UCD: Physics 9C Lab

The LibreTexts libraries are Powered by NICE CXOne and are supported by the Department of Education Open Textbook Pilot Project, the UC Davis Office of the Provost, the UC Davis Library, the California State University Affordable Learning Solutions Program, and Merlot. This material is based upon work supported by the National Science Foundation under Grant No. 1246120, 1525057, and 1413739.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation nor the US Department of Education.

This text was compiled on 04/15/2025

TABLE OF CONTENTS

Licensing

*A detailed breakdown of this resource's licensing can be found in **Back Matter/Detailed Licensing**.*

Read Me: About Labs in Physics 9

The Purpose of Labs

There are many reasons to include a mandatory lab component to the Physics 9-series. Among the benefits to a STEM education are:

- experiencing physical phenomena first-hand, to supplement the mathematically-abstract experience of lectures and problem-solving
- learning very broadly how one can go beyond what just intuitively seems right and actually *test an idea* by devising an experiment
- learning experimental skills, like minimizing errors and controlling for irrelevant factors
- learning data analysis skills, like using graphs and statistical examination
- learning to use uncertainty analysis to determine when a proposition is confirmed or refuted by the data

Some of the earliest labs in Physics 9A are somewhat less about physics, and more about developing some of these skills. At that point not a lot of physics has been learned yet, and these skills are needed throughout the 9-series.

Experiment Types

There are four basic varieties of experiments that will occur in these labs. Occasionally an experiment may have elements of more than one of these types.

- **Simple, repeatable, observations –** These are the most informal sorts of experiments. They typically do not involve a lot of mathematical modeling, and instead are focused on more general features. The most challenging aspect of these kinds of experiments is objectivity – the experimenter must come into them with an open mind, simply documenting what is observed without constructing elaborate explanations for what they are witnessing. One of the worst mistakes that can occur in these is to inadvertently "put your thumb on the scale" (introduce human error) because a certain result is expected. You should go to great lengths to avoid this critical error.
- **Confirmation of a Single Hypothesis** – A prediction is made regarding the outcome of a specific scenario. The result is never *exactly* what is predicted, but the amount of uncertainty measured and computed is used to determine if the experimental result is "close enough" to the predicted to result to be considered a confirmation.
- **Independent Confirmations –** Armed with the theoretical background to compute a physical quantity, the experimenter devises two separate, completely independent experiments to measure that value. Each experiment gives its own result and its own uncertainty range, and the goal is to check if the two experiments confirm the same number within these uncertainties.
- **Choose the Better Theory** – Two mathematical models are proposed to explain a single observed phenomenon. The experiment seeks to determine which of the two theories best describes the relationship between the variables present.

Typical Elements of Lab Meetings and Reports

Below is a list of common tasks performed in laboratory meetings, and items included in submitted lab reports:

- Short test runs of an apparatus are performed to "get a feel" for what is going to happen, and to assist in designing the setup in an optimal manner. These do not include actual data acquisition, and also should not be overused – some variation in results is expected, and variation is not an indication that the design needs to be tweaked indefinitely.
- Careful runs of the apparatus are performed, with multiple experimenters observing or playing a role in maintaining a smooth operation.
- Multiple runs are taken for each data point, to reduce statistical uncertainty. Sometimes the statistical uncertainty is computed and included in the analysis, other times just an average result of a few runs is used (because the statistical uncertainty only contributes a very small amount to the overall uncertainty). Doing this also helps weed-out weird anomalous runs where something unexpected and unnoticed happens (i.e. the removal of rogue data).
- Data tables are created (and included in the lab report). These include both raw data and values computed from that data, and are organized in a fashion that's easy for someone reading the lab report to review.
- Graphs (virtually always linearized – see here for more details) are produced, and best-fit curves (i.e. lines) are used to draw conclusions about the mathematical model used to explain the phenomenon tested in the experiment.
- Uncertainties of two types are computed:

- statistical – standard deviations of measurements with random errors introduced by the imperfect apparatus or by human involvement
- estimated – educated guesses about how accurately one can expect a measuring device to function.

- Lab reports are written with contributions from all group members. The text does not need to be verbose or overly-details, but should get to the point and include most or all of the following points:
  - what you set out to test (explain the problem)
  - how you set up your apparatus to accomplish the test
  - what you expect to see (hypothesis)
  - your results (data tables, graphs, computations, general discussion, etc.)
  - checking to see if your results confirm the hypothesis to within the uncertainties (it is okay if this is not confirmed – staying agnostic about the final result is an important quality)
  - an accounting of the weaknesses in your apparatus or procedure, and suggestions for how these can be improved in future attempts

Organization of Reports

You are not required to follow a specific template for the format of your lab reports. However, it might be helpful to keep things organized in your head to follow something resembling this:

- **Goal** – Give a description of what you hope to accomplish or learn in this particular lab.
- **Hypothesis** – If the lab is one in which an hypothesis is tested, then expressing it explicitly is a good idea.
- **Procedure** – Give a details description of what you did in your experiment, from the preparation.calibration of the equipment, to the method of taking data. It is tempting here to sometimes give some numbers you recorded, but for the sake of organization it's a good idea to resist this. Also, while it is appropriate at times to give a short explanation of why you did something a certain way, this should be kept very brief, or this section will start treading heavily on the later section on analysis.
- **Data** – Display all the data you recorded, without including any discussion of what it means. This includes one-time measurements as well as tables. It's okay to include computed values (if, for example, every recorded number needs to be squared to be put into a graph), but save the main calculations toward a result for the next section.
- **Analysis and Conclusions** – This includes everything else:
  - physics that needs to be explained to get to your answer (free-body diagrams, algebra, etc.)
  - graphs and calculations of final results or uncertainties
  - a description of likely sources of error, and ways to improve the experiment (i.e. reducing errors/uncertainties)
  - final narrative that ties together the results of the experiment vis-a-vis the goal and/or hypothesis

A Final Word

These labs are intentionally not set up to be "cookbook" exercises. There will be some guiding questions to answer in the lab report, and some hints for how to proceed, but for the most part, the design of the experiment and the layout of the lab reports are up to you (your time is limited, so don't get too fancy with this). Keep in mind that you have two goals: The first is to convince yourself of the conclusion (i.e. perform a detail-oriented experiment), and the second is to write a clear lab report that conveys a convincing argument to the reader. Pro-tip for successful experimenters: Try to be more skeptical of your own work than the audience you seek to convince.

CHAPTER OVERVIEW

Lab 1: Static Electric Charge

1.1: Background Material

Text References

- electric charge and force
- dipoles
- conductors

Producing Static Charge

For this lab, you will need a means for producing large amounts of static charge. All of the most effective methods with common household items consist of cloth-rubbing insulating materials such as plastic, acrylic, rubber, and latex. Various materials can also be used as the rubbing cloth, including natural fibers like wool or cotton, as well as synthetic materials like polyester and nylon, or blends between both. Different rubbing materials may work better with certain insulating materials, and you may want to experiment to determine what works best.

Removing Static Charge

In order to keep controls on your experiments, you may wish to *remove* charge from something you have already charged. There are a couple of useful methods for this. The first involves humidity. It turns out that water molecules in the air are quite effective at picking up static charge off surfaces, and carrying them away. This explains why, in colder northern climates, static discharges, like shocks to fingers when touching doorknobs, are more common in the winter, when the humidity is significantly lower. If you are doing this lab in a humid climate, you may find it challenging to keep an object charged for any significant period of time. Anyway, this does provide a means for removing charge – *breathing hot breath* on the object a few times often does the trick. Touching the object on a grounded metal like a water faucet can also help, though since the object is an insulator, you will want to make contact with as many places on the rod as possible, as the charge will not flow across the insulator to a single point of contact.

1.2: Activities

Equipment

- scotch tape
- drinking straws and cups
- balloons
- foam pads
- aluminum foil balls on thread
- plastic tubes
- pvc pipe segments
- plastic bottles
- aluminum cans

The General Idea

This lab is all about static electric charge. We are going to explore three elements of this phenomenon, though this exploration will be observational, and not quantitative like most of our experiments are. These three elements are:

1. Cataloging the signs of charge accumulated on various objects.
2. Recording the importance of the specific action on the sign of charge accumulated (can one object be made to hold different signs of charge if different actions are taken?).
3. Examining the difference between how insulators (non-metals) and conductors (metals) behave with static charge present.

Atoms are neutrally-charged, but we can separate a few of the electrons from their atoms, making the object where the electrons accumulate negatively-charged, and the object from which they were taken positively-charged. We will do this with "surface interactions" – namely, friction and adhesion (pulling sticky tape from a surface). We won't know specifically when we charge something positive or negative, but if we define one case as "positive," we can use attractive or repulsive static electric force to determine the signs of all the other charge accumulations we manage to create.

Some Things to Think About

- You will need to create what is essentially a "detector." This is just something that you can use to observe the attraction/repulsion of the charges you are cataloging. This detector should have the following properties:
  - It should be *sensitive*. That is, it should move easily and unambiguously under the influence of a static electric attraction or repulsion.
  - The sign of charge held on this detector needs to be consistent and repeatable. It is a disaster for consistent results if your detector has a positive sign at the start of your experiment and a negative charge at the end. Note that this means that if you need to "recharge" it, you better do it exactly as you did the first time.
- Always remain aware of your procedures. Electric charge can be carried on your hands, for example. One good rule of thumb is to always "discharge" objects and your hands before embarking on a new measurement. Probably the best way to do this is with humidity – hot breath provides water vapor that picks up spare charge and carries it into the air. Another is to touch a "grounded conductor" such as a chalk tray, or doorknob, but keep in mind that this will tend to only discharge the part of your insulator that comes in contact with it, and charge can be left elsewhere on it.
- The scotch tape is particularly interesting. Sticking it to a surface and pulling it off suddenly will charge it, and different signs of charge can be produced for different surfaces. You have lots of surfaces to work with to see this in action (and you can even pull two pieces of tape apart!).
- Aluminum cans don't require a lot of force to get them rolling, so laying them on their sides may produce some interesting results. In particular, try attracting/repelling a can that you have not charged at all. Try it with both signs of charge. Can you explain the result? Ask your TA if you have the explanation right.
- Your lab report should include a catalog (perhaps in tabular form?) of objects that you charged, the specifics of how you charged them, and the sign of the charge (relative to your detector, which you can define as "positive") in each case. It should also give an account of what you observed with a conductor like the aluminum can, along with some speculation about what might be happening in that case.

Lab Report

Craft a lab report for these activities and analysis, making sure to include every contributing group member's name on the front page. You are ***strongly encouraged*** to refer back to the Read Me as you do this, to make sure that you are not leaving out anything important. You should also feel free to get feedback from your lab TA whenever you find that your group is at an impasse.

Every member of the group must upload a separate digital copy of the report to their lab assignment in Canvas *prior to leaving the lab classroom*. These reports are not to be written outside the lab setting.

Controls

There are only a few things to keep in mind in order to keep your experiment under control. Remembering to neutralize charge between tests, as mentioned above is one of them. Another has to do with when the experiment turns to conductors. As these materials will allow charge to flow through them, a single point of contact is enough to discharge the entire object, so if you wish to keep a conductor charged, you will want to insulate it from its surroundings. Also, don't forget that your own body can collect and distribute charge. It is not a great conductor, but if in one part of the experiment you collected charge on your fingertips, this charge could have an adverse effect on a later part of the experiment.

Also keep in mind that after a cloth is used to rub the insulator, *the cloth is charged* (charge is conserved, so if there is net charge on the insulator, there is the opposite net charge on the cloth). If that cloth is reused, it may deposit charge and have the opposite of the desired effect. Humidity should help with this as well.

CHAPTER OVERVIEW

Lab 2: Electrostatic Potential

2.1: Background Material

Text References

- force and potential energy
- electric fields at conducting surfaces
- relationship between electric potential and field, equipotential surfaces
- using graphs to determine functional dependence

Potentials in General

It's quite possible that you are taking on this week's lab without having seen the topic of electric potential in lecture (or perhaps you have seen it only briefly). Given that this is a lab about electric potential, this might seem to pose a problem, but a brief review of the concept of potential energy from Physics 9A (see the first text reference above) should be sufficient to get you where you need to be for this lab.

In Physics 9A, we linked the ideas of potential energy and force. We found that the force vector at a point in space is determined from the *gradient* of the potential energy function at that point. In conceptual terms, it works like this: Place yourself at a point in space, and note the potential energy at that position. Then turn around and around, noting the nearby potential energies that you see in every direction. Whichever direction points to the nearby potential energy that is the biggest drop from where you are positioned, that is the direction that the force is exerted.

If you turn to look in a direction in which the potential energy doesn't change at all, then there is no component of the force in that direction. If you start traveling around in the space, always moving in directions where the potential remains the same, then your motion is confined to something called an *equipotential surface*. With no component of the force acting parallel to the equipotential surface, the total force vector must be perpendicular to it.

Now in Physics 9C, we are using language we did not use in Physics 9A. What we called a "potential energy function" we now refer to as a "scalar field." Note that it means the very same thing – every point in space has associated with it a scalar number. The force vectors we derived from gradients of this field are different at every point in space, so with a vector defined at every point in space, we refer to that as a "vector field." The only other leap we take in Physics 9C is that we use a scalar field that is not potential energy, and a vector field that is not force. Instead, they are electrostatic potential and electric field, respectively. They have different physical meanings and are measured with different units than their 9A counterparts, but the basic ideas are exactly the same: There are equipotential surfaces – surfaces of equal electrostatic potential (voltage) – and a vector (electric) field that is perpendicular to those surfaces everywhere.

Measuring Device for Potential Differences

This week's lab involves a voltage supply connected to a pair of conductors that can come in different shapes. One conductor will be held at a lower potential, and the other at a higher potential. This potential difference will produce an electric field between the two conductors, which is manifested as a continuously-varying electric potential in the space separating them.

We will use a device called a *multimeter* to measure the potential difference between two points in our apparatus. We will be measuring AC voltages (we will not worry about what "AC" means, or why we use it for this lab) in the 0-20 volt range, so the setting to use on the multimeter is, unsurprisingly, AC 20V (in the "V~" section).

Figure 2.1.1 – Multimeter

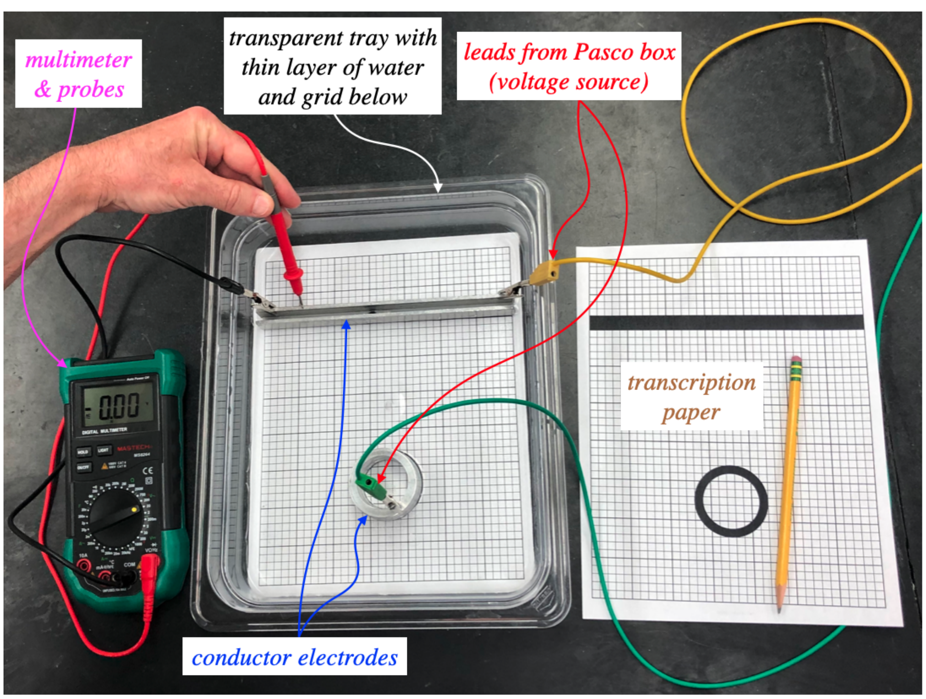
The two ports where you plug the probe wires are the black "COM", and the red "$V\Omega Hz$". In order to measure a potential difference between two points in the apparatus, the leads (probe wires) of the multimeter need to touch those two points.

Apparatus

In order to create a potential field that we can measure with this device, we will connect two conductors to sources of positive and negative charge, and probe the region between them to map surfaces of equal potential. The multimeter can't measure the potentials in the air between the conductors, but it *can* do it in water, so the two conductors are positioned inside a tray with a thin layer of water in it.

We obviously cannot mark the points in the water that we have probed, so we have a piece of graph paper positioned beneath the transparent tray that we can use to note the location we have probed, and an identical piece of graph paper where we can record the positions of our measurements.

Figure 2.1.2 – The Apparatus



Equipotential Surfaces

At least part of this lab will consist of determining the equipotential surfaces. As with all potentials, we need to set a zero reference point. We know that conductors are equipotentials (i.e. every point on and in a piece of metal is at the same potential), so we will declare one of the two conductors in the apparatus to be at potential $V=0$. It is standard practice to call such a place the "ground" and it is labeled with a symbol resembling this: ⏚. You will find just such a label on the Pasco box. If you connect the "COM" probe of the multimeter (with an alligator clip) to the conductor connected to this ground, then the other probe will measure the potential of other positions relative to that ground. Note that in the picture above, both probes are touching the same conductor, so the potential difference shown on the multimeter display is zero.

To find surfaces of equal potential (well, as we are confined to measuring in two dimensions, these are actually curved lines rather than surfaces), we only need to choose a potential (say 1 volt), and probe different positions in the water until the multimeter reads 1 volt, and record that position on the transcription paper. With several points recorded, we can "connect-the-dots" with a smooth curve to trace the equipotential. Then we can move on to 2 volts, 3 volts, and so on. With each of the conductors itself being an equipotential, we should expect the equipotential surfaces to gradually "morph" from one conductor to the other.

2.2: Activities

Equipment

- clear plastic tray containing a thin layer of water
- aluminum electrodes (one flat, one small cylinder, one large cylinder)
- multimeter with probe wire
- Pasco box and laptop
- graph paper template
- data sheet
- wires
- alligator clips

The General Idea

There are two parts to this lab. In the first part, your goal is simply to map the equipotential surfaces of integer voltages ($1\ volt$, $2\ volts$, etc.) that exist between two conductors (electrodes) – one flat, and one a small cylinder – across which a total potential difference of approximately $5\ volts$ has been created. You should show that this map is consistent with the fact that the electrodes are themselves equipotentials, and use the map to approximate the electric field lines that pass between the two electrodes.

The second part of the lab is more quantitative, and seeks to experimentally settle the following dispute: If we arrange two cylindrical electrodes coaxially, then we find that the equipotential surfaces are (unsurprisingly) circular, centered at the common axis of the electrodes. But we also notice that unlike equipotentials between parallel flat electrodes, these circular equipotentials are not equally-spaced. Both parties in the dispute agree that this reflects the fact that the electric field gets weaker as the position gets farther from the axis (measured by the radial distance r from that axis), but one group claims that the field gets weaker in proportion to $\frac{1}{r}$, while the other group claims it gets weaker in proportion to $\frac{1}{r^2}$. By making measurements of voltage at many distances from the axis, you will use graphical techniques to determine which of these assertions is correct.

Some Things to Think About

- **Warnings**
  - No, you don't have to worry about being electrocuted in this lab, though your instincts about mixing electricity and water are good ones!
  - Don't let the electrodes touch each other when the power is on, as this will short the Pasco output.
- **Setup** – You should be familiar with most of this from the Background Material:
  - Connect one wire to the flat electrode and one to the small circular electrode using the alligator clips, and the plug the other ends of the wires into the ⏚ and ∿ ports of the Pasco box.
  - Place the appropriate template face-up under the transparent tray, add a *thin* (no more than a quarter-inch) layer of water to the tray, and place the two electrodes into the tray directly above their template positions.
  - Connect the wire from the black "COM" port of the multimeter to one of the electrodes using an alligator clip, and connect the probe wire to the red "$V\Omega Hz$" port of the multimeter.
  - Put the multimeter into the $20V$ setting in the "~V" sector of the dial.
  - Make sure the laptop is connected to the Pasco box through the USB cable, start it up, and in the 9C folder on the desktop, run the "Electrostatic_Potential" application. You should *not* change any of the default settings. Turn the power on when you are ready to take data.
  - The data sheet provided has one side for transcribing points of the equipotentials in part 1, and a handy table available for recording data for part 2.

Part 1

- You should confirm that the minimum and maximum potentials are where you think they are.
- Note that while you will stick the point of the probe into the plastic below the surface of the water, it is the *water* where the potential is being measured, which means you will want to make sure that the probe tip is *vertical* when taking a measurement (you will note that in regions where the potential is changing very fast, slanting the tip of the probe can account for a substantial potential difference compared to the vertical).

- Mark several points at each integer voltage, though you will find that there are weird effects that occur near the edges of the water (edges of regions always cause issues with electric fields), so you may not want to record points too close to the edges.
- In your lab report, you should include:
  - a picture of your logged data points, along with the sketched equipotential lines they create, and a sketch of the *electric field lines* derived from these equipotentials
  - analysis of how the equipotentials and field lines "make sense"

Part 2

- The most important thing to keep in mind here is that the two prospective theories are about the electric field, but what you will be measuring is electric potentials – *these are not the same thing*, and you will need to "translate" between the two before you can even decide which graphs you need to generate! [*Reminder:* $\vec{E} = -\nabla V = -\frac{\partial}{\partial r} V \hat{r}$ *, so given the functions you are testing for* $E(r)$*, what are you testing for* $V(r)$?]
- This is the quantitative portion of the lab – you are not restricted to integer potentials, nor are you looking to sketch equipotentials. This should make the acquisition of data easier than in part 1. Nevertheless, it would be a good idea to informally confirm that the equipotentials are roughly what you expect them to be.
- As you are only looking for a functional dependence, you can use whatever units of length measurement you wish. You might find "grid squares" easier to work with than (say) centimeters.
- Use the usual online graphing calculator for the best-fit lines. Here is a reminder of how to use this tool:
  - click the "+" button in the upper-left corner and select "table"
  - enter the values you wish to graph (those that reflect the functional dependence you are testing, not the raw values you recorded!)
  - include a formula in the next box that looks like: $y_1 \sim mx_1 + b$, and a best-fit line will be drawn through the points (the subscripts are added by inserting an underscore: "y_1" is "y_1")
- In your lab report, you should include at least:
  - your table of recorded values
  - best fit line graphs for the two proposed "theories", along with a conclusion of which one fits better
  - analysis/discussion of the result
- As an extra "bonus," you can explore what is going-on *inside* the center ring. Do you expect there to be an electric field in there? From your answer to this question, what would you expect to find the potential to look like in there? Go ahead and test it! If you think you have it figured out, this is your chance to show-off to your TA – see if they confirm your brilliant conclusions.

Lab Report

Craft a lab report for these activities and analysis, making sure to include every contributing group member's name on the front page. You are ***strongly encouraged*** to refer back to the Read Me as you do this, to make sure that you are not leaving out anything important. You should also feel free to get feedback from your lab TA whenever you find that your group is at an impasse.

Every member of the group must upload a separate digital copy of the report to their lab assignment in Canvas *prior to leaving the lab classroom*. These reports are not to be written outside the lab setting.

CHAPTER OVERVIEW

Lab 3: Capacitors

3.1: Background Material

Text References

- networks of capacitors

The Equipment

There are a number of things one needs to know about the equipment in order to navigate this lab without mishaps.

Safety and Good Habits

The first thing to remember is that the main purpose of a capacitor electrical component is to store electrical energy, often so that it can be discharged quickly. While the capacitors you are using do not boast of large capacitances, nor will we charge them using a high voltage, it is a good idea to get in the habit of never (intentionally or accidentally) completing a circuit involving yourself and the two leads of a capacitor. (This includes when you *think* it is uncharged.) When you are done using a capacitor (i.e. between experiments) it is good practice to discharge it completely by connecting a wire across is. This not only removes any possible shock danger, but also gives you a capacitor whose state of charge you know about for the next experiment.

Polarity of Capacitors

The capacitors you will be using in this lab contain an electrolyte. This particular design of capacitor has a "polarity", which means that it only charges properly in one direction – you need to connect a specific lead of the capacitor to the (+) side of a charging battery, and the other lead to the (–) side. Connecting them backward not only causes them to function improperly, but in extreme cases can ruin the component. You will use capacitors connected to a plastic component board, and their leads are colored red (positive) and black (negative). When connected to a battery, the signs of the capacitor leads need to be matched to those of the battery (positive-to-positive, negative-to-negative). You will also use some loose capacitors, and the polarity of those is determined by the length of the wires protruding from them – the ***longer of the two leads is the positive one***.

Figure 3.1.1 – Component Board

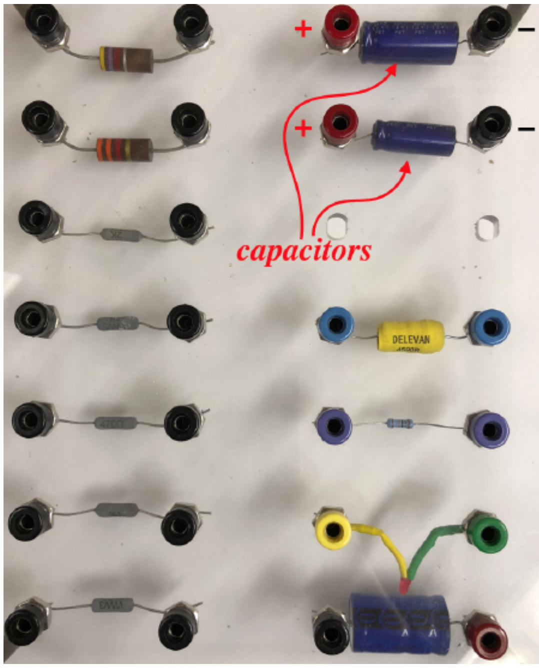
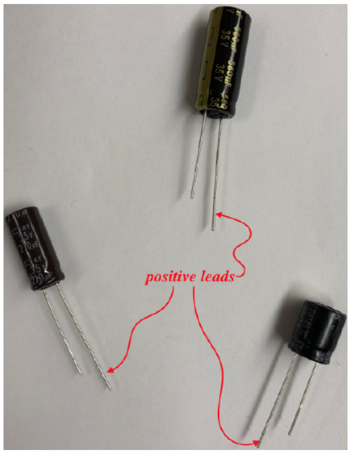


Figure 3.1.2 – Loose Capacitors



The "Battery"

The device you will be using for a battery doesn't look like any battery you have seen before (the wire coming from it that plugs into an outlet is a dead giveaway). While it is clearly drawing electrical energy from the outlet, this nevertheless behaves exactly like a battery – it provides a fixed voltage for circuits. And it has the added bonus that it doesn't run down and end up in a landfill. While the voltage is supposed to be 9 volts, it will not be precisely this, and as usual, you will want to do a pre-experiment calibration check by measuring the true voltage directly with the multimeter.

The Multimeter

We will be measuring DC voltages in the 0-20 volt range, so the setting to use on the multimeter is, unsurprisingly, DC 20V. The two ports where you plug the probe wires are the black "COM", and the red "$V\Omega Hz$".

Figure 3.1.3 – Multimeter

Measuring Capacitance

This lab involves testing what we have learned about capacitance, and using this knowledge to compute unknown capacitance. The "obvious" way to measure the capacitance of a component is to put a known voltage across it, then measure the charge that accumulates, and compute the ratio $C=\frac{Q}{V}$. The problem with this plan is that while we have a multimeter to measure voltage, we don't have a device to measure charge on a capacitor plate. So instead what we will do is use what we know to measure *relative* capacitance, and then is this to compare an unknown capacitance with a known one. For example, if we know that two capacitors possess equal charge (how do we assure this?), and we happen to know the voltages across each of them (measured by a multimeter), then we can compute the ratio of their capacitances:

$$Q = C_1V_1 \qquad Q = C_2V_2 \quad \Rightarrow \quad \frac{C_1}{C_2} = \frac{V_2}{V_1} \tag{3.1.1}$$

So if we know one of the capacitances, we also know the other.

3.2: Activities

Equipment

- component board
- 9V DC power supply ("battery")
- multimeter
- loose capacitors
- wires
- alligator clips

The General Idea

There are two parts to this lab. In the first part, you are given two different capacitors from a manufacturer who asks that you check that they have capacitances in approximately the correct ratio. In part 2, you are given a known capacitor and must use it to find the approximate capacitance of another unknown capacitor. For confirmation purposes, you are asked to do this latter measurement two different ways. One of these ways must involve charging one capacitor with another (rather than charging both with the battery). In both cases, all you have at your disposal to work with is a battery and a voltmeter.

Some Things to Think About

Part 1

- In the Background Material, a way of comparing capacitance ratios is discussed. How can we be assured of charging both capacitors equally?
- You are told that the ratio of the two capacitances of the capacitors on the component board is supposed to be 0.47.
- The percentage uncertainty in capacitances acceptable to the manufacturer that has hired you is fairly large – about 15%. Discuss whether the ratio you find is "correct" to within this tolerance
- Indicate which capacitor is the one with the larger of the two capacitances.

Part 2

- You now are told that the larger of the two capacitances on the component board is $1000\mu F$.
- Choose one of the three varieties of loose capacitors to measure.
- Use the alligator clips to make connections with the loose capacitor, and ***be sure to observe proper polarity***!
- Naturally one method you can use is the same as part 1. But you will have to give some thought about how to perform the second measurement. Obviously to charge one capacitor with another, the first capacitor needs to already be charged, and this you will do with the battery. Again, when connecting the charged capacitor with the uncharged one, make sure they are connected positive-to-positive, negative-to-negative.
- When you charge one capacitor with the battery, does it matter which one you choose to charge?
- Your capacitor-charges-capacitor calculation will depend upon starting with one capacitor uncharged, so you need to make sure that this is true by shorting it beforehand.

Lab Report

Craft a lab report for these activities and analysis, making sure to include every contributing group member's name on the front page. You are ***strongly encouraged*** to refer back to the Read Me as you do this, to make sure that you are not leaving out anything important. You should also feel free to get feedback from your lab TA whenever you find that your group is at an impasse.

Every member of the group must upload a separate digital copy of the report to their lab assignment in Canvas *prior to leaving the lab classroom*. These reports are not to be written outside the lab setting.

CHAPTER OVERVIEW

Lab 4: DC Circuits

4.1: Background Material

Text References

- resistance
- measuring devices and systems of resistors
- Kirchhoff's rules

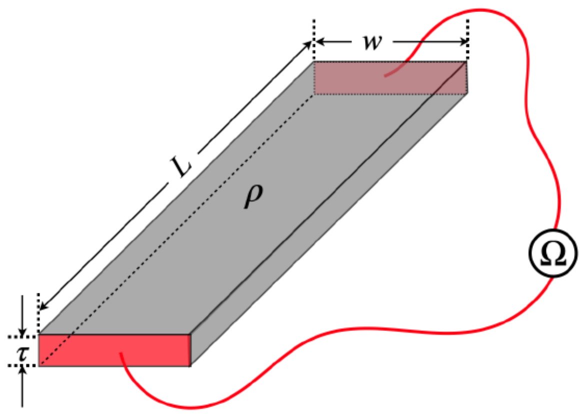
Measuring Resistance

The first part of this lab requires that we measure the resistance through a piece of conducting paper. There are a couple ways we can measure a resistance. The first that comes to mind is to use Ohm's law: Measure the voltage across the "resistor" with a voltmeter, and the current that passes through it with an ammeter, and the ratio of these gives the resistance. But our multimeter does both of these jobs at once – just turn the dial into the ohmmeter region (labeled with an "Ω"), and connect the leads (one in the black COM port and the other in the red VΩHz port) to the opposite ends of the resistor, and the display reads the resistance. You will likely have to adjust the dial to find the right range of values – you can select maximum values from 200Ω to 200MΩ ("M" stands for "mega" = "million").

Resistivity

While resistance is a property of a specific object, resistivity is a property of a *material* that can have any shape or size. The shape and size combined with the resistivity is what determines an object's resistance. The simplest model to discuss the relationship is a rectangular prism:

Figure 4.1.1 – Resistor Model



The ohmmeter in this figure is measuring the resistance along the direction joining the two leads – down the length L of the prism. If current were to flow along this direction, it would pass through a cross-sectional area equal to the product of the width and thickness: $A = w\tau$. The resistance of this object is related to the resistivity of the material from which it is constructed according to:

$$R = \frac{\rho L}{A} \tag{4.1.1}$$

In our lab, we will measure the dimensions of such an object, and use an ohmmeter to measure its resistance, thereby allowing us to compute the resistivity of the material.

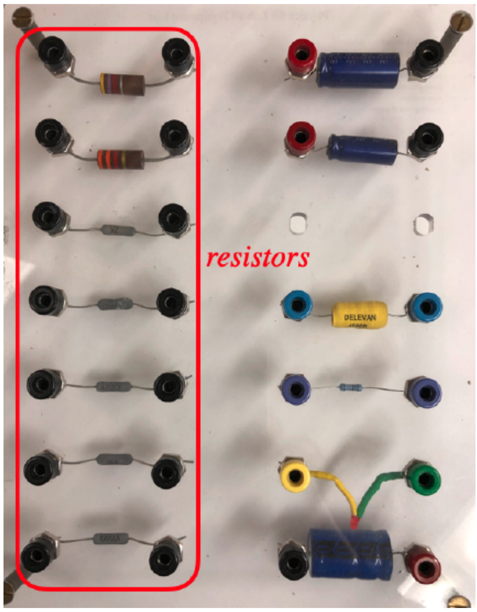
Confirmation of Kirchhoff's Rules

The second part of this lab consists of connecting a small network of batteries and resistors in order to confirm Kirchhoff's rules. In order to make this confirmation, one needs to measure both voltage drops with a voltmeter and currents with an ammeter. Both these meters can be selected in the multimeter. The voltmeter you already know from a previous lab. The ammeter section of the dial is labeled with an "A" with dots and dashes after it (not the wavy line). Just as in the case of the voltmeter from the previous lab, this meter is for *direct current* circuits like we are working with here.

There is one critical piece of information about connecting these two types of meters to measure quantities in a circuit. Not following this can damage (or at least temporarily disable) the ammeter. While voltmeters can be used in a "probing manner" connect each lead to opposite ends of a resistor to measure the voltage drop, ***ammeters must be connected into the circuit***. That is, if you want to measure current with an ammeter, you must disconnect your circuit and connect the ammeter *into* the branch through which you wish to measure the current. If you are not taking your circuit apart to put your ammeter into it, then you are using the ammeter incorrectly, and are likely to disable your multimeter and aggravate your TA. If you have any questions about your connection, ask your TA for confirmation that your setup is okay before powering it up.

In order to create this network, you will need two batteries and several resistors. The batteries are the plug-in DC power supplies like you used in the previous lab. The resistors you will find on one side of the component board – they are the objects with two black jacks:

Figure 4.1.2 – Component Board



4.2: Activities

Equipment

- metal board with conducting paper strips
- magnetic electrode plates
- component board
- 15V & 9V DC power supplies
- multimeters
- wires
- ruler

The General Idea

This lab consists of two very distinct parts. In Part 1, you will be measuring the resistivity of some conducting paper, confirming your answer with two separate sets of data. In Part 2, you will set up a DC network (subject to certain requirements) and use it to test/confirm Kirchhoff's rules.

Some Things to Think About

Part 1

- The formula that relates the resistance to the resistivity includes the dimensions of the resistor (see Figure 4.1.1 in the Background Material). In our case, the "rectangular prisms" are strips of paper. It's difficult to measure their thicknesses, so it is provided for you: $\tau \approx 0.1mm$.
- Note that the magnetic electrodes have holes into which the banana leads of the wires fit nicely. They also stick to the board and make it easy to define endpoints of the strip "resistor." The electrodes and wires are also very good conductors, so since they are in series with the strips, they contribute a negligible amount to the resistance measurement.
- We are able to vary the length of the strip resistor by simply moving the electrodes, and we can vary the width of the resistor by using different paper strips.
- You are expected to treat each of the dimension variables separately (i.e. hold one fixed while varying the other), generating for your lab report a data table and a best-fit linear graph *for each one*. (Use the usual desmos online graphing calculator.)
- The resistivity can then be extracted from the two best-fit lines, and compared.
- Comment on what conditions might affect the outcome. This can be speculation or actual weird fluctuations in results whose cause you were able to deduce. You should feel free to do ancillary quick tests to check your ideas.

Part 2

- Here are the required elements of your network:
  - It must include at least four resistors and two batteries.
  - It must include at least two loops (i.e. there must be branch points).
  - The batteries must appear in different branches.
  - Each branch with a battery in it must also include at least one resistor (this is to avoid any nasty short-circuiting).
- Your lab report needs to include a *large* circuit diagram that matches the network that you wired in the real world. It needs to be large enough that you can label everything that you measure, including:
  - the resistances (use the ohmmeter, as you did in Part 1, and don't do these measurements while they are connected to anything else!)
  - the emfs of the batteries
  - the currents through each branch
  - the voltage drops across the resistors (you need to indicate a loop direction to do this)
- When measuring the battery emfs and voltage drops around loops, you need to be especially careful to record the proper *signs*, which means you have to remain consistent with the direction of the voltmeter.
- *Before* you measure the currents, check with your TA to make sure you are doing it right, because connecting an ammeter incorrectly can result in a nuclear detonation and the extinction of all life within a 5-mile radius. Okay, it isn't that bad, but we don't want to damage/disable the multimeters. When you get the green light from the TA, be sure to make a note of the *directions* of the currents you measure.

- With all the data gathered in one place on the schematic, do the arithmetic to show that the loop rule holds for at least two loops, and that the junction rule holds for at least one junction.

Lab Report

Craft a lab report for these activities and analysis, making sure to include every contributing group member's name on the front page. You are ***strongly encouraged*** to refer back to the Read Me as you do this, to make sure that you are not leaving out anything important. You should also feel free to get feedback from your lab TA whenever you find that your group is at an impasse.

Every member of the group must upload a separate digital copy of the report to their lab assignment in Canvas *prior to leaving the lab classroom*. These reports are not to be written outside the lab setting.

CHAPTER OVERVIEW

Lab 5: RC Circuits

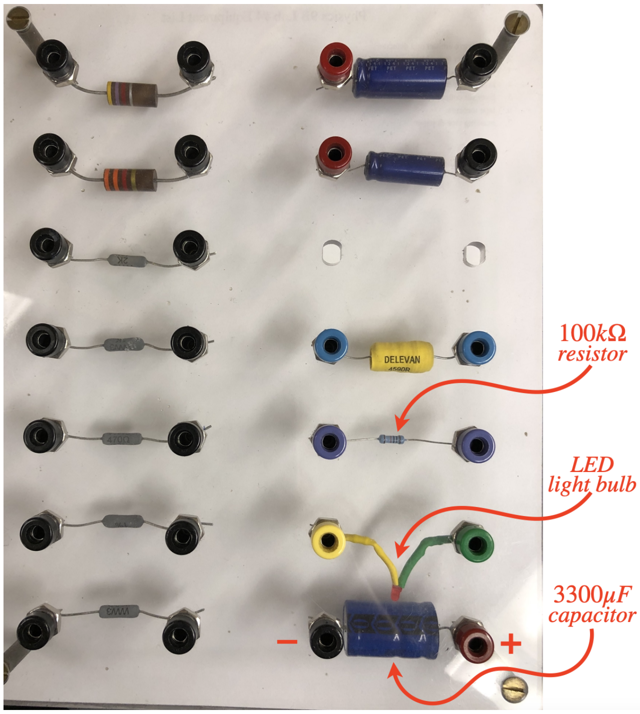
5.1: Background Material

Text References

- discharging capacitor
- charging capacitor

Component Board Again

We'll be using the component board again for various parts of this lab. See the diagram below for the components you will be using in this lab:



Reading an Oscilloscope

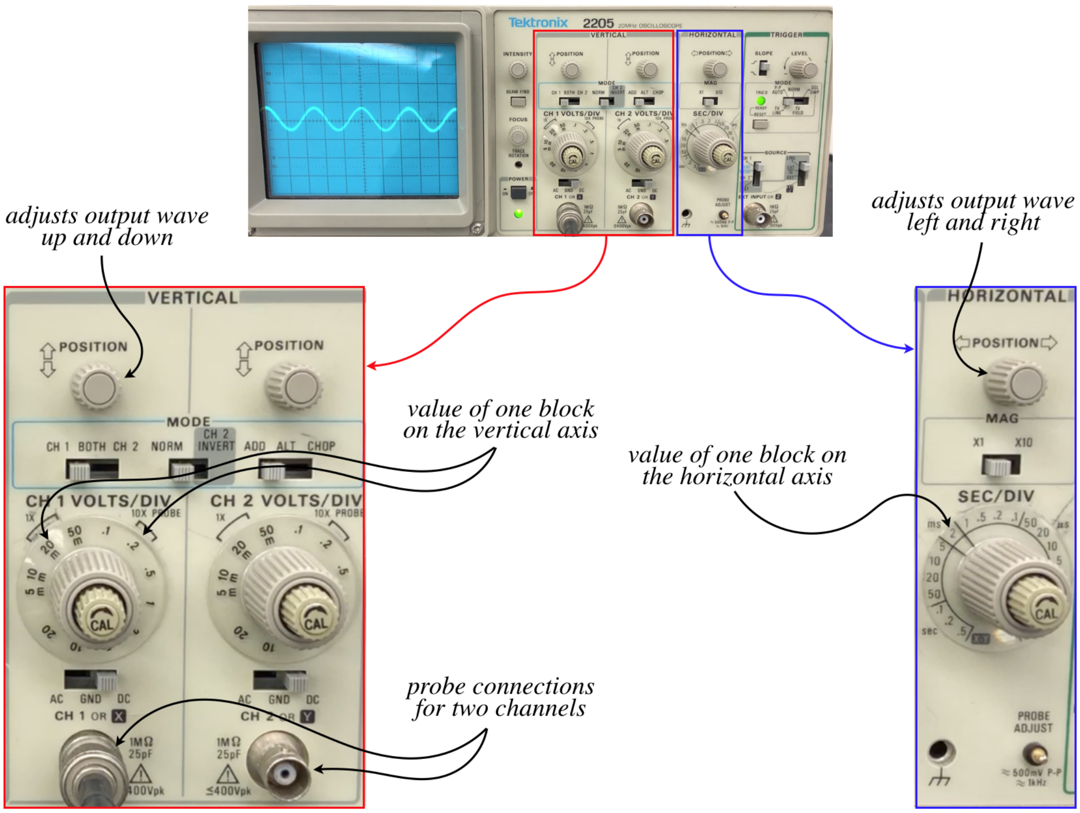
At first glance, an oscilloscope is an intimidating device, with a daunting number of knobs and switches. We will not concern ourselves with the various nuances of this device, and will instead focus on taking away some of the mystery, so that we can use it. First and foremost, this device is a voltmeter. Two leads come out of each "channel," and the o-scope measures the difference in voltage between these two leads.

Where an oscilloscope differs from a standard voltmeter is that it also reflects the time dependence of that voltage difference. If we connect a regular voltmeter across a component for which the voltage is varying with time, the needle of the voltmeter would jump around in response to the changing voltage drop. An oscilloscope *graphs* the time dependence of that changing voltage – the vertical axis of the output is the voltage drop, and the horizontal axis is time.

The scope does not graph the voltage between fixed starting and ending times – it graphs continually. It's easiest to think of it as "wrapping around" – when the plot gets to the right side of the screen, it continues plotting from the left side. For this reason, this device is most effective for studying *periodic* time dependence (thus the prefix "oscillo-"). These plots repeat themselves, leaving a static pattern on the screen that can easily be studied.

Let's look at what some of the important knobs do (again, we will not take the time to learn every nuance of this device here):

Figure 7.1.1 – Oscilloscope



The simplest of the knobs to understand are the position knobs – these move the whole graph up/down and right/left. This adjustment is available to make it easier to read values off the graph. At the bottom of the vertical part of the front panel are the ports where the probes connect to the device. For our lab, we will only be measuring a single voltage difference, so there is only a cable attached to channel 1.

The important knobs to understand are those labeled "VOLTS/DIV" and "SEC/DIV" (for our experiment, only the knob setting for channel 1 matters). We'll look at each knob in turn, but first you should note that the o-scope screen is divided into a grid of large squares, which are each subdivided horizontally and vertically with 5 tick marks. It is the lattice of grid lines (the blocks) that are calibrated to the knob settings – the smaller tick marks represent one fifth of these measurements.

1. VOLTS/DIV – The number found within the bracket equals the value of each vertical division of a block. You'll note that there are *two* brackets – so which one gives the proper number? Both, because they measure in different units. The multiplier next to each bracket indicates how much the actual value is amplified by the oscilloscope before graphing it note that in both cases, a difference of one vertical block represents a voltage difference of 0.02 volts:
    - Reading the left bracket: The signal is multiplied by 1, and a block measures 20 millivolts.
    - Reading the right bracket: The signal is multiplied by 10, and a block measures 0.2 volts.
2. SEC/DIV – In this case, there is only one place to read the time intervals for blocks – between the two lines that radiate from the center of the knob. This particular knob is set at 2 milliseconds.

It should be clear that turning the vertical knob clockwise will make a graph shorter (each block's vertical value is increased), and turning the horizontal knob clockwise will squeeze together the wave peaks (each block's horizontal value is increased).

5.2: Activities

Equipment

- component board
- 15V DC power supply
- variable capacitor
- Pasco box and laptop
- oscilloscope
- wires

The General Idea

The experiment portion of this lab is straightforward. You are given a variable capacitor, and are asked to compute its capacitance based on what you know about its geometric structure. Then you are tasked with checking this computation by connecting it into an RC circuit with a known resistance, and viewing the time dependence of its voltage on an oscilloscope. There is, however, an exploratory preamble to the experiment, in which you will write up only a brief summary of your findings in the lab report. The first part of this preamble consists of spending a little time exploring the properties of an LED light bulb (in the context of an RC circuit, of course). The second involves tinkering with an oscilloscope until you become familiar with its most basic functions.

Some Things to Think About

Part 1: Exploration – LED

Just about everyone has heard of LED lights. Far fewer know what "LED" stands for (light emitting diode). Fewer still know what the properties of such a component are in a circuit. Your task here is to find out, and to use it in an RC circuit to observe that circuit's time-dependent behavior. Like any other light, its brightness indicates the amount of current running through it. Besides the LED light on the component board, you will need the $3300\mu F$ capacitor next to it (see the Background Material for a picture), and of course the $15V$ DC power supply. Feel free to connect the LED with one or more of the other two components in any way you see fit, subject only to the following restriction:

Like capacitors we have used in past labs, this one has a specific polarity. When connected to the power supply, the positive (red) lead of the capacitor must be connected to the positive lead of the battery.

Make a mention of whatever you discover about any special properties of the LED in your lab report. You may want to ask your TA if what you have discovered "is really a thing."

Part 2: Exploration – Oscilloscope

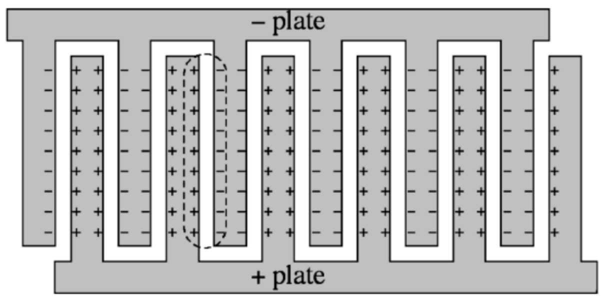
- **reference** – You may want to refer back to the Background Material during this activity, to help you keep track of how the oscilloscope knobs affect what you see.
- **practice** – Throughout this exploration, you should not be satisfied with seeing how knobs affect the pattern on the screen ("Oh, this knob makes the wave taller!") – you should become comfortable with *reading the numerical values that the device measures*, and how to read the new numbers shown when the knob settings are changed.
- **settings** – to check and then never change once they are correct are:
  - In the TRIGGER section set the slide switches to...
    - MODE: P-P AUTO
    - SOURCE: CH 1 and LINE
  - All the smaller dials labeled "CAL" within the three largest dials (for voltage and time) should be turned fully clockwise.
  - In the HORIZONTAL section, set the slide switch to X1.
  - In the CH 1 part of the VERTICAL section set the slide switches to...
    - upper slide switch: CH 1
    - lower slide switch: DC
  - The CH 2 part of the VERTICAL section can be ignored (the probe wires should be connected into the CH 1 connector).
- **calibration** – Turn on the oscilloscope, and once you see its “trace” (the blue-green luminescent line), set the voltage in the CH1 part of the VERTICAL section to 5 volts per division (we use 1x, so ignore the 10x), and set the time scale in the

HORIZONTAL section around the middle of its settings. Then place the oscilloscope leads across your 15V “battery,” black to black and red to red. While watching carefully, temporarily move the bottom slide switch in the CH1 part of the VERTICAL section to GND (essentially making the input zero) then back to DC. This should tell you something about the positioning of the beam.

- **play time!** – Open the laptop computer file “RC_Circuits,” and click the ON button in the Signal Generator window. Place the scope leads across the Output 1 signal generator outputs of the Pasco box, black to ⏚, and red to ∿. Play around with the onscreen Waveform, Frequency and Amplitude settings (in the interest of efficiency, 2 or 3 waveforms should be plenty), and scope Volts/Div, Sec/Div, and Position controls. ***Note: The defaults obscured under "Offset and Limits" in the laptop software are chosen to protect our equipment – don’t change them!*** As noted earlier, be sure that you can read numbers off the screen properly, and that they confirm what signal you know is being sent from the Pasco box. Consult your TA to confirm that you are getting things right, or if you have any problems with the equipment.

Part 3: Experiment – Confirming Capacitance

- **variable capacitor** – The device in the plastic box with a know that turns some interleaving metal plates is a variable capacitor. Turning the dial can move the plates into parallel positions, or remove them from those positions, thereby changing it total capacitance. The plates that rotate are charged with one sign, and the stationary plates are charged with the opposite sign, giving something (when the plates are meshed) that looks like the diagram below, up-close. The important thing to note is that each gap represents an individual capacitor, and since all of the positive plates are at the same potential as each other, as are all the negative plates, these individual capacitors are connected in parallel.



- **safety** – For your own safety, and to protect this quite delicate instrument (did we mention that the plates are separated by a quarter of a millimeter?!), please:
  - **Never touch the plates!**
  - **Be careful not to drop the device or try to "repair" it.** If you suspect that it is shorted because it doesn't seem to be functioning properly, and/or you can feel/hear the plates rubbing each other when you turn the dial, just let your TA know, and they will check it and get you a replacement if needed.
  - Be sure to connect a conductor (short the capacitor) between tasks or when you are done with it, so that there is no lingering charge within it.
- **specifications –** The semicircular plates of this capacitor have a diameter of about $3.5cm$ and the spacings (when interleaved) are about $0.25mm$.
- **compute capacitance –** The main thrust of the experiment is to compare the capacitance found using the oscilloscope readings for an RC circuit to the computed capacitance. The information above should be sufficient to compute an approximate capacitance from its geometrical structure.
- **RC circuit** – The RC circuit you will be building consists of the variable capacitor, the $100k\Omega$ resistor (see the Background Material for a reminder of which component this is), and the Pasco signal generator. (Question to ponder: Why can't we just use the DC power supply?) Here are a few suggestions for the settings of the signal generator:
  - **waveform**: square
  - **frequency**: $1000Hz$
  - **amplitude**: $2.5V$ (since amplitude is half the total maximum fluctuation, this is a $5V$ variation in the voltage)
- **oscilloscope connection** – Remember that the oscilloscope is a voltmeter, which means we can use it to indirectly measure the time dependence of either the current (if we measure the voltage across the resistor) or the charge (measuring the voltage across the capacitance). *Important additional note: The oscilloscope won’t read voltage properly unless its black lead is effectively attached to the signal generator’s ⏚ jack, i.e., either to that jack or to a wire going there. So pay attention to the order in which*

you wire the resistor and capacitor in series; if you want to "look" at the capacitor voltage, make sure it has one lead going to the signal generator's ⏚ jack, and if you want to "look" at the resistor, make sure it has one lead going there. Of course, in this series circuit, they can't both go there.

- **observe the effect of changing capacitance –** When everything is set up and your oscilloscope is reading values properly, turn the dial of your variable capacitor to see what effect it has on the output. Explain this effect in your lab report.
- **oscilloscope readings and math –** You will be computing the *maximum* capacitance of this variable capacitor (the same thing you computed earlier, when all the plates are interleaved). To compute the capacitance from the data you take, you will need to properly read the numbers from the oscilloscope, and apply them to the mathematical relation for either $Q\left(t\right)$ or $I\left(t\right)$ for a charging or discharging RC circuit. You know the resistance of the circuit, and the time dependence, and that is all you need.
- **sources of error –** Be sure to make a brief approximate accounting of where errors can creep into this experiment. Mentioning error sources is useful, making reasoned approximations of percentage error, when possible, is better.
- **things to include in lab report –** Besides the items explicitly mentioned above and details of the computations you make, it's always a good idea to have some record of your raw data in the report, so you should include a photo of the oscilloscope reading + dial settings.

Lab Report

Craft a lab report for these activities and analysis, making sure to include every contributing group member's name on the front page. You are ***strongly encouraged*** to refer back to the Read Me as you do this, to make sure that you are not leaving out anything important. You should also feel free to get feedback from your lab TA whenever you find that your group is at an impasse.

Every member of the group must upload a separate digital copy of the report to their lab assignment in Canvas *prior to leaving the lab classroom*. These reports are not to be written outside the lab setting.

CHAPTER OVERVIEW

Lab 6: Engineering with Magnetism

6.1: Background Material

Text References

- a direct-current motor

Building a Commutator for a DC Motor

From the standpoint of designing a dc motor, the trickiest part is designing the commutator (see the text reference given above for an explanation of what this is). In this lab, we will stick to the simplest design for a commutator possible. Unlike the diagram of the motor in the text reference, our commutator will not reverse the direction of the current with every 180 degree rotation. Rather, it will simply cut off the current for 180 degrees out of every full revolution. So for half of every revolution there will be a torque driving the rotation, and for the other half, the motor's angular momentum will carry it around until it can get it's next "kick" of torque.

To accomplish this, we will exploit the fact that the wire we will be using for our coil is insulated. In our simple design, the wire used for our coil also serves the purpose of the motor's axle. The wire is wound several times until a coil has been fashioned, with the ends of the wire sticking out both ends. Then those loose ends are wound around the opposite sides of the coil, so that the coil is held tightly together, and the loose ends provide an axle for the coil's rotation.

Figure 6.1.1 – Single Wire Makes Both Coil and Axle

Now if the insulation is stripped from the two loose ends, this can be rested on leads that are at a potential difference – with gravity assuring a good connection, but nothing to impede the coil's rotation – and current will flow through the coil. But as stated above, we don't want the current to flow through the coil at all times, but only half of every rotation, so for one side of the axle, we should only strip off the insulation on 180 degrees of the wire. You will have to determine where that stripping begins and ends, based on what orientation you want the coil to have in the magnetic field when the current begins and ends (hint: see the diagram in the text reference!).

Building a Speaker

We know that the force on a wire in a magnetic field depends upon the current flowing through that wire. So if, in some fixed magnetic field, we vary the current in a wire in some periodic fashion (let's say harmonically), then the force on that wire varies with the same period. This varying force leads to mechanical vibration of that wire with the same period, and this mechanical vibration can produce sound with – you guessed it – the same frequency. This is how a speaker works.

Like the motor, we will need a coil to concentrate a lot of current into a small space in order to get a decent amount of magnetic force. Unlike the motor, we will not need to use wire heavy enough to work as an axle. Thinner wire is also preferred in part because it has less inertia, which means it is accelerated more by a magnetic force. This allows it to vibrate more effectively, especially at higher frequencies.

Also, the coil itself does not move a lot of air when it vibrates, so it is best to attach it to a sort of "bladder" (in our case, the bottom of a lightweight cup) which will move a lot of air when it vibrates with the coil.

6.2: Activities

Equipment

- wire (2 or 3 different gauges)
- magnets
- dc power supply
- paper clips
- tape
- assorted cups
- sandpaper
- Pasco box and laptop
- banana-tip connecting wires
- alligator clips

The General Idea

This lab involves no experimentation. Rather, it is an opportunity to use some of our knowledge about magnetic forces and torques on current-carrying wires to design and construct two basic devices: a direct-current electric motor, and a sound speaker. The main goal is to get these working, but if you do this relatively quickly and have some spare time, then you can feel free to improve your design – have some fun with this!

Some Things to Think About

Part 1: DC Motor

- **safety** – The power supply you use for the motor in this lab has the potential to hurt you, so be careful with it. If you want to see how your motor functions at higher voltage (which results in a faster speed), *ask your TA to assist you*. Otherwise the setting at which you find the voltage will be plenty to demonstrate your motor's operation.
- **axle** – The parts of the wire that serve as an axle need to rest on the conducting leads connected to the battery, and must be free to turn while not falling off the leads. Using paper clips with small loops in them (into which the axle goes) work well for these conducting leads. Also note that you want the axle as straight as possible – if the coil "dips", then the weight imbalance provides torque that the magnetic torque may not overcome.
- **commutator** – The Background Material describes how to create a working commutator for your motor. You need to figure out what orientation the coil needs to have when the current flips from 'on' to 'off', and then use the sandpaper to take off the insulation such that this is actualized. Be sure that you are correct (maybe check with your TA?) before actually sanding, or you may end up wasting wire.
- **magnets** – This motor works best when the magnetic field at the coil is as strong as possible. These fields weaken with distance, so getting the magnets as close as possible to the coil (without the coil rubbing on it) is key.
- **starting it up** – You will need a small "kick" to get it going, but then it should keep going (and even speed up!). You'll find that it only maintains it rotation in one direction (why?), but typically a kick in either direction will do the trick (if you kick it the wrong way, it will reverse direction and keep going).

Part 2: Speaker

- **bladder** – As mentioned in the Background Material, the vibration of the coil can best be heard when it causes a bladder to vibrate that compresses/rarefacts larger volumes of air than the coil would by itself. You don't need to be fancy about this attachment – just taping the coil to the bottom of a cup works fine.
- **function generator** – The Pasco application "Engineering_with_Magnetism" is used here to provide the periodic time-varying voltage (and therefore current) needed to get the coil to vibrate. Just connect the two jacks from the Pasco box to the two leads of your coil. You may need to increase the amplitude somewhat from the default in order raise the decibel level of the sound to the audible range. You should check several frequencies to see that the pitch of the sound changes as you would expect.
- **magnets** – There is no need to attach the magnets to your speaker. Once the current is flowing, just bring the magnets close to the coil, and listen for the sound (and note that when you take them away, the sound goes away!).

Clean Up

When you are finished, you need to disassemble your devices, so that future lab participants can work from scratch like you did. We would like to re-use most of the seemingly-disposable materials (certainly the cups, and possibly even the paper clips). Your wire coils you can take home, or give to your TA for recycling.

Lab Report

The lab report you upload in this case will consist of a short video of your two working prototypes (obviously sound will be necessary for the speaker video). The videos should include a piece of paper in the frame with the names of your group members.

CHAPTER OVERVIEW

Lab 7: Electromagnetic Induction

LibreTexts

7.1: Background Material

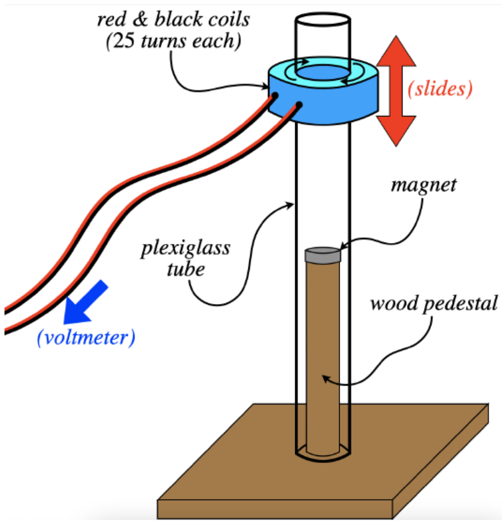
Text References

- Faraday's Law
- Magnetic Field of a Loop

Faraday's Law with a Coil and a Magnet

In the first part of the lab, we slide a coil of wire past a permanent magnet (whose field is oriented perpendicular to the surface of the coil). The magnetic field is not uniform, which means that the strength of the flux of the field through the coil changes as the coil gets closer to or more distant from the magnet. Thus moving the coil in such a situation should induce an emf in the coil. This coil can then act like a battery, "pushing" current out from whichever coil lead becomes the higher potential (determined by Lenz's law).

Figure 7.1.1 – Experimental Apparatus, Part 1

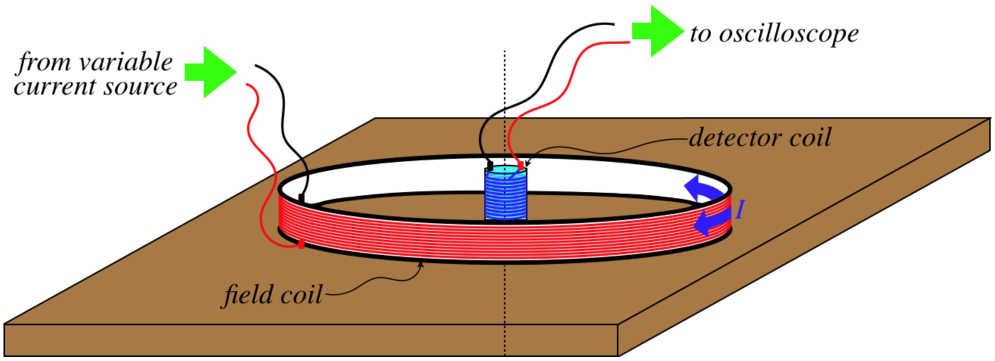


Faraday's Law with Two Coils

If we arrange two conducting coils coaxially, and run a current through one of them, it will produce a magnetic field that passes through the other. If we vary this current over time, then the magnetic flux through the second coil will change with time, inducing an emf in the second coil according to Faraday's law. This lab explores this very scenario. A computer generates a sinusoidal current through one coil, and the second coil is connected to an oscilloscope that measures the emf induced. With the current varying periodically, the flux (and therefore the emf) varies periodically as well, making the oscilloscope the perfect device to measure the time dependence of the emf.

Here is the experimental setup:

Figure 7.1.2 – Experimental Apparatus, Part 2



The analysis of this experiment (i.e. "solving the physics problem") consists of three steps:

1. Determine the magnetic field $B(t)$ in the region of space where the detector coil is located, in terms of the current $I(t)$ flowing through the field coil. In this case the "region of space" is the center of the field coil, and the radius of the detector coil is sufficiently small that the field is reasonably uniform across its area, simplifying the next step...
2. Compute the flux of magnetic field $\Phi(t)$ through the detector coil.
3. Derive the induced emf $\mathcal{E}(t)$ in the detector coil from Faraday's law.

7.2: Activities

Equipment

- coil with magnet-on-pedestal
- compass
- large wire coil
- solenoid
- oscilloscope
- Pasco box with voltmeter connection wires
- laptop
- wires

The General Idea

The goal of this lab is to look at Faraday's law of induction and Lenz's law, qualitatively in the first part, and quantitatively in the second. In each case the source of the magnetic field is different – a permanent magnet is used in the first part, and a current-carrying coil in the second.

Part 1 – Moving a Coil Near a Permanent Magnet

You have at your disposal a small dowel pedestal (on top of which rests a magnet), and a plastic loop that contains two coils of wire (one red, one black). The magnetic field of the magnet is not uniform, so moving a coil near it should change the flux and induce an emf across the leads of the coil. The only restriction we have on "moving the coil near it" is to keep the coil threaded onto the plexiglass tube. Other than that, you should explore changes with as much variation as possible. At a minimum, you should try different speeds, different directions of motion, different wire connections, and both orientations of the coil. Here are some details you need to know to get this to work:

- The Pasco software on the laptop you will use is "Electromagnetic_Induction_1."
- The voltage sensor cable needs to be connected into port A of the Pasco box. These are the leads across which the induced emf is measured.
- The red and black wires are wound around the coil in the same direction, each with 25 turns. It is possible to experiment with only one color of wire (giving you a result with 25 turns), and then repeat it with both coils involved together in series (giving you a result with 50 turns).
- The voltage sensor wires are colored red and black. When the red lead is at higher potential than the black lead, then this shows up on the graph in the laptop above the axis.
- You have a compass at your disposal to determine which magnetic pole is facing up at the top of the pedestal (it's easiest to test by removing the plexiglass and turning the pedestal sideways). For reference, the Earth's northern pole is actually a *south* magnetic pole (field lines go *into* it).

Part 2 – Varying the Magnetic Field by Varying the Source Current

We couldn't do a lot of quantitative study in part 1, because we don't have a good way of determining the numerical value of the magnetic field flux as a function of time. In this part, we create a varying magnetic field ourselves through the use of a varying current in a loop. Here is some information about the equipment at your disposal:

- The Pasco software on the laptop you will use is "Electromagnetic_Induction_2."
- The large coil of wire has 100 turns in it, and has a radius of $15.7cm$.
- The cylindrical "probe" is a coil with 1000 turns, and it has a radius of $1.3cm$.
- After you click the "On" button, the software provides a periodic signal to the large coil from the ⏚, and ∿ jacks in the Pasco box. You can change the frequency from the default to whatever you want (within reason!). You should not make any changes to the default amplitude.
- The software displays (when you click the "Monitor" button) the output current in the graph on the right. You can use the coordinate tool to get greater precision for values on this graph.
- The oscilloscope is connected to the cylindrical probe, and measures the induced emf in that coil.
- Check to make sure that the oscilloscope settings are on the proper defaults, as they were the last time you used it:
  - In the TRIGGER section set the slide switches to...

- MODE: P-P AUTO
- SOURCE: CH 1 and LINE

- All the smaller dials labeled "CAL" within the three largest dials (for voltage and time) should be turned fully clockwise.
- In the HORIZONTAL section, set the slide switch to X1.
- In the CH 1 part of the VERTICAL section set the slide switches to...
  - upper slide switch: CH 1
  - lower slide switch: DC

Some Things to Think About

Part 1

Here are some questions for you to consider when explaining how (or if) the behavior you observe is consistent with Faraday's and Lenz's laws.

- What seems to affect the peak emf that is measured?
- If you want to compare the results of one coil (say just red) to two coils (both red and black)...
  - ... how you will need to connect the leads?
  - ... how will you keep the speed variable unchanged between these two tests?
- How does the result of moving the loop upward compare to moving it down?
- What effect is there (if any) when you turn the loop over and repeat the procedure?
- If you move the coil at different speeds, the *rate* of flux change is different, but what about the *total* flux change, added up over the whole time of the drop? Does this depend upon the speed of coil movement? [Note: There is an "area-under-curve" tool  in the software, and $\Delta\Phi_B = \int \frac{d\Phi_B}{dt} dt$. To use this, select the part of the graph that you which to integrate using the  tool.]
- Do the polarity of the magnet and the sign of the induced emf agree with Lenz's law?

You can take screen shots of what is displayed on the laptop for your lab report to help you make clearer descriptions of the behavior of the induced emf under various conditions.

Part 2

The point to this experiment is to confirm Faraday's law with a known magnetic field. Clearly the signal generator is providing the measurable current that makes this field, but we only have a limited knowledge of field strength in the vicinity of a loop of current. We need to exploit this knowledge to be able to claim that we know the (approximate) field strength. Some questions to consider as you work your way through this:

- Are the frequencies of the oscillating current and induced emf equal? Should they be?
- Is the orientation of the probe (e.g. standing upright vs. laying on its side) important to the experiment?
- We know that the current varies sinusoidally, and we know the frequency of that oscillation. How do we go from this to induced emf?
- What do you think are the biggest sources of error in the experiment, and approximately what is the weakest link percentage error? Do your results confirm Faraday's law within this margin?

You can take screen shots of what is displayed on the laptop and pictures of the oscilloscope output (and knob settings) for your lab report.

Lab Report

Craft a lab report for these activities and analysis, making sure to include every contributing group member's name on the front page. You are ***strongly encouraged*** to refer back to the Read Me as you do this, to make sure that you are not leaving out anything important. You should also feel free to get feedback from your lab TA whenever you find that your group is at an impasse.

Every member of the group must upload a separate digital copy of the report to their lab assignment in Canvas *prior to leaving the lab classroom*. These reports are not to be written outside the lab setting.

CHAPTER OVERVIEW

Lab 8: Inductance

8.1: Background Material

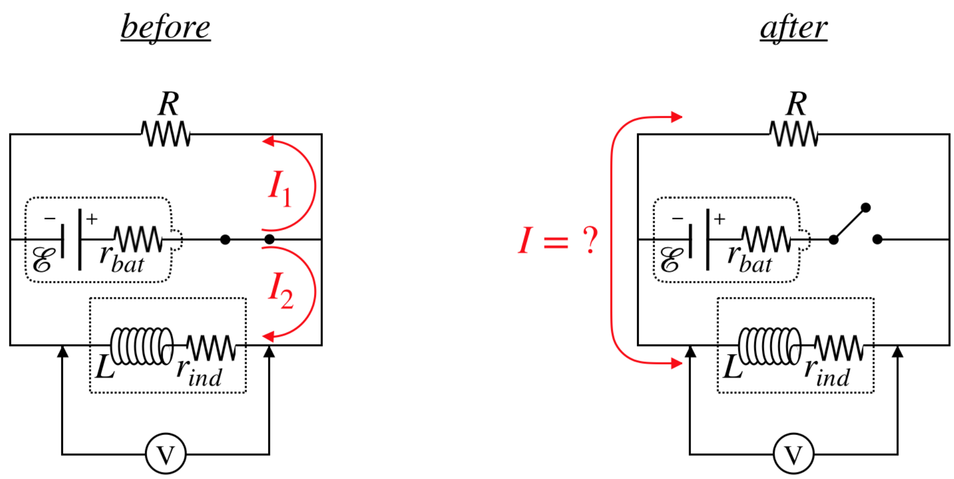
Text References

- LR Circuits

A Decaying Circuit

To study the effect of inductance, we will create a circuit in which an initial current that flows steadily through the inductor, decays down to zero. To set up this scenario, we employ the following circuit:

Figure 8.1.1 – Decaying LR Circuit



The circuit includes a battery, a resistor, an inductor, and a switch. A voltmeter is used to measure the voltage drop across the inductor at all times. Note that the circuit diagram includes the internal resistances present in the battery and inductor.

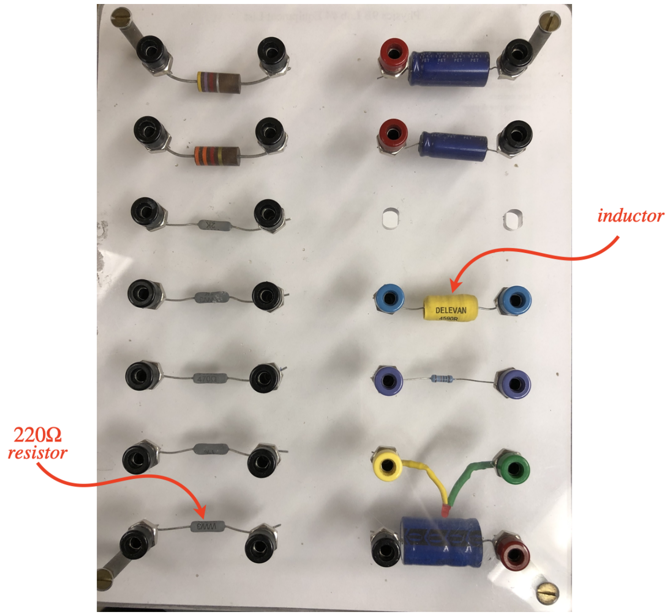
The process begins with a closed switch, such that currents are flowing through both the resistor and the inductor. It is left closed a long time, so that the inductor has no potential drop resulting from a varying current – it only comes from its internal resistance. The graph of the voltage measured by the voltmeter as a function of time is a flat horizontal line while the switch remains closed. We will make direct measurements of the resistances of the resistor and the inductor with an ohmmeter, but this doesn't work for the battery. To get a measurement of the battery's internal resistance, we will measure its terminal voltage with no current (i.e. with a voltmeter), and compare it to the current that flows from the battery in the "before" setting, which we can get from the voltmeter reading and the load resistances.

Very suddenly the switch is then opened, taking the battery out of the circuit. One question we will seek to answer is, "What should the voltmeter measure at the moment when the switch is closed, and as a function of time thereafter?" Then from the time-dependence of the voltmeter reading after the switch is opened, we'll use our usual graphical approach of converting the data into what we expect to be a straight line in order to find the time constant of this circuit, and from that the value of the inductance of our inductor.

Where to Find Things

We will be using the component board one last time in this experiment. Here is where you will find the components we will be using:

Figure 8.1.1 – Component Board


inductor
DELEVAN
220Ω
resistor

8.2: Activities

Equipment

- component board
- multimeter
- power supply
- Pasco Box, voltage probe leads, and laptop
- wires

The General Idea

We are looking to study the exponential decay of the current in an LR circuit. To accomplish this, we need to design a circuit that gets current flowing through an inductor connected to a resistor, and then allow it to run down. This is tricky, because to get the current flowing we need a battery (power supply), but when the decay begins, the battery can no longer be present.

The circuit diagram in the Background Material shows us exactly how we can accomplish this: We create two parallel branches from the battery, one where current is flowing through the inductor, and one where current is flowing through a resistor. If we then suddenly open the switch to the battery, taking it out of the circuit (in our case, this requires unceremoniously yanking a lead out of the power supply), then there is current present in the inductor when it is alone with a resistor in a circuit.

What we will be measuring is the time-dependent voltage drop across the inductor, the exponential behavior of which will mimic that of the current flowing through it. The ultimate "problem" we are asked to solve is to determine the inductance of the inductor from voltage-vs-time data. Given that we know (or can look-up) the role that inductance and resistance play in the time evolution of the decaying current, an appropriate best-fit line for the data (as well as a direct measurement of the resistance with an ohmmeter) will give us what we seek.

Here are some of the details you will need to know for the procedure:

- See the Background Material page for a picture of where the inductor and resistor are located on the component board.
- You have a multimeter with which you can measure the resistance of the inductor, and check the 220Ω indicated resistance for the resistor.
- The voltage sensors should be connected to the Pasco box in port A, and the software on the laptop that should be running is "Inductance."
- After you get the circuit connected and start the current flowing for a short time, you can assume that there is a steady current through the inductor. All you need to do then is:
  - start the recording of data in the software
  - quickly pull one of the leads out of the power supply (*Note: The software is written to automatically stop recording after one second, so you need to disconnect the power supply pretty soon after you start recording.*)
  - check to see if the data is fairly "clean" (you will have to blow-up the graph to look at its features better), and if it is not, go ahead and run it again
- If you have trouble getting a graph to come out without wild jumps (especially during the exponential decay), ask your TA for assistance.
- The graph is created from data points that are plotted, and while it should certainly *look* like an exponentially decaying function, you will need to use the actual data to create a best-fit line and extract the information you need.

Some Things to Think About

There are a few details that need to be incorporated into and some things to look out for in what is otherwise a very straightforward procedure.

- The inductor has an internal resistance that needs to be accounted for – you have a multimeter at your disposal for this.
- You should check to see if the minimum and maximum voltages encountered are what you would expect them to be. The flat line before the switch is opened is easy enough to check, but the sharp peak poses a little physics puzzle for you to solve.
- The simplest approach for analyzing the data from the decaying voltage is something you have done many times in past labs (with the exception of the first two steps):
  - magnify the screen until you can distinguish the data points

- use the  tool to extract the voltage values of 8 to 10 data points (It's probably a good idea to just choose the data points at regular intervals)
- construct a table of raw data, adding a column for some calculated values that you expect to demonstrate a linear relationship
- plot the expected linear function in the usual graphing calculator
- run the linear regression to get the slope
- extract the value you are looking for from the result

- Be sure to include (at a minimum) a screen capture of your Pasco data, the data table you constructed, the best fit line and their results, and of course your analysis discussion, in your lab report.

Lab Report

Craft a lab report for these activities and analysis, making sure to include every contributing group member's name on the front page. You are ***strongly encouraged*** to refer back to the Read Me as you do this, to make sure that you are not leaving out anything important. You should also feel free to get feedback from your lab TA whenever you find that your group requires clarification or is at an impasse.

Every member of the group must upload a separate digital copy of the report to their lab assignment in Canvas *prior to leaving the lab classroom*. These reports are not to be written outside the lab setting.

Index

Glossary

Sample Word 1 | Sample Definition 1

Detailed Licensing

Overview

Title: UCD: Physics 9C Lab

Webpages: 49

All licenses found:

- CC BY-SA 4.0: 81.6% (40 pages)
- Undeclared: 18.4% (9 pages)

By Page

- UCD: Physics 9C Lab - *CC BY-SA 4.0*
  - Front Matter - *Undeclared*
    - TitlePage - *Undeclared*
    - InfoPage - *Undeclared*
    - Table of Contents - *Undeclared*
    - Licensing - *Undeclared*
  - Lab 1: Static Electric Charge - *CC BY-SA 4.0*
    - 1.1: Background Material - *CC BY-SA 4.0*
    - 1.1: Background Material (remote) - *CC BY-SA 4.0*
    - 1.2: Activities - *CC BY-SA 4.0*
    - 1.2: Activities (remote) - *CC BY-SA 4.0*
  - Lab 2: Electrostatic Potential - *CC BY-SA 4.0*
    - 2.1: Background Material - *CC BY-SA 4.0*
    - 2.1: Background Material (remote) - *CC BY-SA 4.0*
    - 2.2: Activities - *CC BY-SA 4.0*
    - 2.2: Activities (remote) - *CC BY-SA 4.0*
  - Lab 3: Capacitors - *CC BY-SA 4.0*
    - 3.1: Background Material - *CC BY-SA 4.0*
    - 3.1: Background Material (Remote) - *CC BY-SA 4.0*
    - 3.2: Activities - *CC BY-SA 4.0*
    - 3.2: Activities (remote) - *CC BY-SA 4.0*
  - Lab 4: DC Circuits - *CC BY-SA 4.0*
    - 4.1: Background Material - *CC BY-SA 4.0*
    - 4.1: Background Material (remote) - *CC BY-SA 4.0*
    - 4.2: Activities - *CC BY-SA 4.0*
    - 4.2: Activities (remote) - *CC BY-SA 4.0*
  - Lab 5: RC Circuits - *CC BY-SA 4.0*
    - 5.1: Background Material - *CC BY-SA 4.0*
    - 5.1: Background Material (Remote) - *CC BY-SA 4.0*
    - 5.2: Activities - *CC BY-SA 4.0*
    - 5.2: Activities (Remote) - *CC BY-SA 4.0*
  - Lab 6: Engineering with Magnetism - *CC BY-SA 4.0*
    - 6.1: Background Material - *CC BY-SA 4.0*
    - 6.1: Background Material (Remote) - *CC BY-SA 4.0*
    - 6.2: Activities - *CC BY-SA 4.0*
    - 6.2: Activities (Remote) - *CC BY-SA 4.0*
  - Lab 7: Electromagnetic Induction - *CC BY-SA 4.0*
    - 7.1: Background Material - *CC BY-SA 4.0*
    - 7.2: Activities - *CC BY-SA 4.0*
    - 7.2: Activities (Remote) - *CC BY-SA 4.0*
  - Lab 8: Inductance - *CC BY-SA 4.0*
    - 8.1: Background Material - *CC BY-SA 4.0*
    - 8.2: Activities - *CC BY-SA 4.0*
    - 8.2: Activities (remote) - *CC BY-SA 4.0*
  - Read Me: About Labs in Physics 9 - *CC BY-SA 4.0*
  - Back Matter - *Undeclared*
    - Index - *Undeclared*
    - Glossary - *Undeclared*
    - Detailed Licensing - *Undeclared*