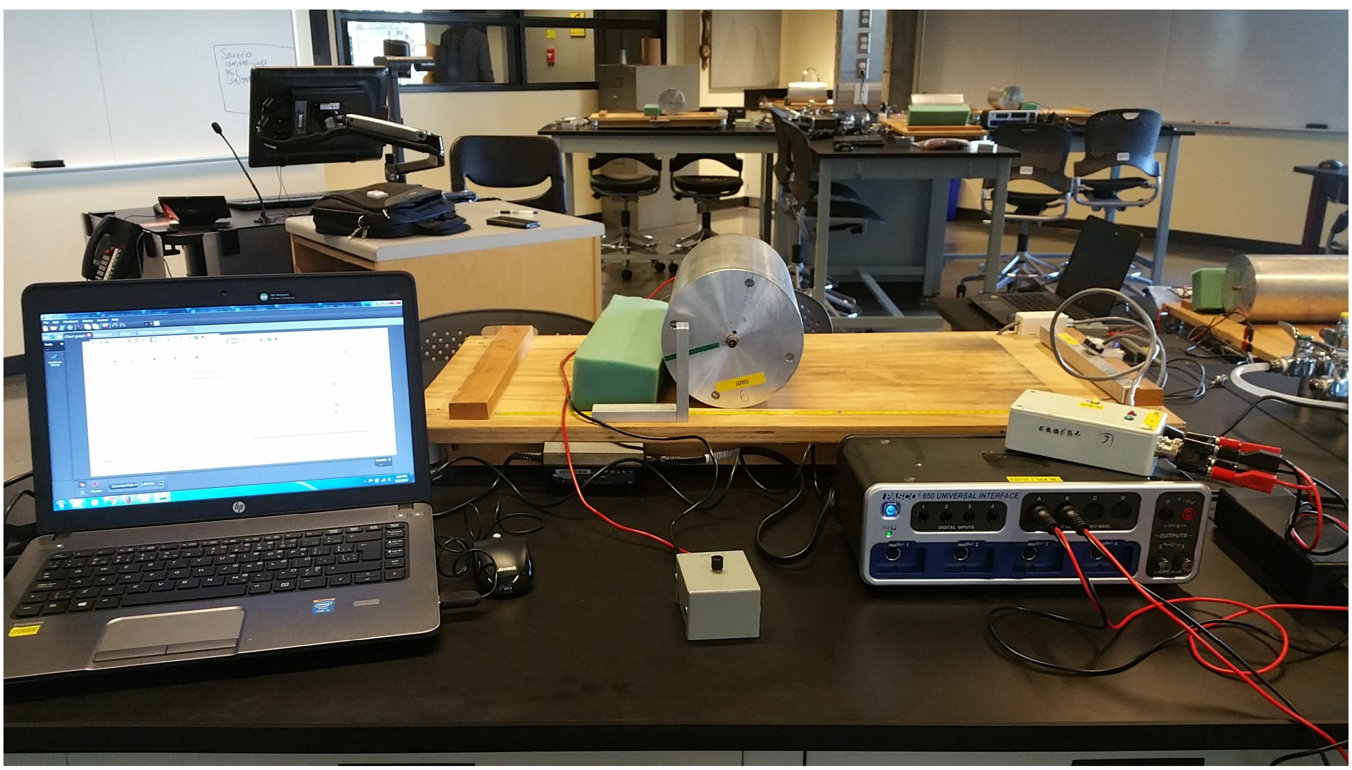
Lab 1

Statistics and Measurements

Introduction

This experiment introduces you to the statistical analysis of experimental data. Specifically, how to use the outcomes of repeated measurements to determine how precisely you can actually determine a measured quantity with the apparatus or instrument being used. Here we will be measuring two quantities; ‘rolling time’ and ‘distance’. We seek to answer the question, “how confident should I be in my measurements?” Or, put another way, “How uncertain am I about the true-value of the measured quantity?” You should read chapters 1 and 2 of your text (I. Hughes and T. Hase, *Measurements and their Uncertainties: A practical guide to modern error analysis* (Oxford University Press, 2010)) as well as this manual ***before*** coming to the lab

This lab will also introduce you to the use of the PASCO 850 Universal Interface and associated Capstone software. The PASCO unit is a simple, user-friendly, digital data acquisition system (DAQ) very similar to that used in research-grade physics labs. The PASCO unit will be used in several other PHYS257 experiments. A mini-lecture on the principals of digital data acquisition will be given at the start of the lab period.



The Physics

In this lab we will be studying one of the classic model systems of elementary classical mechanics; a cylinder rolling down an inclined plane.

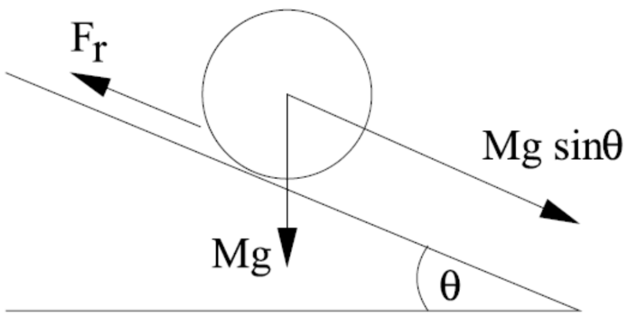


Figure 1) A cylinder rolling down an inclined plane.

Applying Newton's second law of motion at any point on the inclined plane, the acceleration, *a*, of a cylinder of mass *M* is given by:

$$Mg\sin\theta - F_r = Ma$$

Here F_r is the frictional force which ensures that the cylinder rolls (rather than slides) down the plane. If F_r and the plane angle, θ, are constant, the above result predicts that acceleration is also constant at every point on the plane. In this experiment we will test this prediction by comparing the average acceleration of the cylinder, a_{avg}, for different rolling distances, *x*. Applying the kinematic equations of motion to the particular case of a cylinder starting from rest yields:

$$a_{avg} = \frac{2x}{t^2}$$

Where *t* is the rolling time.

To determine a_{avg} you will measure the rolling time, *t*, taken for the cylinder to travel a (variable) distance, *x*, down a plane when the cylinder starts from rest. The rolling time, *t*, will be measured using 'manual' and electronic switches that are connected to the PASCO Universal Interface. The rolling distance, *x*, will be measured using a ruler mounted to the setup.

Procedure

1. Connect components as shown Figure 2. Have a technician or lab demonstrator verify the setup before turning the power on. In particular, verify that Chanel Aon the PASCO interface is connected to the green light of the homemade interface and Chanel B is connected to the red one.

2. Login to the laptop with your McGill username (email address) and password. Open the PASCO capstone file ('en0081.cap') on your laptop. The exact path to the file will be indicated on the white board in the lab. ***See Appendix 1 for a tutorial on using the software and using it to make rolling time measurements***

3. **'Automated' rolling time measurement (~50 cm)**. Measure the rolling time of the cylinder between the top switch and the bottom switch on the rolling board using the capstone software 20 times. The distance to the bottom switch is approximately 50 cm, but the precise number for your apparatus is given in one of the tabs associated with the capstone file. In order to have consistent measurements, you want to measure the switch-to-switch time with the cylinder in the same starting orientation. For example, make all your measurements starting with the green line (drawn on the cylinder) pointing vertically down towards the rolling board. ***Think about the role of the sampling rate in determining the precision with which you are able to make this measurement.*** Calculate the mean and the standard deviation for your data set as we described in lecture. Does the software find the same value for the standard deviation?

4. **Manual rolling time measurements (10, 20, 30 and 40 cm)**. Using the push-button switch provided as a 'stop watch', manually measure the time it takes the cylinder to roll 10, 20, 30 and 40 cm down the ramp. A right angle bracket is provided to help you mark these distance and "eye-ball" when the cylinder passes the required distance/point. Practice this measurement a few times before starting your data taking. That is what a good experimentalist would do!

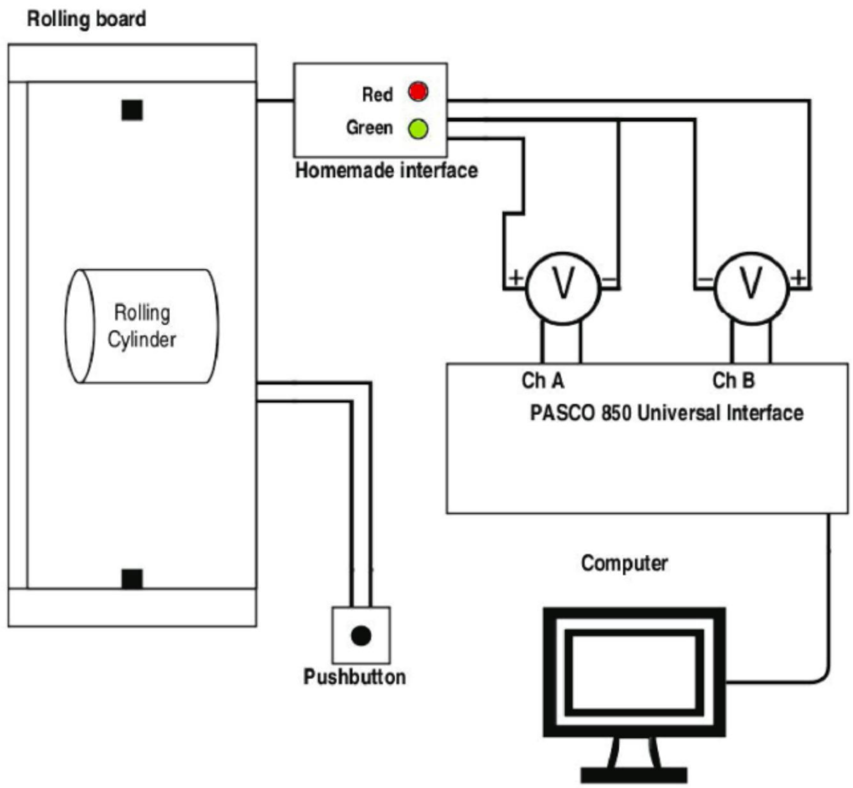


Figure 2) Schematic of the experimental setup

Analysis

1. **Plot a histogram* (by hand on graph paper provided)** for the data at a distance of your choice. Use a convenient bin width of approximately ½ σ (where σ is your best estimate of the standard deviation). Indicate the position of the mean and σ on the histogram. Superimpose (by hand) a Gaussian distribution on your histogram with the same mean, σ and total area as your data.

2. **Compare** the standard deviation of the manual measurements at 40 cm with the automated measurements made at ~50 measurements. Which measurement is more reproducible/precise? Comment on the difference. Assuming that systematic errors are absent, what effect does this have on the uncertainty in your measurement of rolling time at these distances? *Be quantitative in your answer, not vague and qualitative.*

3. **Calculate** the mean acceleration of the cylinder for each distance. Estimate the uncertainty on the mean acceleration at each distance based on your repeated measurements. **Tabulate** your results in a properly formatted table*.

4. **Plot a graph (by hand on graph paper)*** of the acceleration measured as a function of distance indicating your estimated uncertainty in each measurement with appropriate

error bars

5. **Test** the hypothesis that the acceleration of the cylinder is a constant, independent of the distance rolled. Compare your determination of a_{avg} for each distance with the mean of all your measurements computed using the method of weighted averages (see section 4.5 of your text). Indicate this mean value for a_{avg} and its uncertainty on your graph (point 3 above). Plot residuals from the mean acceleration for each data point (i.e. distance). Does your data support the idea that acceleration is a constant? Why or why not?

***Note: See the hand out on formatting tables and graphs posted to myCourses in the 'Hand Out' folder before plotting and tabulating you data for hand-in!**

Questions

1. Imagine you were designing this experiment from scratch with the goal of determining the most precise value of a_{avg}. Which of the measured quantities (x or t) needs to be determined to higher relative precision? Explain your reasoning. Note: relative precision is the uncertainty as a fraction (or percent) of the quantity itself. You may wish to consult Sections 4.2 and 4.3 of your text while thinking about this question.

2. Complete Assignment 1

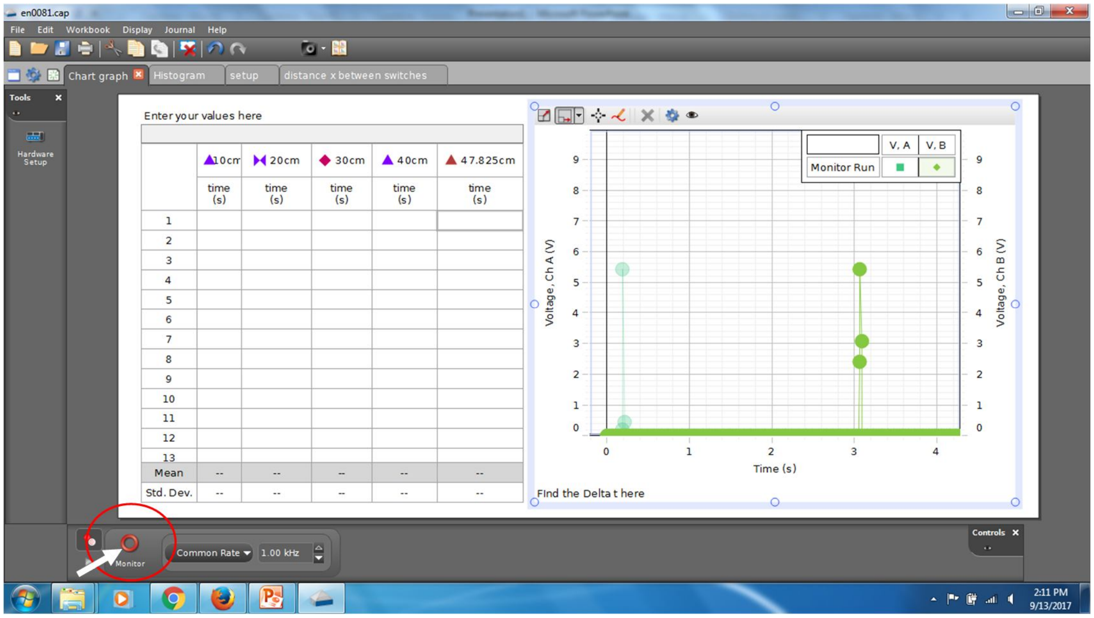
What should I hand in?

Your work must be well organized, clearly written (or word processed) and stapled or bound. Loose paper will not be accepted. Clear presentation is a requirement of good experimental work. ***It is also not in your interest to make your hand-ins difficult to mark***

1. Your raw data (rolling times at each distance) in a properly formatted table.
    a. **5 points**.
2. Your histogram (Analysis, point 1). Remember to suitably label your axes and provide an appropriately descriptive figure caption.
    a. **10 points**.
3. Your comparison of the manual and 'automated' measurements and the associated discussion.
    a. 5 points
4. Your properly formatted table of results, a_{avg} at each distance (Analysis, point 3). You must also include a sample calculation for each tabulated quantity and its associated uncertainty. ***Note: Sample calculations are a general requirement in PHYS257. This applies to all computed quantities in every hand-in assignment (not just to this quantity). You must always make it clear how you arrived at any result you report.***
    a. **5 points**.
5. Your plot of acceleration vs. distance. (Analysis, point 4). Remember to suitably label your axes and provide an appropriately descriptive figure caption.
    a. **10 points.**
6. Your discussion of point 5; i.e. Does your data support the idea that acceleration is a constant? Why or why not? **10 points**
7. Answers to Questions 1 **5 points**
8. **Assignment 1**

Appendix 1: Using the Capstone Software (file: "en0081.cap")

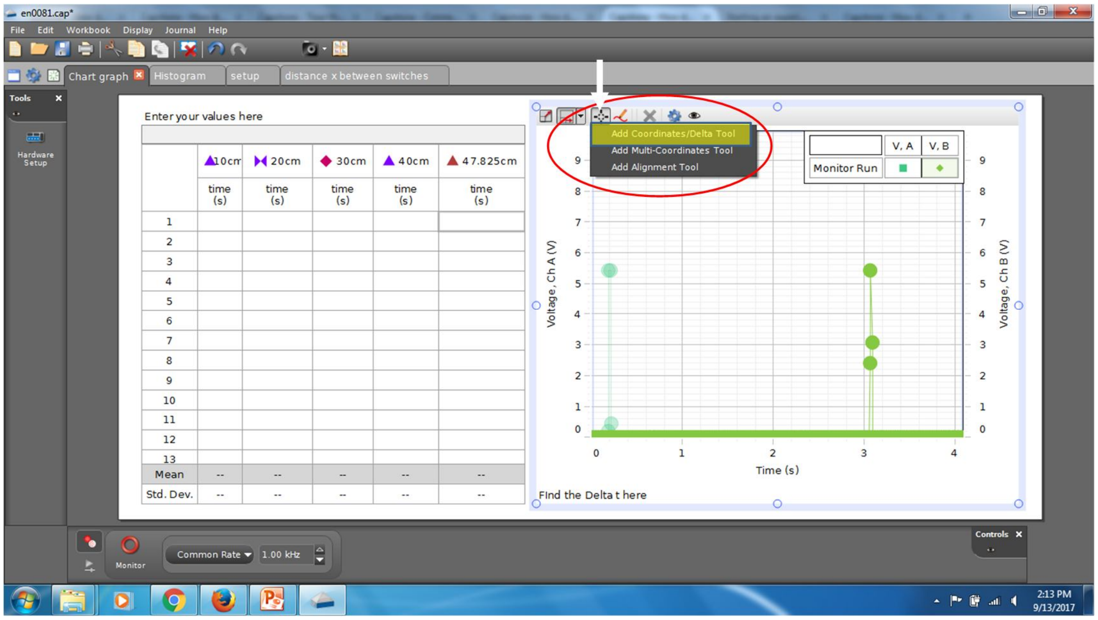
Open the file "en0081.cap". The Capstone software associated with the PASCO universal interface will open, displaying 2 windows as below. The right window displays signals traces from the switches that will be used to determine rolling-times. The left window provides a table you can use to record the data from each experimental trial.



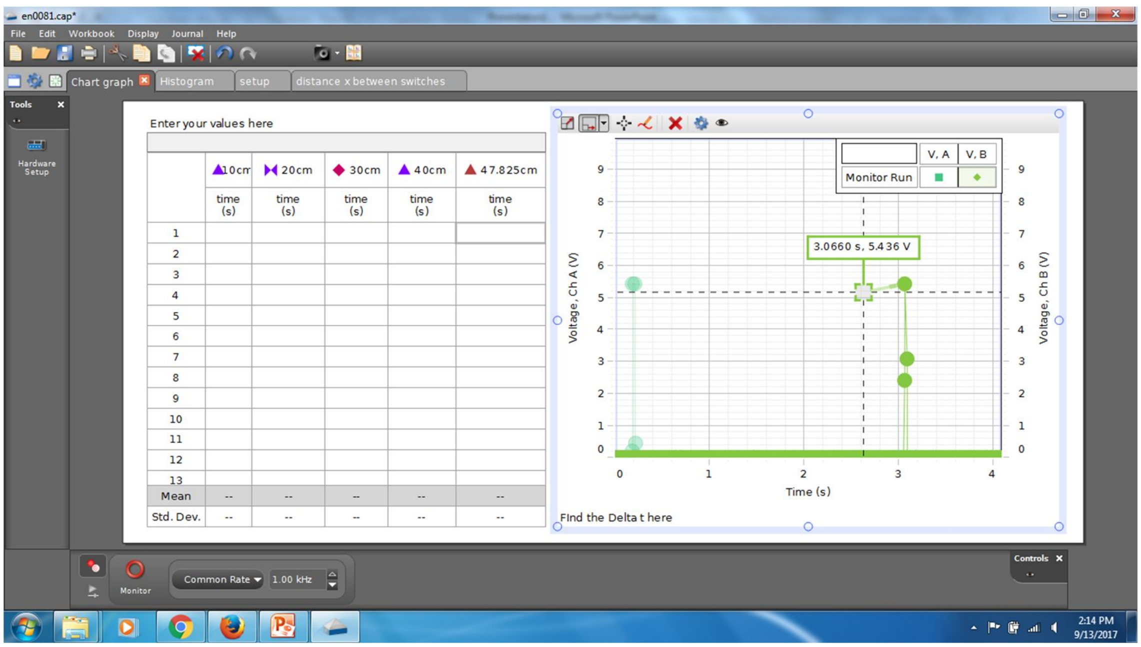
To start an experimental trial, click the "Monitor" button (indicated above) to start acquiring signals from the switches/home-made interface with the PASCO system. The "Monitor" button will change to "Stop" while PASCO is acquiring signals. ***Let go of the cylinder that is being held at the top of the ramp (against the top switch) soon after clicking the "Monitor" button***. Use the manual switch (or the switch at the end of the ramp) to make a "rolling time" measurement. ***Click "Stop" to end the signal acquisition as soon as possible after the second switch has been activated.***

In the right panel you can use the mouse wheel to scale the time-axis (i.e. x axis) range in the plot window. You can also move the traces left or right by left-clicking the mouse and dragging inside the figure. With a suitably chosen time-axis range, you should see (at least) 2 pulses as above.   Do you understand why? What is this trace/figure showing you? What are these pulses?

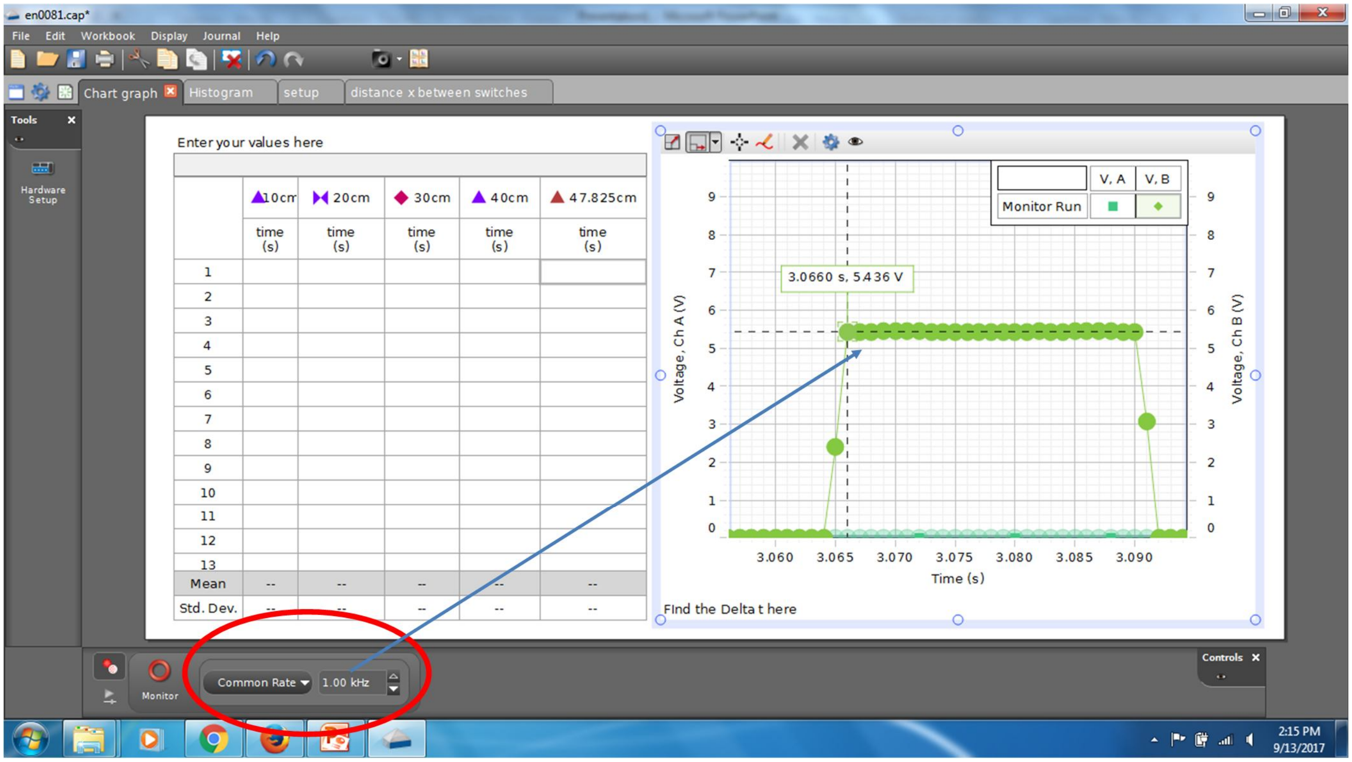
There is a ‘measurement tool’ that can be used to obtain coordinates directly off the plot. Click on the ‘cross-hairs’ in the top menu and select ‘Add Coordinates/Delta Tool’ as indicated below



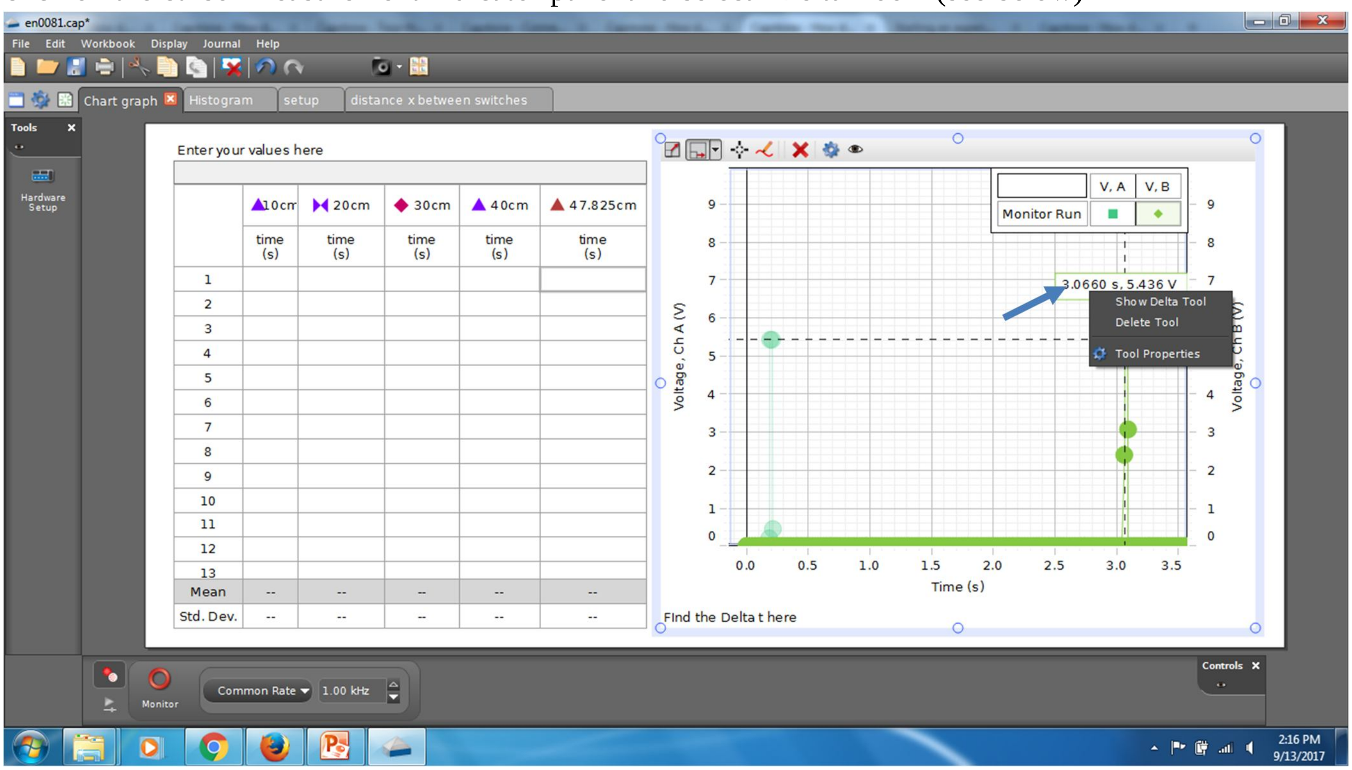
A cursor will appear in the window (as below) that you can drag with the mouse by left-clicking on it. This cursor will ‘snap’ to data points if you hold it to the left of them (as below) and let go of the mouse button.



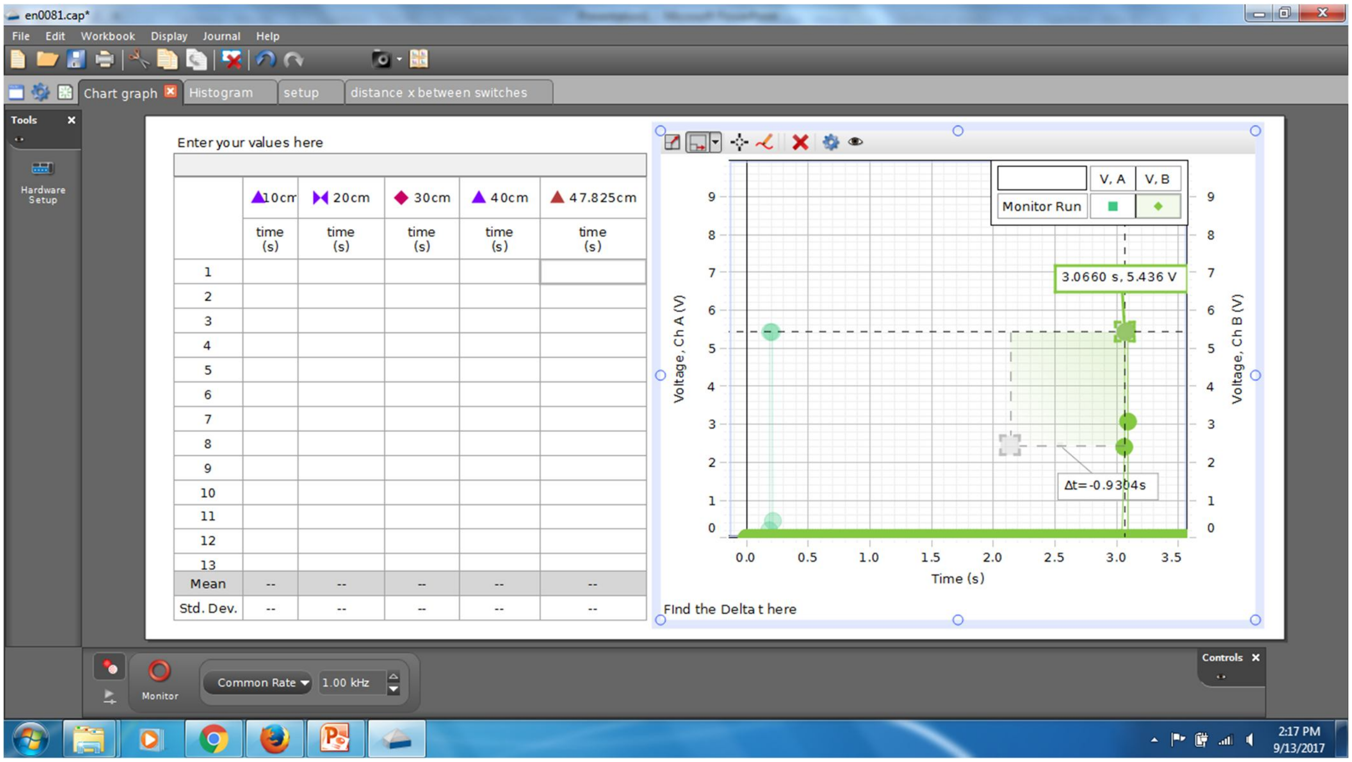
Again, you can zoom in on your signal traces using the mouse wheel to check to see where the cursor snaps to the data (see below). What point should you use for your timing measurements? Note the sampling rate being used (indicated in red). Does the spacing between points in the figure make sense based on the sampling rate setting?



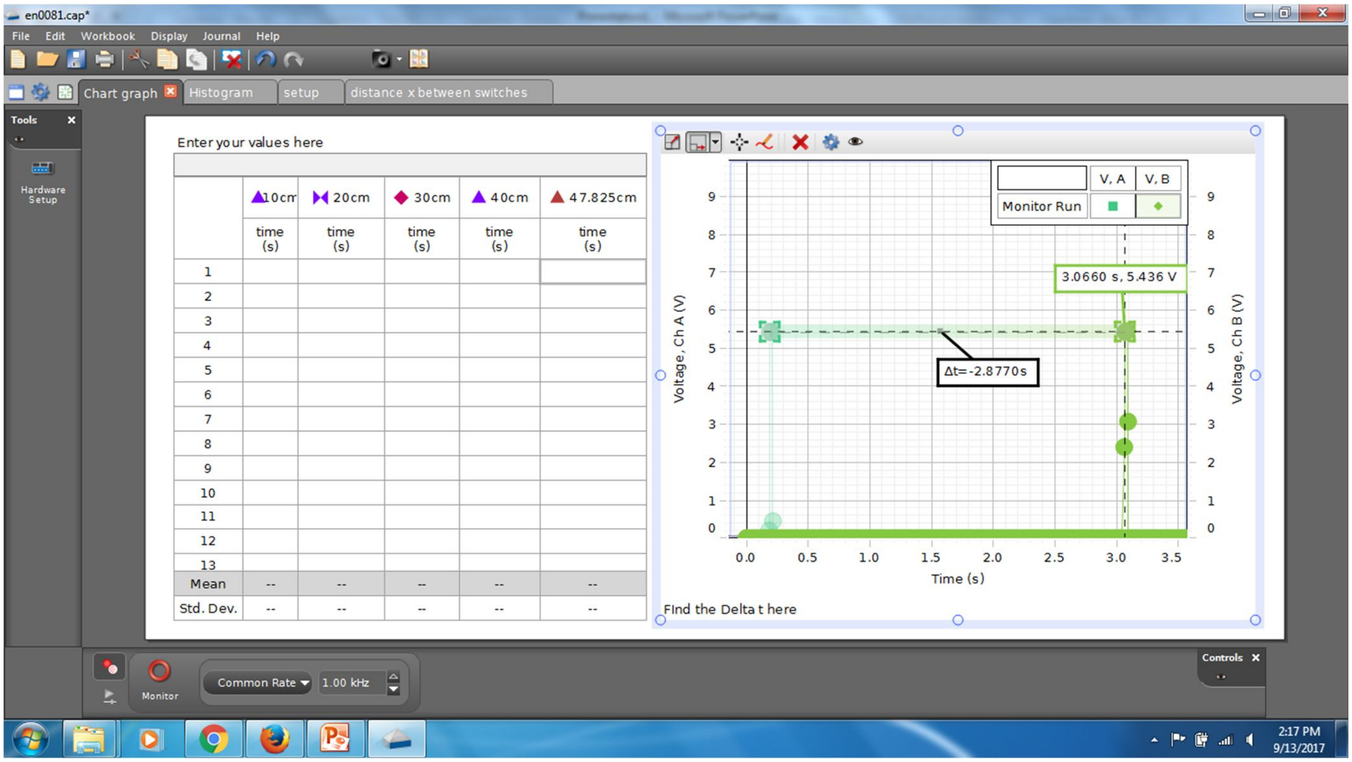
To determine the relative timing (or difference in time, Δt) between pulses use the ‘Delta Tool’. Right click on the cursor measurement indicator panel and select “Delta Tool” (see below)



A new cursor will appear as below



Drag and snap the new cursor ***to the appropriate place*** on the first pulse. The relative time, Δt, will be indicated as below. Record this number in the data table on the left. Repeat this procedure for each experimental trial.



SETTING THE SAMPLING RATE:

Click on the "Common Rate" tab beside the "Monitor" button and select the sensor channel (A or B). Once a sensor is selected, you will be able to adjust the sampling rate as indicated below. The default rate is 1kHz. You should investigate the impact of changing this rate (up and down) on the traces that you acquire.