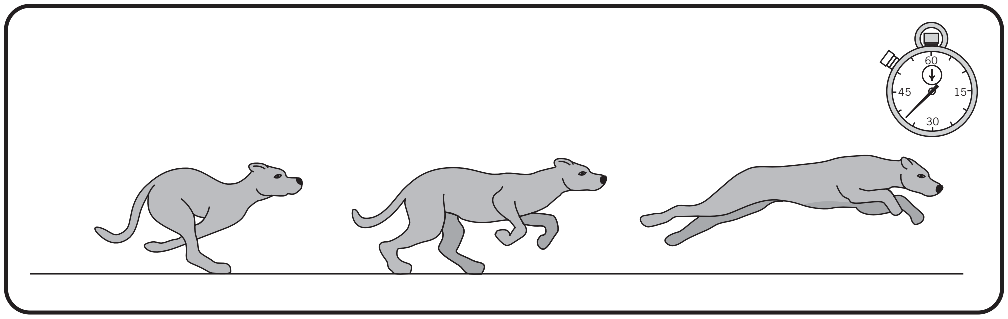
RealTime Physics

Active Learning Laboratories

Module 1

Mechanics



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

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Contents

Name________________________ Date________________

Pre-Lab Preparation Sheet for Lab 2: Changing Motion

(Due at the beginning of Lab 2)

Directions:
Read over Lab 2 and then answer the following questions about the procedures.

1. In Activity 1-1, how do you expect that your position–time graph will differ from those you observed in Lab 1, where you were moving with a constant velocity?

2. Show how you would add the two vectors shown below:

3. Show below how you would subtract the second vector from the first.

4. In words, write down definitions for average velocity and instantaneous velocity.

5. What do you predict the direction (sign) of acceleration will be for the experiment in Activity 3-2: Speeding Up Toward the Motion Detector?

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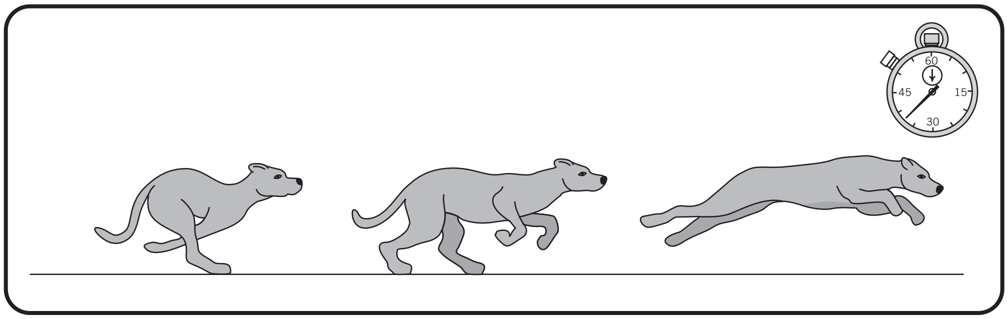
Name________________________________ Date______________ Partners_________________________________

Lab 2: Changing Motion



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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 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 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 some relatively simple motions of a cart on a smooth ramp 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.

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 ramp or other level surface. You will focus on cart motions with a steadily increasing velocity.

You will need the following materials:

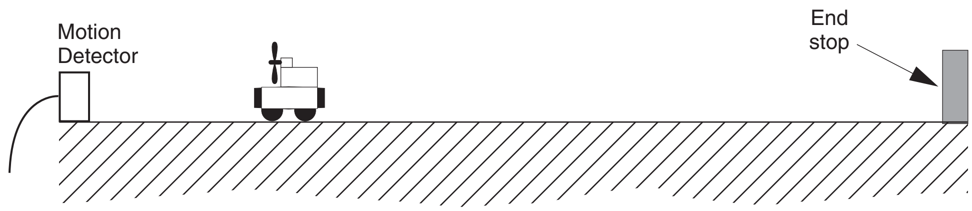
- computer-based laboratory system
- motion detector
- *RealTime Physics Mechanics* experiment configuration files
- cart with very little friction
- smooth ramp or other level surface 1.2–2.5 m long
- fan unit attachment with batteries and dummy cells (or with a speed adjustment control)

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. Set up the cart on the ramp, with the fan unit and motion detector as shown below. Attach 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.)*
2. If the cart has a friction pad, move it out of contact with the ramp so that the cart can move freely.



3. Open the experiment file called **Speeding Up (L02A1-1)** to display the axes that follow.
4. 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 slightly.
5. Make sure the switch is off, then place half batteries and half dummy cells in the battery compartment of the fan unit (or use all batteries, and set the dial

at about half maximum speed of the fan blade). *To preserve the batteries, switch on the fan unit only when you are making measurements.*

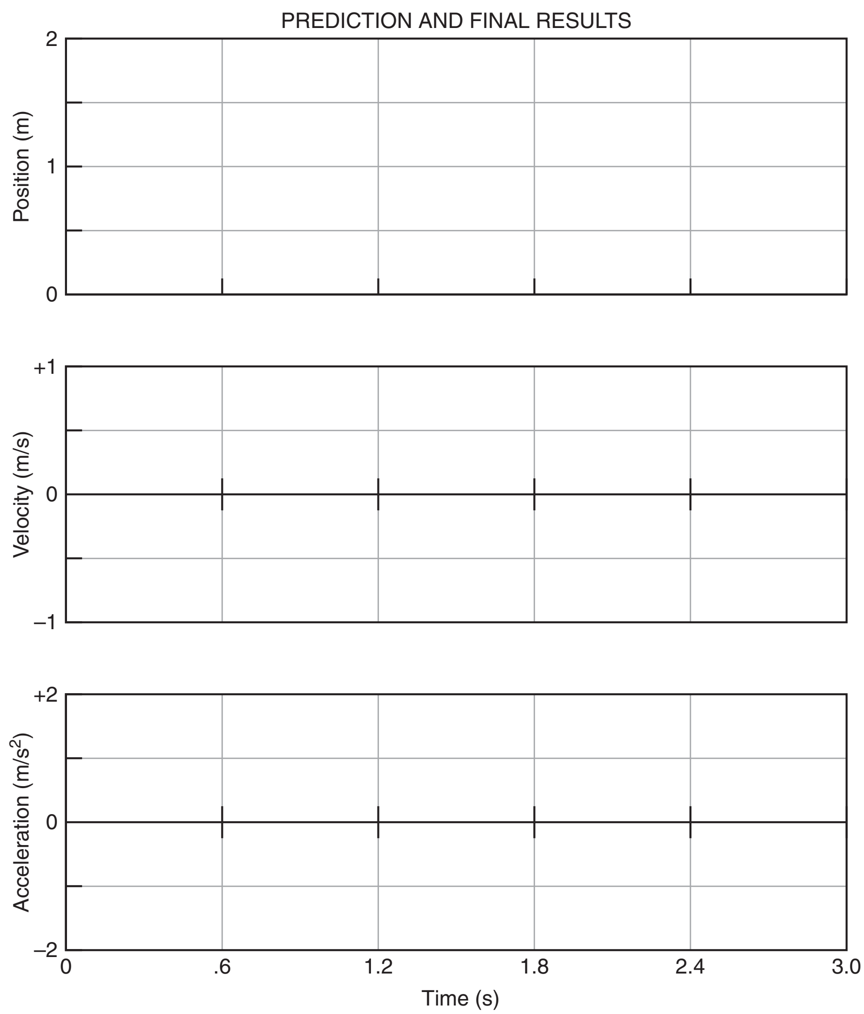
6. Hold the cart with your hand on its side at least the minimum specified distance from the motion detector. **Begin graphing,** switch the fan unit on and when you hear the clicks of the motion detector, release the cart from rest. *Do not put your hand between the cart and the detector. Be sure to stop the cart before it hits the end stop. 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. Use the features of your software to transfer your data so that the graphs will remain **persistently displayed on the screen.**

   Also **save your data** for analysis in Investigation 2. (Name your file **SPEEDUP1.XXX,** where **XXX** are your initials.)

7. Sketch your position and velocity graphs neatly on the axes that follow. Label the graphs *"Speeding Up 1."* (Ignore the acceleration axes for now.)



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

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

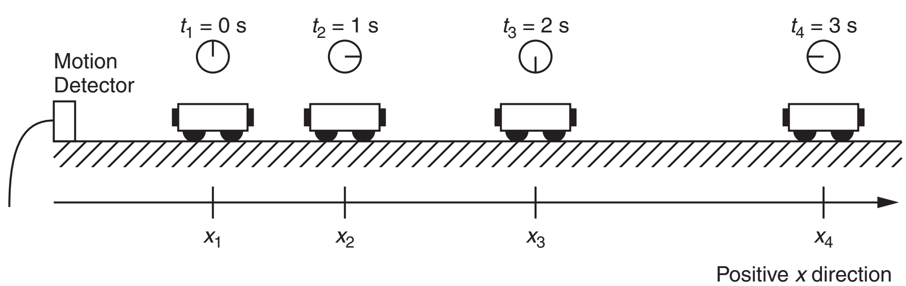
8. Adjust the acceleration scale so that your graph fills the axes. Sketch your graph on the acceleration axes above, and label it *"Speeding Up 1."*

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. It takes two points on the velocity–time graph to calculate the rate of change of velocity.)

Question 1-5: How does the velocity vary in time as the cart speeds up? Does it increase at a steady (constant) 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 a cart at equal time intervals as it speeds up. Assume that the cart is already moving at t_1.



At each indicated time, sketch a vector above the cart that 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: Show below how you would find the vector representing the change in velocity between the times 2 and 3 s in the diagram above. (**Hint:** Remember that the change in velocity is the final velocity minus the initial velocity, and the vector difference is the same as the sum of one vector and the negative of the other vector.)

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? 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 previous set of axes.

1. Test your predictions. Make velocity and acceleration graphs, beginning at least the minimum specified distance away from the motion detector. This time accelerate the cart with the maximum number of batteries in the battery compartment (or set the dial to the maximum speed of the fan blade). *Remember to switch the fan unit on only when making measurements.*

   Repeat if necessary to get nice graphs. (Leave the original graphs **persistently displayed on the screen.**) When you get a nice set of graphs, **save your data** as **SPEEDUP2.XXX** for analysis in Investigation 2.

2. Sketch your velocity and acceleration graphs with solid or different color lines on the previous set of axes, or **print** the graphs and affix them over the axes. Be sure that the graphs are labeled *"Speeding Up 1"* and *"Speeding Up 2."*

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?

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.

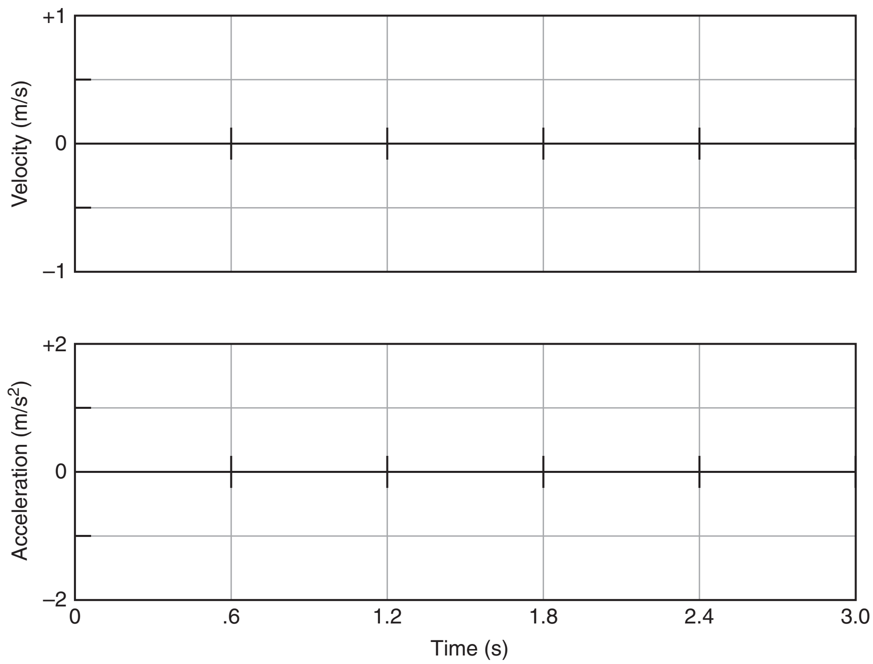
You will need the computer-based laboratory system and the data files you saved from Investigation 1.

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

1. The data for the cart accelerated along the ramp with half batteries and half dummy cells (Investigation 1, Activity 1-1) should still be **persistently on the screen.** (If not, **load the data** from the file **SPEEDUP1.XXX.**)

   Display velocity and acceleration, and **adjust the axes** if necessary.

2. Sketch the velocity and acceleration graphs again below, or **print,** and affix a copy of the graphs. Correct the scales if necessary.



3. Find the average acceleration of the cart from your acceleration graph. Use the **analysis feature** in the software to read a number of values (say 10) of the acceleration, which are equally spaced in time. (Only use values from 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 (mean) acceleration: ______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 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.

4. Calculate the slope of your velocity graph. Use the **analysis feature** of your software to 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 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?

Question 2-2: Does the average acceleration you just calculated agree with the average acceleration you found from the acceleration graph in (3)? Do you expect them to agree? How would you account for any differences?

Activity 2-2: Speeding Up More

1. **Load the data** from your file **SPEEDUP2.XXX** (Investigation 1, Activity 1-2). **Display velocity and acceleration.**
2. Sketch the velocity and acceleration graphs or **print** and affix the graphs. Use dashed lines on the previous set of axes.
3. Use the **analysis feature** of the software to read acceleration values, and find the average acceleration of the cart from your acceleration graph.

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

Average (mean) acceleration: ______m/s^2

4. Calculate the average acceleration from your velocity graph. Remember to use two points as far apart in time as possible, but still having typical values.

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

Calculate the *average* acceleration.

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

Question 2-3: Does the average acceleration calculated from velocities and times agree with the average acceleration you found from the acceleration graph in (3)? How would you account for any differences?

Question 2-4: Compare this average acceleration to that with half batteries and half dummy cells (Activity 2-1). Which is larger? Is this what you expected?

If you have additional time, do the following Extension.

Extension 2-3: Using Statistics and Fit to Find the Average Acceleration

In Activities 2-1 and 2-2, you found the value of the average acceleration for a motion with steadily increasing velocity in two ways: from the average of a number of values on an acceleration–time graph and 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 Activities 2-1 and 2-2. The equation of this line includes a value for the slope.

1. *Using **Statistics:*** **Load** your **SPEEDUP1.XXX** file. You must first **select the portion** of the acceleration–time graph for which you want to find the mean value.

   Next, use the **statistics feature** and read the mean value of acceleration from the table: ______m/s^2

Question E2-5: Compare this value to the one you found from 10 measurements in Activity 2-1.

2. *Using **Fit:*** You must first **select the portion** of the velocity–time graph that you want to fit.

   Next, use the **fit routine** to try a linear fit, $v = b + mt$.