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## Revitalizing Labs for Physics 115

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## **Abstract**

The purpose of this project was to add hands-on equipment to the experiments of the Physics 115 lab and create a new delivery of instruction in the form of tutorial screencasts. This was accomplished through meetings with the project advisor, Dr. Chronis, discussing new content and new procedures for three particular experiment topics given priority. The topics of Ohm's Law, a resistor and capacitor (RC) circuit, and an inductor and resistor (LR) circuit, were deemed to be the priority experiments. New procedures covering the concepts behind these topics had to be created that adequately utilized the hands-on equipment. Tutorial videos demonstrating these new procedures with the equipment were then created as an addition to the lab manual. The addition of these tutorials allows the students to come into the lab more prepared and releases the individual running the lab of tedious procedural questions. The combination of these two things creates a lab environment conducive to the exploration of deeper conceptual relationships and ideas.

## **Introduction**

This manuscript documents the process of revitalizing the Physics 115 laboratories. Dr. Chronis acted as my project advisor as we worked to create new experiments utilizing recently bought equipment with a different approach to the instruction. At this academic level, it is uncommon for a lab to be full of equipment an engineer might use daily in their job, which is one of the things we wanted to change. This project worked to incorporate more hands-on equipment into the lab manual and create lab procedure tutorial videos that would deliver the information to the students in a new more complete way so that they are better prepared for more complicated experiments. While the tutorial videos' main objective was to demonstrate how the equipment works and what each student will be doing in each lab, they also introduce the experiment's concepts and relationships to be covered in the lab. The hardest thing about succeeding in a lab is trying to understand a brand-new concept in under three hours when you are not really sure what is being done, or how, or why. The videos take a portion of that unknown away, and students can focus on the topics being covered and the relationships they should be looking for.

Our priority was rewriting three major laboratories and completing tutorials for each. These lab topics were the Ohm's Law, a resistor-capacitor circuit, and an inductor-resistor circuit. Within the summer, all three were completely revised and had tutorials covering each part of the revised procedure, so we decided to create videos for one more lab, covering thermodynamics. We also included a tutorial video for each piece of vital equipment used in the new labs, the digital multimeter, the oscilloscope, and the function generator. The background, the process of rewriting the procedure, and the creation of tutorial videos is discussed in detail for each lab in the chapters below.

## Chapter 1: Ohm's Law

### Background

The Ohm's Law is the most foundational law in electrical circuits; it relates current, voltage, and resistance. It is stated in Equation 1 in its most basic form.

$$V = IR \quad (1)$$

In Equation 1, (V) represents voltage, (I) represents current, and (R) represents resistance. This law is true for any electrical component or circuit, meaning it can be evaluated for the entire circuit using total circuit resistance and maximum supplied voltage, or for a specific resistor using its resistance and the current across only that resistor.

If the Ohm's Law were to be used for an entire circuit, the circuit's total resistance would need to be calculated. Resistors in a circuit are added together differently depending on which configuration they are in, series or parallel. Resistors in series are added according to Equation 2, while resistors in parallel are added according to Equation 3 both shown for (n) number of resistors.

$$R_{eq} = R_1 + R_2 + R_3 + \dots + R_n \quad (2)$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n} \quad (3)$$

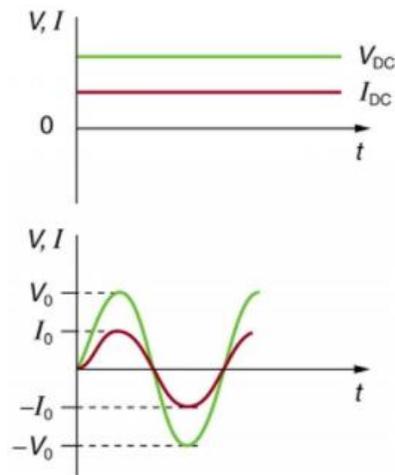
For a series circuit, the current through an individual resistor is the same but they have varying voltage drops across each one. For a parallel circuit, the opposite is true; all resistors have equal voltage and varying current.

In contrast to resistors, which hold constant resistance, there are electrical elements that do not have constant resistance and therefore display non-ohmic behavior, meaning that element does not follow the Ohm's Law. A light bulb is a common example of this; its filament

undergoes a temperature change when experiencing current, and the addition of that variable changes the light bulb's resistance [4]. When temperature is the cause of non-ohmic behavior, the notion of "cold resistance" is introduced, meaning an element can have a certain value of resistance when "cold" or without any current, but that value is not constant. Once the element experiences current, the resistance is now "hot" and changes with the temperature of the element, which in the light bulb example, would be its internal filament.

An insulator is another common example of an element that display non-ohmic behavior. Insulators act, as the name would imply, resisting (or insulating) current, but when enough voltage is applied to the component, the insulator will allow current to flow through it [5]. Insulators have a property known as "break voltage," also known as "dielectric strength" which is this value of voltage that must be overcome for current to flow through the insulator [5]. When current does flow through an insulator, there is an initial rush after overcoming the break voltage [5]. This rush causes the current to be non-linear and therefore non-ohmic.

The "current" and "voltage" that have been discussed so far, also have varying properties, meaning a power source can have direct current or alternating current. Direct current (commonly known as DC) is a constant flow of charge in only one direction [6]. Alternating current (commonly known as AC) is a time-varying flow of charge that oscillates between two directions of flow [6]. A graphical depiction of DC versus AC power can be seen in Figure 1.



**Figure 1:** Graphical Depiction of DC (top) and AC (bottom) Power [6]

AC power can be delivered in various waveforms, including a sine wave or a square wave, although sine is most commonly used. Because of the oscillating nature of AC power, an average is needed of the current and voltage values; these are known as “RMS” values of current and voltage, where “RMS” stands for “root mean square” [6]. The derivations for ( $I_{rms}$ ) and ( $V_{rms}$ ) can be seen in Equations 4 and 5, where subscript (0) is to mean the peak values of current and voltage within the AC fluctuations.

$$I_{rms} = \frac{I_0}{\sqrt{2}} \quad (4)$$

$$V_{rms} = \frac{V_0}{\sqrt{2}} \quad (5)$$

These “rms” values are what are to be used in the Ohm’s Law.

### **Preliminary Work**

This was the first experiment that was worked through, because unlike the other material, a good general knowledge base surrounding the Ohm’s Law was already established. Meetings began with Dr. Chronis nearly every day to discuss what we thought were the necessary components to fully understanding the Ohm’s Law. We knew we had to cover resistors, both in

series and parallel to illustrate the basic Ohm's Law principles. It was also decided to include elements that displayed non-ohmic behavior as a counterpart to the resistors. This was accomplished by adding a circuit with a bulb, which demonstrated the principle of cold/hot resistance to the students, and a circuit with an insulator, which conveyed the idea of break voltage. Lastly, we wanted to be sure a circuit with alternating current instead of direct current was examined in the laboratory. This meant the experiment would consist of five different circuit configurations, with various elements.

With the content decided, the procedure was worked on next. We both individually worked on what we thought the best procedure would be for understanding these concepts in multiple settings, but ultimately, we continued with Dr. Chronis's established procedure. At our next meeting, Dr. Chronis talked me through the new procedure and how he wanted me to practice, while he finished writing up the new manual and perfecting the values we would use. After a few days, the new official procedure was ready, and began to be practiced exactly as stated in the lab manual while verifying the results to find any discrepancies or issues. Once confidence was established in the lab procedure, the creation of screencasts began to capture someone working through the lab. This was often the part of the process where problems were encountered and had to be solved.

An issue would arise whenever the procedure's results did not match the theoretical or expected values. With this being a first encounter with the new instruments, most of the problems experienced within this lab were small and purely a result of lack of comfortability with the new equipment. During one of the initial procedure practices, there was difficulty matching the voltage output values from the function generator and the digital multimeter. Although it was later decided to use a power amplifier for the DC portions of the lab, which the

videos reflect, at the time of practice the current was supplied with the DC setting on the function generator. From the established knowledge of Ohm's Law, it was known that the displayed value on the function generator was correct, but the lab manual stated to record the multimeter value, which was known to be incorrect. The discrepancy using placeholder values can be seen below.

$$\text{Current Given} = 8 \text{ mA}$$

$$\text{Resistance Used} = 30 \Omega$$

$$\text{Function Generator Displayed Value of Voltage} = 0.24 \text{ V}$$

$$\text{Function Generator Value Justification (from Equation 1)} - V = IR = 0.008 * 30 = 0.24 \text{ V}$$

$$\text{Digital Multimeter Displayed Value of Voltage} = 0.17 \text{ V}$$

The value displayed on the digital multimeter seemed unjustified. At the time, it was decided to make a note to ask Dr. Chronis later, and continue with the experiment procedure, which was the AC portion. The function generator was changed from a constant direct current to a sine wave of alternating current. It was then noticed that the readout of the digital multimeter matched the RMS voltage value displayed on the function generator. At the time, it was unknown to me why the multimeter would be accurate for AC voltage but not DC voltage, so a meeting was set with Dr. Chronis the next day to discuss. This was when the different settings of the multimeter were first discovered. It was realized the multimeter had been set to the AC voltage setting, which calculates the RMS value using the peak voltage, for the DC portion of the lab. The proof of this mistake can be seen below using the same placeholder values as before.

$$\text{Current Given} = 8 \text{ mA}$$

$$\text{Resistance Used} = 30 \Omega$$

$$\text{Digital Multimeter Displayed Value of Voltage} = 0.17 \text{ V}$$

$$\text{Peak Voltage / Constant DC Voltage (from Equation 1)} - V = IR = 0.008 * 30 = 0.24 \text{ V}$$

$$\text{RMS Voltage Value (from Equation 5)} - V_{rms} = \frac{V_0}{\sqrt{2}} = \frac{0.24}{\sqrt{2}} = 0.17 \text{ V}$$

The mistake was quite foolish, but thankfully for my patient project advisor, it was remedied quickly. This type of issue happened occasionally throughout the process of all labs, but eventually enough expertise of the equipment was gained, and issues could be solved within the day without assistance until they were few and far between.

### **Creation of Screencasts**

When confidence was established in the procedure of the experiment and its results, the creation of tutorial screencasts of the laboratory began, while still periodically meeting with Dr. Chronis to give updates and receive feedback. This experiment contained the most tutorial videos out of all other experiments covered, with a total of six. Each video covered a different section of the lab material: a circuit with resistors in series, a circuit with resistors in parallel, a circuit with a bulb, a circuit with an insulator, and a circuit using alternating current instead of direct current. This lab also included an introductory video which provided a basic overview of the experiment with some tips on how to create circuits and how to use the new equipment for the particular goals of this laboratory.

The first portion was focused on basic circuitry and demonstration of the Ohm's Law using resistors. Two tutorial videos were dedicated to this portion; one showing two resistors connected in series with each other, and the other showing two resistors connected in parallel. In order to maximize new equipment used, the circuit consisted of a direct current power supply, a resistor box, and a circuit board containing a ten Ohm resistor and a thirty-three Ohm resistor. Both videos demonstrated the proper way to establish the circuits and highlighted the constant ratio seen between voltage and current values on the power supply because of Ohm's Law. Resistance properties were also discussed, like the proper way to add resistors in each circuitry and how the circuitry affects both the voltage and current. From background, it is known that

resistors in series have equal current but different voltages, and that the opposite is true for resistors in parallel. The video then demonstrated how to verify these properties with the digital multimeter. In each circuitry, the voltage across each resistor was measured with the multimeter and compared to the total voltage and to the voltage across the other resistor. This allows students to visually see how circuitry affects resistor elements and properties. These concepts had been introduced in class prior to this experiment, but the addition of tutorial videos helped show how those concepts were being utilized within the experiment as well as ensured that students had seen all the equipment in work at least once before. The students still had to make further connections than those discussed in the videos, but this way students had a general idea of what they should be observing. The videos were likely most helpful regarding the circuitry setup and those general principles. Many students have not set up a circuit prior to this lab, and a video showing the correct way it should be done is very helpful for the visual learners.

The next portion of the lab showed an example of non-ohmic behavior, or an element that does not linearly vary with voltage and current, using a bulb. The tutorial video for this section started with using the multimeter to measure the cold resistance on the bulb, in the same way that was demonstrated in the introduction video. As the circuit was established and voltage was increased and decreased to the bulb, the video highlighted the fact that the displayed current and voltage no longer had a constant ratio throughout values, and that if you used the displayed current and voltage values to calculate resistance, it would not equal the cold resistance measured prior in the bulb. The video then included a short discussion as to why this element was displaying non-ohmic behavior. The conclusion being that as you increase voltage to the bulb and the bulb increases its brightness, the temperature of the filament in that bulb increases as well. It was mentioned that an increase in temperature increases resistance as well and that

this is likely where the Ohm's Law is disturbed, but it was left intentionally vague so that the students could determine why that may be the case. Presenting the lab information in this manner gives students a better general idea of the relationships they are seeing and allows them more time and mental capacity to dive deeper into those relationships.

The next portion of this laboratory examined an insulator example using a diode and its semi-conductor properties. Like the bulb portion, the multimeter was used prior to establishing the circuit to measure the diode's intrinsic properties. Unlike the bulb, the diode did not carry cold resistance, but a capacitance known as break voltage. The discussion of this property in the tutorial video helped seal terminology like this for the students. When the power began being supplied to the diode, it did not immediately turn on, like the bulb did. In fact, the diode did not turn on until you overcame the break voltage previously measured. This demonstration helped highlight what break voltage really means. The lab contained another important concept which was shown by measuring voltage across each side of the inductor to observe the differences, and to see how the two sides increase unproportionally to each other if the total voltage is increased. The video mentioned an observation that the side with the diode has the higher voltage of the two and increases less than the other, but it was left to the student to determine why this happens.

The final portion of this laboratory was dedicated to using alternating current in the circuit instead of direct current, as the previous experiments had. That small change meant the addition of new equipment, specifically an oscilloscope and a function generator, but from there it closely resembled the direct current resistor portions. The tutorial video included instruction and tips on using the oscilloscope and where to place the probes, which was covered in greater detail in the oscilloscope tutorial. While moving through the motions of this lab, important tips were highlighted but not fully explained. We did not want the videos to simply give students the

answers to their lab report, but rather ensure the students knew what to do so that they could focus on the “why” behind those actions. For example, the video mentioned how to convert maximum voltage into RMS voltage and that RMS values are what need to be used for Ohm’s Law calculations, but the reason behind these things was left unanswered by the video. This allowed students more time and mental energy to devote to further understanding the principles of the Ohm’s Law.

## Chapter 2: Resistor and Capacitor (RC) Circuit

### Background

A capacitor is an electrical element that can act as a temporary energy source by storing energy. The term “charging” refers to the capacitor gaining energy, and the term “discharging” is used to describe the capacitor supplying energy to the circuit [1]. As the capacitor charges from the deliverance of current, the voltage across the capacitor will increase while the current decreases [1]. In a RC circuit, a capacitor (C) is connected in series with a resistor (R) and the capacitor begins gradually charging through the resistor until the voltage across the capacitor is equivalent to the supplied voltage [2]. The voltage charging or discharging of a capacitor’s energy does not happen instantaneously, and the amount of time it takes to charge up to 63% of its maximum voltage value (or discharge to 37% of its maximum value) is known as one full time constant (tau,  $\tau$ ) [2]. In a RC circuit, the tau time constant is defined by Equation 6.

$$\tau \equiv RC \quad (6)$$

With (R) representing the resistance of the circuit, measured in  $\Omega$ , and (C) representing the capacitance of the circuit, measured in Farads. Relating voltage (V) to the charge on the capacitor, the voltage across the capacitor ( $V_C$ ) can be solved for any point in time during the discharging period using Equation 7.

$$V_C = V_S \left( 1 - e^{\left(\frac{-t}{RC}\right)} \right) \quad (7)$$

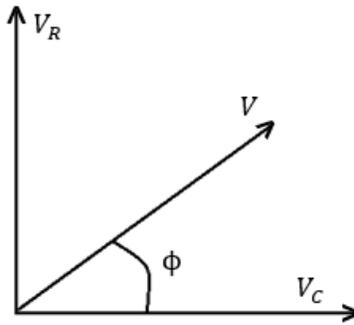
Where ( $V_S$ ) represents the supplied voltage, measured in volts, (t) is the value of time, measured in seconds, and (RC) is the tau time constant of the RC circuit. Using Equation 7 and the definition of the time constant, an unknown capacitance could be solved for, assuming knowledge of the resistance of the circuit and the supplied voltage, by setting the time elapsed equal to the one time constant, or finding the time needed to reach 63% of the supplied voltage.

When a capacitor is in an AC circuit, the capacitor is being charged and discharged at a rate set by the frequency of the supplied AC power. As the capacitor fluctuates between charging and discharging, the current flowing through it is impeded by a resistance within the capacitor, known as reactive capacitance (or capacitive reactance) [7]. This internal property is denoted as ( $X_C$ ), measured in Ohms, and can be calculated using Equation 8.

$$X_C = \frac{1}{2\pi fC} \quad (8)$$

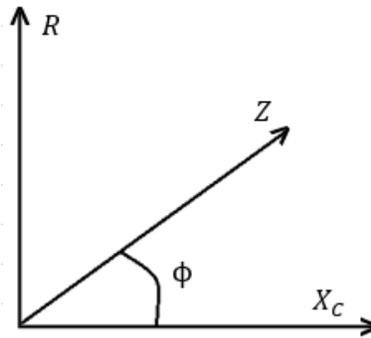
As Equation 8 states, reactive capacitance is determined from the frequency supplied to the capacitor, ( $f$ ), measured in Hertz [Hz], and the capacitance of the capacitor, ( $C$ ), measured in Farads (F). A higher frequency supplied increases the current flow through the capacitor, decreasing its internal impedance [7]. Likewise, a lower frequency of current supplied results in a higher reactive capacitance. This inversely proportional relationship can be seen in Equation 8. Because reactive capacitance is an internal resistance, it can be used in place of ( $R$ ) in Equation 1, with corresponding  $V_{rms}$  and  $I_{rms}$  values.

Because of the capacitor's property to charge and discharge, there is a lag that can be visibly seen between the circuit's voltage and the capacitor's voltage. This lag is known as a phase angle, or phase shift, and is a characteristic of the capacitor. The capacitor's voltage in a RC circuit, lags instead of leads because of the time it takes the voltage to react to the current [8]. A RC circuit's phase relationship can be graphically seen in Figure 2, with  $V_R$  denoting the voltage of the resistor,  $V_C$  denoting the voltage of the capacitor, and the vector  $V$  showing the vector of the circuit.



**Figure 2:** Vector Diagram of Capacitor Phase Angle ( $\phi$ )

The impedance of an RC circuit has a similar relationship and vector diagram as the voltage depicted in Figure 2, and it is shown in Figure 3.



**Figure 3:** Vector Diagram of Total Impedance and Capacitor Phase Angle ( $\phi$ )

From Figure 3, the total impedance of the circuit can be calculated using Equation 9.

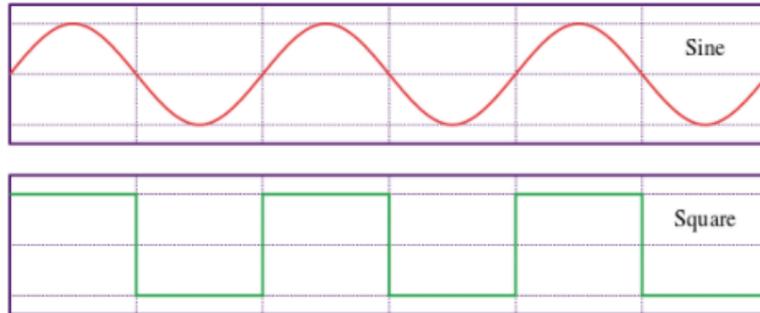
$$Z = \sqrt{R^2 + (X_C)^2} \quad (9)$$

The corresponding equation to derive the phase angle, using the vector diagram depicted in Figure 3 can be seen in Equation 10.

$$\phi = \tan^{-1}\left(\frac{R}{X_C}\right) \quad (10)$$

As mentioned before, an AC current usually utilizes a sine wave, however other waveforms can be used such as square, triangle, or sawtooth. The sine wave is helpful because it graphically shows peak values and the oscillations of them, while a square wave shows only

maximum and minimum peak values with an instantaneous change between each. They are both shown in Figure 4.



**Figure 4:** Sine and Square Waveforms [9]

The square wave is most helpful for capacitors because the time a capacitor is charging or discharging, creates a shark fin affect within the square wave. When the oscilloscope shows both the circuit in a square wave and the capacitor in a square wave, the lag from the phase angle can be seen very clearly through this shark fin. This is shown in Figure 5.



**Figure 5:** Oscilloscope Screenshot of Circuit Square Wave (yellow) and Capacitor Square Wave (blue)

## **Preliminary Work**

While the tutorial videos for the Ohm's Law were still being created, we began working on the circuitry for a resistor and a capacitor in series with each other, conventionally called a RC circuit. There were a multitude of important concepts to cover within this lab, including various properties of the capacitor such as phase shift or its lag from the circuit, that corresponding capacitor phase angle, the time constant of the capacitor, and the idea of reactive capacitance. We also decided to include the comparison between square and sine waves because we felt that both together created a very good visual demonstration of the capacitor's lag from the circuit.

With the content decided, we started working together to make sure no steps were missed in writing the procedure. Whatever had been written would be practiced in the lab while also noting any necessary steps that were missed. Note was also taken of any steps that were unclear, but this was done to ensure the tutorial video was extremely clear when made and would act as a good addition to the lab manual. In this way, we used the screencasts to provide clarity on places of concern within the lab procedure as well as introduce the topics to be covered. This was one of the harder experiments to complete because the foundation of knowledge was unsteady, and the equipment was still being mastered. So, there were many meetings with Dr. Chronis to discuss issues being faced and to verify the results obtained.

A few issues arose at the arrival to the time constant portion of the procedure. The goal of this portion of the lab was to demonstrate how the capacitance could be verified using the RC time constant. As discussed in background, one RC time constant is defined as the amount of time it takes for the capacitor to reach 63% of the peak voltage value. Therefore, if the time constant could be derived from the oscilloscope, and the resistance of the circuit is known,

capacitance could be found using Equation 6. The beginning of this procedure was quite simple. It was clear what had to be discovered, and it was understood that is one oscilloscope cursor was placed at the peak voltage value and the other was placed at 63% of that value, the oscilloscope could calculate the delta time between each cursor, which would correspond to the RC time constant value. The rest of the procedure would be a simple calculation using Equation 6 of \ resistance and the time constant to solve for capacitance, which was already known for the capacitor, allowing verification of the obtained value.

Although this procedure seemed straightforward, when the practice began, the capacitance calculated did not match the known capacitance. Several attempts of the procedure were done before taking it to Dr. Chronis. We worked on it for a day or so, until we discovered the mistake. The theory behind the time constant is working under the assumption that the peak voltage value is also the value of total amplitude. However, the oscilloscope captures the voltage from the minimum value to the maximum value. So, for this experiment, the maximum voltage was 3 V, and the minimum voltage was -3 V. In earlier practices, the maximum voltage displayed on the oscilloscope was used to determine the RC time constant, because Dr. Chronis had not realizes this graphing system either and the lab manual stated to use the maximum voltage in the time constant calculations. However, the term maximum really means total, and in this experiment that means the total amplitude of the waveform, which would be the addition of the positive and negative 3 V amplitudes to give a total of 6 V amplitude. That discovery solved one issue, and we were able to get the correct voltage value after one time constant, which is shown in Equation 11.

$$0.63 * 6 = 3.78 \quad (11)$$

Then, we also had to add in a step of converting that value into a value that could be found on the oscilloscope. Again, the graphing of the oscilloscope had to be considered, so we thought if we subtract the theoretical time constant value from the oscilloscope peak value, we should obtain the oscilloscope time constant value.

$$3 - 3.78 = -0.78 \quad (12)$$

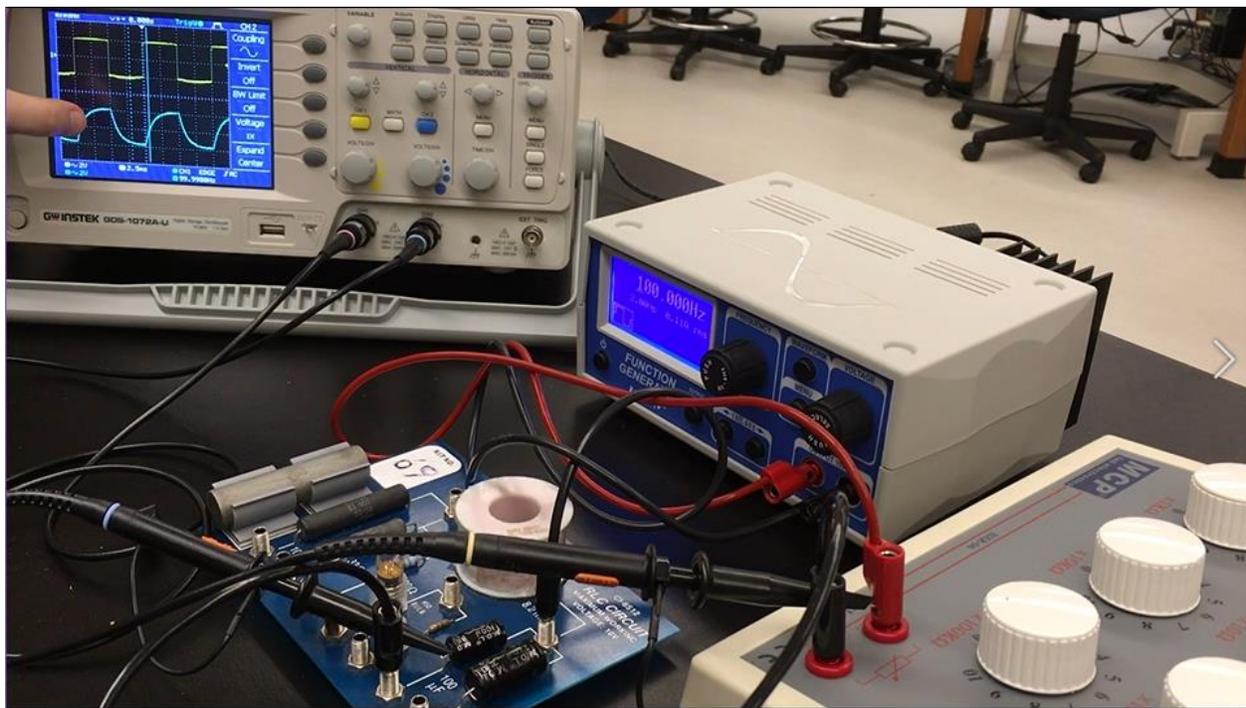
Therefore, this was the value that should be found with the second cursor on the oscilloscope display, a negative 780 millivolts. From there, the procedure continued as discussed and the calculated capacitance was equal to the known capacitance.

### **Creation of Screencasts**

This experiment in particular had many possible pitfalls a student could fall into. This made the tutorial videos even more important, to draw attention to these possible mistakes mentioned in the previous section and show how to account for them. The lab contained a total of three tutorials, one of which was mostly the setup for the experiment. That beginning video covered how to establish the circuit and lightly discussed the importance of the correct configuration. This displays another time the tutorials highlight some key concepts but do not fully explain them. From background, it is known that the power should go through the resistor first and then through the capacitor so that the capacitor can charge up through the resistor, but determining that was left up to the students.

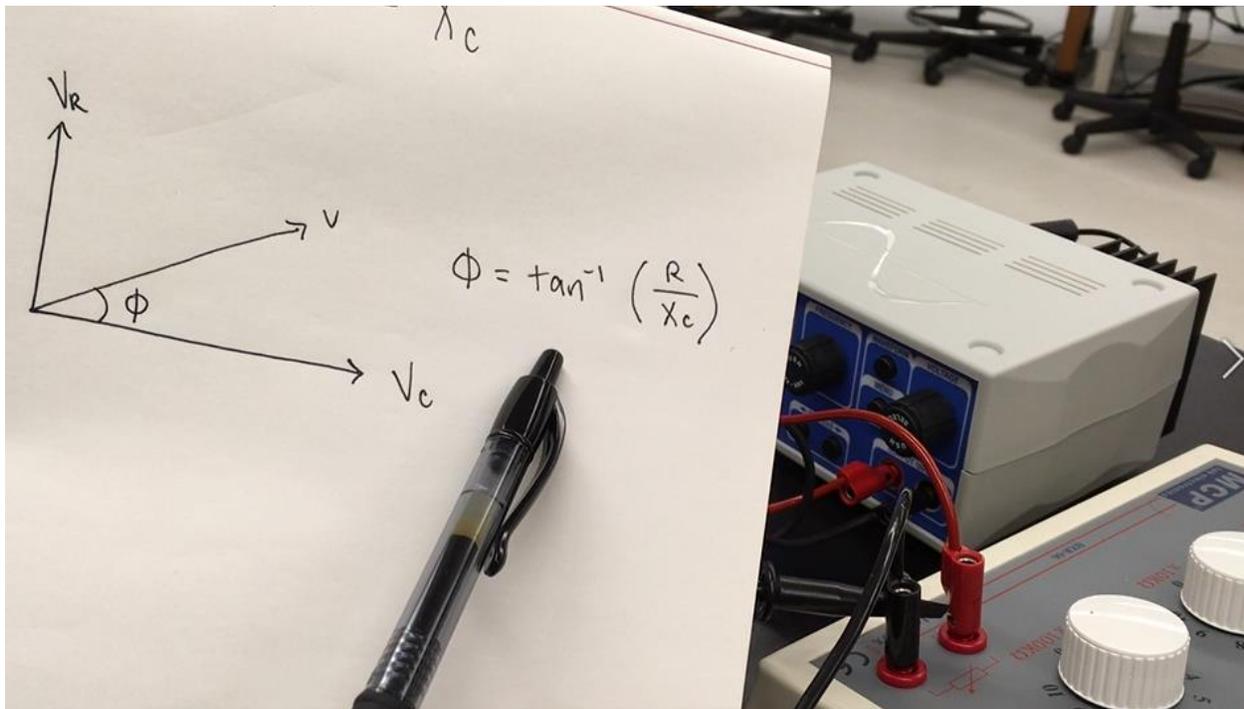
The second video started demonstrating the experiment procedure and highlighting key concepts within the lab. A large portion of the video was dedicated to discussing reactive capacitance as that was a major concept for this experiment. The definition was discussed, including its formula from Equation 8, and the various relationships reactive capacitance forms between parameters like frequency and voltage were visually demonstrated with the

oscilloscope. The video proceeded to show how the reactive capacitance could be verified using the Ohm's Law and corresponding  $I_{rms}$  and  $V_{rms}$  values. The major concept explored in this portion of the experiment was the lag of the capacitor, also known as a phase shift, from the entire circuit. This was demonstrated as both a square wave and a sine wave. A screenshot from the tutorial showing the square wave demonstration can be seen in Figure 6. The explanation of the lag of the capacitor, that it was due to charging and discharging time, was left to the students to discover.



**Figure 6:** Tutorial Video Screenshot from RC Circuits Lab (discussing the circuit's voltage wave – yellow, and the capacitor's voltage wave – blue)

A considerable amount of time in the tutorial was spent discussing the phase shift because it was such an important concept; this included pictorially and mathematically, and then by use of the oscilloscope. A portion of that discussion is captured in another tutorial screenshot in Figure 7.



**Figure 7:** Tutorial Video Screenshot from RC Circuits Lab (discussing phase angle definition)

Students would calculate the phase angle of the capacitor theoretically and then verify that value by placing one oscilloscope cursor on the peak of the circuit sine wave and the other on the peak of the capacitor sine wave. The oscilloscope could then determine the delta between the two and students could convert that back into an angular measurement. This first video served to ensure each student knew how the equipment worked and could be manipulated to perform in this lab.

The last video for this experiment demonstrated the theory and procedure for calculating the RC time constant. If students were not careful or did not pay very close attention, they could make multiple mistakes, as discussed in the earlier section. Walking through the procedure, the formula we would be using (Equation 7) was discussed as well as where to place the first oscilloscope cursor. Most students would be familiar with the procedure to calculate the value after one time constant, which I have outlined in background. However, the values needed are total amplitude, and most students would instinctively use the maximum value displayed on the

oscilloscope. The video described in detail the issues with using that maximum value and the procedure to manipulate the voltage values back and forth between the theoretical procedure and what was needed on the oscilloscope. The video concluded by discussing how you could use Equation 7 to let the time elapsed and RC value equal one another, and from there use the calculated time constant to determine the capacitance of your capacitor. This was another exercise in exposing various ways to verify element properties. This video in particular was likely one of the most important and helpful to the students. Without the prior knowledge of the many possible mistakes in this lab, it would be extremely difficult to accurately verify the capacitor using the oscilloscope.

## Chapter 3: Inductor and Resistor (LR) Circuit

### Background

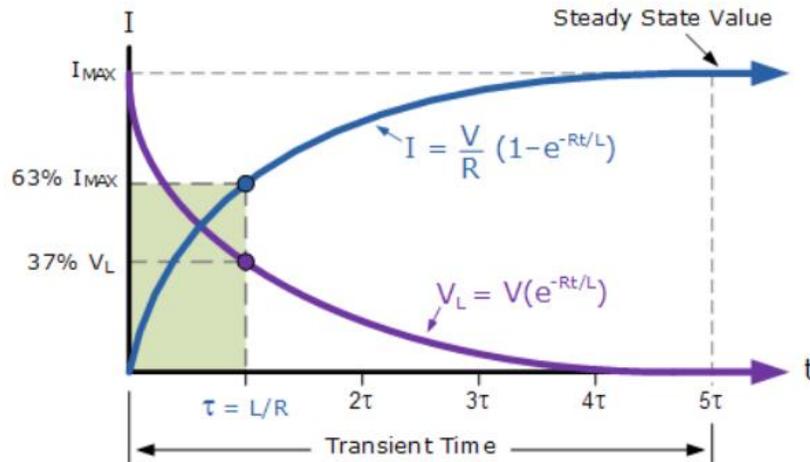
An inductor is an electrical component that naturally stores energy, similar to a capacitor, but it is stored in a magnetic field versus the capacitor's electrical field [1]. It usually is made of wire, which carry inductance (denoted by variable L), wrapped tightly around a central core coil [3]. A LR circuit is created when an inductor (L) is placed in series with a resistor (R). When current is carried through the inductor, the coil produces a magnetic flux around itself proportional to the current [3]. The inductor's current increases when connected to a voltage source and the voltage across it decreases [1]. The opposite is true for a charging capacitor; therefore, the graphical depiction of a LR circuit is similar to the discharging of a capacitor.

Inductors do hold an amount of electrical reactance, just like capacitors do. It is commonly known as reactive inductance, and it is a measure of that inductor's internal resistance to current, meaning it would be measured in Ohms, similar to any resistance [11]. However, because inductors store energy in a magnetic field, the reactance resists current, instead of voltage like capacitors because a resistance to voltage occurs in an electrical field [11]. Reactive inductance is calculated according to Equation 13, where ( $f$ ) is the supplied frequency, measured in Hertz, and (L) is the inductance of the inductor.

$$X_L = 2\pi fL \quad (13)$$

Although the formula for internal impedance is different for capacitors and inductors (compare Equation 13 with Equation 8), Equation 9 is still valid for calculating the circuit's total impedance (Z).

The change in voltage and current does not happen instantaneously across an inductor. The time needed for the inductor to reach 37% of its maximum voltage value is defined as one LR time constant ( $\tau$ ,  $\tau$ ) [10]. This can be seen graphically in Figure 8.



**Figure 8:** Graphical Depiction of LR Circuit Current (blue) and Voltage (purple) [10]

The equation to determine the inductor's voltage at any point in time is slightly different from the capacitor voltage equation. This relationship can be seen in Figure 8, and in Equation 13.

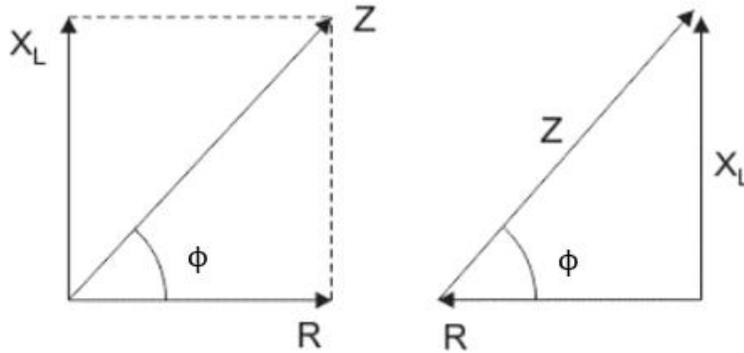
$$V_L = V(e^{-\frac{Rt}{L}}) \quad (13)$$

This equation also defines the LR time constant, which can be seen in Equation 14.

$$\tau \equiv \frac{L}{R} \quad (14)$$

This is a slight but important variation from the RC time constant. More generally, the relationship between inductance and resistance in a LR circuit does not reflect the relationship between capacitance and resistance in a RC circuit.

The different relationship with resistance can be seen better within the concept of the inductor's phase angle. Figure 9 shows the vector diagram for total impedance and the corresponding phase angle.



**Figure 9:** Vector Diagram Showing Total Impedance ( $Z$ ) and Phase Angle ( $\phi$ ) [12]

Comparing Figure 9 to Figure 3, a variation in the vector diagram is noticed. This variation can also be seen in Equation 15 (when compared with Equation 10) to calculate the inductor phase angle.

$$\phi = \tan^{-1}\left(\frac{X_L}{R}\right) \quad (15)$$

It is possible to calculate inductance purely from geometrical properties. This process is not the most accurate, because it does not consider the resistance of the wire that the inductor is made of. For a small coil, with determinable geometry, inductance can be solved using Equation 16, where ( $\mu_0$ ) is the physical constant with a value of  $4\pi \times 10^{-7}$  [H/m], ( $L$ ) is the solved inductance, ( $N$ ) is the number of windings around the coil, ( $r$ ) is the radius of the coil, and ( $l$ ) is the length of the coil.

$$L = \frac{\mu_0 N^2 (\pi r^2)}{l} \quad (16)$$

Inductors can be placed within each other to increase the magnetic field created. When this is done, a relationship develops between the inner and outer coils. This relationship can be seen in Equation 17, where ( $V$ ) is the  $V_{rms}$  drop across each inductor, ( $r$ ) is the radius of each conductor,

(L) is the inductance of each conductor, and subscripts (out) and (in) denote which coil is placed within the other.

$$\frac{V_{out}}{V_{in}} = \frac{r_{out}}{r_{in}} \sqrt{\frac{L_{in}}{L_{out}}} \quad (17)$$

With the multiple possible ways to calculate inductance, they can all be used to verify one another as well.

### **Preliminary Work**

This lab was one of the denser ones worked on. It incorporated everything from the resistor and capacitor (RC) lab, but in more detail and further configurations, and then also asked the students to compare what they learned to the principles from the RC lab. We decided to keep the main portion similar to the RC lab, with a discussion between concepts like phase angle, time constant, and reactive properties for an inductor. We did add an investigation between two coils, one with a large radius and one with a smaller radius, both with unknown inductance. This addition would allow the students to use what they have learned to discover something new, a situation not unlike something they would encounter in the professional world.

After establishing the important concepts for the lab, we began working on the best way to present those concepts to the students. We decided to use the inductor on the Pasco circuit board to find the phase angle, tau time constant, and reactive inductance. Each of these processes would have their own tutorial video and then one video would be dedicated to the Pasco inductor providing an overview of all concepts. As practice began on these processes in preparation for making the tutorials, we also thought to include how the inductor compared to the capacitor. This addition was not difficult, as the RC lab videos were just finishing. The difficult part came when the investigation began for the inductors with unknown inductance.

From background, there are multiple ways to find an inductor's inductance, and we made sure to include all of these methods somewhere in the lab procedure. This will be described in more detail in the next section, but our desire to include all these different procedure possibilities and verify inductance through them all, caused many initial problems while writing the procedure. The biggest issues surrounded the coils with unknown inductance, and this was primarily because we had no sure way to verify the various values calculated. The inductance for the smaller coil investigated, was first calculated through geometric properties, using Equation 16. This is depicted through Equations 18 – 22.

$$r = 0.2 \text{ cm} = 0.002 \text{ m} \quad (18)$$

$$l = 12 \text{ cm} = 0.12 \text{ m} \quad (19)$$

$$N \approx 120 \quad (20)$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ H/m} \quad (21)$$

$$L = \frac{\mu_0 N^2 (\pi r^2)}{l} = \frac{4\pi \times 10^{-7} (120^2) (\pi (0.002^2))}{0.12} \cong 19 \mu\text{H} \quad (22)$$

This inductance value was then verified through the Ohm's Law method. The  $V_{rms}$  was found using the digital multimeter across the inductor, and the  $I_{rms}$  value was displayed on the function generator for the circuit. The internal resistance of the conductor could then be solved for using a variation of Equation 1. A variation of Equation 13 could then be used to solve for inductance.

This Ohm's Law method toward inductance is depicted through Equations 23 – 26.

$$I_{rms} = 0.34 \text{ A} \quad (23)$$

$$V_{rms} = 0.21 \text{ V} \quad (24)$$

$$X_L = \frac{V_{rms}}{I_{rms}} = \frac{0.21}{0.34} \cong 0.62 \Omega \quad (25)$$

$$L = \frac{X_L}{2\pi f} = \frac{0.62}{2\pi(1000)} \cong 98 \mu\text{H} \quad (26)$$

Comparing Equation 22 and 26, the two inductances calculated are not equivalent as they should be. Because the geometric procedure requires a human to measure and approximate various properties of the coil, such as radius, length, and number of windings on the coil, human error was deemed the cause of the discrepancy. To try and remedy this, the geometric portion was repeated many times until we both concluded there must be a larger underlying reason. Dr. Chronis was asked for assistance and we started re-working the Ohm's Law portion of the lab many times to look for any possible mistakes. Dr. Chronis had the idea that maybe the circuit we had established was incorrect, so after one day of experimenting with the procedure and multiple inductors of various sizes, we started to do more research. Eventually we learned that we had forgotten to account for the internal resistance of the wires wound around the coil. It is accounted for in the Ohm's Law method because of the voltage and current measurements taken right off the circuit, however calculating inductance purely from the geometrical properties does not account for the wire and therefore cannot be verified experimentally.

### **Creation of Screencasts**

For this lab, a total of five tutorial videos were created, four covering the Pasco inductor and the multiple processes for that, and one dedicated to the investigation of two coils with unknown inductance. All of the videos used a digital multimeter, a function generator supplying alternating current, an oscilloscope, and a resistor box. Four out of five of the tutorials utilized a Pasco circuit board and its corresponding inductor, but the last one used the above equipment to investigate a thick wired inductor with a small radius and an inductor with a thinner wire and a larger radius. The last two inductors had unknown inductance, so it was left to the students to discover and verify.

The first video was dedicated to finding the inductance from the LR time constant. There are some pitfalls to this procedure, such as manipulating the voltage values in theory to finding them on the oscilloscope, but these were all previously discussed in the RC time constant tutorial, so this video was able to focus on deeper conceptual observations. The video began with a demonstration of establishing the circuit, while mentioning some important things to observe and ponder, such as why you would have power go through the resistor before the inductor. One oscilloscope's probe was placed before the inductor, and the waveform was switched to be a square wave to see the decaying exponential. From there, one cursor was placed at the peak and the second was placed at 63% of the max voltage, or the value after one time period. From there the oscilloscope can calculate the time period between the two and the student can calculate the corresponding inductance, using Equation 14. This video walked through every step of the procedure, but it was kept relatively short because the process had been covered in the RC time constant tutorial.

The next video introduced the concept of reactive inductance, including comparisons to reactive capacitance from the previous lab. The formula was first discussed, seen in Equation 13, which shows it is only applicable if the inductance and the frequency are known. Because the Pasco inductor's inductance is known, the video first demonstrated how you could use this formula but moved on to a procedure if inductance was not known utilizing the Ohm's Law. Because the circuit is connected in a series configuration, the current throughout the components will be equal. The video walked through how the measured  $V_{rms}$  across the inductor and the displayed circuit's  $I_{rms}$  on the function generator, could be used with the Ohm's Law (Equation 1) to calculate a corresponding resistance of the inductor, or the reactive inductance. This value would be verified from Equation 13 as discussed above. Although these procedures seem

redundant, the tutorial walked through these manipulations in detail because the utilization of reactive inductance and its different relationships would be critical in the future portions of the lab.

The next video explored the phase angle of the Pasco inductor from the circuit. This process began similarly to the RC phase angle procedure but there were some distinct differences. Once the circuit was established correctly and the oscilloscope's probes were placed in the proper positions, the video began reviewing the theory of waveform phase angles. Using the relationship that one period of the circuit corresponds to 360 degrees, some other time period, like the time between wave peaks, corresponds to some unknown angle. Up to here, the process was exactly the same as the RC phase angle lab, but because of the difference in vector diagrams (as seen in Figures 9 and 3) the angle calculated in the same way as the RC lab would yield the resistor phase angle, not the inductor phase angle. The inductor phase angle would be ninety minus the found angle. This had been mentioned pictorially in the RC lab, but this was the first time the students were utilizing that information, so it was discussed thoroughly in the video. Part of that discussion was introducing the math operation on the oscilloscope to display the wave of the resistor and to show that the phase angle between the two circuit elements, the inductor and resistor, was equal to ninety degrees, which can also be seen in Figure 9. Another method using the reactive inductance was briefly discussed in the tutorial, but only for the students' edification and to further demonstrate how reactive inductance can be utilized and manipulated. The video then pointed out some important observations the student should be making during the lab, like the fact that the inductor was leading the circuit versus the capacitor lagging behind the circuit. The reason behind that observation was left to the students to determine. This is a moment where the addition of the tutorial videos offers helpful insight into

the lab manual. Showing the students a correctly set up lab experiment displaying the desired results, gives them a benchmark to go off of. They know the observations they should be making, which releases some of the guesswork from the lab, and allows the students to concentrate on connecting and understanding the core concepts.

The next video supplied a brief overview of the Pasco inductor and everything conducted for that portion of the lab. The video began with demonstrating the correct circuit to establish, and then moved on to reviewing the multiple ways reactive inductance could be found. This was primarily included to demonstrate a helpful procedure using reactive inductance that would be needed in the next portion of the experiment.

The last video for this lab was dedicated to the investigation of two coils with unknown inductance. At this point in the lab, working with an unknown inductance, the students were expected to utilize the processes explored previously with only a very general procedure, which made this tutorial video, and the one previously mentioned, vitally important to the students. One of the coils had a thick enough wire that the windings of it could be counted by hand, so the video began with demonstrating how the geometrical properties of the coil could be used to calculate inductance, using Equation 16. The coil was then put into a circuit and the reactive inductance, and subsequently the inductance, was calculated using the Ohm's Law method laid out in the previous section. There is a significant discrepancy between the inductance calculated geometrically and the inductance calculated through the reactive inductance, and the video mentioned this discrepancy and hinted towards the reason but did not give away that it was due to the resistance from the wires being neglected in the geometric methodology. The video then demonstrated both the small coil and a coil with a larger radius, interacting together and the observations that should be made from that interaction. First the small coil was placed in the

center of the bigger coil, with power going through the small coil, and the  $V_{rms}$  across both coils was measured. A distinct relationship was discussed in background between the ratios of the inductors' radii, inductances, and  $V_{rms}$  values, which the video began discussing. It was also demonstrated how a metal rod placed into the small coil might affect both inductor's  $V_{rms}$  values; they increased, but proportionally, again suggesting this ratio relationship. This is a relationship the students should be familiar with from class, but the configurations to explore this relationship can be complicated. If the students were unsure how to measure the  $V_{rms}$  across both inductors separately for example, or had they set up their circuit incorrectly, they would have missed observing this relationship and therefore would not have solidified that concept in the lab.

## Chapter 4: Thermodynamics

### Background

The Ideal Gas Law is a general equation of state for a hypothetically ideal gas [13]. It is shown in its most common form in Equation 27, where (P) (V) and (T) represent the pressure, volume, and temperature of the gas, (n) is the amount of substance, and (R) is the ideal gas constant.

$$PV = nRT \quad (27)$$

It is a combination of Boyle's Law (Equation 28), Charles's Law (Equation 29), and Avogadro's Law (Equation 30) [14].

$$PV = C_1 \quad \therefore \quad P_1V_1 = P_2V_2 \quad (28)$$

$$\frac{V}{T} = C_2 \quad \therefore \quad \frac{V_1}{T_1} = \frac{V_2}{T_2} \quad (29)$$

$$\frac{V}{N} = C_3 \quad \therefore \quad \frac{V_1}{N_1} = \frac{V_2}{N_2} \quad (30)$$

Each substance has a specific heat capacity, which is a property of the substance. The value of specific heat is a representation of the amount of heat (or energy) that must be added to a substance for its temperature to increase one unit on the Kelvin scale [15]. It is generally noted with the variable ( $c_p$ ) and measured in units joule per kelvin per kilogram (J/K\*kg) [15]. A substance's specific heat can be used to describe the speed at which that substance will heat and/or cool. A higher specific heat equates to a longer heating/cooling time because it requires a greater amount of energy to change temperatures, and oppositely a lower specific heat equates to a faster heating/cooling time because it does not require a great amount of energy to fluctuate temperature.

## **Preliminary Work**

This was the final lab worked on for the project. These tutorial videos were actually added on kind of late. Ideally, tutorials would have been made for all of the labs, but the first three discussed were always the main objective for the summer. Dr. Chronis and I wanted to prioritize those and have them absolutely finished, and thankfully we did. With the small amount of time at the end of the summer, other labs were worked on, and this one was finished.

This lab was not a priority because there were no necessary content changes to be made, and none of the new equipment would be used. The procedure was streamlined a little bit more, but videos were included primarily because of the DataStudio work. For many students, this lab is their first time working with DataStudio and it can be an unintuitive program. So, at the end of the summer, it was decided to create a few more tutorials covering this thermodynamics lab.

## **Creation of Screencasts**

This lab consisted of two tutorials, one dedicated to the constant pressure and volume relationship of the Ideal Gas Law, and the other covering temperature and specific heat capacity. It was a last priority because this lab did not use any new equipment.

The first video discussed the Ideal Gas Law's constant pressure-volume relationship, seen in Equation 28 and began the experiment demonstration using DataStudio and an Ideal Gas Law apparatus. This apparatus was essentially a pressure chamber within a test tube. That apparatus was connected to a pressure sensor, which connected to a link that logged the pressure information into DataStudio. The video began by discussing all of this equipment and how it all would be working together for this lab. The video then walked through opening DataStudio and how to set up the program for this experiment, such as inputting the variables to be used and changing the option so that data is collected only when commanded. Some time was spent

discussing what the students should be looking for, which in this lab should be a constant linear graph depicting the constant relationship between changing pressure and changing volume. The possible mistakes were also highlighted for students to avoid, such as collecting the data on DataStudio too quickly which would cause the temperature change from the moving gas to affect the linearity of the graph. The video then demonstrated the rest of the procedure for the lab. The syringe was pushed to a volume level, the gas was allowed to come to equilibrium, then the pressure was clicked to be collected by DataStudio. The volume the syringe was set at was inputted as well with the pressure point collected by the pressure sensor. Repeating this with various volume levels, the student create a graph of their inputted volume points and the corresponding pressure in the syringe at that volume. All of these steps were shown in the tutorial, specifically the DataStudio setup. If all the students watch this, there should be no questions on how to use DataStudio, which frees up the teaching assistant or professor running the lab for deeper conceptual questions.

The second video for this lab explores specific heat capacity by heating and cooling water and alcohol, recording the data with DataStudio, and observing the differences in temperature. The video began by introducing the equipment and setting up the experiment. It demonstrated setting 100 milliliters of water and 100 milliliters of isopropyl alcohol onto a hot plate and placing the temperature probes into each beaker. It also mentioned to the student to be sure the probe stays at the bottom of the beaker for the entire duration of the experiment. Then the tutorial walked through opening and setting up the Datastudio program, including adding the two temperature sensors to the proper channels on DataStudio. The hotplate is then turned on to start heating the two liquids up to 50° F. The video also demonstrated how to collect and observe the temperature data on DataStudio while the liquids heat up. The tutorial mentions an observation

that the alcohol was heating faster than the water. The specific heat property was mentioned in the video as the possible cause of that, but it was left to the students to determine if that was true, and how that affects the cooling portion of the lab. The addition of the video helps the students know the proper way to set up the experiment and what they should be observing.

## Chapter 5: Equipment

The last contribution of this project were tutorial videos on each piece of equipment. A great deal of new equipment was bought for this revitalization, and part of the project was first learning about this new equipment and then mastering it all. These videos were created to provide a basic overview of the more complex instruments, separate of any specific lab material to serve as a point of reference for all laboratories, and any other possible future use.

The first video created covered the function generator. This piece of equipment can supply either an alternating current or a direct current, but it was generally used as an AC power supplier. The video demonstrated how to change the waveform and the supplied frequency, as well as other attributes that were necessary in various labs. The most important thing it covered was the possibility of overcurrent in the function generator, meaning the circuit either has too little resistance or too much voltage, and ways to avoid damaging both the function generator and the circuit.

The oscilloscope tutorial was likely the most important video because of that instrument's complexity. The oscilloscope captures AC waveforms and calculates a multitude of other parameters by placement of probes throughout the circuit. The screencast discussed a general overview of this and tips on how to use an oscilloscope to your best advantage. This started with where to best place the probes. For the labs worked in Physics 115, the circuits were generally no more than two elements. The oscilloscope's probe measures from placement to ground, so wave 1 was best placed before any circuit elements in order to measure the entire circuit's voltage drop and wave 2 was placed before the element of interest to capture the power through that element. The oscilloscope contains a "math" function that allows a variety of mathematical operations to be done to the two waves. In these labs, the subtraction operation was mostly used between the

two waves because, if the probe placement is correct, this would yield the last element's waveform. The video also mentioned that the oscilloscope needed several data points to calculate values correctly, so if the frequency could not be calculated by the oscilloscope, the other calculated measurements were likely untrustworthy. The oscilloscope is very complex and can do many things, so only the primary functions used in the labs were covered in the video. This was helpful to perform the lab, and also created curiosity in the students as to what else the oscilloscope was capable of.

The last equipment video covered the digital multimeter used in nearly every lab experiment. While most students may have used one of these prior to Physics 115, the video demonstrated how that instrument would be used in a context they likely had not experienced. The basic functions of the multimeter were demonstrated, like the proper settings for DC and AC voltage, but also the various operations used in the following laboratories. The multimeter can be used to measure an element's internal resistance or capacitance. Doing this is an example of investigating your design elements, which is a critical skill in the professional world. An engineer should avoid an unknown output by examining all of the intrinsic properties of their elements beforehand. The screencast also demonstrated how one could use a multimeter to verify the voltage readings displayed on the function generator. This skill introduces the idea of verification to the students working the lab. Even if that step is not properly stated in the lab manual, the addition of the tutorial encourages the students to start thinking about verifying their answers, which is another skill highly sought after in industry.

## References

1. Capacitors and Capacitance vs. Inductors and Inductance - Video Tutorial. (n.d.). Retrieved November 23, 2020, from <https://www.allaboutcircuits.com/video-tutorials/inductance-and-capacitance/#:~:text=Capacitors%20and%20inductors%20are%20electronic,energy%20in%20a%20magnetic%20field>
2. RC Charging Circuit Tutorial & RC Time Constant. (2020, August 26). Retrieved November 23, 2020, from [https://www.electronics-tutorials.ws/rc/rc\\_1.html](https://www.electronics-tutorials.ws/rc/rc_1.html)
3. Inductor and the Effects of Inductance on an Inductor. (2020, November 2). Retrieved November 15, 2020, from <https://www.electronics-tutorials.ws/inductor/inductor.html>
4. P. (2006, Spring). Expt. 2: DC Circuits. Retrieved November 21, 2020, from [https://sites.fas.harvard.edu/~scphys/courses/E1b/E1b\\_2.pdf](https://sites.fas.harvard.edu/~scphys/courses/E1b/E1b_2.pdf)
5. Insulator Breakdown Voltage: Physics Of Conductors And Insulators: Electronics Textbook. (n.d.). Retrieved November 14, 2020, from <https://www.allaboutcircuits.com/textbook/direct-current/chpt-12/insulator-breakdown-voltage/>
6. OpenStax. (n.d.). Physics. Retrieved November 21, 2020, from [https://courses.lumenlearning.com/physics/chapter/20-5-alternating-current-versus-direct-current/#:~:text=Direct%20current%20\(DC\)%20is%20the,charge%20that%20periodically%20reverses%20direction.](https://courses.lumenlearning.com/physics/chapter/20-5-alternating-current-versus-direct-current/#:~:text=Direct%20current%20(DC)%20is%20the,charge%20that%20periodically%20reverses%20direction.)
7. Capacitive Reactance - The Reactance of Capacitors. (2018, September 02). Retrieved November 15, 2020, from [https://www.electronics-tutorials.ws/filter/filter\\_1.html](https://www.electronics-tutorials.ws/filter/filter_1.html)

8. RC Oscillator Circuit - The RC Oscillator Tutorial. (2020, March 25). Retrieved November 23, 2020, from [https://www.electronics-tutorials.ws/oscillator/rc\\_oscillator.html](https://www.electronics-tutorials.ws/oscillator/rc_oscillator.html)
9. Square wave. (2020, November 19). Retrieved November 23, 2020, from [https://en.wikipedia.org/wiki/Square\\_wave](https://en.wikipedia.org/wiki/Square_wave)
10. LR Series Circuit a series Inductor and Resistor. (2018, July 23). Retrieved November 23, 2020, from <https://www.electronics-tutorials.ws/inductor/lr-circuits.html>
11. Electrical4U. (2020, October 11). Electrical Reactance: What is it? (Inductive & Capacitive). Retrieved November 23, 2020, from <https://www.electrical4u.com/electrical-reactance/>
12. Electrical4U. (2020, August 19). RL Series Circuit Analysis (Phasor Diagram, Examples & Derivation). Retrieved November 23, 2020, from <https://www.electrical4u.com/rl-series-circuit/>
13. Ideal gas law. (2020, November 3). Retrieved November 23, 2020, from [https://en.wikipedia.org/wiki/Ideal\\_gas\\_law](https://en.wikipedia.org/wiki/Ideal_gas_law)
14. (n.d.). Retrieved November 23, 2020, from [https://www.chem.fsu.edu/chemlab/chm1045/gas\\_laws.html](https://www.chem.fsu.edu/chemlab/chm1045/gas_laws.html)
15. Specific heat capacity. (2020, November 4). Retrieved November 24, 2020, from [https://en.wikipedia.org/wiki/Specific\\_heat\\_capacity](https://en.wikipedia.org/wiki/Specific_heat_capacity)

## **Conclusion**

This has been a valuable and successful project. It was set out to rework the Physics 115 lab manual and create tutorial videos for the more complicated procedures, which has been accomplished. We were actually able to go above our initial goals and include screencasts for other labs and each piece of equipment. The addition of a screencast showing the experiment's procedure is a valuable addition to lab manuals. Watching these beforehand, allows the student to go into the experiment with a wealth of base knowledge. They know the observations they should be making and can think solely about what these observations say about the concepts.

If anything could have been done differently, this project should have been completed within a senior year instead of a sophomore year. The foundation of knowledge could have been solidified after a few more years of instruction, which would have resulted in clearer, more thorough tutorial videos. Overall, many lessons were learned. Learning the process for designing experiments, has been an assistance throughout other work as well.