PHYSICS 100 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 automobile 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 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

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 this investigation you will be asked to predict and observe
the shapes of velocity-time and acceleration-time graphs of a
cart (or toy car) moving along a smooth ramp which is slightly
tilted. You will focus on cart motions with a steadily increasing
velocity.

**Activity 1-1: Speeding Up**

1. Set up the cart on the ramp, with the ramp tilted by placing a
small block under the end nearest 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 and **Velocity**
from -1.0 to 1.0 m/sec for a time interval of 3.0 sec, as shown
on the next page.

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.
3. Hold the cart, press Collect, 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.**

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

Change the position and velocity scales if necessary so that the graphs fill the axes. Store the data by selecting **Store Latest Run** under **Experiment**. Then click on **Data-> Data Set Options->Run1** to change the name of the data set to **SpeedUp1_xxx** where xxx is your initials. Each person in this group should have their own data set. Hide your saved data set by selecting your data set under **Data->Hide Data Sets** before your partner repeats the same experiment. This way your and your partner’s graphs will not overlap.

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

**PREDICTION AND FINAL RESULTS**
**Question 1-1:** What feature of your velocity graph signifies that the motion was *away* from the 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?

4. Change the **Position** display to **Acceleration** by clicking on the Position axis and scrolling to Acceleration. 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.

**Question 1-5:** How does the velocity vary in time as the cart speeds up? Does it increase at a 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 equal time intervals.
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:** Show below how you would find the vector representing the change in velocity between the times 1 sec and 2 sec 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?

---

**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 axes on page 2-3.

1. Test your predictions. Make velocity and acceleration graphs. This time tilt the track a little more.
   Repeat if necessary to get nice graphs. When you get a nice set of data, save it as SpeedUp2_xxx.
2. Sketch your velocity and acceleration graphs with solid or different color lines on the axes on page 2-3, 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?
In this investigation you will examine more quantitatively the motion of an accelerating cart. 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 Logger Pro software and the data sets you saved from Investigation 1.

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

1. Show the data for the cart accelerated along the ramp with the least tilt (Investigation 1, Activity 1-1) by selecting Data->Show Data Set->SpeedUp1_xxx. Make sure you select your OWN data set. Display velocity and acceleration, and adjust the axes if necessary.

2. Find the average acceleration of the cart from your acceleration graph. Click on Page 1 icon near the top left corner and select Page 2. Record a number of values (say ten) of acceleration (from your OWN data set), which are equally spaced. (Only use values from the portion of the graph after the cart was released and before the cart was stopped.)

<table>
<thead>
<tr>
<th>Acceleration Values (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

Average acceleration (mean): ________ m/s²

Comment: Average acceleration during a particular time period 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.

3. Calculate the slope of your velocity graph. From the same table read the velocity and time values for two typical points. (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.)

<table>
<thead>
<tr>
<th></th>
<th>Velocity (m/s)</th>
<th>Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Speeding Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in velocity (m/s)</td>
</tr>
<tr>
<td>Time interval (sec)</td>
</tr>
<tr>
<td>Average acceleration (m/s²)</td>
</tr>
</tbody>
</table>

**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? Do you expect them to agree? How would you account for any differences?

**Activity 2-2: Speeding Up More**

1. Show the data for the cart accelerated along the ramp with more tilt (Investigation 1, Activity 1-2) from your SpeedUp2_xxx data set. Display velocity and acceleration.
2. Read acceleration values from the table, and find the average acceleration of the cart from your acceleration graph.

<table>
<thead>
<tr>
<th>Acceleration Values (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
</tbody>
</table>
Average acceleration (mean): __________ m/s²

3. Calculate the average acceleration from your velocity graph. Remember to use two points as far apart in time as possible.

<table>
<thead>
<tr>
<th></th>
<th>Velocity (m/s)</th>
<th>Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Calculate the average acceleration.

**Speeding Up More**

<table>
<thead>
<tr>
<th>Change in velocity (m/s)</th>
<th>Time interval (sec)</th>
<th>Average acceleration (m/s²)</th>
</tr>
</thead>
</table>

**Question 2-3:** 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 this average acceleration to that with less tilt (Activity 2-1). Which is larger? Is this what you expected?
INVESTIGATION 3: SLOWING DOWN AND SPEEDING UP

In this investigation you will look at a cart (or toy car) moving along a ramp or other level surface 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, ramp, and motion detector should be set up as in Investigation 1 except tilted the other way.

Now, when you give the cart a push away from the motion detector, 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 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. Test your predictions. Open the experiment L2A3-1 (Slowing Down) to display the velocity-time and acceleration-time axes shown below.
3. Graph velocity first. Collect with the back of the cart near the 0.50 meter mark. 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.

You may have to try a few times to get a good run. Don't forget to change the scales if this will make your graphs easier to read.

Store the data set as SlowingDown1.xxx.

4. Neatly sketch your results on the axes above or print the
graphs and affix them over the axes.

Label your graphs with—

- "A" at the spot where you started pushing.
- "B" at the spot where you stopped pushing.
- "C" at the spot where the cart stopped moving.

Also sketch on the same axes the velocity and acceleration graphs for *Speeding Up* 2 from Activity 1-2.

**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 equal time intervals. (This is like overlaying snapshots of the cart at equal time intervals.) 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.

---

©1993-94 P. Laws, D. Sokoloff, R. Thornton

Supported by National Science Foundation and U.S. Department of Education (FIPSE)
Question 3-5: Show below how you would find the vector representing the change in velocity between the times 1 sec and 2 sec in the diagram above. (Remember that the change in velocity is the final velocity minus the initial velocity.)

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?

Question 3-6: Based on your observations in this activity and in the last lab, 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 ramp, and let it speed up 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.)

Sketch your predictions for the velocity-time and acceleration-time graphs on the axes which follow.

1. Test your predictions. First clear any previous graphs. Graph the cart moving towards the detector and speeding up. Graph velocity first. 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 meter line.

2. Sketch these graphs on the velocity and acceleration axes below. Label these graphs as "Speeding Up Moving Toward."

**FINAL RESULTS**

<table>
<thead>
<tr>
<th>Velocity (m/s)</th>
<th>0</th>
<th>-1</th>
<th>-</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration (m/s/s)</td>
<td>0</td>
<td>-2</td>
<td>-1</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

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

**Question 3-8:** 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 3-9:** The diagram below shows the positions of the cart at equal time intervals. 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 3-10: In the space below, show how you would find the vector representing the change in velocity between the times 1 sec and 2 sec in the diagram above. 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 3-8?
Question 3-11: Was your general rule in Question 3-6 correct? If not, modify it and restate it here.

Question 3-12: 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 3-13: The diagram below shows the positions of the cart at equal time intervals for the motion described in Question 3-12. 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 3-14: In the space below, show how you would find the vector representing the change in velocity between the times 1 sec and 2 sec in the diagram above. 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 3-12?

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 before.
Prediction 3-3: 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.**

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.

<table>
<thead>
<tr>
<th></th>
<th>Moving Away</th>
<th>At the Turning Point</th>
<th>Moving Toward</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acceleration</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sketch on the axes which follow your predictions of the velocity-time and acceleration-time graphs of this entire motion.
1. Test your predictions. Set up to graph velocity and acceleration on the following graph axes. (Open the experiment L2A3-1 (Slowing Down) if it is not already opened.)

**FINAL RESULTS**

```
+1
-1
0

Velocity (m/s)

+2
-2
0

Acceleration (m/s²)

0 1 2 3 4 5
Time (seconds)
```

2. Start with the back of the cart near the 0.5 meter mark. 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 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.)

**Be sure to stop the cart by the 0.5 meter line, keep it from hitting the motion detector.**

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

**Question 3-15:** Label both graphs 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.

Explain how you know where each of these points is.
Question 3-16: 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 3-17: 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 any different from the acceleration during the rest of the motion? Does this agree with your prediction?

Question 3-18: Explain the observed sign of the acceleration at the turning point. (Hint: remember that acceleration is the rate of change of velocity. When the cart is at its turning point, what will its velocity be in the next instant? Will it be positive or negative?)

Question 3-19: On the way back toward the detector, is there any difference between these velocity and acceleration graphs and the ones in Data B which were the result of the cart rolling back from rest (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.

<table>
<thead>
<tr>
<th></th>
<th>Moving Up--after release</th>
<th>At Highest Point</th>
<th>Moving Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acceleration</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Question 3-20: In what ways is the motion of the ball similar to the motion of the cart which you just observed?