INTRODUCTION TO 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 how various motions are represented on a distance (position)-time graph
- To explore how various motions are represented on a velocity-time graph
- Discover the relationship between position-time and velocity-time graphs

**Overview:**
In this lab you will examine two different ways that the motion of an object that moves along a straight line can be represented graphically. You will use a motion detector to plot distance-time (position-time) and velocity-time graphs of the motion of your body and a cart. The study of motion and its mathematical and graphical representation is called *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. The motion detector has a couple of minor limitations:

- The motion detector **detects the closest object** directly in front of it (including tables, chairs, other people, your arms if you swing them as you walk, etc.)
- The motion detector cannot measure anything closer than a certain distance (usually about 20 cm)
- The motion detector has **two settings**: one for large objects (like the people in this experiment) and another for smaller objects (like the carts you will be using in later experiments). The switch is on the body of the detector.

The main educational purpose of this lab is to improve your conceptual understanding of basic motion concepts. A secondary purpose is to familiarize you with the motion detector and software.

**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:**
The number line (in the diagram above) is optional.
Investigation 1: Distance (position)-time graphs of your motion

The purpose of this investigation is to learn how to relate graphs of position as a function of time to the motions they represent.

**Comment:** The distance (and direction) of an object relative to some origin is often called the position of the object. Since the motion detector is at the origin of the coordinate system (and the objects are always in front of the detector), it is correct to refer to the distance from the detector as the position of the object.

Activity 1-1: Making and interpreting position-time graphs

1. Plug in the motion detector. Make sure the motion detector is set to detect large objects. (The PASCO motion detectors have a switch on the part of the detector that rotates).

2. Start the “DataStudio” software. Open the file “MotionIntro_A1-1.ds” (This file sets up the motion detector to collect and graph position vs. time data at a rate of 20 points per second).

3. Begin graphing and make distance-time graphs for different walking speeds and directions.

   Q1-1: Describe the difference between a graph made by walking away *slowly* and one made by walking away *quickly*.

   Q1-2: Describe the difference between a graph made by walking away and one made by walking toward the detector.

4. Predict the position-time graph produced when a person starts at the 1-m mark, walks away from the detector slowly and steadily for 5 s, stops for 5 s, and walks back toward the detector twice as fast. Sketch your prediction graph below. Compare your prediction with others in your group. Sketch the group’s prediction below.

   ![Graph](image)

5. Test your prediction. (You may need to try several times to get a graph your group is satisfied with). Sketch the results in your notes.

   Q1-3: Is your prediction the same as the final result? If not, describe how you would move to make a graph that looks like your prediction.

Adapted from RealTime Physics (Sokoloff et al.) for P3
Revised: 5/2004
Activity 1-2: Matching a position-time graph

By this point, you should be pretty good at predicting the shape of a position-time graph of your movements. In this section, you will try it the other way around: try to move to reproduce a position-time graph.

1. Begin graphing. Try to match the position-time graph shown above. You may try a number of times. Work as a team. Get the times right. Get the positions right. Each person should take a turn.

   Q1-4: What was the difference in the way you moved to produce the two different sloped parts of the graph you just matched?

2. Try to make each of the graphs shown below. In the spaces below, describe how you must move to produce each position-time graph.

   How you would move to produce Graph A:

   How you would move to produce Graph B:

   How you would move to produce Graph C:
Q1-5: What is the general difference between motions that result in a straight-line position-time graph and those that result in a curved-line position-time graph?

Investigation 2: Velocity-time graphs of your motion

So far, you have plotted your position along a line versus time. Now you will examine velocity-time graphs.

Activity 2-1: Making and interpreting velocity-time graphs

1. Open the file “MotionIntro_A2-1.ds” (This file sets up the motion detector to collect and graph velocity vs. time data at a rate of 20 points per second).

2. Begin graphing and make velocity-time graphs for different walking speeds and directions.
   
   Q2-1: Describe the main difference between a velocity-time graph made by walking away slowly and one made by walking away quickly.

   Q2-2: Describe the main difference between a velocity-time graph made by walking away and one made by walking toward the detector.

3. Predict the velocity-time graph produced when a person starts at the 1-m mark, walks away from the detector slowly and steadily for 5 s, stops for 5 s, and walks back toward the detector twice as fast. Sketch your prediction graph below. Compare your prediction with others in your group. Sketch the group’s prediction below.

4. Test your prediction. (You may need to try several times to get a graph your group is satisfied with). Sketch the results below, or get a printout, label it and affix it to this handout.
Activity 2-2: Matching a velocity-time graph

In this section, you will try to match a velocity-time graph. This is much harder than matching a position-time graph.

1. Describe in words how you would move so that your velocity matched each part of the velocity-time graph below. Write your description on the graph.

2. Begin graphing. Try to match the velocity-time graph shown. You may try a number of times. Work as a team. Get the times right. Get the velocities right. Each person should take a turn. Sketch your group’s best match below (or get a printout).

Q2-3: Describe how you moved to match each part of the graph. Did this agree with your predictions?

Q2-4: Is it possible for an object to move so that it produces an absolutely vertical line on a velocity-time graph? Explain.

Q2-5: Did you run into the motion detector on the return trip? If so, why did this happen? How did you solve the problem? Does a velocity graph tell you where (i.e. at what position) to start? Explain.
Investigation 3: Relating position and velocity graphs

You have looked at position and velocity graphs separately. Since both are representations of the same motion, it is possible to figure out the velocity of an object by examining the position-time graph. Similarly, it is possible to find the change in position of an object from a velocity-time graph.

Activity 3-1: Predicting velocity graphs from position graphs

1. Predict the velocity-time graph for the motion shown in the position graph below. Make your prediction as specific as possible and plot the prediction graph on the axes below. (Hint: Can you predict the speed of the object during each part of the motion?)

2. Open the file “MotionIntro_A3-1.ds” (This file sets up the motion detector to collect and graph position and velocity data at a rate of 20 points per second. The time axes of the two graphs are aligned vertically, like the two graphs shown above).

3. Test your prediction using the software. Once you have made a good duplicate of the position graph, sketch the results for the position and velocity graphs on the axes above (or get a printout).
Activity 3-2: Calculating average velocity

In this activity, you will calculate the average velocity from the velocity-time graph in Activity 3-1 and then from the position-time graph.

4. Find the average velocity from your velocity graph in Activity 3-1. You can do this using your calculator or by using the statistics feature of your software. Try both methods.

   • Using your calculator: Read and record values of velocity (about 10 points from the portion of your velocity graph where your velocity is relatively constant) and use them to find the average value.

   • Using the statistics tool in the software: Select (highlight) the portion of the velocity graph for which you want to find the mean value. Use the statistics feature to read the mean value during that portion.

   Q3-1: Compare these two values for average velocity. Do you expect them to agree? How do you account for any differences?

5. Find the average velocity from the slope of your position graph in Activity 3-1. You can do this using your calculator or by using the fit feature of your software. Try both methods.

   • Using your calculator: Read the position and time coordinates for two typical points while you were moving. (For a more accurate answer, use two points as far apart as possible but still typical of the motion). The average velocity is the change in position divided by the time interval.

   • Using the fit tool in the software: Select the portion of the position-time graph you want to fit. Use the fit routine and select a linear fit, $y = a + bt$, and record the equation of the line.

   Q3-2: What does $a$ represent? What are the units of $a$?

   Q3-3: Compare the two values for average velocity you just found to each other. Do you expect them to agree? How do you account for any differences?

   Q3-4: Compare the values of mean velocity you just calculated from the position graph from the values you calculated from the velocity graph. Do you expect them to agree? How do you account for any differences?
Investigation 4: Introduction to acceleration

There is another quantity besides position and velocity used to describe the motion of an object – acceleration. Acceleration is defined as the rate of change of velocity with respect to time (just like the velocity is defined as the rate of change of position with respect to time). In this investigation, you will begin to examine the acceleration of objects.

Because of the jerky nature of the motion of your body, the acceleration graphs are very complex. It will be easier to examine the motion of a cart. In this investigation, you will examine the cart moving with constant (steady) velocity.

Activity 4-1: Motion of a cart at constant velocity

To graph the motion of a cart you can give the cart a quick push with your hand and then release it.

1. Set the motion detector at the end of the track. Set the switch on the detector for small objects.

Prediction 4-1: How should the position, velocity and acceleration look if you move the cart at constant velocity away from the detector? Sketch your predictions on the axes that follow. Base you prediction for acceleration on the definition of acceleration.
2. So far, you have been opening files to set up the axes and configure the detector to take the data you want. Now, you will learn to configure the software yourself. This is done in two basic steps. First, configure the software to collect the data you want. (In DataStudio, click on the “Setup” button, set the appropriate choices on the menu that appears and close the menu). Then configure the graphs. To create a graph, click on an item in the Data panel (e.g. Position) and drag that item to the word Graph in the Displays panel. Axes for a graph of the quantity you selected versus time will appear. At the same time, a new item will appear in the Display window (in this case it will be called “Graph 1”). To graph another quantity using the time axes, drag the other quantity (e.g. Velocity) to “Graph 1”). Notice that the time axis of the new graph is aligned vertically with the time axis. If the time axes are aligned, you can easily spot how events on the one graph correspond to events in the other graph. Once you are done, maximize the graphing window, so that the graphs are as large as possible.

3. Set up position-time, velocity-time and acceleration-time graphs with aligned time axes.

4. Test your predictions. Be sure that the cart is never closer than about 20 cm from the detector and that your hand is not between the cart and the motion detector. Begin graphing. Try several times until you get a fairly constant velocity. Sketch your results on the axes above. (Use a different color or dashed lines so you can tell results from your predictions).

   Q4-1: Did your position-time and velocity-time graphs agree with your predictions? What characterizes constant velocity motion on a velocity-time graph?

   Q4-2: What characterizes constant velocity motion on a velocity-time graph?

Comment: To find the average acceleration of the cart during some time interval (the average change rate of change of its velocity with respect to time), you must measure its velocity at the beginning and end of the interval, calculate the difference between the final value and initial value and divide by the time interval.

   Q4-3: Does the acceleration-time graph agree with this method of calculating acceleration? Explain. Does it agree with your prediction? What is the value of acceleration of an object moving at constant velocity?
Q4-4: The diagram below shows positions of the cart at equal time intervals. (This is like overlapping snapshots of the cart at equal time intervals. The motion detector also looks at the cart’s position at equal time intervals,) At each indicated time, sketch a vector above the cart that might represent the velocity of the cart at that time while it was moving at a constant velocity away from the motion detector.

Comment: To find the average acceleration vector from two velocity vectors, you must first find the vector representing the change in velocity by subtracting the initial velocity from the final one. Then you divide this vector by the time interval.

Q4-5: Show below how you would find the vector representing the change in velocity between times 1 and 2 s in the diagram in Question 4-4. From this vector, what value would you calculate for the acceleration? Explain. Is this value in agreement with the acceleration graph?