Motion II

Goals and Introduction

As you have probably already seen in lecture or homework, and if you've performed the experiment Motion I, it is important to develop a strong understanding of how to model an object's motion for success in this course. This requires you to be fluent in using the terms *position*, *displacement*, *time*, *average velocity*, *instantaneous velocity*, and *acceleration*. In this lab you will investigate the definitions of and relationships between these quantities by creating and analyzing plots of the velocity of an object versus time.

Examples of *velocity vs. time* plots are shown in Figure 4.1. An object's *velocity* (v) is its speed and direction of motion at a particular time. The magnitude of the velocity is the speed and, for one dimensional motion, the direction of motion is indicated by the sign of the velocity. If the velocity is positive, the object must be moving in the positive x direction, while if the velocity is negative, the object must be moving in the negative x direction. By tracking the velocity of an object relative to some origin, as time goes on, we can plot the velocity as a function of time. This is represented by the red lines in each of the panels in Figure 4.1.

The acceleration an object experiences is the change in the object's velocity (Δv) over a certain time interval (Δt). We could choose any two points along any of the red lines and calculate the change in velocity from one time to the next. In a scenario where an object moves with a constant velocity, the change in velocity is always 0. This is depicted in Figure 4.1(a). Note that a horizontal line on a velocity versus time graph represents an object that is not accelerating.

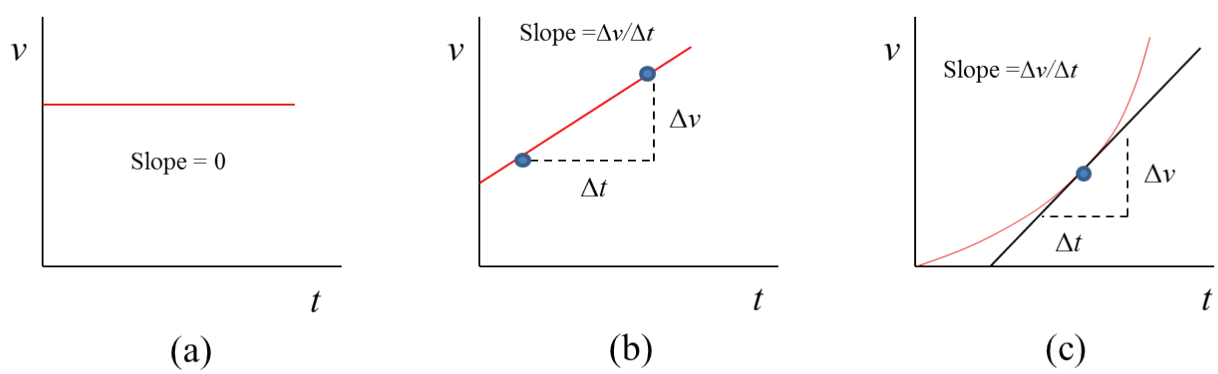


Figure 4.1

Recall that the slope of a line on a plot can be found by considering two points on that line and calculating the *rise*/*run*. But this is more than a math problem, just as it was in the experiment Motion I! These plots represent physical measurements, with time on the horizontal axis (run), and velocity on the vertical axis (rise). The "run" is the time interval between two points and the "rise" is the change in velocity of the object. This means that when we calculate the slope of a line on a velocity vs. time graph, we are calculating a quantity with units of m/s per s or m/s^2, in SI units (or rise/run). When applied to two points along the red line representing the object's velocity, the slope is the *average acceleration* the object must have had between those two points (Eq. 1). Note that this does not necessarily mean the object had that exact acceleration at any moment – it just means that to change from the first velocity to the second in that time interval, the object must have been speeding up or slowing down with some average amount of acceleration.

$$a_{avg} = \frac{\Delta v}{\Delta t} \qquad \text{(Eq. 1)}$$

Consider the velocity vs. time plot in Figure 4.1(b). Like Figure 4.1(a), the plot is a line with a constant slope, but here the slope is some positive amount, whereas the slope in Figure (a) is 0. In cases where the slope is constant, the slope, or average acceleration, actually represents the acceleration of the object. This can be verified by repeatedly choosing any two points along the line to calculate the slope. The rate at which the object changes velocity is constant. No matter which points you choose, you will calculate the same slope. The actual acceleration of an object at any instant in time, is the *instantaneous acceleration* at that time. We can say the instantaneous acceleration is equal to the average acceleration in cases where an object's velocity vs. time plot is a straight line.

It is also possible that an object's acceleration changes. You acquired a velocity in order to arrive at class, which required speeding up, but it is highly unlikely that you continued to accelerate at a constant rate all the way to class. In fact, your acceleration needed to change in order for you to slow down and then stop at the classroom. Figure 4.1(c) illustrates how the velocity vs. time plot is different when an object is changing acceleration. Note that the red line, representing the object's velocity, is now a curve, along which the slope is constantly changing! If the slope is changing, the acceleration must also be changing. In this scenario, it would only make sense to describe the slope at a specific point on the curve since it is changing from point to point. To do this, we consider a line, tangent to the curve, that intersects our point of interest. We then find the slope of that line. The slope of that line represents the instantaneous acceleration of the object at that moment in time.

Realize that the plots in Figure 4.l are just examples of three specific motions. The variations are endless. You could have lines with lesser or greater slopes than that shown in Figure 4.1(b). You could have lines with negative slopes! You could also have curves that turn every which way, or even look like a sine function. Think about some of these possibilities and what they would say about the acceleration of the object from moment to moment. What is happening to the slope on the velocity vs. time graph? What is happening if an object's velocity vs. time graph looks like a sine function?

Today, you will use a motion detector connected to a computer to collect data on your velocity as a function of time. The computer will help you plot this data and you will then work to understand the plots you've created and reflect on the mapping of motion with velocity vs. time plots.

Goals: (1) Be able to define and understand the relationships between velocity, acceleration and time.
(2) Consider the velocity vs. time plot for an object's motion and understand its creation, and its analysis.

Procedure

Equipment –motion detector, computer with the DataLogger interface and LoggerPro software

WARNING: The motion detector may have difficulty recording your velocity if you are too close to the detector. Try to stay more than 0.5 m away from the detector.

The motion detector is at the origin in the coordinate system (or $x = 0$). When you move faster, either towards or away from the detector, the magnitude of your velocity will be greater. However, the positive x axis runs out away from the detector so you will always be moving with a positive velocity if you are moving away from the detector (say 0.9 m/s, for example). If you move closer to the detector, you will be moving with a negative velocity (-1.2 m/s, for example).

1) Check to see that the motion detector is connected to the DataLogger interface and open a blank Microsoft Word document. Your TA should be able to ensure that this is done properly.

2) Open the LoggerPro program by clicking on the **LoggerPro** link on the webpage in lab. A blank graph with axes labeled *velocity* (m/s) *vs. time* (s) should appear on the screen.

3) Double-click anywhere on the graph. This will display a dialog box. Click on "Axes Options". Select *velocity* for the vertical axis and set the range from *-2 to +2* m/s. Change the *time* scale to read *0 to 5* s. This should give you a blank graph with appropriate units along the axes. If you need to alter the velocity or time scales so that the plot fills nearly all of the available space, again, double-click anywhere on the graph and change the velocity and/or time ranges which appear in the dialog box. Look at the graph and verify that the changes you selected were implemented. Check with your TA before proceeding to the next step if you are unsure.

4) You will need about a 2 or 3 m region to walk toward and away from the detector in order to use the motion detector to create plots of velocity. At the beginning, have one lab partner operate

the computer and another take on the role of the moving object. Place the motion detector on the desk and aim it away from the desk towards a region where the "moving student" has room to walk.

HINT: in all instances in this lab, when you are asked to create a plot, *each* student should take turns taking on *each* role! The goal is to experience the motion and see its appearance on the position vs. time plot.

5) Recall that you must stay at least 0.5 m away from the detector for it to work properly. Measure a distance of 0.5 m away from the detector and use the tape to mark this location on the floor.

6) Measure a distance of 2.5 m away from the detector and use the tape to mark this location on the floor. This will indicate the moving student's maximum position from the detector for this experiment.

HINT: Your plots may not look as "clean" as those in Fig 4.1 because the detector will "catch" you before you start moving and after you finish, as well as any small variations along the way. They will also not necessarily be as flat. That is okay. Just try to make the plot as accurate as possible during the time that you are recording the motion.

7) Begin by having the "moving student" stand motionless at any location in front of the detector. Then hit the *green* button on the top-center of the screen in LoggerPro (each time you hit the *green* button, the previous plot is erased and a new one is created). You should see a green line being drawn on the velocity vs. time plot, indicating the velocity of the "moving student". Hit the *red* button (where the green button was) to end the data collection. Does the line indicate a stationary object?

8) When you are satisfied with your results, **create** a plot for an object that is standing motionless in front of the motion detector. This plot will be *Graph #1*. Once you have a plot that looks correct in LoggerPro, click on the graph, go to the drop-down menu bar at the top of LoggerPro and click on the "Edit" menu and then "Copy". Then go to your Word document and click on the "Edit" drop-down menu and select "Paste". Your plot should appear in the Word file. Hit the "Return" key a few times while in Word to move the cursor below your plot. Resize your plot appropriately so that it appears clearly in the Word document.

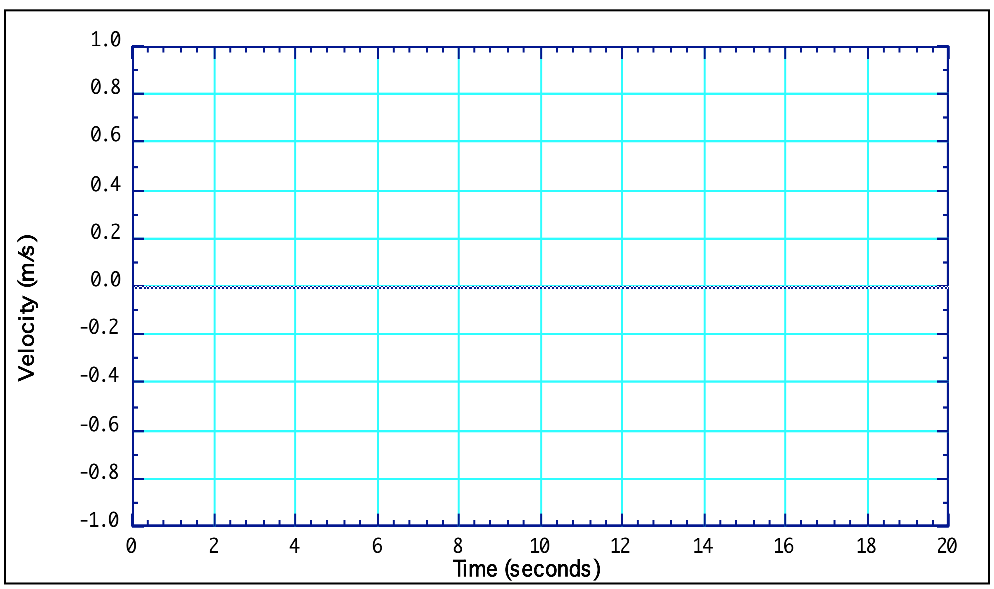
9) Go back to the LoggerPro window. Have the "moving student" begin at the 0.5 m tape mark and walk towards the 2.5 m tape mark. The goal is to move from one mark to the other in approximately 2 s, moving at a constant velocity – (similar to Figure 4.1(a)). What should the velocity be? Take turns taking on the role of both the "moving student" and the computer

operator. **Create** a plot for this motion! This will be _Graph #2_. When you think you have a good plot that shows a student completing this motion, follow the procedure in step 8 for copying and pasting this plot into your Word document.

10) Go back to the LoggerPro window. Have the "moving student" begin at the 2.5 m tape mark and walk towards the 0.5 m tape mark. The goal is to move from one mark to the other in approximately 2 s, moving at a constant velocity – (again, similar to Figure 4.1(a)). What should the velocity be? How should this graph differ from the last one? Take turns taking on the role of both the "moving student" and the computer operator. **Create** a plot for this motion! This will be _Graph #3_. When you think you have a good plot that shows a student completing this motion, follow the procedure in step 8 for copying and pasting this plot into your Word document.

11) Double-click anywhere on the graph. This will display a dialog box. Click on "Axes Options". Select *velocity* for the vertical axis and set the range from *-1 to +1* m/sec. Change the *time* scale to read *0 to 20* s. Look at the graph and verify that the changes you selected were implemented. Check with your TA before proceeding to the next step if you are unsure.

12) Go back to the LoggerPro window and consider the motion described here: *a) walk from the 0.5 m to the 2.5 m mark at a constant velocity in 10 s, b) stand motionless for 5 s, c) walk back to the 0.5 m mark at a constant velocity in 5 s*. Predict what this plot should look like on the chart below. Then, attempt to reproduce this motion as best you can, using the motion detector. **Create** the plot! When you have a plot that is close and you are satisfied with the result, follow the procedure in step 8 for copying and pasting this plot into your Word document. This will be _Graph #4_.



13) Double-click anywhere on the graph. This will display a dialog box. Click on “Axes Options”. Select *velocity* for the vertical axis and set the range from *-2 to +2* m/sec. Change the *time* scale to read *0 to 5* s. Look at the graph and verify that the changes you selected were implemented. Check with your TA before proceeding to the next step if you are unsure.

14) For this last exercise, attempt to **Create** a velocity versus time plot that shows the “moving student” moving with a constant acceleration, similar to Figure 4.1(b). What feature(s) is(are) required here? When you have a plot that you feel illustrates an accelerating object and you are satisfied with the result, follow the procedure in step 8 for copying and pasting this plot into your Word document. This will be *Graph #5*.

15) Once all five of your Graphs are in the Word document, examine them and be sure they are sized how you would like them for your lab report. Be sure that the numbers on the axes are clearly visible in each graph because you will need to see them for analysis! You should also type a label below each graph, labeling them (i.e. “*Graph #1*, *Graph #2*, …). **Print** 2 copies (one for each lab partner). You might also save your Word document electronically by using Myfiles, a flash drive, or by emailing yourself the results.

As always, be sure to organize your data records for presentation in your lab report, using tables and labels where appropriate.

Data Analysis

Question 1: Consider your *Graph #1*. In what way is your plot indicative of a person who is not moving?

Question 2: Consider your *Graph #2*. Did the student move at a constant velocity from the 0.5 m tape mark to the 2.5 m tape mark? How can you tell? What is the slope while the student is moving? Is the velocity positive or negative?

Record the value of your constant velocity and label this as v_2.

HINT: As always, support your results by showing your calculations. In this case, it is appropriate to draw on your graph to indicate how you found the slope, as in Figure 4.1.

Question 3: Consider your *Graph #3*. Did the student move at a constant velocity from the 2.5 m tape mark to the 0.5 m tape mark? How can you tell? What is the slope while the student is moving? Is the velocity positive or negative?

Record the value of your constant velocity and label this as v_3.

Question 4: Consider your *Graph #4*. How well did your graph match the expectation you plotted in step 11 of the procedure? Describe what might have made it more difficult to get the motions exactly correct, and how you can tell you deviated from the expectation.

Record the value of your velocity in each step of the 3 steps of the motion from your graph.

Question 5: Consider your *Graph #5*. Did the student exhibit constant acceleration in the graph? How can you tell? Is the velocity increasing or decreasing? Describe what is happening to the velocity in the graph.

Calculate and record the constant acceleration from your graph (using Eq. 1).

Error Analysis

Look back to steps 9 and 10 in the procedure. There were very specific motions desired in each of those cases for creating *Graph #2* and *Graph #3*. Calculate the expected velocity for each of those motions and label them v_{exp2} and v_{exp3} respectively.

Then, calculate the percent difference between your actual velocities, v_2 and v_3 (from your graphs), and the expected value in each case.

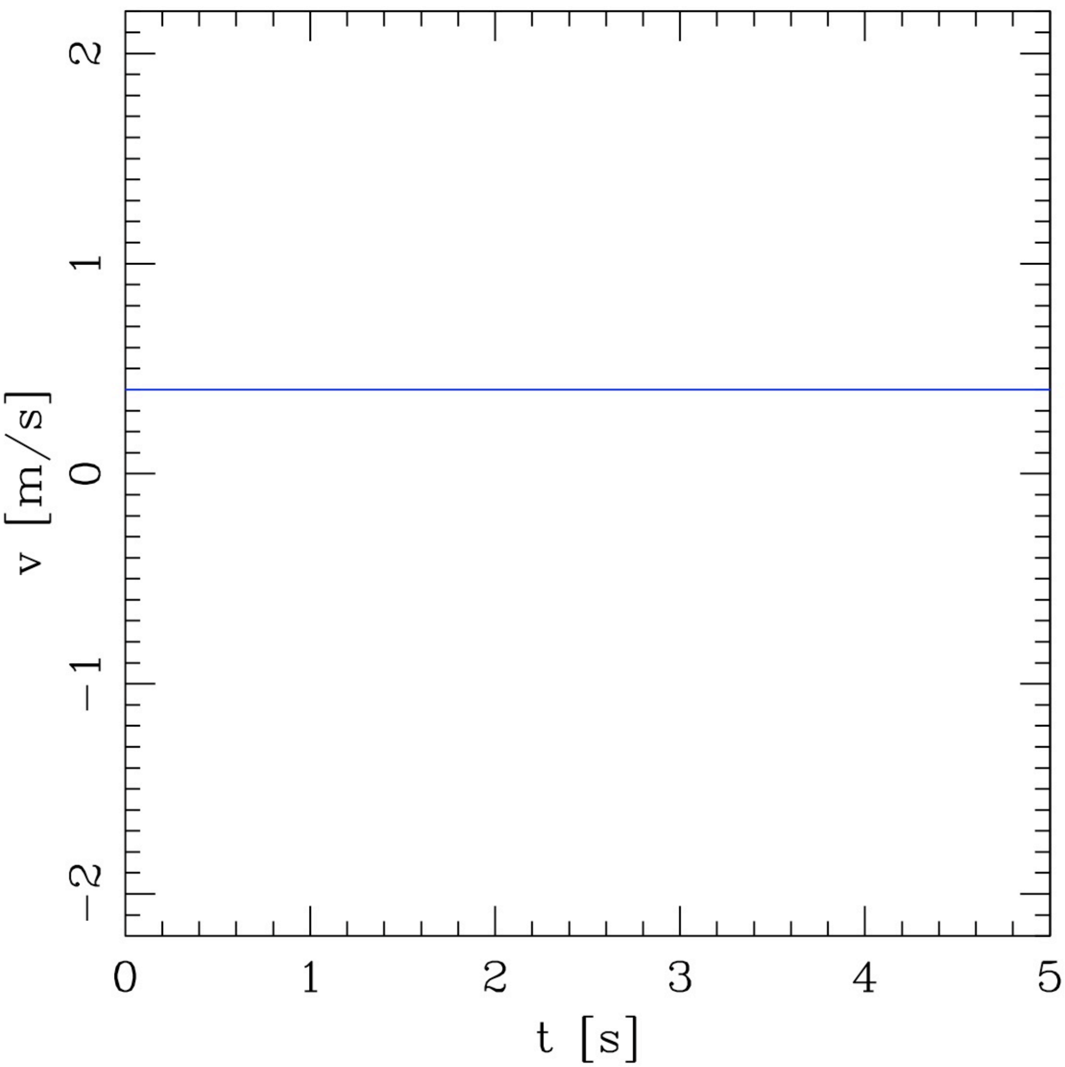
Questions and Conclusions

Be sure to address Questions 1-5 and describe what has been verified and tested by this experiment. What are the likely sources of error? Where might the physics principles investigated in this lab manifest in everyday life, or in a job setting?

Pre-Lab Questions

Please read through all the instructions for this experiment to acquaint yourself with the experimental setup and procedures, and develop any questions you may want to discuss with your lab partner or TA before you begin. Then answer the following questions and type your answers into the Canvas quiz tool for “Motion II,” and submit it before the start of your lab section on the day this experiment is to be run.

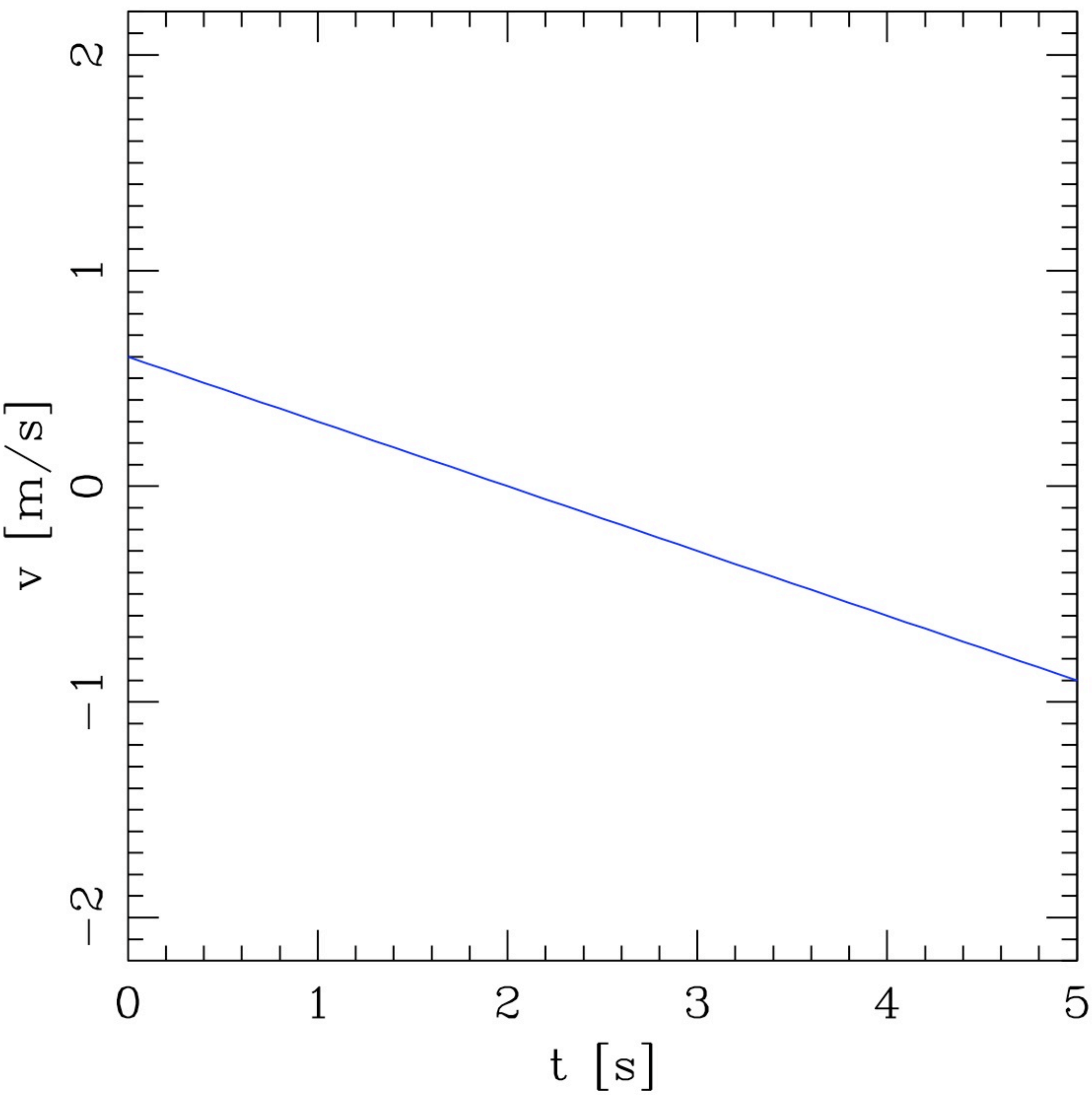
PL-1) A student is performing the “Motion II” experiment. She is moving along the *x*-axis according to the following velocity *vs.* time plot.



The student is

- (A) not moving (at a fixed position),
- (B) moving at a constant speed in the +*x* direction,
- (C) moving at a constant speed in the –*x* direction,
- (D) accelerating in the +*x* direction,
- (E) accelerating in the –*x* direction.

PL-2) A different student moves along the *x*-axis and creates the following velocity *vs.* time plot.



The student is

- (A) not moving (at a fixed position),
- (B) moving at a constant speed in the +*x* direction,
- (C) moving at a constant speed in the –*x* direction,
- (D) accelerating in the +*x* direction,
- (E) accelerating in the –*x* direction.

PL-3) Consider again our student moving along the *x*-axis with the velocity vs. time plot shown in PL-2. Calculate the student's average acceleration, in m/s^2, over the 5-sec interval. *[Note: if your answer includes a negative sign, your browser may display a red warning saying "only numerical values accepted" -- please ignore this warning.]*

PL-4) Jenny performs the "Motion II" experiment, making the following motions over a total span of 3.0 s: She starts from rest and moves away from the detector for 1.0 s, when she reaches a speed of 2.0 m/s. She then slows down to 0.0 m/s by the end of the next 1.0 s, and then moves back toward the detector, increasing her speed to 1.0 m/s by the end of the next 1.0 s. What is her average acceleration, in m/s^2, over the interval from **0 to 2 s**? Assume the positive *x*-axis points away from the detector. *[Hint: use the definitions in the experiment procedure for positive and negative velocity; ignore any red "only numerical values accepted" messages.]*

PL-5) Still considering Jenny's motion from PL-4, what is her average acceleration, in m/s^2, over the **entire** 3.0 s interval (t = 0-3 s)? Assume the positive *x*-axis points away from the detector. *[Reminder: She starts from rest and moves away from the detector for 1.0 s, when she reaches a speed of 2.0 m/s. She then slows down to 0.0 m/s by the end of the next 1.0 s, and then moves back toward the detector, increasing her speed to 1.0 m/s by the end of the next 1.0 s.] [Ignore any red "only numerical values accepted" messages.]*