**ONE DIMENSIONAL MOTION**

**Topic:** Motion along a straight line (a.k.a. 1D kinematics)

**Objectives:**
- To learn how to use the motion detector and associated software
- To explore graphical representations of various types of motion along a straight line
- To explore connections between position-time, velocity-time and acceleration-time graphs

**Overview:**
The study of motion and its mathematical and graphical representation is called *kinematics*. In this lab, you will examine motion along a straight line (i.e. *one-dimensional kinematics*).

The basic setup is shown below. The motion detector measures the distance to the nearest object directly in front of it, transfers the information to the computer, and the computer displays graphs of your motion. Some things to note about the motion detector:

- The motion detector detects the closest object directly in front of it.
- The motion detector cannot measure anything closer than a certain distance (~ 10 cm).
- The motion detector has two settings: one for large objects (like people) and another for smaller objects (like the carts you will be using in this experiment). The switch is on the body of the detector.
- The head of the motion detector pivots with respect to the body.

In the first part of the lab, you will solve a series of “problems.” In each problem, you will be provided with a motion graph and/or a verbal description of the motion and be asked to provide other graphical and/or verbal descriptions of the same motion. You will use the cart and the motion detector to check your understanding. You will also learn how to use the computer's software to calculate various motion quantities from the graph(s).

In the second part of the lab, you will closely examine the motion of a fan cart as it slows down, reverses direction and then speeds up.

**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. The completed handout serves as your notes. Instead of a traditional lab report, you will do a lab homework assignment. The lab homework will test how well you understand the material covered in this lab.

**Notes:**
Multicolored pens are nice to have for this lab. (Often, more than one set of data is sketched on a single set of axes).
Concept Check: Making motion graphs

The main purpose of this part of the lab is to solidify your understanding of how kinematics graphs (such as position-time, velocity-time and acceleration-time) are related to each other and the motions they represent. You will also use the software’s analysis tools to calculate various motion quantities from the kinematics graphs.

Comment: The motion detector measures the distance to the object (a scalar quantity). Throughout this lab, we refer to this distance as “position.” However, position (as defined by most physicists) is a vector quantity that indicates both the distance and direction of an object’s location relative to some origin. By referring to the distance that the motion detector reports as “position,” we are tacitly choosing a coordinate system with the detector at the origin and positive x-axis pointing from the detector to the object. For motion in one dimension, the direction of vector quantities is indicated by the algebraic sign. Positive quantities indicate vectors which point away from the detector; negative quantities indicate vectors which point toward the detector.

1. Plug in the motion detector. Make sure the motion detector is set to detect small objects. (The switch is on the part of the detector that rotates). Start the “Data Studio” software. Open the file “1D_Motion.ds” (This file sets up the motion detector to collect and position, velocity and acceleration data at 20 points per second. The time axes are aligned vertically so that events on the position graph line up with corresponding events on the velocity and acceleration graphs).

2. This part of the lab consists of a few short problems to check your understanding of kinematics graphs. In each problem, you will be given one of the following descriptions of motion: a written description of the motion or an acceleration-time graph or a position-time graph or a velocity-time graph. Each “problem” is followed by questions to help you learn to use the software’s graphical analysis tools to answer questions about the motion.

- **Predict** the other descriptions of motion, and then
- **Check** the predictions using the motion detector by having the fan cart execute the motion given in the description. **Check your predictions one-by-one**, rather than checking several problems at once.
- In some cases, you may need to turn on the fan motor to get the cart to reproduce the desired motion. **Preserve batteries! Turn the fan on only when it is needed.** The fan drains four batteries in about two hours!
- **Sketch** your results on the graphs provided. (Since predictions and results go on the same set of axes, you might find it helpful to use two colors of pens).
- **Answer** the questions that follow each graph.
- **Note:** Motion detector data is noisy. Draw idealized prediction and result graphs that emphasize the most important features.

Take turns at the computer! Every student should learn how to take data and how to use the software’s features.
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3. **Example:** This problem has been worked as an example.

**Description of Motion:**

The cart moves toward the detector at (essentially) constant speed. (You may need to adjust the slope of the track somewhat to make this happen).

Use the motion detector to check the graphs above. Place the cart at its starting location. When you are ready, click the “start” button in the software and give the cart a push toward the motion detector. Click “stop” before the cart reaches the motion detector. Catch the cart before it hits the detector.

**Using the analysis features of the software to calculate average velocity**

**Method 1:** One way to calculate the cart’s average velocity is to use the software’s *statistics* feature on the velocity-time graph. Before doing so, discuss the following questions with your group:

- Q: How much data should you include in the average? Why?

- Q: Is there data that should not be included in the average? Explain.

Determine the velocity of the cart from the velocity graph and record the result here (don’t forget units). Notice the algebraic sign of the average velocity.

**Method 2:** Since average velocity during a particular time interval is defined as the change in position divided by the length of the time interval, you can also calculate the average speed by recording the position and time data for the cart at two times when the cart was moving. (The change in position is often called *displacement*). For motion with constant velocity, this is also the slope of the position-time graph.
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Q: Which data points from the position-time graph should you choose to find the slope? Should the data points be close together or far apart? Why?

Use the computer’s analysis tools to read the position and time coordinates for two typical points while the cart was moving.

<table>
<thead>
<tr>
<th></th>
<th>Position (m)</th>
<th>Time (s)</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 position (a.k.a. displacement) and the change in time (a.k.a. time interval). Divide the displacement by the time interval to get average velocity.

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

Q: What does the algebraic sign of displacement indicate? How is the sign of the displacement related to the sign of the average velocity? What does the sign of the velocity indicate?

**Method 3:** You can use the software’s *fit* feature on the position-time graph to determine the average velocity. Before doing so, answer the following questions:

Q: How much data should you include in the fit? Why?

Q: What fit should you use? What assumption are you making about the cart’s motion?

Select the portion of the data that you will fit, select the appropriate type of fit and record the results below.
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Q: Interpret all constants in the fit equation. Which constant tells you the object’s velocity? What information does the other number tell you about the motion? List units for each of the constants in the fit equation.

Q: How could you create a position-time graph with a steeper (but still negative) slope? How would the new velocity graph compare to the original?

Q: How could you create a position-time graph with a positive slope?

Test your answers to the last two questions using the cart and the motion detector.

4. **Problem 1**: Given the velocity-time graph, predict the shapes of the graphs and give a verbal description of the motion.

**Description of Motion:**

Compare the graphs with other members of your group. Resolve any inconsistencies. Use the motion detector to check the answers. You may need to do this more than once to get good data. Resolve any inconsistencies between your group’s prediction and the results.

Q: Describe how the cart moved to produce each part of these graphs.
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Q: Is it possible to make an object move so that it produces an absolutely vertical line on a velocity-time graph?

Q: Did the cart run into the detector on the return trip? If so, why did this happen? How did you solve the problem? Does a velocity graph tell you where to start?

Finding the displacement from the velocity graph

The displacement of the cart during a given time interval can be found either by reading it directly from the position graph or by finding the area under the velocity graph.

Q: Find the displacement of the cart during the first part of the motion by reading the position graph. Record the initial and final positions and subtract to find the displacement of the cart during this time interval.

Q: Find the area underneath the velocity graph during the first part of the motion using the software’s area tool. In DataStudio, highlight the part of the graph you want to find the area under and choose area from the “statistics” menu. Compare the result to the answer to the previous question. What are the units associated with the area under the velocity-time graph?

Q: Can you tell an object’s position from a velocity graph? What information about the object’s position can you glean from the velocity graph?
5. **Problem 2:** Figure out how to produce this velocity-time graph using the cart. Fill out the other graphs for the motion.

**Description of Motion:**

![Graphs showing position, velocity, and acceleration over time.]

Compare your graphs with other members of your group. Resolve any inconsistencies.

Use the motion detector to check the answers. Resolve any inconsistencies between your group’s prediction and the results.

Q: How does the position-time graph for this motion differ from the position-time graph for an object moving with constant velocity?

Q: How are the velocity and acceleration graphs for this motion related?

Q: What quantity remains unchanged as the object speeds up?

Q: How does the acceleration-time graph for this motion differ from the acceleration-time graph for an object moving with constant velocity?

**Using the analysis features of the software to calculate average acceleration**

Average acceleration during a particular time interval is defined as the change in velocity divided by the time interval. By definition, the average acceleration is the (average) slope of the velocity-time graph. You can Data Studio’s analysis tools to measure the cart’s acceleration for this example. There are several different ways to do this.

**Method 1:** You can use the software’s *statistics* feature on the acceleration-time graph. Highlight the points that you will average and use the statistics feature to find the average acceleration. Record the result below. (Remember how you should choose the points for the best results).
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\[ a = \_\_\_\_\_\_\_ \quad (\text{Don't forget the units}) \]

**Method 2:** You can calculate the slope of the velocity-time graph by using the \textit{fit} feature on the velocity graph. Select the portion of the data that you will fit, select the appropriate type of fit and record the results below.

- **Q:** Interpret the constants in the fit equation. Which constant tells you the object’s acceleration? What information does the other number tell you about the motion? List units for each of the constants in the fit equation.

**Method 3:** You can also use the \textit{fit} routine on the position graph.

- **Q:** What type of fit should you use on the position graph to find the cart’s acceleration? What assumption are you making about the cart’s motion by choosing this fit?

Select the portion of the data that you will fit, select the appropriate type of fit and record the results below.

- **Q:** Interpret the constants in the fit equation. Which constant tells you about the object’s acceleration? What information do the other numbers tell you about the motion? List units for each of the constants in the fit equation.

- **Q:** Compare the acceleration values you determined using the three different methods.
6. **Problem 2:** How can you get the fan cart to produce the following position graph?

*Make the following additional predictions before checking your graph:*

- When, if ever, does the cart’s velocity vector reverse direction? Explain.

- When, if ever, does the cart’s acceleration vector reverse direction? Explain.

**Description of Motion:**

![Position Graph](image1)

![Velocity Graph](image2)

![Acceleration Graph](image3)

Discuss your predictions with an instructor.

Check your predictions above. Resolve any inconsistencies. *Leave the data displayed on the screen.* These data will be used in the next part of the lab.

Q: Is it possible to have: a positive acceleration and slow down? a negative acceleration and speed up? State a general rule for determining the sign (direction) of acceleration vector if you know the sign (direction) of the velocity vector and whether the object is speeding up or slowing down.

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Revised for P13: 9/2005
Investigation: A closer look at the fan cart’s motion

In this investigation, you will examine the “out and back” motion of the fan cart produced in Problem 2 in more detail.

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

- The concepts you applied to the problems were definitions of kinematics quantities. These concepts apply 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.

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

   Q: Briefly describe your method and explain your rationale for choosing it.

   Q: Record the result here. For now, keep a few digits beyond what you think might be reasonable to keep:

   ________________________ (Don’t forget units).

2. Use the analysis tools to measure the acceleration of the cart during the part of the motion when the cart is speeding up as it travels away the detector. Use the same method as before to determine the acceleration.

   Q: Record the result here. Again, for now, keep a few extra (in)significant digits:

   ________________________

3. At this point, it might seem reasonable to claim that the two acceleration values you’ve measured are different, but how can this conclusion be justified? One way to provide support for such a claim is to perform the experiment several times and examine the variation in the results. Performing multiple trials serves two main functions:

   - Multiple trials provide a result which is more reliable than result of a single trial
   - Multiple trials provide a measurement of the reproducibility of the results

4. Conduct at least four more trials of the out and back motion of the fan cart. Measure the acceleration for the two different part of the motion for each trial and record the results in the table on the next page. (For now, you can keep extra digits).
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<table>
<thead>
<tr>
<th>Trial</th>
<th>Accel. while slowing down (in m/s²)</th>
<th>Accel. while speeding up (in m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<tr>
<td>2</td>
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<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
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</tbody>
</table>

5. Calculate the averages for the two accelerations.
6. Post your results for each trial and your average on the blackboard. For now, keep extra (in)significant digits.
7. As you wait for other groups to finish, consider the following questions:
   - Q: How many digits in your results are really reliable? How many should you keep when reporting the number to someone else?
   - Q: How can you construct a convincing argument from your data to support the position that the acceleration of the cart while it is slowing down is noticeably different than the acceleration of the cart while it is speeding up? Can a convincing argument be based on the average values alone, or is something else needed to make the argument convincing?
   - Q: Brainstorm some possible causes for the difference.

Once all groups have posted their results, the TA will lead a short discussion about the issues raised in this part of the lab.

8. Copy down the results for all groups.
9. After the class discussion, record the ideas from the group discussion.
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Q: What do you think the variation in the class’ acceleration values during the “speed up” phase might be due to: variations in fans, or inexact measurements? Defend your position, using the ideas developed in the class discussion.

Q: Different fans have different strengths (as shown by the wide range of acceleration values during each phase of the motion). Can you still conclude that the acceleration during the “speed up” phase is different than the acceleration during the “slow down” phase? Does the class data make the conclusion stronger or weaker? Explain.