An Undergraduate Guide into Experimental Physics: Thermodynamics and Electricity and Magnetism

by Mark Sterrett
mws0002@alumni.uah.edu
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Chapter 1

Boyle's Law

1.1 A Brief History

Robert Boyle observed a relation between the pressure and volume in a gas in 1662. **Boyle's Law** depicts a special case of the *Ideal Gas Law*. There is an *inverse* proportionality between the pressure and the volume of a gas when the temperature of that system is kept constant. During today's experiment you will observe the relationship Boyle's Law describes.

1.2 Notes

1. Always read the lab manual before coming to class. Daily quizzes will be given at the beginning of each class covering material in this manual.

2. It is always a good idea to bring a flash drive to class in case you may want to save images or data gathered during the experiment. I would recommend that each group member bring their own flash drive; relying on a single group member to email relevant data is never a good idea. This manual and your TA will remind you one class in advance if a flash drive is absolutely necessary.

3. By the way, you will need a flash drive for the next Chapter, Specific Heat.

4. Throughout the semester you will find that the necessary theory to solve some of the problems in the labs will be developed within the procedure. Read ahead!

5. Items outlined in boxes are questions that you may try to answer during class however it is more of an individual task to answer those questions outside of class time. They should be addressed in the results section of your lab report.

6. If you are in the Honors section, be sure to review all of the Honors questions before leaving class. Sometimes steps will be required in the class to answer those questions. It is also a good idea to work on those problems with your group mates so as to not pull an all-nighter trying to figure out if something is a 2 or a 3.

7. Expect typos in this manual. This is the first semester it is in use and there are bound to be errors. Send an email to mws0002@alumni.uah.edu to report any typos. Your TA may or may not give extra credit for this.

1.3 Definitions

1. *Boyle's Law*-The principle that at a constant temperature the volume of a confined ideal gas varies inversely with its pressure[1].

2. *Pressure*-The force per unit area that one region of a gas, liquid, or solid exerts on another. Pressure is usually measured in Pascal units, atmospheres, or pounds per square inch[1].

3. *Volume*-The amount of space occupied by a three-dimensional object or region of space[1].

4. *Temperature*-A measure of the ability of a substance, or more generally of any physical system, to transfer heat energy to another physical system. The temperature of a substance is closely related to the average kinetic energy of its molecules[1].

[1]Definitions were provided by *The American Heritage Science Dictionary*

1.4 Laboratory Objectives

By the end of today's exercise it is in the hopes of this Author that you will understand how the relationships of Pressure, Volume, and Temperature behave in a closed system.

1.5 Equipment

Pressure Sensor w/ Syringe Attachment, Datastudio

1.6 In Class Lecture

1. The TA will introduce the concepts that will be covered in this lab as well as go over the syllabus.

2. The TA will go over the ideal gas law and the portions of it that will be held constant.

1.7 Procedure

1. The lab apparatus should be ready-to-go before the lab begins as set up by the instructor. Your instructor will give you the temperature of the room in Celsius. It is up to you to convert it to Kelvin for the purposes of this experiment.

   T: _____ °C $\longrightarrow$ T: _____ K

2. Open **Datastudio** and allocate the **Pressure Sensor** (**Absolute**) to Channel 1. Click on the **Pressure Sensor** (**Absolute**) icon and select *Sensor Properties*, select the *Slow* option with a **1** second sample rate. Confirm and then select the *Options* option to configure *Sampling Options*. Select the *Keep data only when commanded* option. Type *Volume* as a label and *ml* for the units. Confirm the setup and exit.

3. Adjust the **Syringe** such that the piston located inside of the **Syringe** is located at the **15 ml** line.

4. On **Datastudio**, click the *Start* button. Now slowly increase the **Volume** inside of the **Syringe** such that the piston is located at the **20 ml** line. On **Datastudio**, click the *Keep* button. When **Datastudio** prompts you to enter a value, enter the value of **20 ml**.

5. Reduce the **Volume** of the **Syringe** to *19 ml* and on **Datastudio** press the *Keep* button. When **Datastudio** prompts you to enter a value, enter the value of **19 ml**.

6. Reduce the **Volume** of the **Syringe** to *18 ml* and on **Datastudio** press the *Keep* button. When **Datastudio** prompts you to enter a value, enter the value of **18 ml**.

7. Continue this process of reducing the **Volume** by **1 ml** per interval until the **Syringe** piston reaches the **10 ml** line. Once the piston has reached the **11 ml** line, on **Datastudio** click the *Stop* button.

8. Drag the data you gathered to the **Graph Display** icon. Verify that the graph is Pressure vs Time, that is to say that Pressure is listed on the y-axis and Time is listed on the x-axis. As it stands this is *incorrect* because Time was not a factor in this experiment. Instead, drag the volume data you gathered to the x-axis of the graph to display Pressure vs Volume.

9. Also drag the data for the Pressure to the **Data Table** icon to record those values. Record the Pressure data points for the corresponding volume below.

Vol (ml)	Pressure (N/m^2)	Vol (ml)	Pressure (N/m^2)
20 ml		15 ml	
19 ml		14 ml	
18 ml		13 ml	
17 ml		12 ml	
16 ml		11 ml	

10. Delving into the Ideal Gas Law we know that

$$PV = nRT \tag{1.1}$$

where P is the pressure, V is the volume, n is the number of moles of gas, R is the gas constant which is always 8.31 J/molK, and T is the temperature. For Boyle's Law, we know that nRT must be constant. Thus (11.1) becomes

$$PV = C \tag{1.2}$$

where $C = nRT$ and is always constant.

> **Question 1**: What are the units of C? How do these units compare with PV? What are the units of PV? Discuss this in the results section of your lab report.

11. Find what PV is for all cases that you measured. *Careful with your units, I would not recommend using ml. Perhaps changing it to m^3 would be best.*

Vol (ml)	Pressure x Volume (Nm)	Vol (ml)	Pressure x Volume (Nm)
20 ml		15 ml	
19 ml		14 ml	
18 ml		13 ml	
17 ml		12 ml	
16 ml		11 ml	

> **Question 2**: Were all the values of PV approximately the same? What do you think would happen to this experiment if the Temperature T was not held constant? Could we still use Boyle's Law? Discuss this in the results section of your lab report.

12. From Boyle's Law you can easily observe that if we divide both sides by V that P is inversely proportional to some constant divided by V. Go ahead and calculate what 1/V is in each case, this should be relatively simple considering you used V as your control in this experiment.

Vol (ml)	1/Volume (m^{-3})	Vol (ml)	1/Volume (m^{-3})
20 ml		15 ml	
19 ml		14 ml	
18 ml		13 ml	
17 ml		12 ml	
16 ml		11 ml	

13. Make a rough sketch of Pressure vs 1/V below.

Question 3: Using a graphing program of your choice plot a graph of Pressure vs 1/V and include it in your lab report. Discuss this in the results section of your lab report.

Question 4: Using an arbitrary pair of P and V that you measured above, calculate the number of moles of gas that are present inside of the Syringe. Discuss this in the results section of your lab report.

⋆**Honors Question A**: If a gas at 25.0C occupies 3.60 liters at a pressure of 1.00 atm, what will be its volume at a pressure of 2.50 atm?

⋆⋆**Honors Question B**: Assuming you are wearing scuba gear and swimming under water at a depth of 15.0 m. You are breathing air at 3.00 atm and your lung volume is 0.011 m^3. Your scuba gauge indicates that your air supply is low so, to conserve air, you make a terrible and fatal mistake: you hold your breath while you surface. What happens to your lungs? Why?

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QUIZ 11 - Boyles Law

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Chapter 2

Specific Heat

2.1 A Brief History

The idea that an object has a certain specific heat associated with it carries a lot of weight in determining useful and interesting aspects of that object. If we know the specific heat of an object we may quantify the amount of thermal energy that the object can transfer and absorb. In today's experiment you will explore and observe the transfer of heat from a piece of metal to its surroundings and quantify the amount of thermal energy transferred.

2.2 Notes

1. You will need a flash drive for the next chapter, Electric Field.

2.3 Definitions

1. *Specific Heat*-The ratio of the amount of heat required to raise the temperature of a unit mass of a substance by one unit of temperature to the amount of heat required to raise the temperature of a similar mass of a reference material, usually water, by the same amount.[1]

2. *Calorimeter*-An apparatus for measuring the heat generated by a chemical reaction, change of state, or formation of a solution.[1]

3. *Calorie*-Unit of energy with 1 calorie equalling 4.1868 Joules.

   [1]Definitions were provided by *The American Heritage Science Dictionary*

2.4 Laboratory Objectives

By the end of today's exercise it is in the hopes of this Author that you will understand how

1. Thermal Energy is **transferred** from one medium to another.

2. You may **quantify** the energy transferred from one medium to another.

3. Thermal Energy always transfers from **Hot to Cold** with no exceptions.

2.5   Equipment

Calorimeter w/ Inner Metal Cup + Stirrer, Thermometer, Balance, Various Weights, Glass Beaker, Glass Beaker Heater, Gas Burner, Metal Sample, DataStudio, and Temperature Sensor.

2.6   In Class Lecture

1. The TA will introduce the idea and methodology of using a calorimeter to measure the specific heat of an object and why it is useful.

2.7   Procedure

1. Your instructor will give you the temperature of the room in Celsius. It is up to you to convert it to Kelvin for the purposes of this experiment.

   T: _____ °C $\longrightarrow$ T: _____ K.

2. Measure the Mass of the Metal Sample.

   Metal Sample Mass: _____ kg

3. The lab instructor should have 1 or 2 gallons of water sitting out which should be at room temperature. First measure the Mass of the Calorimeter's Inner Metal Cup + Stirrer.

   Inner Metal Cup + Stirrer Mass: _____ kg

4. Now fill the Inner Metal Cup approximately 3/4 full of water and measure the Mass of the Calorimeter's Inner Metal Cup + Stirrer + 3/4 Water.

   Inner Metal Cup + Stirrer + 3/4 Water: _____ kg   Mass of the Water: _____ kg

5. On **Datastudio** allocate the **Temperature Sensor** icon to Channel A.

6. Insert the **Temperature Sensor** into the water filled Inner Metal Cup and on **Datastudio** click the *Start* button to record the temperature of the water. Find the Mean value of the temperature and record its value, this is the initial temperature of your water.

   T_i^w: _____ °C $\longrightarrow$ T_i^w: _____ K.

Question 1: What is the initial temperature of your Metal Sample?

   T_i^m: _____ °C $\longrightarrow$ T_i^m: _____ K.

7. Fill the glass beaker with water from the tap until it is approximately 1/4 full. Place the 1/4 water filled glass beaker on the beaker heater. Turn the beaker heater to the maximum setting and allow the water inside of the Beaker to boil. After the water is boiling insert the Metal Sample such that it is completely submerged and let it sit for approximately five minutes to bring the metal sample to the same temperature as the boiling water. *Record* the temperature of water after five minutes has past. *Do not use the conventional temperature for boiling water as it is incorrect when used in experiments*

across the world. The ideal gas law predicts different boiling temperatures for different altitudes on Earth.

T_{boil}^w: _____ °C $\longrightarrow$ T_{boil}^w: _____ K.

8. On **Datastudio**, click the *Start* button. Prepare the calorimeter by lifting the lid and the metal stirrer out of the water filled inner metal cup. Now use the metal tongs to grab the heated metal sample and place it into the water filled inner metal cup, immediately close the chamber such that the Temperature Sensor never comes into contact with your heated metal sample. Using the stirrer, stir the water inside of the inner metal cup until the **Temperature Sensor** records a constant temperature.

9. Once the temperature has become constant click the *Stop* button on **Datastudio**. Drag the data you recorded to the *Graph Display* icon. Using the x-y Smart tool, find the value where the temperature is constant. Record this as the final temperature of all items in the system.

T_f: _____ °C $\longrightarrow$ T_f: _____ K.

10. Now you have all the pieces of information you will need to find the specific heat of the Metal Sample. Let us delve into some theory in order to solve this problems. From your coursework you know that

$$\Delta Q = cm\Delta T \tag{2.1}$$

where ΔQ is the heat energy, c is the **specific heat**, m is the mass, and ΔT is the change in temperature. Your goal is to use this equation to find what the **Specific Heat** of the metal sample is. Let us use some physics "hand waving arguments" in order to get equations (12.1) into the correct form for the heat of the entire system. The idea behind a calorimeter is that the energy in a system is not lost to an outside system. It is completely isolated and the heat energy only transfers from one object in a system to another object in the same system until and equilibrium is approached. Therefore we may equate

$$\Delta Q_{sample} = \Delta Q_{water} + \Delta Q_{calorimeter} \tag{2.2}$$

more explicitly written

$$c_s m_s (T_{fs} - T_{is}) = c_w m_w (T_{fw} - T_{iw}) + c_c m_c (T_{fc} - T_{ic}) \tag{2.3}$$

where the subscript s denotes the metal sample, the subscript w denotes the water, and the subscript c denotes the calorimeter. Fortunately we know that

$$(T_{fw} - T_{iw}) = (T_{fc} - T_{ic})$$

therefore

$$c_s m_s (T_{fs} - T_{is}) = (c_w m_w + c_c m_c)(T_{fw} - T_{iw}) \tag{2.4}$$

There is only one piece of information needed to solve for c_s, and that is c_c. Luckily for you, c_c is listed on the outside of the calorimeter. Record that value:

c_c _____ J/kg K

> **Question 2**: Find the specific heat of the metal sample using (12.4). Use a search engine of your desire and find what metal your metal sample is. Calculate the percent difference in the currently accepted value and what you measured. Discuss this in the results section of your lab report.

⋆**Honors Question A**: A 5.8 kg sample of a metal with a specific heat of 0.43KJ/KgC is heated to 100.0C then placed in a 25.0 g sample of water at 30.0C. What is the final temperature of the metal and the water?

⋆⋆**Honors Question B**: The element hydrogen has the highest specific heat of all elements. At a temperature of 25C, hydrogens specific heat capacity is 14300J/(kg K). If the temperature of a .34kg sample of hydrogen is to be raised by 25 K, how much heat will have to be transferred to the hydrogen?

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QUIZ 12 - Specific Heat

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Chapter 3

Electric Fields

3.1   Background

Electric Fields are produced by charges. Charges may one of two signs, positive, negative. Today you will observe how placing positive and negative charges at specific distances can alter an electric field.

3.2   Definitions

1. *Electric Field*-A vector quantity from which is determined the magnitude and direction of the force (electric force) on a charged particle due to the presence of other charged particles, accelerated charged particles, or time-varying currents [2].

2. *Charge*- The attribute of matter by which it responds to electromagnetic forces responsible for all electrical phenomena, existing in two forms to which the signs negative and positive are arbitrarily assigned.

3.3   Laboratory Objectives

By the end of today's exercise you will understand how charges behave in different configurations.

3.4   Equipment

EM Field Program

3.5   Procedure

1. Open the program titled <u>EM Field</u>. Click the *Sources* button and select *3D Point Charges*. Click the *Display* button and then select *Show Grid*.

2. Located at the bottom of the program is an assortment of charges both positive and negative. Drag a +1 charge to the center of the grid. Click the *Field and Potential* button and select *Field Vectors*. This will show the electric field vectors associated with the +1 charge once you click on some arbitrary point on the screen. The direction is given by the arrow head and the magnitude is given by the length of the vector.

3. Using a not so arbitrary approach, try clicking at different intervals on the x-axis. Notice how the magnitude of each vector changes as you approach and distance yourself from the +1 charge.

> **Question 1**: Which direction is the field vector pointing relative to the charge? Does the magnitude increase or decrease as you approach the charge? Discuss this in the results section of your lab report.

4. Replace the +1 charge with a -1 charge and place some arbitrary and not so arbitrary vectors around it.

> **Question 2**: Which direction is the field vector pointing relative to the charge? Does the magnitude increase or decrease as you approach the charge? Discuss this in the results section of your lab report.

5. Take a screen shot using the PRTSC button located on your keyboard, using Microsoft Paint, paste the screen shot and save it to your flashdrive for later use in your lab report.

6. Replace the -1 charge with a +2 charge and place some arbitrary, and not so arbitrary vectors around it.

> **Question 3**: Which direction is the field vector pointing relative to the charge? Does the magnitude increase or decrease as you approach the charge? How does the magnitude differ from the +1 charge? Discuss this in the results section of your lab report.

7. Take a screen shot using the PRTSC button located on your keyboard, using Microsoft Paint, paste the screen shot and save it to your flashdrive for later use in your lab report.

8. Clear the grid and add a +1 charge in the center. Click the *Field and Potential* button and select *Field Lines*. Now click arbitrarily around the +1 charge a few times. Now click the *Field and Potential* button and select *Field Vectors*. Click on the field lines around the charge.

> **Question 4**: Are the vector field lines tangential to the field lines? Discuss this in the results section of your lab report.

9. Take a screen shot using the PRTSC button located on your keyboard, using Microsoft Paint, paste the screen shot and save it to your flashdrive for later use in your lab report.

10. Clear the grid and add a +1 charge and then a -1 charge approximately two box units away. Draw the field lines around each charge. Now add several field vectors along those lines.

> **Question 5**: What direction does the field point with respect to the -1 charge? Are there any points in which the field lines overlap? If a positive test charge that was free to move were placed inside the electric field, along what path would it move? Would it try to approach either of the charges? Discuss this in the results section of your lab report.

11. Take a screen shot using the PRTSC button located on your keyboard, using Microsoft Paint, paste the screen shot and save it to your flashdrive for later use in your lab report.

12. Clear the grid and add a +1 charge and then another +1 charge approximately two box units away. Draw the field lines around each charge. Now add several field vectors along those lines.

> **Question 6**: What direction does the field point with respect to either of the +1 charges? Are there any points in which the field lines overlap? If a positive test charge that was free to move were placed inside the electric field, along what path would it move? Would it try to approach either of the charges? Discuss this in the results section of your lab report.

13. Take a screen shot using the PRTSC button located on your keyboard, using Microsoft Paint, paste the screen shot and save it to your flashdrive for later use in your lab report.

14. Click on the *File* button and then select *Get charges or currents from file*. Select qplates.emf which should simulate two charged plates. Place several field lines in between the two charged plates. Arbitrarily place field vectors inside and outside of the plates. Take care in noting the structure of the electric field.

> **Question 7**: Discuss the structure of the electric field found above. If a positive test charge that was free to move were placed inside the electric field, along what path would it move? Discuss this in the results section of your lab report.

15. Take a screen shot using the PRTSC button located on your keyboard, using Microsoft Paint, paste the screen shot and save it to your flashdrive for later use in your lab report.

16. Exit the program completely, *just to be safe*. Now open the program titled <u>EM Field</u>. Click the *Sources* button and select *3D Point Charges*. Click the *Display* button and then select *Show Grid*. Add a +4 charge to the grid. Add several field lines at arbitrary points.

17. Click the *Field and Potential* button and select *Equipotentials with number*. Click at known distances like 1 box unit, 2 box units, 3 box units etc...until about 6 box units. Make note of the numbers displayed next to each line.

18. Make several field vectors along the equipotential lines.

> **Question 8**: What did you notice about the magnitude and direction of the field vectors that were placed on the same field line at different locations? Discuss this in the results section of your lab report.

19. Take a screen shot using the PRTSC button located on your keyboard, using Microsoft Paint, paste the screen shot and save it to your flashdrive for later use in your lab report.

20. From your coursework you know that work(w) over some distance l done by a charge q is defined as

$$w = \int \vec{F}(r) \cdot d\vec{l} \tag{3.1}$$

where

$$\vec{F}(r) = \frac{q^2}{4\pi\epsilon_0 r^2}\hat{r} \tag{3.2}$$

where $\hat{r}$ is the unit vector that points in the r vector direction. This notation may have jumped your coursework a bit, but just realize that it just tells us that direction of the Force, and that is all we care about for this experiment. Plugging (13.2) into (13.1) yields

$$w = \int \frac{q^2}{4\pi\epsilon_0 r^2}\hat{r} \cdot d\vec{l} \tag{3.3}$$

Lets ignore everything in the equation except for the dot product between $\hat{r}$ and $d\vec{l}$. From the definition of the dot product we know that if the two vectors are orthogonal then the dot product is 0, if they are parallel it will be non zero. So lets examine two cases, the first case being if the two vectors are orthogonal.

If $d\vec{l}$ points perpendicular to the radial vector it means that an imaginary test charge is moving tangent to the electric field lines. Thus the dot product is 0. If $d\vec{l}$ points parallel to the radial vector, it moves in the same direction as the radial vector thus the dot product is not 0. Moreover,

$$w = \int \frac{q^2}{4\pi\epsilon_0 r^2}\hat{r} \cdot d\vec{l} = 0 \tag{3.4}$$

when $\hat{r}$ is perpendicular to $d\vec{l}$ and

$$w = \int \frac{q^2}{4\pi\epsilon_0 r^2}\hat{r} \cdot d\vec{l} \neq 0 \tag{3.5}$$

when $\hat{r}$ is not perpendicular to $d\vec{l}$

Question 9: If an imaginary test charge is placed on an equipotential line, if it moves with the line will the work be 0? If an imaginary test charge is placed on an equipotential line, if it moves perpendicular to the line will the work be 0? Discuss this in the results section of your lab report.

⋆**Honors Question A**: What must the charge of a .05 kg particle be for it to remain balanced against gravity when placed in a downward-directed electric field of magnitude 500 N/C?. What is the magnitude of an electric field in which the electric force it exerts on a proton is equal in magnitude to the proton's weight?

⋆⋆**Honors Question B**: A charge q acts as a point charge to create an electric field. Its strength, measured at a distance of 92 cm away, is 52 N/C. Find the electric field strength.

⋆⋆⋆ **Theory — Honors Question C**: A small positive charge is placed in the electric field of a fixed positive point charge. Is the acceleration of the small positive charge constant? What if the charge was negative? Explain your answer.

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QUIZ 13 - Electric Fields

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Chapter 4

Power and Work

4.1 A Brief History

The concepts of power and work are useful in many areas of interest such as physics, electrical engineering, and chemical engineering. When applying an electrical current to a resister it will heat up. You may calculate the amount of thermal energy the resistor is generating. Using a calorimeter you may measure the amount of thermal energy the resistor releases into the surroundings similar to the way you did before in chapter 12.

4.2 Definitions

1. *Power*-The rate at which work is done, expressed as the amount of work per unit time and commonly measured in units such as the watt and horsepower.[1]

2. *Work*-The transfer of energy from one physical system to another, especially the application of a force to move a body in a certain direction. It is calculated as the product of the force and the distance over which it is applied and is expressed in joules, ergs, and foot-pounds.[1] [1]Definitions were provided by *The American Heritage Science Dictionary*

4.3 Equipment

Electrical Calorimeter, Ammeter, Voltmeter, Power Supply, Wires, DataStudio, Temperature Sensor, Balance, and Masses.

4.4 Procedure

1. Measure the mass of the inner calorimeter cup.

   m_{cal}: _____

2. Fill the cup 3/4 full of water and then measure the combined mass.

   m_{w+cal}: _____

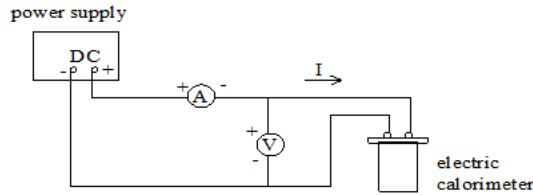3. Determine the mass of the water added.

   m_w: _____

Figure 4.1: Equipment Setup

4. At no point should the Power Supply be turned on until the TA has confirmed that your circuit is connected correctly. Connect an Ammeter and Power Supply in series. Now connect the Calorimeter to the Voltmeter and Power Supply as shown in the diagram above.

5. On Datastudio, connect the Temperature Sensor. Place the physical temperature inside the closed Calorimeter cup. On Datastudio click the Start button. After a few seconds click the Stop button.

6. Drag the data to the Table Display icon. Click the Statistics button and select Mean from the menu. Record the value, which consequently is the Initial Temperature of the water.

   T_{w_i}: _____

7. After the Initial Temperature of the water has been recorded delete the Data and Data Table. Open the Sensor Properties window. Adjust the Sample Rate to be Slow and 30 s. Click OK.

8. On Datastudio, select the Options button. Enter 600 s for the Automatic Stop. Drag the Graph Display to Channel A and then turn on the Power Supply.

9. Set the Power Supply to 2 Amperes. Record the accompanying Voltage. On Datastudio press the Start button to begin recording data.

10. Gently stir the water for the next 10 minutes. When Datastudio automatically stops reduce the current on the Power Supply to 0 and then turn the device off.

11. Display the graph created and click the Scale to Fit button in the event that the graph is too small. Determine the temperature for every two minutes. Record those values.

   T_1: _____ T_2: _____ T_3: _____ T_4: _____ T_5: _____

   Using the same equation from chapter 12,

   $$Q = cm\Delta T. \tag{4.1}$$

   Expanding this to include all relevant terms we have that

   $$Q = (c_w m_w + c_c m_c)\Delta T. \tag{4.2}$$

12. Using (14.2) calculate the heat energy.

13. Express the answer you got in the previous step in joules. Recall that 4.184 joules = 1 calorie.

14. To find the electrical power and electrical energy in the same time interval we may use

$$P = IV \tag{4.3}$$

where P is the power, I is the current, and V is the applied voltage. To find the electrical energy dissipated we may use

$$E = Pt \tag{4.4}$$

where E is the electrical energy, P is the power, and t is the time.

15. Plot the thermal energy as a function of the electrical energy.

⋆**Honors Question A**: What is the difference between power and energy? Also state the difference between kw (kilowatt) and kWh (kilowatt-hour).

⋆**Honors Question B**: Define kWh. Using the standard relation connecting power and energy, show the relation between kW, kW and hour.

⋆ **Honors Question C**: Write down the conversion between kWh and Joules and hence show that 1kWh=3.6MJ.

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QUIZ 14 - Power and Work

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Chapter 5

Circuit Basics

5.1 Background

Circuitry is such a large field of study that you may even pursue a degree in it, or perhaps you already are if you are an Electrical Engineer. Circuits are the ushers of the information era and today you will observe how current flows, the difference between components in series and components in parallel, and the necessary requirements for a circuit to work.

5.2 Definitions

1. *Circuit*-A closed path followed or capable of being followed by an electric current[1].

2. *Series*-A number of components in a circuit arranged one after the other in linear succession.

3. *Parallel*-An arrangement of components in a circuit that splits the current into two or more paths[1].

4. *Resistance*-The opposition of a body or substance to current passing through it, resulting in a change of electrical energy into heat or another form of energy[1].

5. *Volts*-The SI-derived unit of electric potential and electromotive force, equal to the difference of electric potential between two points on a conducting wire carrying a constant current of one ampere when the power dissipated between the points is one watt[1].

6. *Amperes*-The basic unit of electric current, equal to one coulomb per second and equivalent to the current, flowing in two straight parallel wires of negligible cross section separated by a distance of one meter, that produces a force between the wires of 2.0×10^{-7} newtons per meter of length[1].

7. *Ohm*-The SI-derived unit of electrical resistance of a conductor through which a current of one ampere flows when subjected to a one-volt potential across its terminals[1].

8. *Rheostat*-A continuously variable electrical resistor used to regulate current[1].

   [1]Definitions were provided by *The American Heritage Science Dictionary*
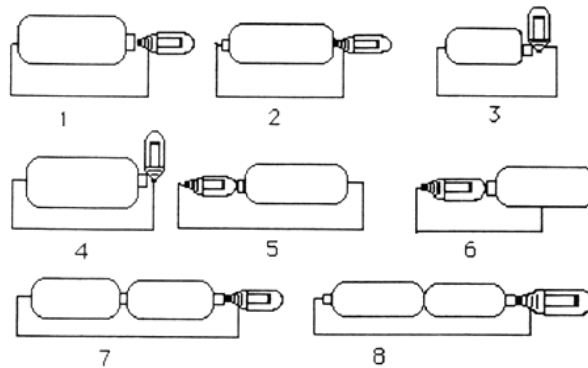
5.3 Laboratory Objectives

By the end of today's exercise it is in the hopes of this Author that you will understand how basic circuits work.

5.4 Equipment

Bulbs, Bulb Socket, Battery, Resistor, Rheostat, Voltmeter, Ammeter, and Connection Wires.

5.5 Procedure

1. Take a look at these poorly drawn diagrams depicting various configurations that you may test. The white cylinders are batteries. The lines are the connector wires. The bulbs are...well they are the bulbs.
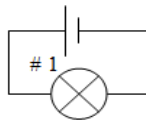

2. Use 1 bulb, 1 connector wire, and multiple batteries to test each configuration and record below whether or not it works.
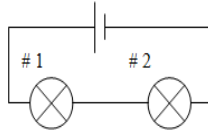
1: _____   2: _____   3: _____   4: _____

5: _____   6: _____   7: _____   8: _____

> **Question 1**: Briefly describe your results and discuss these results in the results section of your lab report.

3. Now set up the following configuration where the ⊗ denotes the light bulb , 1, that has been placed in a holder and the parallel lines represent the battery.
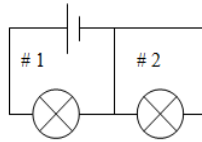

4. Remember the relative brightness of bulb 1 for comparison with the next apparatus. Now set up the following configuration.
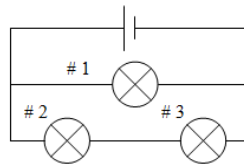
#1   #2

Question 2: How does the brightness of the two bulb configuration compare to the one bulb configuration? Are the bulbs in parallel or series? Feel free to make notes about their brightnesses on the diagrams themselves. Discuss these results in the results section of your lab report.
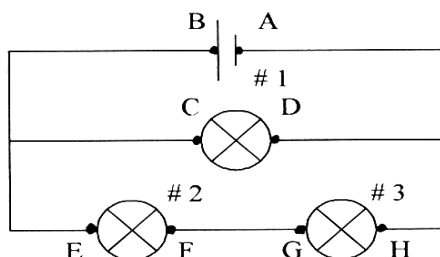
5. Now set up the following configuration.

#1   #2

Question 3: How does the brightness of this two bulb configuration compare to the other two bulb configuration? Are the bulbs in parallel or series? Feel free to make notes about their brightnesses on the diagrams themselves. Discuss these results in the results section of your lab report.

6. Now set up the following configuration.

#1

#2   #3

Question 4: How does the brightness of this configuration compare to the other configurations? Which bulbs are in parallel and which are in series? Feel free to make notes about their brightnesses on the diagrams themselves. Discuss these results in the results section of your lab report.

7. Using the same configuration, change the wires such that one of the wires is absurdly long. Note if the brightness changed. Try moving this wire around and changing the wire's shape. Note if the brightness changed.

8. Below is the same configuration you have already set up. You will check the voltages across several points denoted by the letters.

9. Using your voltmeter, place your reference pick-up at point A. Now measure voltage from A to B, denoted by $V_{A \to B}$.

$V_{A \to B}$: _____V

10. Now find the remainder of the voltages from point A to the rest.

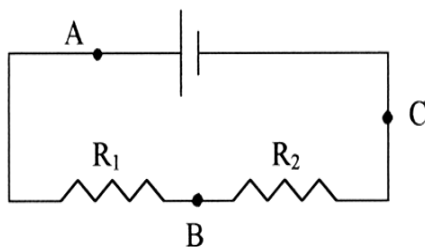$V_{A \to C}$: _____V $V_{A \to D}$: _____V $V_{A \to E}$: _____V

$V_{A \to F}$: _____V $V_{A \to G}$: _____V $V_{A \to H}$: _____V

> **Question 5**: Which connections had 0 voltage? Which connections had the same voltage? Why do you think this happened? Discuss these results in the results section of your lab report.

11. Now remove bulb 1 from the holder, but do not disconnect the circuit connectors. Note what happens.

12. Place bulb 1 back into the holder. Now remove bulb 2 from the holder, but do not disconnect the circuit connectors. Note what happens.

13. Find a way to short bulb 2 from the circuit without removing it from the holder. Hint: You should use another connector wire to do this. Note what happens to each bulb.

14. Disconnect your previous configuration such that you may make the following circuit. The jagged lines are resistors which your instructor will provide. The dots represent different points, A B C, in which you may measure the voltage.

Recall from your coursework that Ohm's Law is portrayed as

$$V = IR \tag{5.1}$$

where V is the voltage measured in volts, I is the current measured in amperes, and R is the resistance measured in ohms. In chapter 16 you will spend quite a bit of time observing the consequences of this law. Your goal today is to discover what the two values of the resistors are, R_1 and R_2. Previously you measured the voltage by placing the prods at two different locations. This method will not work if you wish to measure the current. To measure the current you need to place the *ammeter in series* with the circuit. Here are some useful equations that were developed in your coursework:
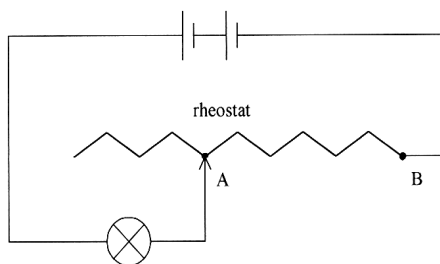
$$R_{series} = R_1 + R_2 \tag{5.2}$$

and

$$R_{parallel} = \left(\frac{1}{R_1} + \frac{1}{R_2} \right)^{-1} \tag{5.3}$$

Question 6: Devise a means in your group to find the values of R_1 and R_2. Discuss these results in the results section of your lab report.

R_1: _____ Ω R_2: _____ Ω

15. Disconnect the configuration and set up the following configuration using the rheostat. There is a sliding connector on the top of the rheostat. This sliding connector should be connected to the light bulb such that upon varying the distance of the rheostat sliding connector you see an effect with the light bulb's intensity.

25

Question 7: Describe what happens to the light bulb when you move the rheostat sliding connector. Why do you think this is happening? How does the rheostat work. Discuss these results in the results section of your lab report.

⋆**Honors Question A**: A series circuit is set up and contains the following: a battery which states '4V' on its side; and two identical lamps. If one lamp breaks, will the other will shine more brightly? If a voltmeter shows the voltage across the first lamp to be 3 volts, can we assume the voltage across the second lamp will be 1 volt? Will the voltage across each lamp be 4V, just like the voltage across the battery?

⋆⋆**Honors Question B**: Describe how voltmeters and ammeters should be connected to circuits.

⋆ **Theory — Honors Question C**: Using any source of information you have at your disposal, describe how you may find which direction electrons flow in a circuit. For fun, ask a physicist which direction electrons flow. Immediately after, ask an Electrical Engineer which direction electrons flow. Who is right? (Before anyone answers, "They are both right!" I will let you know that they are not both right.)

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QUIZ 15 - Circuit Basics

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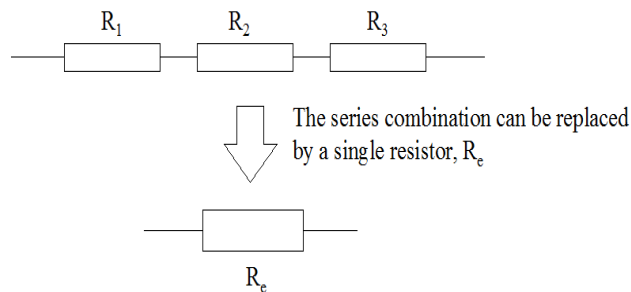
Chapter 6

Ohm's Law

6.1   A Brief History

In 1827 Georg Ohm published his results on resistance in a notable journal of the time. Many of the intricacies he discovered were in part brought about because of Fourier work with heat conduction. Specifically stated, Ohm's law states that the current passing through a conductor between two measured points is directly proportional to the potential difference across those two measured points. One more thing that should be noted is that Ohm's law is not always linear because components on a circuit board are vulnerable to heat. Today you will observe the proportionality between the voltage drop and the current passing through a given component.
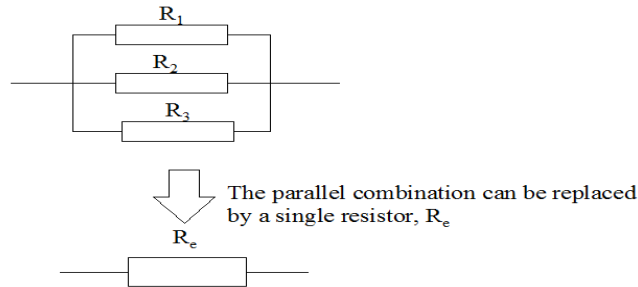
6.2   Definitions

1. *Equivalent Series Resistance*-If resistors are in series, then the sum of those resistors is the equivalent resistance.

$$R_e = R_1 + R_2 + R_3 \tag{6.1}$$

The series combination can be replaced by a single resistor, R_e

2. *Equivalent Parallel Resistance*-If resistors are in parallel, then the sum of the inverse resistances raised to the -1 power is the equivalent resistance of the circuit.

$$R_e = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right)^{-1} \tag{6.2}$$

The parallel combination can be replaced by a single resistor, R_e
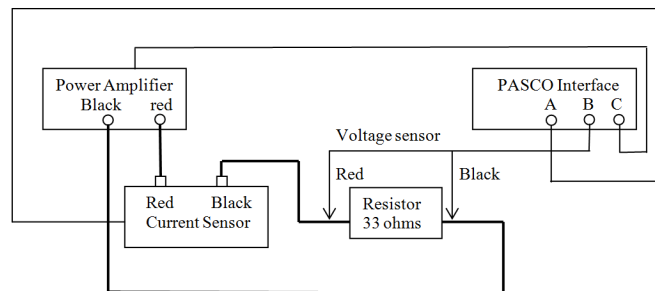
6.3 Laboratory Objectives

By the end of today's exercise it is in the hopes of this Author that you will understand how Ohm's law applies to circuits and how resistor equivalence works.

6.4 Equipment

Power Amplifier, Resistors including a 33Ω resistor, Light bulbs, Voltage Sensor, Current Sensor, Connector Wires, and DataStudio.

6.5 Procedure

1. Set up the following apparatus. To make things easier on yourself, just do one wire at a time and have a group mate check as it is pieced together.

2. Open **Datastudio** and select the *Current Sensor* icon and allocate it to Channel 1. Select the *Voltage Sensor* icon and allocate it to Channel 2. Select the *Power Amplifier* icon and allocate it to Channel 3. Note on the diagram above the PASCAL interface has A,B,C listed. A is Channel 1, B is Channel 2, C is Channel 3.

3. The Signal Generator window should appear. Select *DC Voltage* and set it to **2V**.

4. Turn the **Power Amplifier** on and then on **Datastudio** click the *Start* button. After a few seconds click the *Stop* button. Drag the current data to the *Table Display* icon. Verify that the table shows the Current and the Resistance. Now drag the Voltage data to the same table. Now it should show both current and voltage. Find the mean of these values using the statistics menu.

V_{2V}: _____V I_{mean}: _____A

5. Increase by 2V and repeat this process for the allotted spaces below.

V_{4V}: _____V I_{mean}: _____A V_{6V}: _____V I_{mean}: _____A

V_{8V}: _____V I_{mean}: _____A V_{10V}: _____V I_{mean}: _____A

6. Using the mean values recorded, use **Datastudio** to plot a graph. Click on the *Experiment* menu and then select *New Empty Data Table*. In the x-axis column put the five mean values of current you measured. In the y-axis column put the five mean values of voltage you measured. Now drag this editable data to the Graph Display icon. Use the *Fit* button to display a *Linear Fit* and find the slope of the line.
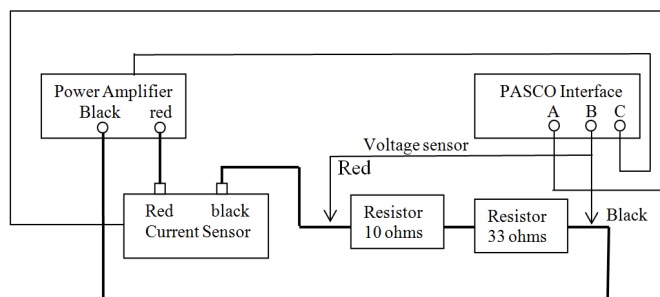
Slope: _____ Ω

Question 1: What does the slope represent? How does it relate to Ohm's Law? Is the relationship approximately linear? Discuss this result in the results section of your lab report.

7. Compare the slope of the line you created to the resistance value labelled on the resistor. That is to say, find the percent difference between what you measured and what the "actual" value of the resistor is.

Percent Difference: _____

8. Now add a 10Ω resistor in series with the 33Ω resistor. Label them as R$_1$ and R$_2$ respectively. Adjust the voltage sensor so that it is taking a voltage reading across both resistors.

9. On Datastudio click the Start button. After a few seconds click the *Stop* button. Drag the run data from Channel 1 to the Table Display icon. Now drag the run data from Channel 2 to the same table. Now it should show both current and voltage. Find the Mean of these values using the statistics menu.

V_{2V}: _____V I_{mean}: _____A

10. Increase by 2V and repeat this process for the allotted spaces below.

V_{4V}: _____V I_{mean}: _____A V_{6V}: _____V I_{mean}: _____A

V_{8V}: _____V I_{mean}: _____A V_{10V}: _____V I_{mean}: _____A

11. Using the Mean values recorded, use Datastudio to plot a graph. Click on the *Experiment* menu and then select *New Empty Data Table.* In the x-axis column put the five mean values of current you measured. In the y-axis column put the five mean values of voltage you measured. Now drag this editable data to the *Graph Display* icon. Use the *Fit* button to display a *Linear Fit* and find the slope of the line.

Slope 2: _____ Ω

> **Question 2**: What does the slope represent? How does it relate to Ohm's Law? Is the relationship approximately linear? Discuss this result in the results section of your lab report.

12. Compare the slope of the line you created to the resistance value of the two resistors in series. That is to say, find the percent difference between what you measured and what the "actual" value of the equivalent resistor is.

Percent Difference: _____

13. Now design the circuit such that the 10Ω resistor is in parallel with the 33Ω resistor.

14. On **Datastudio** click the *Start* button. After a few seconds click the Stop button. Drag the run data from Channel 1 to the *Table Display* icon. Now drag the run data from Channel 2 to the same table. Now it should show both current and voltage. Find the mean of these values using the statistics menu.

V_{2V}: _____V I_{mean}: _____A

15. Increase by 2V and repeat this process for the allotted spaces below.

V_{4V}: _____V I_{mean}: _____A V_{6V}: _____V I_{mean}: _____A

V_{8V}: _____V I_{mean}: _____A V_{10V}: _____V I_{mean}: _____A

16. Using the mean values recorded, use **Datastudio** to plot a graph. Click on the *Experiment* menu and then select *New Empty Data Table.* In the x-axis column put the five mean values of current you measured. In the y-axis column put the five mean values of voltage you measured. Now drag this editable table to the *Graph Display* icon. Use the *Fit* button to display a *Linear Fit* and find the slope of the line.
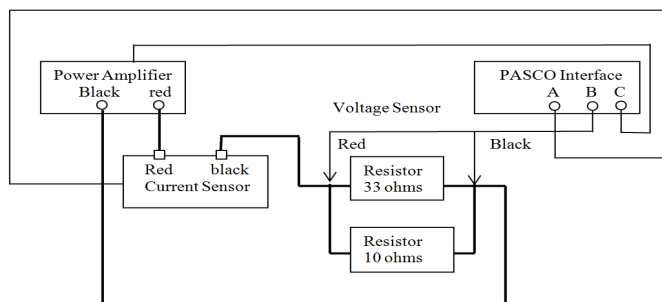
    Slope 3: _____ Ω

    > **Question 3**: What does the slope represent? How does it relate to Ohm's Law? Is the relationship approximately linear? Discuss this result in the results section of your lab report.

17. Compare the slope of the line you created to the resistance value of the two resistors in parallel. That is to say, find the percent difference between what you measured and what the "actual" value of the equivalent resistor is.

    Percent Difference: _____

18. Disconnect the two resistors from the circuit. Place the light bulb into the circuit where the two resistors used to be located. Repeat the same process as before one last time.

19. On **Datastudio** click the *Start* button. After a few seconds click the *Stop* button. Drag the run data from Channel 1 to the *Table Display* icon. Now drag the run data from Channel 2 to the same table. Now it should show both current and voltage. Find the mean of these values using the statistics menu.

    V_{2V}: _____V I_{mean}: _____A

20. Increase by 2V and repeat this process for the allotted spaces below.

    V_{4V}: _____V I_{mean}: _____A V_{6V}: _____V I_{mean}: _____A

    V_{8V}: _____V I_{mean}: _____A V_{10V}: _____V I_{mean}: _____A

21. Using the mean values recorded, use Datastudio to plot a graph. Click on the *Experiment* menu and then select *New Empty Data Table.* In the x-axis column put the five mean values of current you measured. In the y-axis column put the five mean values of voltage you measured. Now drag this editable table to the *Graph Display* icon.

    > **Question 4**: Is the slope linear? If it is not linear, explain why. Discuss this result in the results section of your lab report.

⋆**Honors Question A**: What would the effect be on a person if they stuck their finger into a regular wall outlet that supplies 120V (dont try this) with completely dry skin (R=100,000 ohms)?

⋆**Honors Question B**: What would the effect be on a person if they stuck their finger into a regular wall outlet (again dont try this) after sitting in a bathtub full of salt water (R=100ohms)? Find the percent difference between this answer and question A. Which will let you live?

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QUIZ 16 - Ohm's Law

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Chapter 7

RC Circuits

7.1 A Brief History

Capacitors have the ability to charge and discharge electrical currents and are measured in units of Farads. If a resistor and capacitor are in series, there is a such a thing called the time constant. Prove to yourself that if you multiply resistance by capacitance the resulting units are time. So it is not that far of a stretch to call this product of RC the time constant. Today you will observe the time it takes to charge and discharge a capacitor.

7.2 Laboratory Objectives

By the end of today's exercise it is in the hopes of this Author that you will understand how capacitors charge and discharge in a circuit.

7.3 Equipment

RLC Circuit Board, 500 ohm resistor, 330 microfarad capacitor, Connector Wires, and Datastudio.

7.4 Procedure

1. Open **Datastudio** and allocate the *Voltage Sensor* icon to Channel A. On the *Voltage Sensor* select *Sensor Properties* to select *Fast* with a Sample Rate of **1000 Hz**. Confirm and exit. Allocate the *Power Amplifier* icon to Channel B. In the Signal Generator window, select a *Positive Square Wave* with a frequency of **0.4 Hz** and an Amplitude of **4.0 V** with *Auto* selected. Select the *Options* tab and set an *Automatic Stop* at **4.0 s**.

2. Using the RLC circuit board, place a 500 Ω resistor in series with a 330 μF capacitor using the Connector Wires. From the Power Amplifier, place the Black Ground Wire on the capacitor side of the circuit and the Red Wire to the resistor side of the circuit.

3. Place the **Voltage Sensor** across the capacitor. The black ground wire of the **Voltage Sensor** should be on the same side as the black ground wire for the **Power Amplifier**. Turn the **Power Amplifier** on. On **Datastudio**, click the *Start* button.

4. Drag the voltage data to the *Graph Display* icon. Verify that the graph has voltage on the y-axis and Time on the x-axis. Verify that the graph shows the voltage rising to a certain point and then dropping back to almost the zero point. Select the *Smart Tool* and find where the voltage is maximum

and record that value.

V_{max}: _____ V

From your coursework you know that

$$q(t) = q_{max}e^{-t/RC} \tag{7.1}$$

where $q(t)$ is the charge at some time t, q_{max} is the maximum charge the system reached, t is the time, and RC is the time constant. You also know that charge is associated with capacitance and voltage by

$$q(t) = CV(t) \tag{7.2}$$

which leads to

$$q_{max} = CV_{max}$$

Substituting these results into (17.1) gives

$$CV(t) = CV_{max}e^{-t/RC}$$

obviously the capacitance may be divided out leaving just

$$V(t) = V_{max}e^{-t/RC}. \tag{7.3}$$

At the moment we are focused on the charging cycle, so let us find a point on the graph that may interest us. $t = \tau$ seems to be a reasonable point of interest where $\tau = $ RC. Note that for many systems denoting the time constant as τ is not uncommon.

5. To find the point of interest where $\tau = $ RC, we may take V_{max} - $V_{max}e^{-t/\tau}$. After factoring and substituting $\tau = $ RC, this turns out to be $V_{max}(1 - e^{-1})$ which is approximately $0.63V_{max}$. Take your value of V_{max} and multiply it by 0.63 to find where $t = \tau$ and record this value as V_1.

V_1: _____ V

Find the corresponding time for V_1 and record the value as t_1

t_1: _____ s

6. Now record the value of where the Voltage *begins* to rise and record this value as V_2.

V_2: _____ V

Find the corresponding time for V_2 and record the value as t_2

t_2: _____ s

7. Take the absolute value of the difference of t_2 and t_1, and then compare this value to the value of RC. More to the point, find the *Percent Difference* between absolute value of the difference of t_2 and t_1 and RC .

Percent Difference: _____

Now isolate $e^{-t/RC}$ in equation (17.3) and then take the natural log of both sides of the same equation. This gives

$$ln(1 - \frac{V(t)}{V_{max}}) = -\frac{t}{\tau} \tag{7.4}$$

which will provide a convenient way for us to graph the natural log of voltage vs time.

8. Now manually record four sets of voltage on the rising side of the graph corresponding to four equally spaced sets of time. It is your choice to choose the spacing of the time intervals.

V_3: _____ t_3: _____ V_4: _____ t_4: _____

V_5: _____ t_5: _____ V_6: _____ t_6: _____

Question 1: Graph the results in part 8 above using equation (17.4) with the ln on the y-axis and the time of the x-axis. Is the graph linear or exponential? Include this graph in your report and discuss the graph in the results section of your lab report.

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9. Now allocate your attention to the Discharge section of the data graph you measured. Again the point of interest will be where $\tau = t$, i.e. $RC = t$. The only difference from the previous case to this one is that you will not measure $.63V_{max}$ but instead $.37V_{max}$, record this value as V_1 and its corresponding time as t_1.

V_1: _____ V

Find the corresponding time for V_1 and record the value as t_1

t_1: _____ s

10. Now record the value of where the Voltage *begins* to decrease and record this value as V_2.

V_2: _____ V

Find the corresponding time for V_2 and record the value as t_2

t_2: _____ s

Question 2: Why is it that we are interested in $.37V_{max}$ point instead of the $.67V_{max}$ point? Discuss this in the results section of your lab report.

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11. Take the absolute value of the difference of t_2 and t_1, and then compare this value to the value of RC. More to the point, find the *Percent Difference* between absolute value of the difference of t_2 and t_1 and RC .

Percent Difference: _____

12. Now record four sets of Voltage on the decreasing side of the graph corresponding to four equally spaced sets of Time. It is your choice to choose the spacing of the time intervals.

V_3: _____ t_3: _____ V_4: _____ t_4: _____

V_5: _____ t_5: _____ V_6: _____ t_6: _____

Question 3: Find the time constant for the decreasing side of the graph. Is it the same time constant discovered on the increasing side of the graph? Discuss this in the results section of your lab report.

⋆**Honors Question A**: A 100 mF capacitor is connected in series with a 10.0 W resistor. This combination is connected in parallel with a 25.0 W resistor. Both branches are then connected in parallel to a 4.50 V battery that can be switched on and off. The capacitor starts off fully discharged. What is the time constant in both branches when the switch is closed? What is the maximum charge that the capacitor can attain after the switch is closed? When will the voltage drop across the 10.0 W resistor be equal to 1.50 V after the switch is closed? If the switched is opened, what will be the value of the new time constant and in which direction will the current flow through the 10.0 W resistor? If the switch is opened after the capacitor is fully charged, how long will it take for there to be only one electron on the capacitor? If the switch is opened after the capacitor is fully charged, how long will it take for the voltage across the 25.0 W resistor to drop to 1.50 V?

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QUIZ 17 - RC Circuits

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Chapter 8

Tangent Galvanometer

8.1 A Brief History

A charge has an associated electric field. This is something that you have dealt with through this semester. A slightly new concept is the idea that a moving charge also produces a magnetic field. Incredibly enough, the electric field and magnetic field are two manifestations of the same phenomenon. Today you will observe how a moving charge can produce a magnetic field.

8.2 Definitions

1. *Magnetic Field*-A condition found in the region around a magnet or an electric current, characterized by the existence of a detectable magnetic force at every point in the region and by the existence of magnetic poles[1].

2. *Electric Field*-A region of space characterized by the existence of a force generated by electric charge[1].

   [1]Definitions were provided by *The American Heritage Science Dictionary*
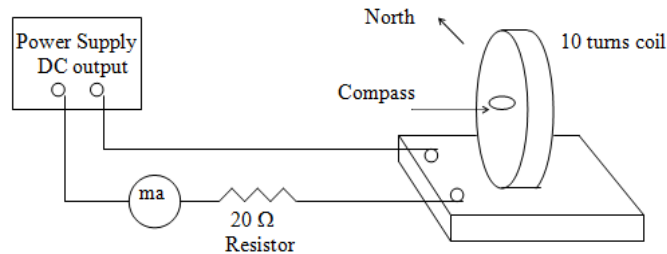
8.3 Laboratory Objectives

By the end of today's exercise it is in the hopes of this Author that you will understand how moving charges produce a magnetic field and what direction that field flows.

8.4 Equipment

10 Turn Coil, Magnetic Compass, Meter Stick, Milliamp Meter, DC Power Supply, variable resistor

8.5 Procedure

1. Using a compass determine which direction is magnetic north. The coil windings will need to be placed parallel to magnetic north as seen in the poorly drawn picture below. Just a reminder that your coil has 10 turns in it exactly. Set up the apparatus as shown:

2. Place the meter stick inside of the coil such that it runs East-West and support it with something so you do not have to hold it for the remainder of the lab. Place the compass on the meter stick such that it is located directly in the center of the coil. Adjust the compass such that it reads **0**. You are looking to observe the deflection of the compass needle by the induced magnetic field upon successfully powering the coils.

3. On the milliamp meter use the **400 mA** setting when recording the current. Accuracy is incredibly important in this experiment so be sure to measure the Compass Needle deflection to the best of your ability. Increase the **Power Supply** current to **50 mA** and record the deflection angle ψ on the compass needle.

    ψ_{50}: _____

4. Now increase the current to **100 mA** and record the deflection angle.

    ψ_{100}: _____

5. Repeat this for the remaining currents below.

    ψ_{200}: _____ ψ_{300}: _____ ψ_{400}: _____

6. Decrease the Power Supply to **0 mA**. Now disconnect the coil from the circuit and switch the direction of current flow by reconnecting the wires oppositely the way they were previously connected. Increase the **Power Supply** to **50 mA** and record the deflection angle ψ'.

    ψ'_{50}: _____

7. Now increase the current to **100 mA** and record the deflection angle.

    ψ'_{100}: _____

8. Repeat this for the remaining currents below.

    ψ'_{200}: _____ ψ'_{300}: _____ ψ'_{400}: _____

Question 1: How do the different directions of current affect the direction of the Compass Needle? Discuss this in the results section of your lab report.

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9. Record the radius of the Coil.

R$_{coil}$: _____

Digressing briefly, from your coursework you are aware that the magnetic field at the center of the coil of wire is given by
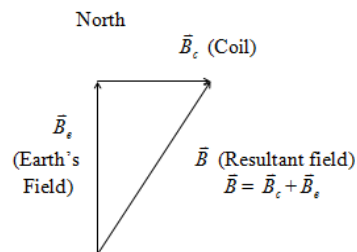
$$B = \mu_0 \frac{nI}{2R} \tag{8.1}$$

where B is the magnetic field, μ_0 is the permeability of free space given by $4\pi \times 10^{-7} \ T \cdot m/A$, n is the number of turns, and R is the radius of the coil. Find the magnetic field, B, inside the coil for all of the above currents. Here is some space to work in:

B_{50}: _____ T B_{100}: _____ T B_{200}: _____ T B_{300}: _____ T B_{400}: _____ T

10. Using your data values for ψ and ψ' plot the $\tan\psi$ vs the values you calculated for B above. Also do this for $\tan\psi'$. Be sure to include these graphs in your lab report and also discuss the results in the results section of your lab report. Here is some room to make some rough sketches of the graphs.

11. Now it will be important to calculate the Earth's Magnetic Field. There is a reason as to why you aligned the experiment with North. Looking at the figure below shows that you may break the Magnetic Field into horizontal and vertical components.

Looking at the diagram it can be seen that

$$\tan(\psi) = \frac{B_c}{B_e} \tag{8.2}$$

where ψ is the angle of the lowest section of the triangle.

Question 2: Devise a means to find the horizontal component of Earth's Magnetic Field using (18.2). What is the relationship between $\frac{1}{B_e}$ and the slope of the line you found in step 14? Discuss this in the results section of your lab report.

12. Increase the current to **400 mA**. Move the compass a distance equal to the radius of the coil and record the deflection of the Compass Needle. Note: Do not move the Compass towards the Coil wall, instead move it perpendicular to the plane of the coil loop.

ψ_R: _____

13. Move the compass a distance equal to twice the radius of the coil and record the deflection of the compass needle.

ψ_{2R}: _____

The derivation of this next equation goes a little beyond the scope of this laboratory but I can assure you that the Magnetic Field it predicts is accurate for a horizontal position perpendicular to a coil. Note: If you decide to take PH 431-Introduction to Electromagnetism, you will derive this equation several times. Since you are approaching the end of this course, I will take a moment and say that if you find this material to be easy to understand, interesting, and useful then perhaps you should look into becoming a Physics Major.

$$B = \mu_0 \frac{NIR^2}{2(R^2 + X^2)^{3/2}} \tag{8.3}$$

where R is the radius of the coil of wire, X is the position where the compass was placed. In this example you used X=R and X=2R. Find the magnetic field for X=R and X=2R. Here is some room to work:

B_R: _____ T B_{2R}: _____ T

⋆**Honors Question A**: Describe a practical use for the tangent galvanometer other than the way it was used in this laboratory.

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QUIZ 18 - Tangent Galvanometer

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Chapter 9

Induced EMF

9.1 A Brief History

Currents may be induced on conductors by the presence of a moving magnet. It is this idea which lets rail guns launch their projectiles without many moving parts. In 1831, Michael Faraday suggested that the Electromotive Force (EMF) produced around a closed circuit is proportional to the rate of change of the magnetic flux through *any* surface bounded by that path.

9.2 Definitions

1. *EMF*-Electromotive Force.

2. *Inductance*-A measure of the reaction of electrical components (especially coils) to changes in current flow by creating a magnetic field and inducing a voltage. Its unit is the henry[1].

3. *Magnetic Flux*-The lines of force associated with a magnetic field. The strength of magnetic flux is equivalent to its magnetic flux density per unit area. The SI unit of magnetic flux is the weber[1].

    [1]Definitions were provided by *The American Heritage Science Dictionary*
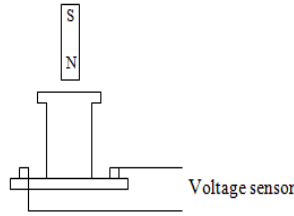
9.3 Laboratory Objectives

By the end of today's exercise it is in the hopes of this Author that you will understand how Magnetic Inductance induces current changes in conductors.

9.4 Equipment

Magnetic Bar, Induction Coil Apparatus, Power Amplifier, Connector Wires, **Datastudio**

9.5 Procedure

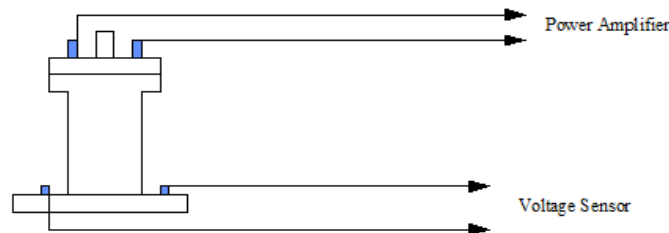1. Create the following configuration if your TA has not already:

Voltage sensor

2. In **Datastudio**, allocate the *Voltage Sensor* icon to Channel A. Connect the **Voltage Sensor** connector wires to the **Induction Coils**. On **Datastudio**, click the *Start* button to begin recording data.

3. Take the bar magnet, regardless of the orientation of N and S, and begin to move it up and down inside of the apparatus. Do this slowly at first and then increase the speed for a few seconds. On **Datastudio** click the *Stop* button and drag the run data to the *Graph Display* icon.

4. Take a mental note of what the graph looks like. Now take the bar magnet and reverse the orientation such that the poles are opposite of the way in the previous step. On **Datastudio** click the *Start* button to begin recording data. Move the bar magnet up and down inside of the apparatus. Do this slowly at first and then increase the speed for a few seconds. On **Datastudio** click the *Stop* button and drag the run data to the *Graph Display* icon.

> **Question 1**: What was the difference in the graphs? Discuss this in the results section of your lab report.

5. On **Datastudio** click the *Start* button. Move the bar magnet in and out of the coil such that it is approximately periodic for about 5 cycles. Now increase the period of oscillation such that it is approximately double for 5 cycles.

> **Question 2**: Is there a difference in voltage amplitude for the different periods? If so, why is it larger or smaller? Discuss this in the results section of your lab report.

6. Delete all data. Now set up the following configuration

Power Amplifier

Voltage Sensor

Allocate the *Power Amplifier* icon to Channel B. In the *Signal Generator* window set the signal to Sine Wave, Amplitude of **1 V**, and the Frequency at **20 Hz**. Click on the *Sensor Properties* window for the *Voltage Sensor* and set the frequency to *Fast* **2000 Hz**. Click the *Option* button and set an Automatic stop at **0.2 s**. Connect the coil to the **Power Amplifier** and insert the soft iron core into the coil.

7. On **Datastudio** click the *Start* button. This will record the output voltage of the secondary coil while the primary coil is oscillating at **20 Hz**. Since **Datastudio** is already set to stop automatically drag the data recorded to the *Graph Display* icon. Record the frequency and maximum voltage. Note: Is the Frequency you set in **Datastudio** the same as the frequency recorded?

f_{20}: _____ Hz V_{max}: _____ V

8. Increase the frequency of oscillation to **40 Hz**. Record the frequency and maximum voltage. f_{40}: _____ Hz V_{max}: _____ V

> **Question 3**: How is the primary coil inducing a voltage in the secondary coil? Does it appear that the voltage is a function of frequency? Discuss this in the results section of your lab report.

9. Delete all data. Remove the primary coil and soft iron core from the apparatus. Now connect the Secondary Coil in series with a 10k Ω resistor. The output of the **Power Amplifier** should now be allocated to this circuit. The Voltage Sensor should be dropped across the Secondary Coil. Note: Recall that a voltage drop is a measurement across an element in a circuit. If you physically drop the voltage sensor on the secondary Coil...well that is just silly.

In **Datastudio** select the *Voltage Sensor* icon and alter some of the *Sensor Properties*. Set the frequency to Fast **10k Hz**. In the *Options* tab, set the Automatic Stop at **0.02 s**. In the Signal Generator window, set the Voltage Amplitude to **10.0 V**.

10. Record the voltage drop on the secondary coil with the power amplifier set to **10 V** with a Frequency of **200 Hz**.

V_{200}: _____ V

11. Record the voltage drops on the secondary coil with the Power Amplifier set to **10 V** with Frequencies of **400 Hz, 600 Hz, 800 Hz, and 1k Hz**.

V_{400}: _____ V V_{600}: _____ V V_{800}: _____ V V_{1k}: _____ V

12. Plot the Voltage Drops as a function of Frequency.

Question 4: What is the slope you recorded? Discuss this in the results section of your lab report.

⋆**Honors Question A**: When a small magnet is moved toward a solenoid, an emf is induced in the coil. However, if the magnet is moved around inside a toroid, no measurable emf is induced. Explain. A piece of aluminium is dropped vertically downward between the poles of an electromagnet. Does the magnetic field affect the velocity of the aluminium? Explain. What happens to the generated current when the rotational speed of a generator coil is increased? If you pull a loop through a non-uniform magnetic field that is perpendicular to the plane of the loop which way does the induced force on the loop act?

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QUIZ 19 - Induced EMF

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Chapter 10

AC Circuits

10.1 A Brief History

AC circuits provide a way to transport electricity over great distances without a ridiculous drop in power. AC stands for Alternating Current. A standard DC current sends a constant signal while an AC current sends a signal that oscillates between "positive" and "negative". Today you will observe how an AC circuit behaves.

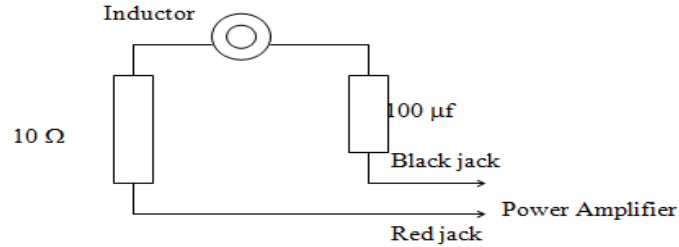## 10.2 Laboratory Objectives

By the end of today's exercise it is in the hopes of this Author that you will understand how useful a free body diagram can be in terms of resolving force vectors. Let us begin by stating Newtons Basic Laws of Motion in a basic form:

10.3 Equipment

RLC Circuit Board, Connector Wires, and DataStudio

10.4 Procedure

1. Allocate the Power Amplifier to Channel A. Set the Signal Generator to 3 V output, Sine Wave, and a Frequency of 10 Hz. Allocate the Voltage Sensor icon to Channel B. Modify the Sensor Properties by setting the Sampling Rate to Fast at 1k Hz.

2. Allocate the Output Voltage icon to the (Oscilli)Scope display. This will display an oscillating wave in real time. Drag the Voltage from Channel B to the same window to display both waves in real time.

3. Create the following circuit:

Inductor

100 µf

10 Ω

Black jack

Power Amplifier

Red jack

Take the Iron Core that is lodged in the RLC circuit board and place it inside of the Induction Coil. Drop the Voltage Sensor across the 10 Ω resistor.

4. Once the circuit is completely turn the Power Amplifier on. On Datastudio click the Start button to begin recording data. Adjust the Volts/Division (V/div) such that both waves are visible. On Datastudio click the Stop button.

5. Use the Smart Tool to record the maximum voltage from the Channel B recording.

V_{10}: _____ V

6. Increase the Frequency by 10 Hz and record the maximum voltage from Channel B. Keep incrementing the Frequency until the Frequency reaches 150 Hz. Note: For each case you may need to adjust the V/div and the ms/div to see both waves.

V_{20}: _____ V V_{30}: _____ V V_{40}: _____ V V_{50}: _____ V

V_{60}: _____ V V_{70}: _____ V V_{80}: _____ V V_{90}: _____ V

V_{100}: _____ V V_{110}: _____ V V_{120}: _____ V V_{130}: _____ V

V_{140}: _____ V V_{150}: _____ V

Analyse your data and find where the voltage reached its peak, this is the resonance frequency of the circuit. Set the Signal Generator to the associated frequency. Adjust the frequency until both waves overlap identically.

7. Set the Scope display to X-Y mode. On Datastudio click the Start button. Drag the Output Voltage to the Vertical Axis of the Scope display and drag the Voltage on Channel B to the Horizontal Axis of the Scope display. If your data is in phase then only a diagonal line will be seen, if they are not in phase a circular oval will appear. Record the exact frequency when a diagonal line is present.

V_{res}: _____ V

⋆**Honors Question A**: What is the resistance of a lightbulb that uses an average power of 75.0 W when connected to a 60 Hz power source with a peak voltage of 150 V?

⋆**Honors Question B**: When a 4.0 μF capacitor is connected to a generator whose output is 30 V, the curent in the circuit is observed to be 0.3 A. What is the frequency of the source?

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QUIZ 20 - AC Circuits

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