WPI | Department of Physics

Discharging of a Capacitor

1120 Lab 3

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Written by Dana

Abstract

A capacitor is a device which stores charge in it. When a capacitor is charged, the charge creates an electric field. Hence, a charged capacitor stores electric energy in the electric field. The energy stored in a capacitor can be used for various purposes like in the camera flash, a defibrillator, etc. Capacitors can be constructed in various shapes and sizes. Some of them are shown in Fig. 1.

Lab Objectives

Study the discharging of a capacitor and measure (i) the time constant of a resistive-capacitive (RC) circuit, and (ii) the capacitance of a single capacitor.

1. Measure the time constant of a resistive-capacitive (RC) circuit.
2. Measure the capacitance of a capacitor.

Lab Materials

- Computer with internet access

Links for this Lab

1. Physlet RC Time Constant

Figure 1: Example of some capacitors. Here you'll see a mix of types as well as sizes.

Capacitance

Capacitance of a capacitor is its capacity to store charge. If a battery is connected between the two plates of a capacitor, the battery drives charge through the circuit and the capacitor plates are charged – one plate with positive charge and the other plate with negative charge of the same amount (Fig. 1).

A simple capacitor consists of two conducting plates with a small separation between them. The space between them is either vacuum/air or filled with some insulating materials called dielectrics.

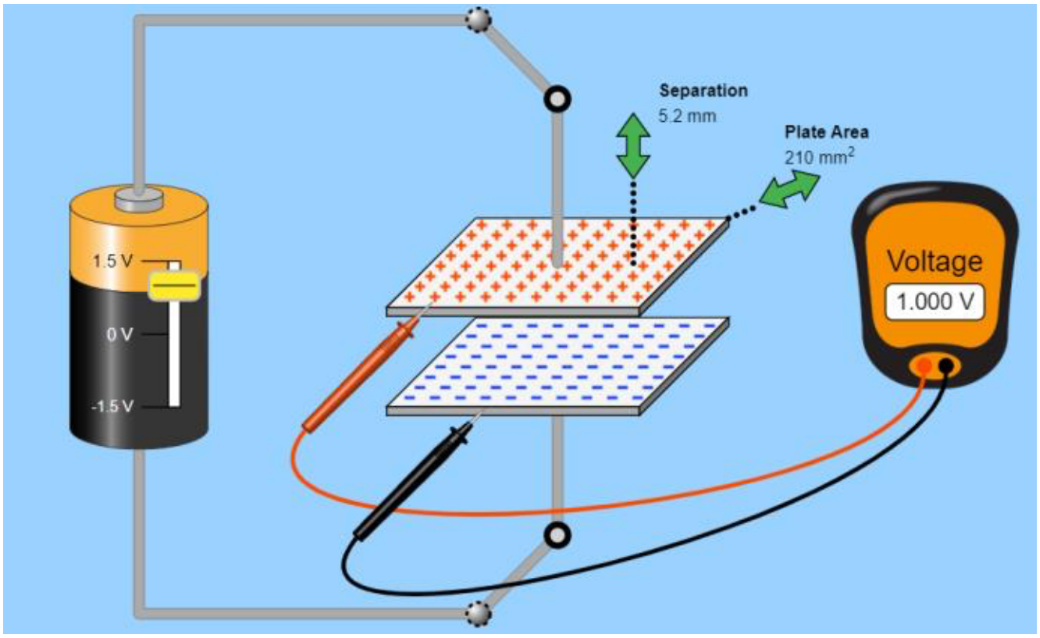

Figure 2: Simulation of a capacitor being charged.

The capacitance C of a capacitor, the magnitude of charge Q on each plate of the capacitor, and the voltage (potential difference) $V_{ab} = V$ across the capacitor (Fig, 3) are related by the formula:

$$C = \frac{Q}{V} \tag{1}$$

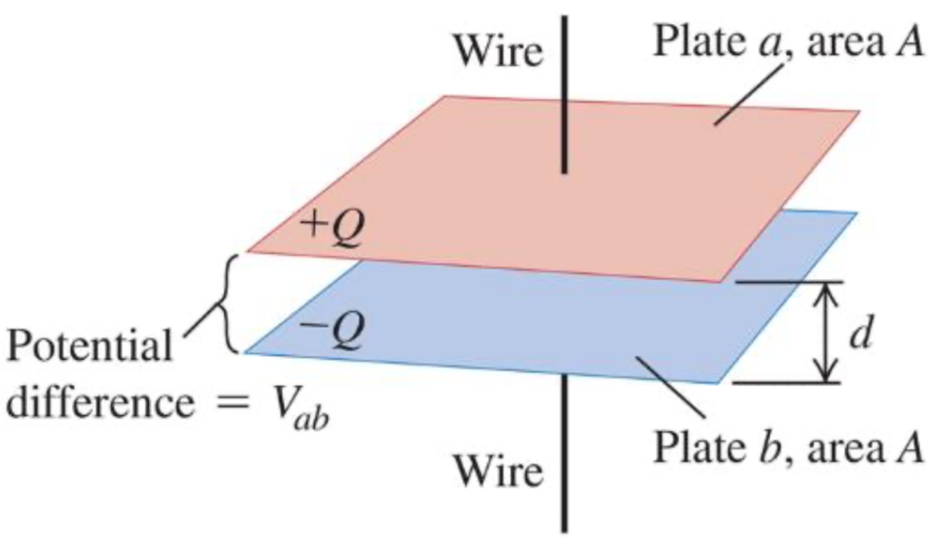

Figure 3: Schematic of a charged parallel-plate capacitor.

The SI unit of capacitance is the Farad (F). 1 F = 1 C/V. The smaller units are $1\mu F = 10^{-6}F, 1nF = 10^{-9}F$, etc.

RC Circuit

An resistive-capacitive (RC) circuit: It is an electric circuit containing a source, a capacitor, and a resistor for charging and discharging a capacitor. Fig. 4 (left) is the circuit for RC circuit charging a capacitor and Fig. 4 (right) is the RC circuit for

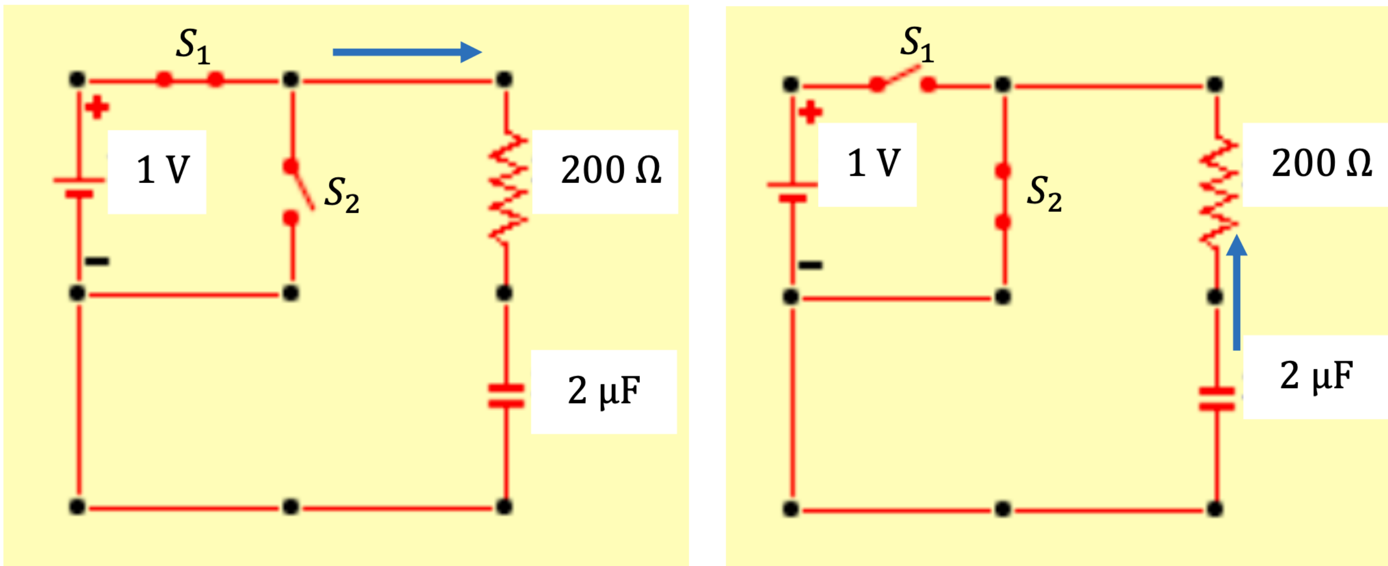

Figure 4: An RC circuit for charging a 2μF capacitor using 200Ω resistor and a 1 V battery (Left). The RC circuit for discharging a 2μF charged capacitor using 200Ω resistor (Right). Note the states (ON or OFF) of the switches S1 and S2 in the two circuits.

discharging the capacitor.

When a charged capacitor with capacitance C is connected with a resistor of resistance R in a circuit (Fig. 4, Right), and the circuit is completed, current starts flowing through the resistor. This process is called the discharging of a capacitor in an RC circuit. In the discharging process, a capacitor loses charge, and hence the potential difference across the capacitor plates decreases which is described by the equation:

$$V(t) = V_0 e^{-\frac{t}{RC}} \tag{2}$$

In Eq. 2 V_0 is the initial voltage across the capacitor, and V(t) is the voltage across the capacitor as a function of time. Eq. 2 shows that the voltage across the capacitor plate decreases exponentially, which can be reduced to a simple linear equation taking natural logarithm in its both sides. It then becomes:

$$lnV(t) = lnV_0 - (\frac{1}{RC})t. \tag{3}$$

Eq. 3 is the form of y = mx + b, which is the equation of a straight line, with the slope m = $-\frac{1}{RC}$. The quantity RC has a unit of time and is called the **time constant of the RC circuit.**

Time Constant

The time constant, τ = RC, of a RC circuit is defined as the time in which the voltage (potential difference) across the capacitor decreases to $\frac{1}{e}$ of the original voltage across it. It has units of seconds. Note that e = 2.718 is the base of the natural logarithm. Fig. 5 shows how the voltage across a capacitor (in red) and the current in the circuit (in green) change with time while a capacitor is being discharged in an RC circuit.

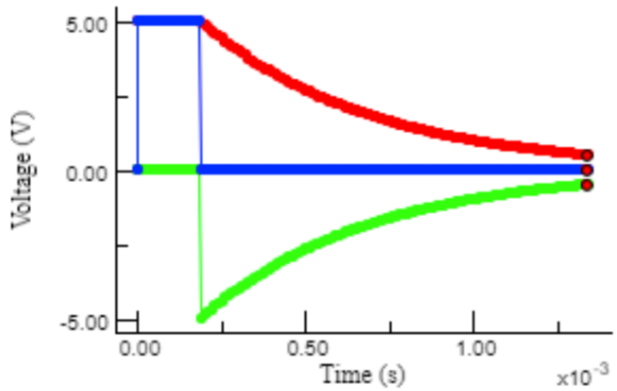

Figure 5: The voltage across a capacitor (red) and the voltage across the resistor (green) as a function of time while a capacitor is being discharged in an RC circuit.

Since the charge stored in a capacitor is proportional to the voltage (Q = CV) across it, the capacitor will be left with $\frac{1}{e}$ of the original charge after one time constant as shown in Fig. 6.

How much charge will the capacitor have after two time constants? Three time constants?

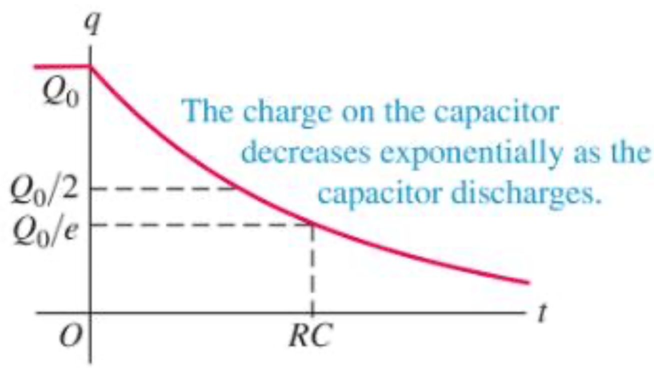

Figure 6: The decay of charge in a capacitor as a function of time.

Procedure

You are strongly recommended to watch the short video in the following link (before or after the lab hour). This video shows that how a charged capacitor is discharged in an RC circuit in a 'real' lab Discharge Capacitor.

You can use either simulation, although we recommend his PhET, the RLC circuit . If you use the

Open the Physlet Physics simulation 'RC Time Constant' window by clicking on the following link: Physlet RC Time Constant.

In the boxes underneath the animation window, set the values of the battery voltage to 5V, capacitance value 2 μ F, and resistance value to 100Ω.

Click on the Play button located right underneath the animation window to run the animation. Let it run for about 3 seconds, making sure that the switch in the branch containing the battery is CLOSED, and the OTHER switch is OPEN.

Question 1 Results, part 1

Please write a Results section based on the results you have collected today. For reference on what it should look like please consult the Generic Deliverables at this link. For guidance on what questions should be addressed please see below.

What is your starting voltage, as shown by the blue curve in this period?

After about 3 seconds, click on Open/Close button so that the battery is disconnected from the circuit, the OTHER switch is closed, and the capacitor starts discharging through the resistor. Run the simulation for about 5 seconds (in simulation time) or so and stop the simulation by clicking on the STOP button.

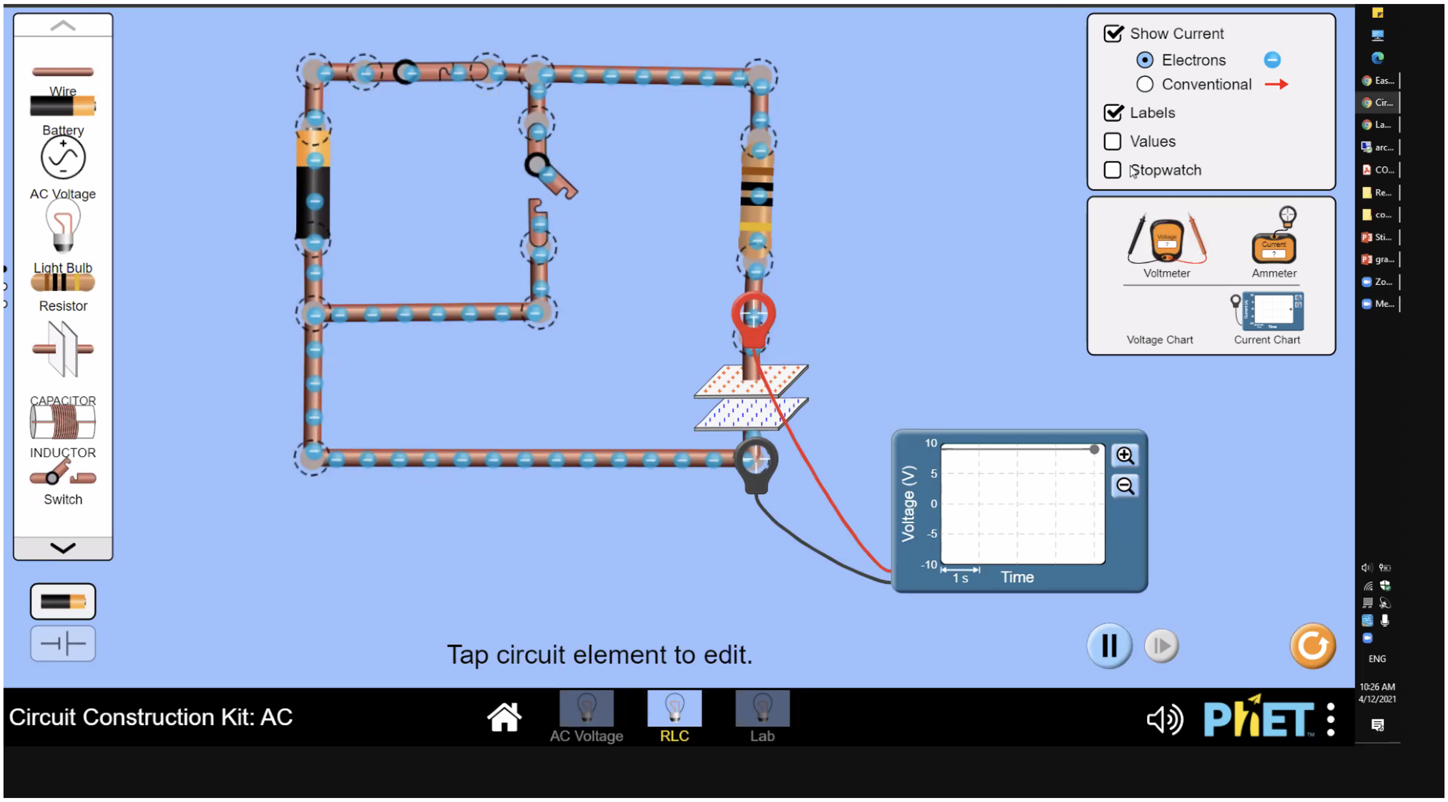

Figure 7: An example of the circuit as drawn in Phet.

Press and hold the computer mouse at the highest point of the red curve. You will see two data points highlighted in yellow. Continue selecting the red curve to extract the data values for different voltages along the curve until you fill up your table. Please choose a variant of values from your highest voltage.

Question 2 **Results, part 2**

Using that yellow highlighted value please fill out a table like this one in your submission. Make sure that the lowest voltage value you record is greater than or equal to 1.

Table for question 2		
No. of observations	Discharging time (s)	Voltage across capacitor (V)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Question 3 **Results, part 3**

- *Transfer this data in an Jupyter Notebook and plot a graph between time on the x-axis and the ln V on the y-axis. Insert a line of best fit to the data. Show the equation of the best fit in the graph. Label the axes properly. Copy and paste the graph in the following space.*

  You can find the sample data and data analysis technique on our Github at this link. If you need more help on these steps, ask your Lab Instructors. [a]

- *Calculate the time constant of the CR circuit from the slope of the line of the best fit and record it on your submitted document.*

- *Estimate the capacitance of the capacitor using the result from above and given value of your inputted resistance, and record on your submitted document.*

- *Calculate the percentage error in your measurement using the given value of the capacitance $C_{given} = 2\mu F$.*

[a] If you do not wish to use Python you can use any other programming language (R, Matlab, C++, etc) you wish. You are not, however, allowed to use Excel or Google Sheets

$$PercentError = (\frac{C_{given} - C_{measured}}{C_{given}}) * 100. \tag{4}$$

Question 4 Results, part 4

Repeat Question 1 through Question 3 with the following values:

- *Battery voltage = 2.5V*
- *Capacitance = 5 μF*
- *Resistance = 1000 Ω*

Record your data in a table like the table above, and include your answers to the other questions through Question 3 in your results section. For reference on what it should look like please consult the Generic Deliverables at this link. For guidance on what questions should be addressed please see above.

Question 5 Conclusion

Please write a conclusion section based on the results you have collected today. For reference on what it should look like please consult the Generic Deliverables at this link. For guidance on what questions should be addressed please see below.

1. *What is the time constant in physical terms?*
2. *What does the calculated error above mean for both circuits? What is is caused by? Why might it be different for the two different values you tested? (1-3 sentences).*
3. *Summarize what you learned from this lab about discharging a capacitor in an RC circuit. (4-5 sentences)*

When you have completed all the questions please save your answers as a PDF, and upload them to the Canvas assignment associated with this lab. If you have trouble converting to a PDF please ask your Lab Instructor(s) for help.

Acknowledgement

This lab was first developed by Dr. Rudra Kafle to replace the on-site labs for D term, 2020 due to the COVID-19 Emergency. They have been iterated upon by Dana, who takes full credit for any mistakes therein.

Appendix

The Figures and Caption Rules

There are a few very important aspects to creating a proper figure and caption. If you follow these rules, not only will you get points on your physics lab grades, you will impress your instructors and peers in the future.

The Caption

- The caption should start with a label so you can reference the figure from other places in your paper/report. For this course you should use "Figure 1", "Figure 2", etc.
- The caption should allow the figure to be standalone, that is to say, by reading the caption and looking at the figure, it should be clear what the figure is about and why it was included without reading the whole paper.
- The caption should contain complete sentences and be as brief as possible while still conveying your information clearly (this is not always easy).
- Please add captions to your tables as well, otherwise we will not know what we are looking at.

The Figure

- **Make sure that the resolution is high enough to not be pixelated at its final size.**
- Check that any text is readable at the final size (Using a smaller graph in Logger Pro will cause the text to be larger in relation to the graph when inserted into another program).
- For graphs, ensure that the axes are labeled (including units) and that there is a legend if you have multiple data sets on the same graphs.

Tables

- The first row of the table should be a header, where each item is labeled with what is contained in that row. If it is a physical measurement it should have the correct units.
- For tables include a short caption of what is contained in the table, or what was examined.
- The caption should start with a label so you can reference the figure from other places in your paper/report. For this course you should use "Table 1", "Table 2", etc. For an example of a good table caption please see Figure 8.

Table 1. Baseline characteristics of study participants

Variables	Intervention group (n=14)	Control group (n=15)
Women (no [%])	7 (50)	5 (33)
Median age (range)	22.0 (19 – 58)	21.0 (18 – 70)
First winter in icy conditions (no [%])	—	1 (7)
Previous falls on ice (no [%])	8 (57)	11 (73)
≥ 1 fall this winter (no [%])	4 (29)	7 (50)
Injury from fall this winter (no [%])	1 (7)	—
Time been walking this route (no [%]):		
<6 months	3 (21)	2 (13)
6–12 months	9 (64)	9 (60)
>12 months	2 (14)	4 (26)

Figure 8: An example table from the paper Lianne Parkin, Sheila M Williams, and Patricia Priest, "Preventing Winter Falls: A Randomised Controlled Trial of a Novel Intervention" 122, no. 1298 (2009): 9.

Python

According to IEEE Spectrum, Python is the most popular programming languages. Python is a free, general purpose, cross discipline programming language that has moved to the forefront of many disciplines.

If you decide to use Python your TA's will help you troubleshoot your code. While they might be able to help you troubleshoot when you use a different program or code, be aware of the fact that they are not familiar with all programming codes. There are many languages (R, Matlab, Opal, Julia, etc.) out there that are just as useful as Python, but we have chosen to use Python here. You may use any programming language you wish, but not Excel or Google Sheets.

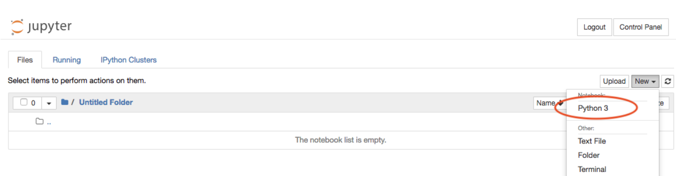

Figure 9: Navigate to `jupyterhub.wpi.edu/hub/login` and sign in with your WPI email address and password, choose an instance to spawn (either is fine) and create a new Python 3 file as shown here

We have set up a Jupyter notebook you may use. The website is https://jupyterhub.wpi.edu/hub/login.[1] There are many ways to learn Python, including reading a book, asking a friend, working through examples, or googling furiously when problems arise. We encourage you to discover which approach works best for you. Going forward this class will provide basic Python examples, but feel free to iterate upon the template we provide. What we provide is a stripped down version, and elaboration is encouraged. See this Github repository for our examples. We hope at the end of this term you will be able to add to your resume "Proficient in Python".

Jupyter uses a cell based system and evaluated variables carry over to the next cell. There are a few different types of cells, Figure 10 shows 2 kinds, the code cell, which we will be using most of the time, and the markdown cell, which you can use to add nicely formatted notes to you file.

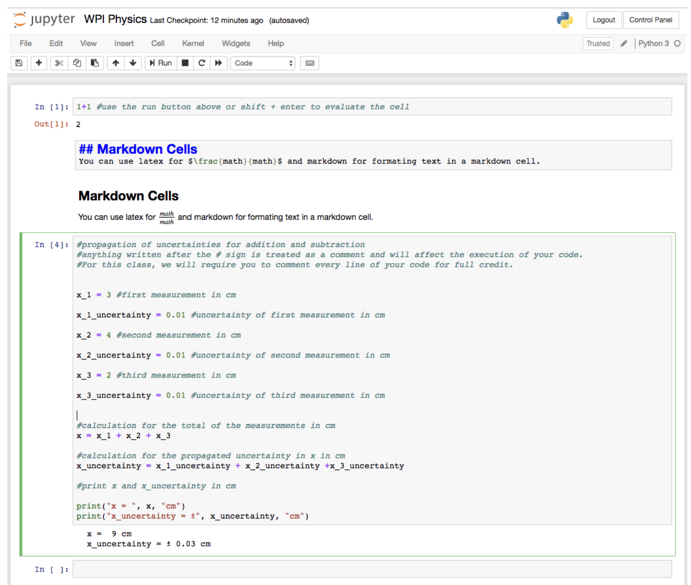

Figure 10: Above is the code that you could use use to propagate uncertainty for values that are added or subtracted. Always remember to comment your code.

If you prefer to work through a book or examples we recommend Mark Newman's book, which is available for free on his website [?]. Chapter Two is a basic introduction to the syntax for Python. Chapter Three covers graphs and visualizations, and we hope you will look into it if you learn best from a book. If you wish to get a head start in this class we recommend reading this book.

If you wish for a more advanced textbook there is a compilation of free online computational physics books here.

[1] If you cannot log in please email WPI's IT department, and they will be happy to help polite students. The first thing they will tell you, however, is to check to make sure you don't have to change your password and try a VPN if you are off campus.