PRELAB: CHANGES IN MOTION

1. In Activity 1-1, how do you expect that your position-time graphs will differ from those for an object moving with a constant velocity?

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

\[ \vec{A} + \vec{B} \]

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

\[ \vec{A} - \vec{B} \]

4. In your own words, write a definition for average velocity:

5. What do you predict the direction (sign) of acceleration will be for the experiment in Activity 3-2? Explain your reasoning.
CHANGES IN MOTION

**Topic:** Accelerated motion in 1D

**Objectives:**
- To understand the meaning of acceleration, its magnitude and direction (for the case of an object traveling along a straight line)
- To discover the relationship between velocity and acceleration graphs
- To discover the relationship between velocity and acceleration vectors
- To learn how to find average acceleration from acceleration graphs and velocity graphs

**Overview:**
When the velocity of an object is changing, it is important to describe how the velocity is changing. The rate of change of velocity with respect to time is called acceleration. To get a feeling for acceleration, it is helpful to create and interpret velocity-time and acceleration-time graphs for some relatively simple motions of a fan-powered cart on a smooth ramp. (The fan accessory is used to produce a smoothly changing velocity).

The main educational aim of the first two parts of this lab is to improve your conceptual understanding of motion. In the last part, you will learn how to use data to support a claim.

**Safety/Equipment Notes:**
- **Be careful with the fan cart and fan blade!**
- **Do not allow the fan cart to run off the end of the track!** Avoid damage to the equipment. Before you start each run, make sure someone is ready to stop the cart at the far end of the track. If the cart accidentally runs off the end of the track, turn the fan motor off before attempting to move the fan accessory or fan cart.
- **Preserve batteries. Turn the fan off immediately after each run.** The fan motor will drain four batteries in about 2 hours of run time.
- **The motion detector detects the object closest to it.** Make sure the fan accessory doesn’t hang off the end of the cart. (Otherwise the detector picks up the motion of the fan blades). Make sure your hand is not between cart and detector, especially when releasing the cart.

**Writing it up:**
In this handout, you will be asked to perform calculations, analyze graphs and answer questions. It is strongly recommended that you do all the calculations and answer all the questions as you go through the experiment. This record is for your purposes only. You will not be graded on it. You will be graded on how well you understand the material covered in this lab, so you should do the entire activity, discuss the questions with your partners and take careful notes.
Investigation 1: Velocity and acceleration

In this investigation, you will examine the relationship between velocity and acceleration graphs. You will also explore the relationship between velocity and acceleration vectors.

Activity 1-1: Speeding up

1. Set up the cart on the ramp with the fan unit and motion detector as shown below. Make sure the track is level. Make sure 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).

![Diagram of setup](image)

2. Start the software. Set up the motion detector to record position, velocity and acceleration data at 50 Hz. Use the software to set up axes for position-time, velocity-time and acceleration-time. Put all the graphs in the same display window so that the time axes of all three graphs are aligned (like the ones shown on the next page).

3. Make sure the fan is turned off. Put two batteries and two dummy cells in the battery compartment of the fan unit. *To preserve the batteries, only run the fan unit while you are making measurements.*

4. Place the cart with the fan near the motion detector, begin taking data, and when you hear the clicks of the motion detector, start the fan and release the cart. *Do not put your hand between the motion detector and the cart. (Remember that the motion detector “sees” the object closest to it). Make sure you stop the cart before it reaches the end of the track.*

5. Repeat, if necessary, until you get a good set of graphs. Adjust the position and velocity axes so that the data fill the axes.

6. **Save your data** for analysis later in this lab. (Name the file SPEEDUP1.XXX, where XXX are your initials).
7. Sketch your position-time and velocity-time graphs below. (Ignore acceleration for now).

Q1-1: How does the position-time graph differ from the position graphs for constant velocity?

Q1-2: Which feature of the velocity graph signifies that the cart was moving *away* from the detector?

Q1-3: Which feature of the velocity graph signifies that the cart was *speeding up*? How would a graph of motion with constant velocity differ?

8. Sketch your acceleration graph on the axes above.

Q1-4: 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?
Q1-5: How does the velocity vary with time as the cart speeds up? Does it increase at a steady (constant) rate, or in some other way? Explain how you can tell.

Q1-6: How does the acceleration of the cart vary in time as the cart speeds up? Is this what you would expect based on the velocity graph?

Q1-7: The diagram below shows the position of a cart at equal time intervals as it speeds up. (This is like overlaying snapshots of a cart at equal time intervals). At each indicated time, draw a vector above the cart that might represent the velocity of the cart at that time. (This type of diagram will be called a velocity diagram in this lab).

Q1-8: Show below how you would find the vector representing the difference in velocity between the times 1 s and 2 s in the diagram. 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 Q1-4?

Activity 1-2: Speeding up more quickly

Prediction 1-1: Suppose you accelerate the cart at a faster rate. How would the velocity and time graphs look 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. This time accelerate the cart with the maximum number of batteries in the battery compartment.

2. Repeat if necessary to get nice graphs. (Leave the graphs from Activity 1-1 persistently displayed on the screen.) When you get a nice set of data, save your data as SPEEDUP2.XXX for analysis in Investigation 2.

Q1-9: Did the shapes of your velocity and acceleration graphs agree with your predictions? How is the magnitude of the acceleration represented on a velocity-time graph?

Q1-10: How is the magnitude 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 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 (Activity 1-1) should still be persistently displayed 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 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. Calculate the average of these acceleration values using the statistics feature in the software. Record your value of acceleration below.

   \[ a = \underline{\text{______________}} \quad \text{(Don’t forget the units)} \]

   Q2-1: Record the steps you performed to find this value for acceleration.
4. Calculate the slope of your velocity graph using your calculator. Use the analysis feature to read the time and velocity coordinates for two typical points on the velocity graph. (For a more accurate answer, use two points that are as far apart in time as possible but still during the time the cart was speeding up). Record the values in the chart below.

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

The average acceleration is the change in velocity divided by the time interval. Calculate the value of acceleration. Show your calculation below:

\[ a = \frac{Q_2 - Q_1}{t} \]

Q2-2: Is the acceleration positive or negative? Is this what you expected?

Q2-3: Does the average acceleration you just calculated agree with the average acceleration found from the acceleration graph? Do you expect them to agree? How would you account for any differences?

5. Calculate the slope of your velocity graph using the fit feature in the software. Select the portion of the graph you want to fit. Use the fit routine and select a linear fit, \( v = b + ct \), and record the equation of the fit line below.

\[ v = \phantom{b + ct} \]

Q2-4: What is the meaning of \( b \)?

Q2-5: What is the meaning of \( c \)?

6. You can also find the acceleration from the position-time graph using the fit routine.

Q2-4a: Which type of fit should you select for the position-time graph? Explain.

Select the portion of the graph you want to fit. Use the fit routine and select the appropriate type of fit. Record the fit equation in the space below:

\[ x = \phantom{b + ct} \]

Q2-4b: How do you find the acceleration from the fit equation? Explain the reasoning behind your answer.

Q2-4c: What do the other numbers in the fit equation represent?

Activity 2-2: Speeding up more

1. Load the data from the file SPEEDUP2.XXX. Repeat the analysis described in Activity 2-1.

Q2-5: Compare the acceleration you found in Activity 2-2 with that with half batteries and half dummy cells. Which is larger? Is this what you expected?
Investigation 3: Slowing down and speeding up

In this investigation, you will examine the relationship between the sign (direction) of the acceleration and the sign (direction) of velocity.

Activity 3-1: 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.

1. The setup should be as shown below - same as before.

Prediction 3-1: You start the fan and give it a push away from the motion detector. It moves away, slows down, reverses direction and then moves back toward the motion detector. Draw a velocity diagram for each part of the motion. Use the velocity diagram after Q1-7 as an example. Represent the cart with a dot. Draw velocity vectors above each position.

Velocity diagram for 1st half of the motion: (slowing down while moving away from the detector)

Velocity diagram for 2nd half of the motion: (speeding while moving toward the detector)

Prediction 3-2: Use your velocity diagrams to sketch your predictions for velocity-time and acceleration-time graphs for the entire motion on the axes below:

Prediction

acceleration (m/s²)

velocity (m/s)

Slow down (while moving away from the detector), reverse direction and return toward the detector
**Prediction 3-3:** For each part of the motion, predict whether the velocity is positive, negative or zero. Also indicate whether the acceleration is positive, negative or zero. Base your predictions on your prediction graphs and/or the velocity diagrams. (All representations of the motion should be consistent!)

<table>
<thead>
<tr>
<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>
</tr>
<tr>
<td>Acceleration</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Discuss your predictions with an instructor.

2. Test your predictions. You may need to try a few times before you get a good round trip. When you get a good set of data, sketch the velocity and acceleration graphs (or attach labeled printouts). Leave your data displayed on the screen. You will use it in Investigation 4.

![Graph](image)

**FINAL RESULTS**

- Slow down (while moving away from the detector), reverse direction and return toward the detector

**Q3-6:** Label both graphs with
- A where the cart started being pushed
- B where the push ended (when your hand left the cart)
- C where the cart reached its turning point
- D where you stopped the cart

Explain how you know where each of these points is.

**Q3-7:** Did the cart “stop” when at its turning point? Explain how you know. Does this agree with your prediction? How much time did it spend at the turning point velocity before it turned back toward the detector? Explain.
Q3-8: 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?

Q3-9: According to your velocity graph, what is the acceleration at the instant the cart reaches the turning point? Is it positive, negative or zero? According to your velocity graph, is the acceleration at the turning point significantly different from the acceleration during the rest of the motion?

Q3-10: Explain the observed sign of acceleration at the turning point. (You may find it helpful to use a velocity diagram. Consider a point just before the turnaround and another just after the turnaround).

Q3-11: Based on your observations in this lab, state a general rule to predict the sign (direction) of acceleration if you know the sign (direction) of velocity and whether the object is speeding up or slowing down.

Q3-12: There is one combination of acceleration and velocity directions you have not tested: slowing down while moving toward the detector. Predict the sign (direction) of acceleration for this motion.

Q3-13: Suppose this entire experiment were performed with the motion detector at the right end of the track. What would happen to the sign of the observed velocities? the direction? What would happen to the sign of the observed accelerations? the directions? Explain.

Check your answers with an instructor.
Investigation 4: Slowing down and speeding up (a closer look)

**Note:** This investigation is different from the previous three in two important ways.

- *What you learned* about acceleration in the first three investigations applies to any accelerated motion that occurs along a straight path. In this investigation, you will examine some specific features of the cart’s motion.

- *The teaching purpose* of the first three investigations was to improve your understanding of velocity and acceleration. The teaching purpose of this investigation is to help you learn how to answer a question and use data to support your claim concerning the answer.

In this investigation, you will examine the data from the previous section (“Slowing down and speeding up”) more closely.

1. Use the analysis tools to measure the acceleration of the cart during the part of the motion when the cart is slowing down. Use the best possible method to determine the acceleration.

   **Q4-1:** Briefly describe your method and explain your rationale for choosing it.

2. Have each person in the group execute your method a couple times (total number of trials should be five or so). Record the values each person gets. (For now, record one or two digits beyond where you might eventually round the numbers off to).

3. Calculate the mean of the values you recorded.

4. Estimate the spread of the values you recorded. (There are many methods for doing this. Use a method you are familiar with to estimate the spread. Do not worry if your method is not mathematically “sophisticated.”) Explain how you determined your estimate.

5. Use the analysis tools to measure the acceleration of the cart during the part of the motion when the cart is speeding up. Use the best possible method to determine the acceleration. Again, do this several times. Record the values here.

6. Calculate the mean and estimate the spread in the values.

   **Q4-2:** Based on results, is it reasonable to conclude that the acceleration was the same for each phase of the motion?

   **Q4-3:** Suppose a classmate suggested that your conclusion is suspect since your results were not exactly the same every time. What argument could you make to defend your conclusion?

7. Post your results on the blackboard.

8. Calculate the class mean for the acceleration during the “slowing down” phase of the motion. Calculate the spread for the class results. Repeat for the “speeding up” results.
Q4-4: What do you think the variation in the class’ acceleration values during the “speed up” phase might be due to? How might you be able to test this hunch?

Q4-5: Does the class’ data suggest anything about the acceleration of the cart? Explain how you can use the class data to provide strong support for your position.