Motion I

Goals and Introduction

As you have probably already seen in lecture or homework, 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 position of an object versus time.

Examples of *position vs. time* plots are shown in Figure 3.1. An object's *position* (x) is its location at a particular time. By tracking the location of an object relative to some origin, as time goes on, we can plot the position as a function of time. This is represented by the red lines in each of the figures. The *displacement* an object experiences is the change in the object's position (Δx) over a certain time interval (Δt). We could choose any two points along any of the red lines and calculate the displacement from one time to the next. In a scenario where an object does not move and its position is constant, the displacement is always 0. This is depicted in Figure 3.1(a). Note that a horizontal line on a position versus time graph represents an object that is not moving.

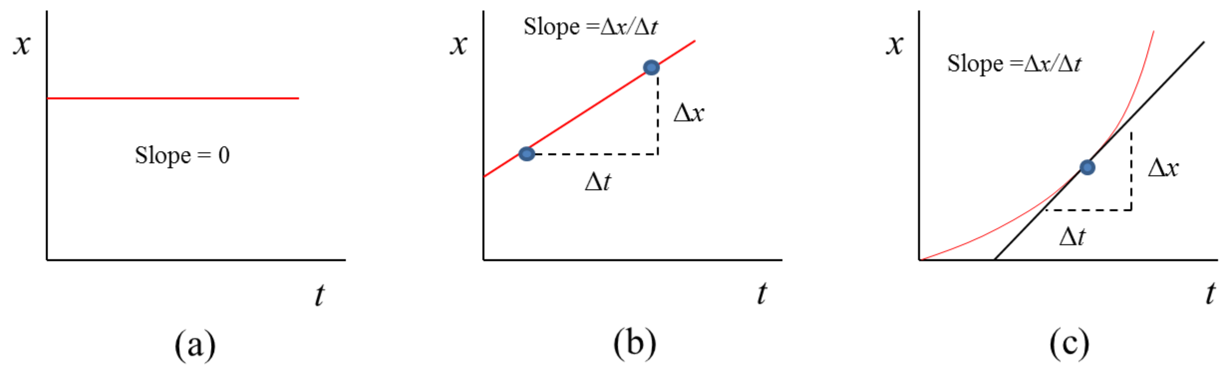


Figure 3.1

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 here! These plots represent physical measurements, with time on the horizontal axis (run), and position on the vertical axis (rise). The "run" is the time interval between two points and the "rise" is the displacement of the object. This means that when we calculate the slope of a line on a position vs. time graph, we are calculating a quantity with units of m/s, in SI units (or rise/run). When applied to two points along the red line representing the object's position, the slope is the *average velocity* the object must have had between those two points (Eq. 1). Note that this does not necessarily mean the object had that exact velocity at any moment – it just means that to go from the first position to the second in that time interval, the object must have been moving with some average amount of velocity.

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

Consider the position vs. time plot in Figure 3.1(b). Like Figure 3.1(a), the plot is a straight line with a constant slope, but here the slope is some positive amount, whereas the slope in Figure (a) is 0. The relationship between position and time in Figure 3.1(b) is linear. In cases where the slope is constant, the slope, or average velocity, actually represents the velocity 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 position is constant. No matter which points you choose, you will calculate the same slope. The actual velocity of an object at any instant in time, is the *instantaneous velocity* at that time. We can say the instantaneous velocity is equal to the average velocity in cases where an object's position vs. time plot is a straight line.

You may recall from class that objects can also experience changes in velocity. You acquired a velocity in order to arrive at class, and lost that velocity once you arrived. Figure 3.1(c) illustrates how the position vs. time plot is different when an object is changing velocities. Note that the red line, representing the object's position, is now a curve, along which the slope is constantly changing! If the slope is changing the velocity must also be changing – or we say there must be an *acceleration*. 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 velocity of the object at that moment in time. We can say that when the plot of an object's position vs. time is a curve, the object is accelerating.

Realize that the plots in Figure 3.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 3.1(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 velocity of the object from moment to moment. What is happening to the slope on the position vs. time graph? What does it mean is happening if an object's position vs. time graph looks like a sine function?

In this lab, you will use a range finder (position detector) connected to a computer to collect data on the position of yourself 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 position vs. time plots.

Goals: (1) Be able to define and understand the relationships between position, velocity, acceleration and time.

(2) Consider the position vs. time plot for an object's motion and understand its creation, and its analysis.

Procedure

Equipment – range finder, computer with the DataLogger interface and LoggerPro software, masking tape, meter stick or tape measure, Microsoft Word.

WARNING: The range finder will not properly record the position of an object that is closer than 0.5 m. The position recorded is the distance between the range finder and you (the object in this experiment. Thus, BE SURE that you are always at least 0.5 m away from the range finder during your motions.

The range finder is at the origin in the coordinate system (or $x = 0$), so your position should always be 0.5 m or greater (see the warning above). The positive x axis runs out away from the detector so you will always be at a positive position away from the detector (say 0.9 m, for example). If you move away from the detector, your position will be greater, (say 1.2 m now, for example). If you move closer, your position will decrease.

Lastly, the range finder "sees" the closest object in its observational cone of about 15° around a centerline directly in front it. Be sure this zone is free of extraneous objects and motions while taking readings. Avoid stray hands or objects that might cause the range finder to "lose sight" of the person moving back and forth.

1) Check to see that the range finder 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 this **LoggerPro link**. A blank graph with axes labeled *position* (m) *vs. time* (s) should appear on the screen.

3) You will need about a 2 or 3 m region to walk back and forth in order to use the range finder to create plots of position. At the beginning, have one lab partner operate the computer and the other take on the role of the moving object. Place the range finder on the desk and aim it away from the desk towards a region where the "moving student" can walk back and forth.

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.

4) 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.

5) 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.

6) Begin by having the "moving student" stand motionless at the location of the 2.5 m tape mark. 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 red line being drawn on the position vs. time plot, indicating the position of the "moving student". Hit the *red* button (where the green button was) to end the data collection. Is the line at a position of 2.5 m? To calibrate this, the student operating the computer should nudge the range finder forwards or backwards until the red line appears at a position of 2.5 m on the plot. This can be done while the range finder is collecting data.

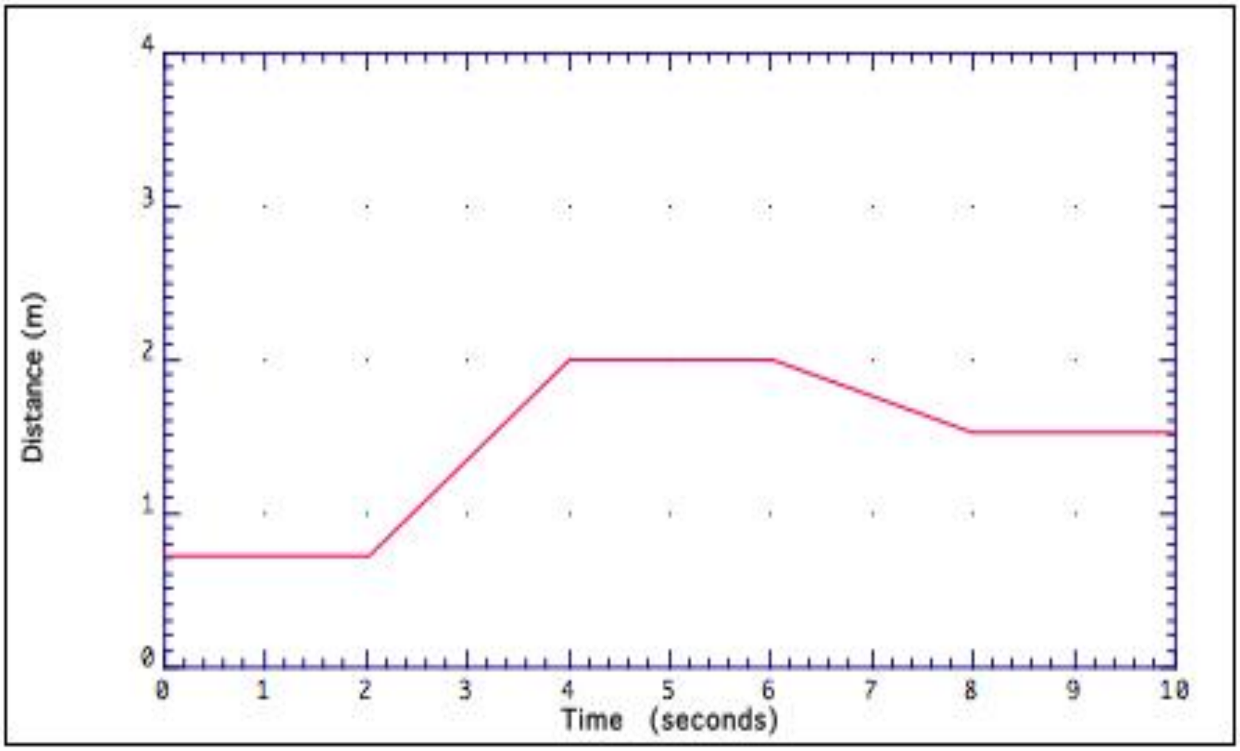
7) When you are satisfied with your calibration, **Create** a plot for an object that is standing motionless at a distance of 2.5 m from the range finder (similar to Figure 3.1(a)) – This will be *Graph #1*. Once you have a plot that looks correct in LoggerPro, go to the drop-down menu bar at the top 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. You should probably 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.

8) 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 exactly 2 s, moving at a constant velocity. Take turns taking on the role of both the "moving student" and the computer operator so you experience both aspects of the experiment. **Create** a plot for this motion! This will be *Graph #2*. When you think you get a good plot that shows a student completing this motion, follow the procedure in step 7 for copying and pasting this plot into your Word document.

9) 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 exactly

2 s, moving at a constant velocity. 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 get a good plot that shows a student completing this motion, follow the procedure in step 7 for copying and pasting this plot into your Word document.

10) Go back to the LoggerPro window and consider the motion depicted in the plot below. Attempt to reproduce this motion as best you can. **Create** the plot! When you have a plot that is close and you are satisfied with the result, follow the procedure in step 7 for copying and pasting this plot into your Word document. This will be *Graph #4*.



11) For this last exercise, attempt to **Create** a position versus time plot that shows the "moving student" accelerating, similar to Figure 3.1(c). 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 7 for copying and pasting this plot into your Word document. This will be *Graph #5*.

12) Now it is your turn to be creative. **Create** a plot of a more complicated set of motions along the line toward and away from the range finder, staying between the 0.5 and 2.5 meter marks. Carefully describe the motion in words (e.g., "I walked quickly toward the 0.5-m mark, gradually slowed and reversed direction, speeding up until I stopped abruptly at the 2.5-m mark."

You will analyze this motion in the Data Analysis section. Follow the procedure in step 7 for copying and pasting this plot into your Word document. This will be <u>*Graph #6*</u>.

13) Once all 6 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 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.

<u>Data Analysis</u>

Remember that you should answer the **Questions** in the Questions and Conclusions section.

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? Is the slope positive or negative? Is the velocity positive or negative?

Choose two points on the line for the motion in *Graph #2*. Use these two points to compute the average velocity of the student (Eq. 1). Note this quantity as v_2.

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? Is the slope positive or negative? Is the velocity positive or negative?

Choose two points on the line for the motion in *Graph #3*. Use these two points to compute the average velocity of the student (Eq. 1). Note this quantity as v_3.

Question 4: Consider your *Graph #4*. How well did your graph match the original? Describe the motions that should be required to reproduce that graph, and what might have made it more difficult to get exactly right.

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

Consider your *Graph #6*. What was the largest and smallest distance from the range finder? Mark these points on your *Graph #6* as points *A* and *B*.

What is the average velocity of the student over the time interval between points *A* and *B* on your *Graph #6*? Show your calculations.

At what point between points *A* and *B* on your *Graph #6* did the moving student have the fastest instantaneous velocity? Mark this point on your *Graph #6* and label it *C*. Was the student moving toward or away from the range finder at this point? Explain how you know the direction.

Error Analysis

Look back to steps 8 and 9 in the procedure. There were very specific motions desired in each of those cases for creating *Graph #2* and *Graph #3*. Calculate the expected average velocity for each of those motions, using Eq. 1, and label them v_{exp2} and v_{exp3} respectively.

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

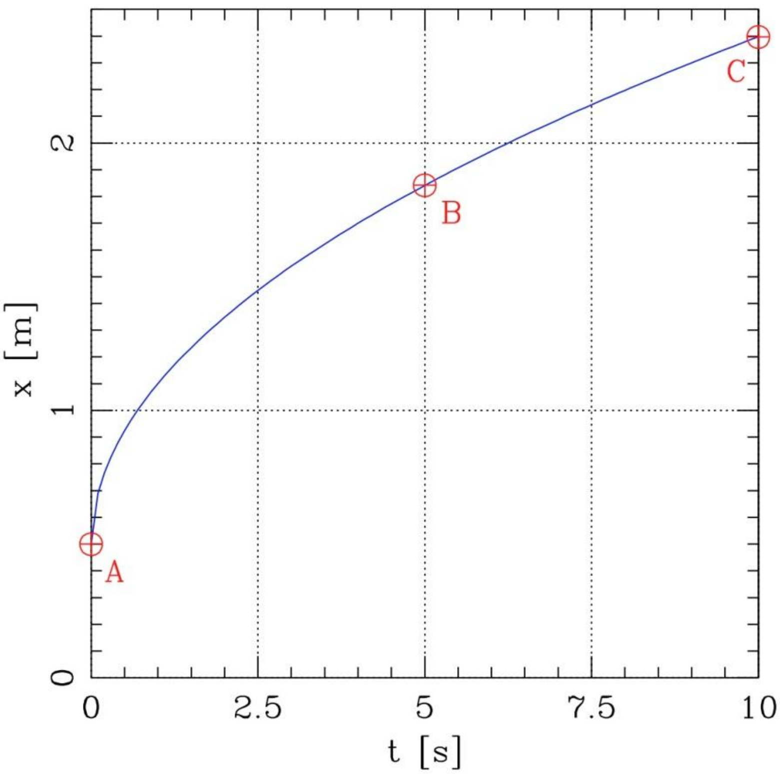
Questions and Conclusions

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 Motion I 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 I, and submit it before the start of your lab section on the day Motion I is to be run.

Ron and John are experimenting with different motions while doing the "Motion I" experiment. The figure shows Ron's motion over a 10 second interval. *[Use this plot when answering questions PL-1 to PL-3].*



PL-1) During the 10-s interval (t = 0-10 s), Ron is

- (A) accelerating (velocity is increasing, Ron is speeding up),
- (B) accelerating (velocity is decreasing, Ron is slowing down),
- (C) moving at a constant velocity (acceleration is zero),
- (D) not moving (velocity is zero).

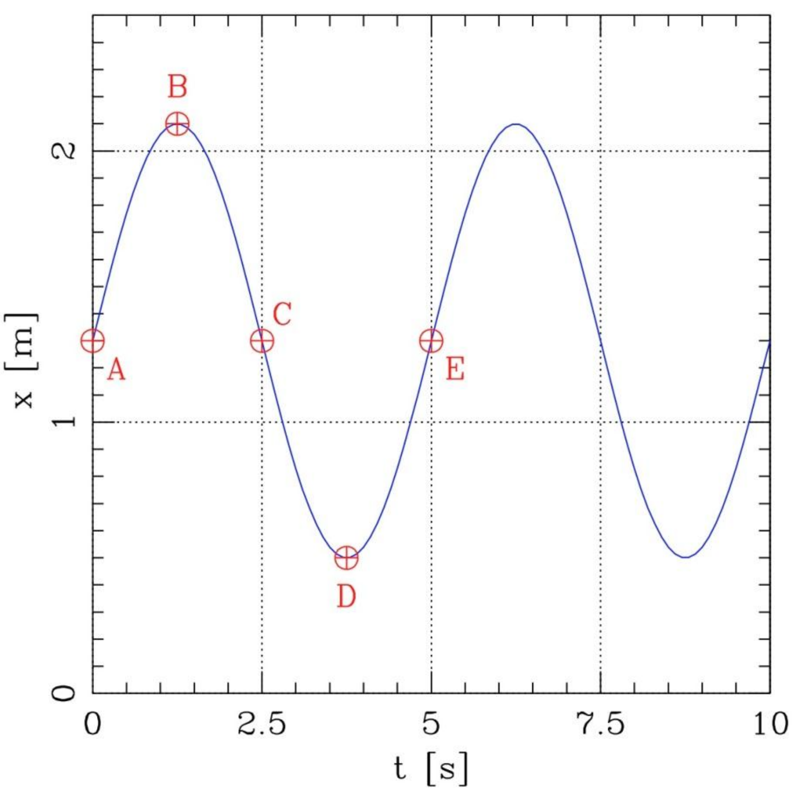
PL-2) At which point is Ron moving the fastest during the 10-s interval (have the largest instantaneous velocity)?

- (A) At point A,
- (B) At point B,
- (C) At point C,
- (D) None of A, B, or C.
- (E) We can’t tell from the given information.

PL-3) What is the average speed, in m/s, over the 10-s interval between points A and C?

PL-4) Ron is moving within the field of the range finder while John watches the motion graph appear on the computer screen, as shown in the following plot. At which of the point(s) does Ron have zero instantaneous velocity? *[Reminder: the range finder is at x=0]*.

- (A) Point A,
- (B) Point B,
- (C) Point C,
- (D) Point D,
- (E) Point E,
- (F) Points B and D,
- (G) Points A, C, and E.



PL-5) Ron is moving within the field of the range finder while John watches the motion graph appear on the screen, as shown in the following plot. At which of the labeled points is Ron closest to the range finder? *[Reminder: the range finder is at x=0]*.

- (A) Point A.
- (B) Point B.
- (C) Point C.
- (D) Point D.
- (E) Point E.