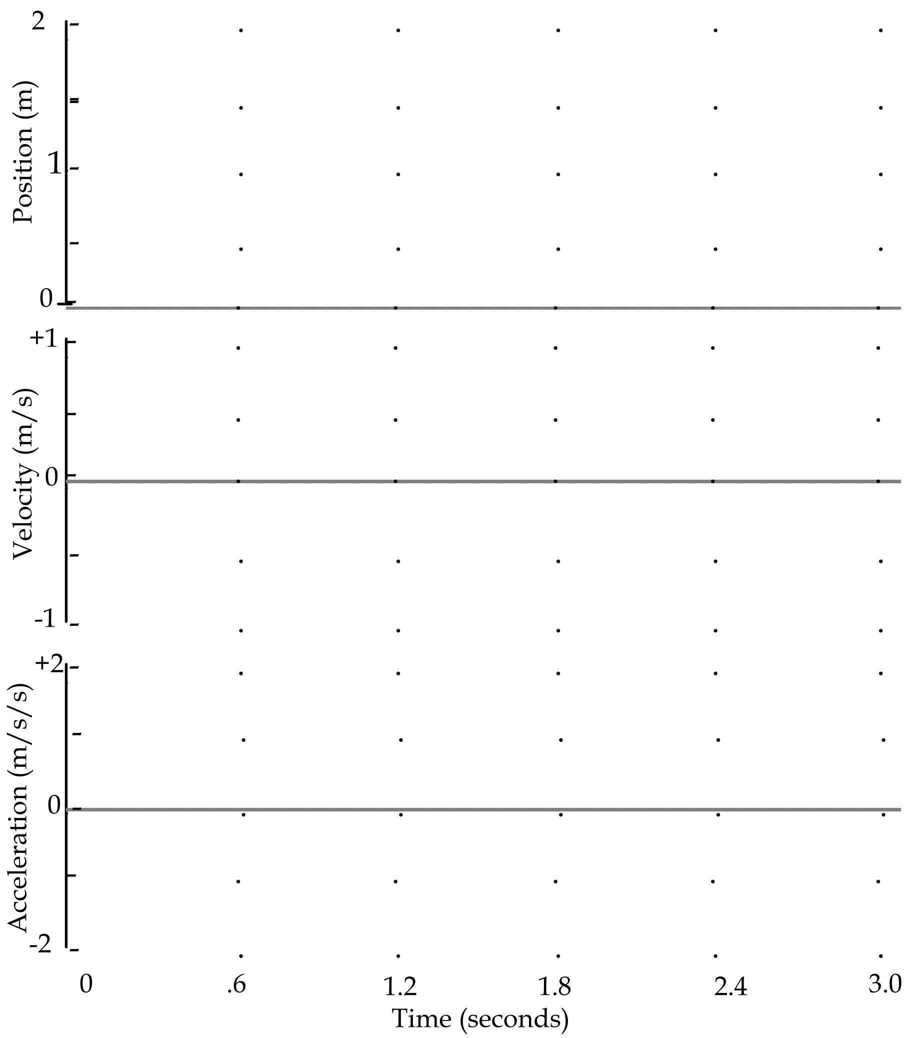
Store your data for future use by selecting “Store Latest Run” in the “Experiment” menu. This will move your data from “Latest” to “Run 1”.

Sketch your graphs *in pencil* neatly on the axes which follow. Start a legend by writing "*Speeding Up 1*" in pencil to the left of the graphs.

RESULTS for Activity 1-1 (Speeding Up 1)
PREDICTIONS and RESULTS for Activity 1-2 (Speeding Up 2)



Question 1-1: How does your position graph differ from the position graphs for steady (constant velocity) motion which you observed in Lab 1: Introduction to Motion?

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Question 1-2: What feature of your velocity graph signifies that the motion was *away* from the detector?

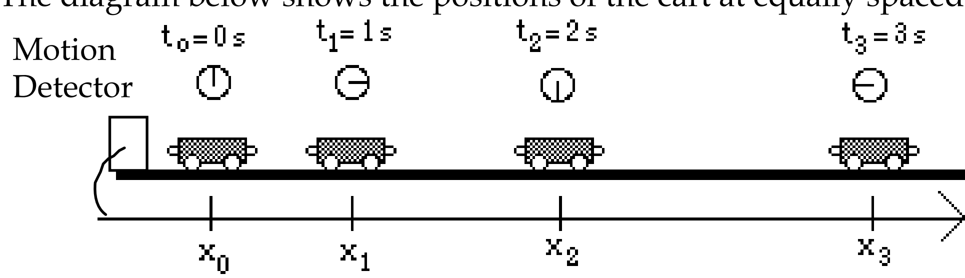
Question 1-3: What feature of your velocity graph signifies that the cart was *speeding up*? How would a graph of motion with a constant velocity differ?

Question 1-4: 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 1-5: How does the velocity vary in time as the cart speeds up? Does it increase at an *approximately* steady rate or in some other way?

Question 1-6: How does the acceleration vary in time as the cart speeds up? Is this what you expect based on the velocity graph? Explain.

Question 1-7: The diagram below shows the positions of the cart at equally spaced times.



At each indicated time, sketch a vector above the cart which might represent the velocity of the cart at that time while it is moving away from the motion detector and speeding up.

Question 1-8: Use a vector diagram to show the calculation of the change in velocity between the times 1 s and 2 s.

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Based on the direction of this vector and the direction of the positive x-axis, what is the sign of the acceleration? Does this agree with your answer to Question 1-4?

Activity 1-2 Speeding Up More

Prediction 1-1: Suppose that the cart speeds up at a greater rate. How would your graphs be different? Sketch your predictions in ink with dashed lines on the same axes as your results for "*Speeding Up 1*".

1. Test your predictions. Make position, velocity and acceleration graphs. These graphs will appear on the same axes as your "*Speeding Up 1*" graphs for comparison. This time accelerate the cart on **HIGH**. **Remember to switch the fan unit on only when collecting data.**

   Repeat if necessary to get acceptable graphs.
2. Use a colored pencil to sketch your final results on the same axes. Add "*Speeding Up 2*" to your legend.

Question 1-9: 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?

Question 1-10: How is the magnitude (size) of acceleration represented on an acceleration-time graph?

Check with your instructor to see if you should save your work at this point; you will be using these graphs in Investigation 2. Make sure to write down which computer you save the file on.

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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 which you observed in Investigation 1. 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.

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

1. You should have velocity and acceleration graphs from Investigation 1 for both speeds of the fan. If you have previously saved the data from Investigation 1, you will need to open the file.

2. Find the average acceleration of the cart from your acceleration graph. Click anywhere on the acceleration graph and select "Examine" in the "Analyze" menu. Read ten values of the acceleration for the "*Speeding Up 1*" graph, which are in the portion of the graph after the cart was released and before the cart was stopped.

Acceleration Values (m/s^2)			
1		6	
2		7	
3		8	
4		9	
5		10	

Average acceleration (mean): __________m/s^2

Comment: Average acceleration during a particular time interval is defined as the average rate of change of velocity with respect to time--the change in velocity divided by the time interval. 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.

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3. Calculate the slope of your velocity graph. Click anywhere on the velocity graph and select "Examine" in the "Analyze" menu. Read the velocity and time coordinates for two typical points on the velocity graph. (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.)

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

Calculate the change in velocity between points 1 and 2. Also calculate the corresponding time interval. Divide the change in velocity by the time interval. This is the *average* acceleration.

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

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

Question 2-2: Does the average acceleration you just calculated agree with the average acceleration you found from the acceleration graph? Do you expect them to agree? How would you account for any differences?

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Activity 2-2: Speeding Up More

Repeat the above readings and calculations to fill in the tables below for "*Speeding Up 2*".

Acceleration Values (m/s^2)			
1		6	
2		7	
3		8	
4		9	
5		10	

Average acceleration (mean): __________m/s^2

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

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

Question 2-3: For "*Speeding Up 2*" does the average acceleration calculated from velocities and times agree with the average acceleration you found from the acceleration graph? How would you account for any differences?

Question 2-4: Compare the average accelerations for "*Speeding Up 1*" and "*Speeding Up 2*". Which is larger? Is this what you expected?

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INVESTIGATION 3: SLOWING DOWN AND SPEEDING UP

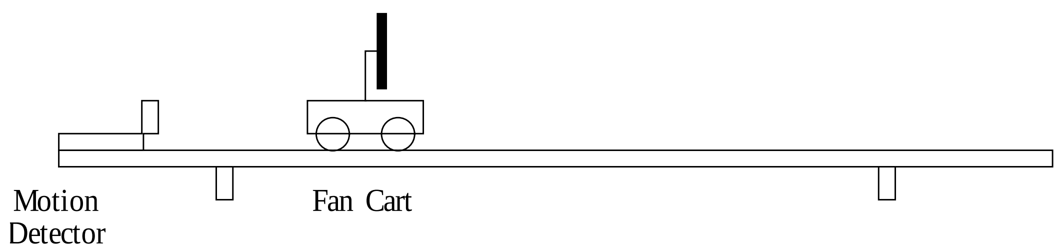
In this investigation you will look at a cart moving away from the motion detector along a level track *and slowing down*. A car driving down a road and being brought to rest by applying the brakes is a good example of this type of motion. Later you will examine the motion of the cart *toward* the motion detector and *speeding up*.

In both cases, we are interested in the shapes of the velocity-time and acceleration-time graphs, as well as the vectors representing velocity and acceleration.

Activity 3-1: Slowing Down

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

1. The cart, track, and motion detector should be set up as in Investigation 1. The fan support post will need to be rotated relative to the cart. The air flow direction should be away from the motion detector and the on/off switch should point away from the motion detector. Use **LOW SPEED**.



Now, when you give the cart a 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 push away from the motion detector and release it, will its acceleration be positive, negative or zero (after it is released)?

Using ink sketch your predictions for the velocity-time and acceleration-time graphs on the following axes.

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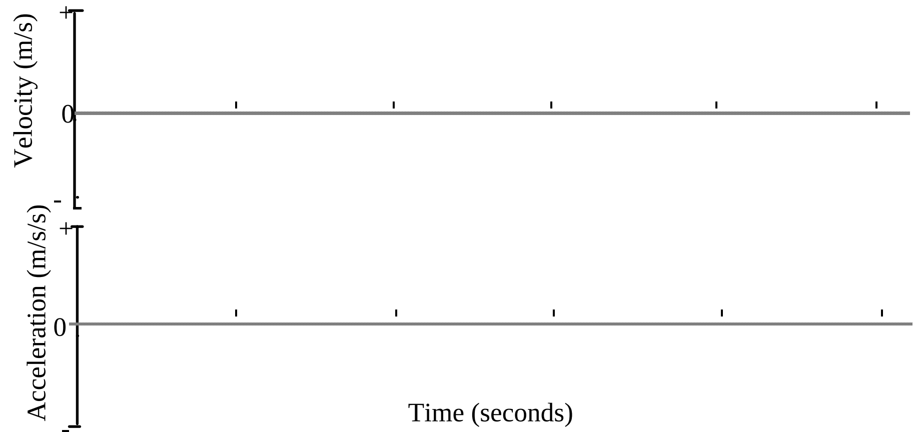
PREDICTION



2. Test your predictions. Open the experiment **L2A3-1 (Slowing Down)** to display the velocity-time and acceleration-time axes which follow.

3. Hold the cart about 40 cm from the motion detector. Click "Collect." When you begin to hear the clicks from the motion detector, turn the fan on **LOW** and give the cart a gentle push away from the detector so that it comes to a stop before reaching 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.**

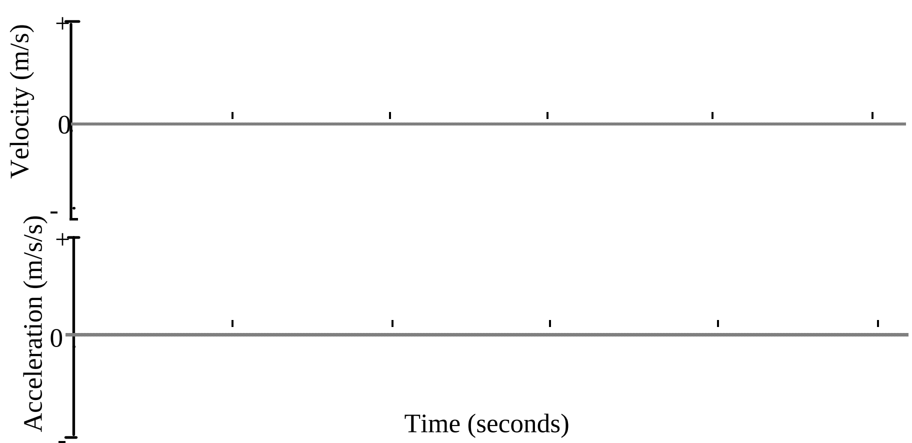
   You may have to try a few times to get a good run.

   Store your data for later comparison by selecting "Store Latest Run" from the "Experiment" menu.

4. Neatly sketch your results on the following axes**.**

   Label your graphs with—
   - "A" when you started pushing the cart.
   - "B" when you stopped pushing the cart.
   - "C" when the cart stopped.

FINAL RESULTS



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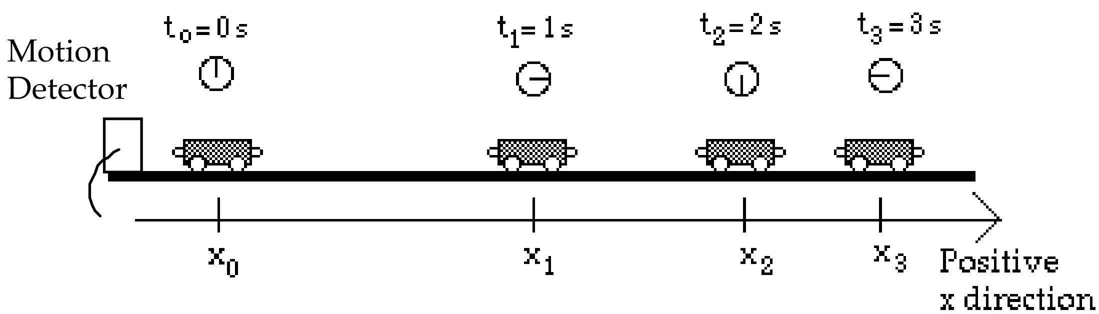
Question 3-1: Did the shapes of your velocity and acceleration graphs agree with your predictions? How can you tell the sign of the acceleration from a velocity-time graph?

Question 3-2: How can you tell the sign of the acceleration from an acceleration-time graph?

Question 3-3: Is the sign of the acceleration 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 3-4: The diagram below shows the positions of the cart at equally spaced times. At each indicated time, sketch a vector above the cart which might represent the velocity of the cart at that time while it is moving away from the motion detector and slowing down.



Question 3-5: Use a vector diagram to show the calculation of the change in velocity between the times 1 s and 2 s.

Based on the direction of this vector and the direction of the positive x axis, what is the sign of the acceleration? Does this agree with your answer to Question 3-3?

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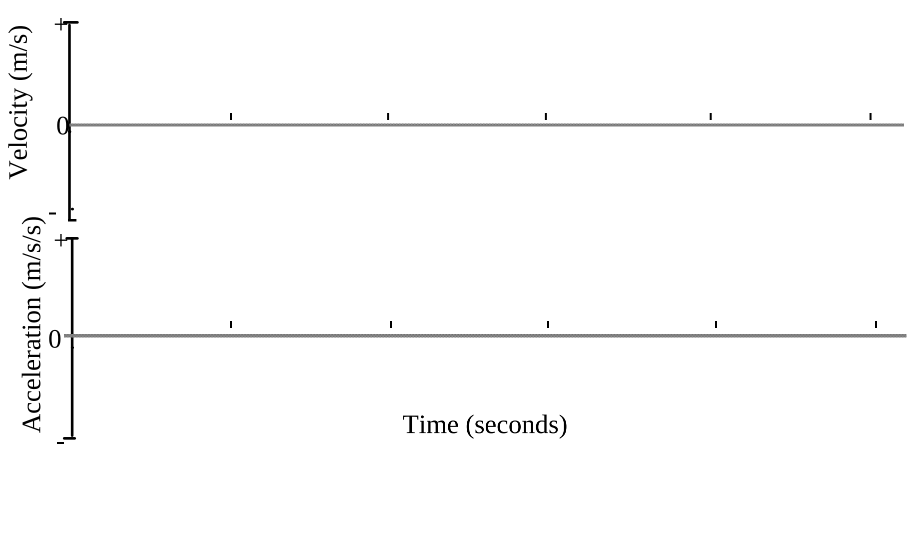
Question 3-6: Based on your observations in this activity and in Investigation 1, state a general rule to predict the sign and direction of the acceleration if you know the sign of the velocity (i.e. the direction of motion) and whether the object is speeding up or slowing down.

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 track, and let the fan push it *towards* the motion detector. As the cart moves toward the detector and speeds up, predict the direction of the acceleration. Will the acceleration be positive or negative? (Use your general rule from Question 3-6.)

Using ink sketch your predictions for the velocity-time and acceleration-time graphs on the axes which follow.

PREDICTION



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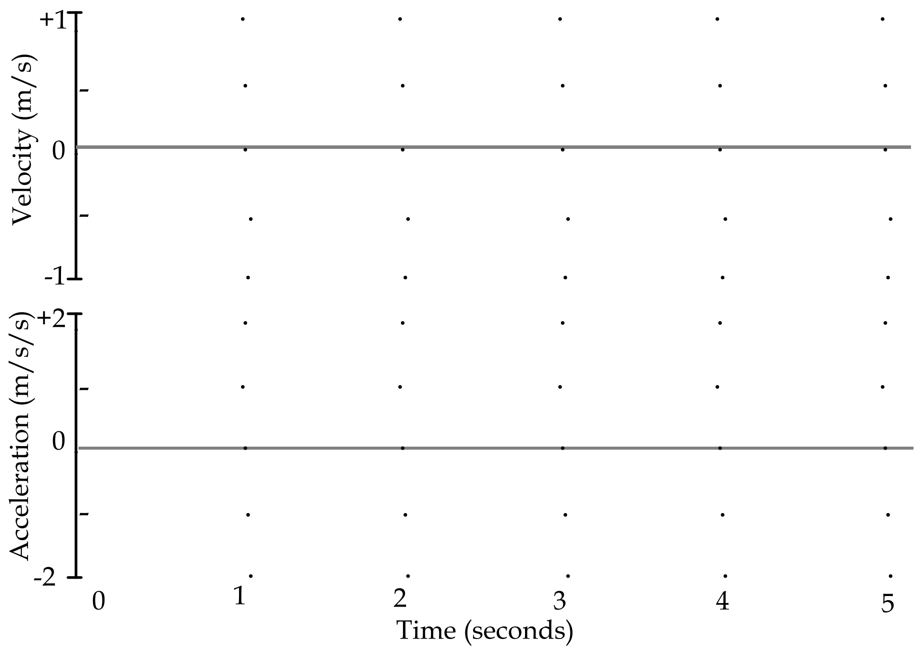
1. Test your predictions**.** Graph the cart moving *towards* the detector and *speeding up*. Hold the cart near the far end of the track. Click "Collect." When you begin to hear the clicks from the motion detector, turn the fan on **LOW** and release the cart from rest. **(Be sure that your hand is not between the cart and the detector.) Stop the cart when it's about 50 cm from the detector and turn the fan unit off immediately. DO NOT LET THE CART CRASH INTO THE DETECTOR.**
2. Sketch these graphs on the velocity and acceleration following. Label these graphs as "*Speeding Up Moving Toward*."

FINAL RESULTS



Question 3-7: How does your velocity graph show that the cart was moving *toward* the detector?

Question 3-8: Compare your velocity graphs for slowing down while moving away from the motion detector (Activity 3-1) and speeding up while moving toward the motion detector (Activity 3-2).

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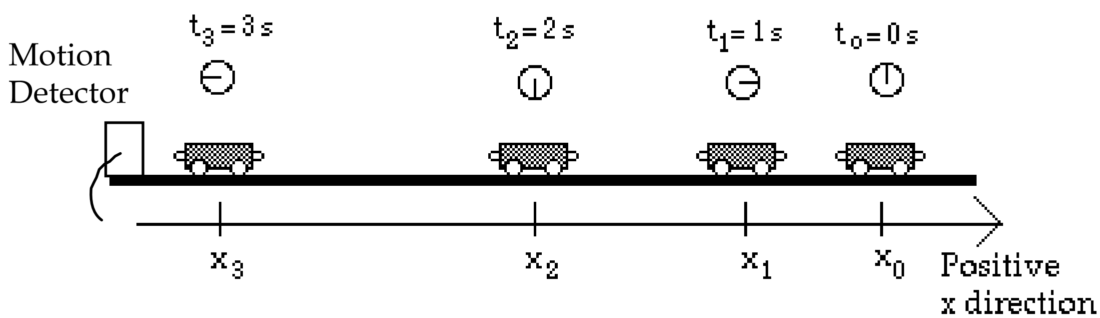
Question 3-9: During the time that the cart was speeding up, is the acceleration positive or negative? Does this agree with your prediction? Explain how *speeding up* while moving *toward* the detector results in this sign of acceleration. Hint: Look at how the velocity is changing.

Question 3-10: Compare your acceleration graphs for slowing down while moving away from the motion detector (Activity 3-1) and speeding up while moving toward the motion detector (Activity 3-2).

Question 3-11: The diagram below shows the positions of the cart at equally spaced times. At each indicated time, sketch a vector above the cart which might represent the velocity of the cart at that time while it is moving toward the motion detector and speeding up.



Question 3-12: Use a vector diagram to show the calculation of the change in velocity between the times 1 s and 2 s.

Based on the direction of this vector and the direction of the positive x axis, what is the sign of the acceleration? Does this agree with your answer to Question 3-9?

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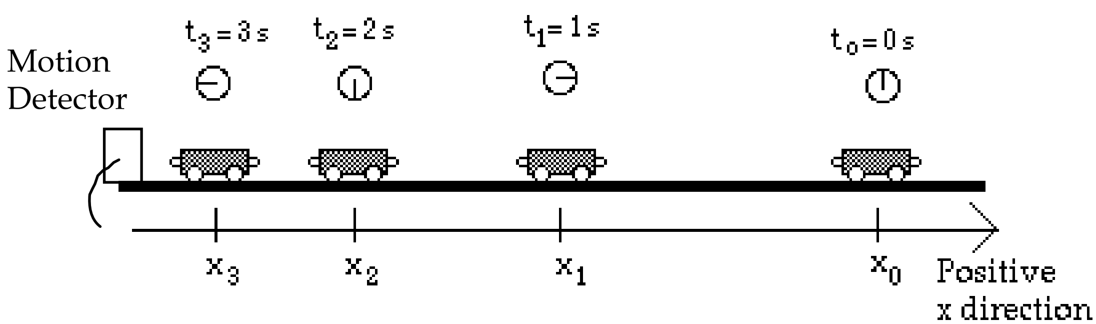
Question 3-13: Was your general rule in Question 3-6 correct? If not, modify it and restate it here.

Question 3-14: There is one more possible combination of velocity and acceleration for the cart, moving *toward* the detector and *slowing down*. Use your general rule to predict the direction and sign of the acceleration in this case. 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.

Question 3-15: The diagram below shows the positions of the cart at equally spaced times for the motion described in Question 3-14. At each indicated time, sketch a vector above the cart which might represent the velocity of the cart at that time while it is moving toward the motion detector and slowing down.



Question 3-16: Use a vector diagram to show the calculation of the change in velocity between the times 1 s and 2 s.

Based on the direction of this vector and the direction of the positive x axis, what is the sign of the acceleration? Does this agree with your answer to Question 3-14?

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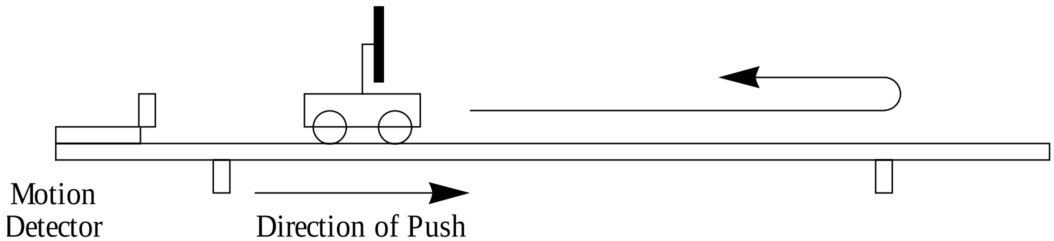
Activity 3-3: Reversing Direction

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 is its velocity changing? What is its acceleration?

The setup should be as shown below--the same as Activity 3-1. The fan should be on **LOW**.



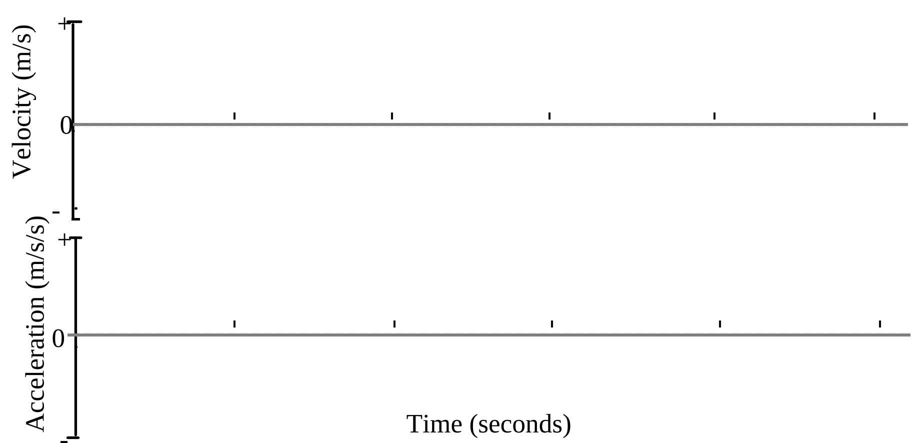
Prediction 3-3: You start the fan, and give the cart a push *away* from the motion detector. It moves away, slows down, reverses direction and then moves back toward the detector. Try it without using the motion detector! **Be sure to stop the cart before it hits the motion detector, and turn the fan off immediately.**

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 is positive, zero or negative. Also indicate whether the acceleration is positive, zero or negative.

	Moving Away	At the Turning Point	Moving Toward
Velocity			
Acceleration			

Using ink sketch your predictions of the velocity-time and acceleration-time graphs of this entire motion.

PREDICTION



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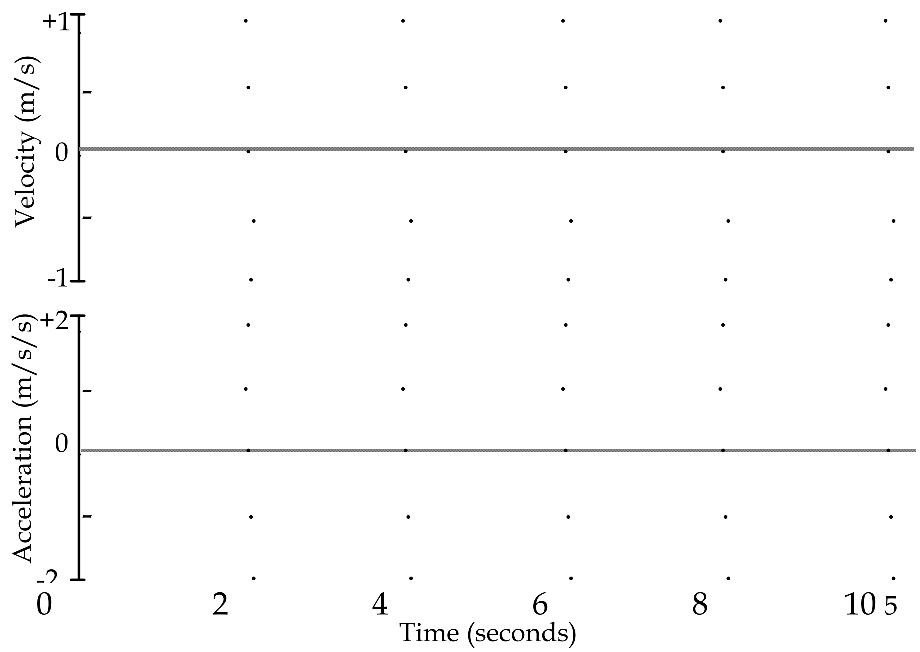
1. Test your predictions. Open the experiment **L2A3-3 (Reversing Direction)**.
2. Hold the cart about 40 cm from the motion detector. Click “Collect”. When you begin to hear the clicks from the motion detector, turn the fan on **LOW** and give the cart a gentle push away from the detector so that it travels about one meter, slows down, and then reverses its direction and moves toward the detector. (Be sure that your hand is not between the cart and the detector.)

   Stop the cart when it’s about 50 cm from the motion detector. Keep it from hitting the motion detector and turn off the fan unit immediately.

   You may have to try a few times to get a good round trip.

2. When you get a good round trip, sketch both graphs on the following axes.

FINAL RESULTS



Question 3-17: Label *both* graphs with—

- "A" when you started pushing the cart.
- "B" when you stopped pushing the cart.
- "C" when the cart reached its turning point.
- "D" when you stopped the cart.

Explain how you know where each of these points is. (Use space on the next page.)

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Question 3-18: Did the cart stop? (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 zero velocity before it started back toward the detector? Explain.

Question 3-19: According to your acceleration graph is the acceleration positive, negative, or zero at the instant the cart reaches its turning point? Is it any different from the acceleration during the rest of the motion? Does this agree with your prediction?

Question 3-20: Explain the observed sign of the acceleration of the cart at the turning point. (Hint: Remember that acceleration is the *rate of change* of velocity. Just after reaching its turning point, will its velocity become positive or negative?)

Question 3-21: What is the sign of the acceleration for the interval while you were pushing the cart (between points "A" and "B")? Explain why the acceleration has this sign.

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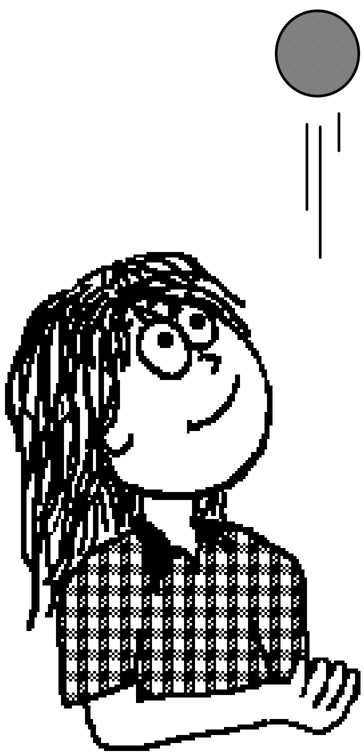
Question 3-22: What is the sign of the acceleration for the interval while you were stopping the cart (slowing it to rest)? Explain why the acceleration has this sign.

Question 3-23: On the way back toward the detector, is there any difference between these velocity and acceleration graphs and the graphs from Activity 3-2? Explain.



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 is positive, zero or negative during each of the three parts of the motion. Also indicate if the acceleration is positive, zero or negative. Hint: Remember that to find the acceleration, you must look at the *change in* velocity.

	Moving Up--after release	At Highest Point	Moving Down
Velocity			
Acceleration			

Question 3-24: In what ways is the motion of the ball similar to the motion of the cart which you just observed?

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