Lab 1

Representing Motion

Continuing Objectives

6. Be able to make a good graph either in your notebook or with a computer (label, scales, units, dependent, and independent variables).

8. Use a computer to collect and analyze data.

Lab-specific Objectives

1. Analyze motion graphically, mathematically, and physically.

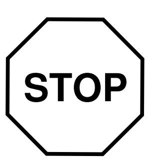
2. Learn the relationships between position, velocity, and acceleration.

3. Learn to use Excel to prepare graphs of position-time and velocity-time.

Introduction

One of the main components of studying physics is the act of observing nature and making testable theories that describe it. This is often done by determining quantitative rules that govern the world around us.

Think of some physical phenomena specfically relating to motion that you encounter in your day-to-day life. What steps do you think you would have to take to explain them quantitatively?



Take a minute to think about the above prompt. Discuss any thoughts with your partner and take notes of the conversation. Share how you would approach explaining an everyday physical phenomenon quantitatively with your instructor or TA.

In this lab, you will use the LabPro interface and Logger *Pro* software with a specific measuring device called a motion sensor to collect data. You will then export that data to Excel to explore the definitions and relationships between the various quantities associated with the motion of an object.

Procedure

Using LabPro

We will begin by familiarizing ourselves with the Logger *Pro* interface and the Logger *Pro* software.

1. Log into the computer and then navigate to the `211Lab` folder which is located within the `PHYS 211_212 Lab` folder on the Lab PC desktop.

2. From the `211Lab` folder click on `1 Representing Motion` and double click on the file `211mot.cmbl`. The screen should display the Logger *Pro* interface.

The motion sensor

Before we begin collecting motion data, we will first need to understand what the motion sensor does and how it does it.

1. Click the `Collect` button and move around in front of the sensor. Work with your lab partner to explore how your movements relate to the data being displayed in the top graph ("Position"). You can click the `Collect` button again to take new data once Logger *Pro* finishes a particular run. There is a white foam board on the table that you may want to use during your experiments. Why might using this help?

   Now respond to the following questions in your lab notebook.

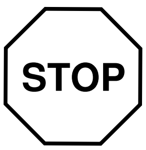
   (a) When you or your partner hits `Collect`, is there anything you notice about the sensor as it takes data? How might this relate to how the sensor works?

   (b) What did the graph for "Position" look like when you moved away from the sensor? What happened when you moved towards the sensor? What point does the sensor define as "Position"= 0? (*To fully utilize the graphical display, you may need to adjust the range of values displayed on the screen. To do this, click on the largest value displayed on an axis. When that number is highlighted, you may change it by typing in a new one and hitting Enter.*)

   (c) Are there regions in front of the sensor where it fails to make good measurements? Why? Later on, you will want to make sure you're inside the region where it makes reliable measurements.

2. Based on your experiments above, develop an explanation for how the motion sensor works and record it in your lab notebook. Feel free to conduct any other experiments to help with this.

Remember: keeping a ***detailed*** *lab notebook will help you think clearly and maintain a log of your exploration. Use it to record anything you think is useful and worthy of note; you will often refer back to notes from previous labs throughout the semester.*



Discuss your results so far with your instructor or TA. Ask them questions if anything is still unclear!

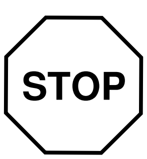
3. Click on the Position plot. In the toolbar at the very top of the window, go to `Analyze` and select both `Examine` and `Tangent`. A small dialog box will appear on the Position plot which will display the position and slope of the curve at any time point where you hover the cursor.

4. Click on the Velocity plot and select `Examine` and `Tangent` for it. You should see the tangent line for both plots follow your cursor, so that the two dialog boxes display information for the same time point on both plots. What values are the same or different between the two plots? Why does this make (or not make) sense?

Understanding motion

Now that you understand what data the motion sensor records, we will use it to understand the relationships between the data and physical movement.

1. To check your understanding of the relationship between a position vs. time graph and actual motion, close the current Logger *Pro* file and open the file called `211mat-d.cmbl`. The computer will display a position vs. time graph. You and your partner are to try to walk in such a way that you match the position vs. time graph. But first . . .

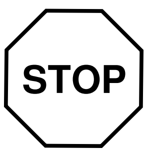


Predict how you will have to move. Discuss your predictions with your instructor or TA.

2. Now press the `Collect` button and try to match the given position vs. time graph. If you don't succeed right away, try again until you get a reasonably good match. You may want to use the `Store Latest Run` feature under `Experiment`. Print a copy of your best results (the Windows keyboard shortcut is `Ctrl+P`) for your lab notebook. Be sure that both you and your partner attempt this task.

3. In your notebook, write a brief description of how you identified the actual motion required to reproduce the given position vs. time graph. Compare this with your prediction and discuss any discrepancies.

4. Now repeat this process with the file `211mat-v.cmbl`, which allows you to try to match a velocity vs. time graph. Again, print your best result and record something about your thought process and why this exercise was easier or harder than the position match that you just completed.



Show the results of your best position and velocity matches to your instructor or TA.

Analyzing motion

Next week (and in many labs this semester), we will use **Excel** to collect and analyze experimental data. To familiarize ourselves with this program, we will now export a set of data taken in Logger *Pro* to Excel where we can use Excel's many tools to determine mathematical relationships between position and velocity.

Excel Basics

1. First, open Excel. Either open the `Start` menu (press the Windows key on the bottom left of your keyboard or click the Windows symbol on the left side of the Search bar at the bottom of the screen) and locate the icon there, or type `Excel` into the Search bar to find the icon. Once Excel has launched, open a blank workbook.

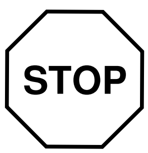
2. When starting a new Excel sheet, it's always a good idea to format it in such a way that it is easily readable by anyone. Put the experiment name in the first cell (`A1`) and hit `Enter`. Enter your name and your partner's name in the next cell below (`A2`), followed by today's date in the cell under your names.

3. Before continuing, you should save your work. Go to `File` and then `Save As`, and save the workbook in your own public netspace folder, which can be found

under `This PC`–look for your own Bucknell username. Do not save the file to the Desktop or anywhere else, or it will be deleted when you log out of the computer at the end of the lab. Once you have saved your workbook to your own netspace, remember to save your work regularly as you make changes to the workbook. The keyboard shortcut for this is `Ctrl+S`: use this often, as Excel could crash at any time.

4. Return to Logger *Pro*, open the file `211mot.cmbl`, and use the motion sensor to generate some new data that consists of some more complex-looking (and interesting) curves.

5. To obtain a copy of your time and position data from Logger *Pro* go to the 'Insert' drop-down menu and select 'table'. Select *ALL* of the collected data for those two variables and copy it with `CTRL+C`. Select an empty cell in your Excel workbook and paste the data there with `CTRL+V`. You should now have columns of your collected data in Excel for time (s) and position (m). **Make sure to label your data columns accordingly!**



Show your Excel workbook to your instructor or TA.

Plotting in Excel

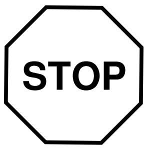
Let's try making a position vs. time plot in Excel using the imported data. Making plots from data is a common task that we will repeat in future labs.

1. To plot data in Excel, first highlight the data. You may do this manually with the mouse, or by clicking the first cell of your desired column and holding `Ctrl+Shift` and the `Down` arrow key. To select a second column of data, keep holding `Ctrl` as you click on its first cell, and then `Ctrl+Shift+Down` again. Next, find the `Insert` tab, followed by the `Charts` section. This will give you multiple options for types of graphs to make. The one we will *always* use is the **Scatter plot**, which places one dot for each pair (x, y) in the data, so select that now.

2. Compare the resulting position vs. time graph to the one produced in Logger *Pro*. Make sure that the graph looks the same and that Excel has plotted the correct quantities on the appropriate axes. Of the two columns you have selected, Excel will typically assume that the leftmost one is the x-axis, and the rightmost one is the y-axis, regardless of which order you highlight

the columns. If you need to edit the plot, right-click on the graph, choose `Select Data` from the menu, and edit the data series.

3. Now, explore the `Chart Elements` menu by clicking on the + icon on the right side of the graph. This will give you options for additions to the plot. Add axes titles to your graph so that others can understand what you have plotted here, as well as for your own records.



Show your plot to your instructor or TA, and then print it and include it in your notebook.

Performing calculations in Excel

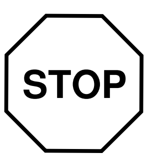
At this time, switch seats with your partner so you both have the chance to work with Excel. Now, do the following exercises.

In the lab, one of the main purposes of Excel is to evaluate equations and mathematical functions. To prepare Excel to perform a calculation in a cell, begin by typing the equals sign, =. After that, you can manipulate numbers in the way that you probably expect: add using the + symbol, subtract using the - symbol, multiply using the * symbol, and divide using the / symbol.

Try this out now by performing some calculations on your data in Excel to understand how position and velocity are related.

1. Create a new column on the Excel spreadsheet. In the cell to the right of the one that is labeled "position (m)" type the label "calculated velocity (m/s)". It's important to always denote what type of data a column holds and the units for those data.

2. Think back to the position vs. time and velocity vs. time graphs you explored in Logger *Pro* and how they were related. What sort of calculation could be made using position and time data to construct velocity data?



Discuss your prediction with a TA or instructor. How can you obtain velocity from position and time data?

Hopefully you noticed that the change in position over the change in time is equivalent to the velocity. Another way of saying this is that the **slope** (or *derivative*) of the position at a particular time is equal to the value of the velocity at the same time. We can test this conclusion by calculating an approximate velocity from the position–time data and comparing it to the Logger *Pro* velocity data.

To obtain a rough estimate of the derivative using Excel, we will use the following relationship:

$$v \approx \frac{\Delta x}{\Delta t} = \frac{x_{\text{current}} - x_{\text{previous}}}{t_{\text{current}} - t_{\text{previous}}} \tag{1.1}$$

where x are position data points at time data points t. Note that, in our case, Δt is a *constant* time difference between consecutive data points and can be found by subtracting any two sequential time data points from each other.

We will use this fact to demonstrate a valuable feature of Excel: absolute referencing. This is useful when you are performing calculations in Excel which involve constants. It is good practice to reserve a specific region on your spreadsheet where you define all your constants. This is usually near the top.

3. Since Δt is the same throughout the data set, we can calculate it just *ONCE* and use that value as a constant in our calculations.

   Find a blank cell near the top of the data columns and label it "Delta t (s) =". In the cell directly to the right, calculate your data's Δt by subtracting some time data point from the one below it. Remember that all Excel formulae *must* begin with =. While typing in a formula which references another cell, you can select the cell by clicking on it or by using the arrow keys.

4. Now use the above formula and your constant Δt to find the first calculated velocity data point. Remember to put it under the column you labeled "calculated velocity (m/s)".

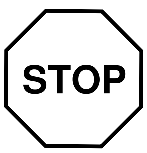
   You may find you cannot calculate the "first" data point, even with the first position and time data points, and need to start at the next cell down. Based on the formula we are using, explain why this is.

5. Now that you have an equation, you would like to repeat it in the next cell down, and then the next cell down, and so on. Excel is ideally suited to do this! To copy the equation into the next 'velocity' cell, hover over the bottom right corner of the cell with the equation you just made. Your cursor will change from a thick, white plus sign to a thinner, black one. Now, click-and-drag the cursor to the bottom of the columns of data. You can also double-click on the bottom right corner once your cursor has changed, and Excel will autofill for you.

Once you've done that, you may immediately notice that only the first calculation worked! The reason for this is Excel increases the cell number that you have referenced for each new line: if you referenced cell `C1` in your first equation cell, the next cell will reference cell `C2`, etc. Look at the formula in each of the "calculated velocity" cells and verify this. **Talk to your instructor or TA if this does not make sense.**

Obviously, that's not desirable. We want Δt to remain constant. Thankfully, Excel has an easy way to do this called **absolute cell referencing**.

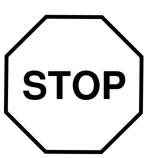
Absolute cell referencing **locks in** the referenced cell. Equations using that referenced cell can be copied anywhere in the spreadsheet without fear of altering the formula itself. To indicate to Excel when you wish to reference a particular cell–and only that cell–place `$` signs on either side of the letter coordinate of the cell to be referenced, e.g. `$C$1`. This is necessary when using a physical constant in an Excel formula. It also allows for easy changes to absolute referenced parameters (say, a test variable) without having to change every single cell's formula if the parameter needs to be updated. When possible in Excel, it is always best to avoid "hard-coding" in constants and parameters. Instead use absolute cell referencing to reference one easily editable cell.



Explain "absolute cell referencing" to your instructor or TA. When and why would you use it? How is it useful? Read the above paragraphs again if you are unsure.

6. Try entering the equation again for calculated velocity, this time being sure to use **absolute referencing** for Δt. Hover over the bottom right corner of the cell with the corrected equation, and click-and-drag down to get your new list of numbers.

7. Now try plotting your calculated velocity vs. time data in the same manner you plotted the position vs. time data. Compare your plot made in Excel with the Logger *Pro* velocity vs. time plot.



How do the Logger *Pro* plot and Excel plots compare? What does this tell you about your prediction about the relationship between position and velocity?

Reflection and Activity: Motion of a Basketball

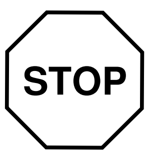
To further deepen your understanding of motion, an activity has been prepared at the back of each lab room. While you wait for the stations to open up, take a couple of minutes to include a reflection of today's lab in your notebook.

In particular, look back at today's lab-specific objectives described at the beginning of the lab.

1. What activities did you do today that helped understand those topics?
2. How has your understanding of those topics changed through today's lab?

When a station opens up, go to the rear of the lab room where you will see a basketball, a ramp, and a motion sensor. Take the basketball and give it a gentle push, so that it rolls up, and back down, the ramp.

1. **Predict** the motion of the basketball by drawing a position-time, a velocity-time, and an acceleration-time graph. Arrange these graphs vertically, one under the other, to line up the the time axes.



Discuss your predictions and graphs with your instructor or TA.

2. Now locate and open the file "211xva.cmbl". You will see that there are now three graphs. Re-roll the basketball (under similar conditions) and record this motion using the motion sensor.
3. Comment on the comparison between your predictions and measurement in your notebook. (What did you predict correctly? What surprised you, and does it continue to do so?) Sketch or print the data you collected in your notebook.

Write a conclusion for this lab, including a summary of your experiments and their results.