LABORATORY III
ELECTRIC ENERGY AND CAPACITORS

Our modern society functions in part because we have learned how to manipulate electrical energy. Almost all of our technology involves electrical energy in one form or another. In this laboratory you will investigate the conservation of energy as it relates to electricity.

A capacitor is the simplest device that can store electrical energy. The problems in this lab involve transforming electrical energy stored in capacitors into light, kinetic energy, and other forms of energy that may be more difficult to detect.

OBJECTIVES:

After successfully completing this laboratory, you should be able to:

- Apply the concept of conservation of energy to solve problems involving electrical phenomena.
- Describe the energy stored in a capacitor based on how it is connected to other capacitors and to sources of potential differences.

PREPARATION:

Read Fishbane: Chapter 6, section 1 and section 5; Chapter 25, sections 1-4.

Before coming to lab you should be able to:

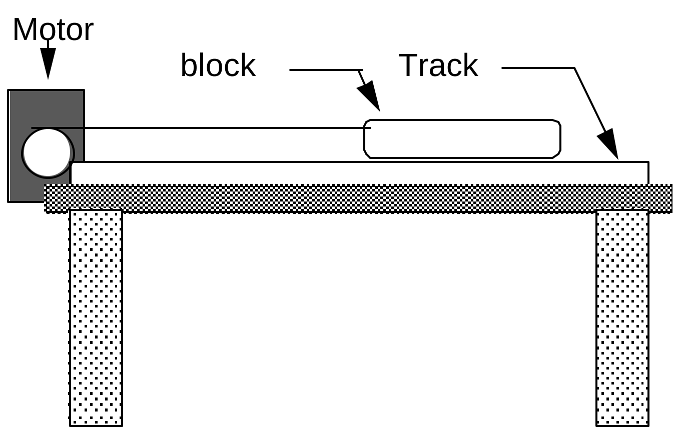
- Calculate the work done by a force exerted on a moving object.
- Calculate the relationship between power and energy.
- Write the equation for the energy stored in a single capacitor and understand the meaning of all the quantities involved.

PROBLEM #1
ELECTRICAL AND MECHANICAL ENERGY

You have a job in a University research group investigating the effect of solar flares on the Earth's magnetosphere. Your team is designing a small, cheap satellite for the investigation. As soon as the satellite achieves a stable orbit, it must extend its two solar panels. Your team must design a lightweight power source for deploying the solar panels. You have been asked to investigate the use of capacitors. You decide to calculate how the mechanical energy transferred to a device powered by a capacitor depends on the capacitance. You will test your calculation using a laboratory model in which a capacitor provides power for a motor that drags a block of wood across a table. You calculate how far the block will move as a function of the capacitance of the capacitor, the efficiency of the system, and other properties of the block and table. You assume that you know the initial voltage on the capacitor.

EQUIPMENT

A block of wood, an aluminum track, a motor, string, several different capacitors, a battery or power supply, a meter stick, and a digital multimeter (DMM).



PREDICTION

Restate the problem. What are you trying to calculate? Express the result as both an equation and a graph.

WARM-UP QUESTIONS

Read: Fishbane Chapter 25 Sections 1 and 2. Also review Chapter 5 Section 2.

1. Draw pictures of the situation before the block moves, while the block is in motion, and after the block has come to rest. Label all relevant distances, masses, forces, and potential differences. Describe the physics principles you need to solve this problem.

2. Define the initial and final times of interest in this problem. Describe (perhaps with your diagrams) what happens to energy in the situation between those times. Indicate interactions that transform energy from one form to another or from one object to another.

3. Are there objects in the problem whose potential or kinetic energy is relevant, and that you can calculate directly in terms of quantities measurable in the lab? If so, write down expressions for their initial and final (potential or kinetic) energies.

4. Draw a force diagram for the block while it is in motion. Are there any relevant forces with magnitudes you *can* calculate, in terms of quantities you can measure in the lab? Write equations for those forces. Are there any relevant forces you *can't* calculate in terms of easily measured quantities? Indicate which forces those are.

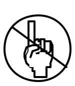
5. Use the work-energy theorem to write an equation for the net work done on the block. Use this equation and equations from previous steps to write the amount of energy transferred from the capacitor to the block, during the entire process, as a function of the distance the block slides and properties of the block and track.

6. How would you define "efficiency" for this situation? Choose a system. Write an energy conservation equation for your system that relates the efficiency, the situation's initial conditions, and properties you can measure in the lab, to the distance the block slides.

7. Use the principal of energy conservation to write an equation for the amount of energy dissipated in this situation, in terms of measurable quantities and the efficiency. Be sure this equation is consistent with your description from step 2.

8. Sketch a graph of the distance the block slides as a function of the capacitor's capacitance. Assume constant efficiency, and that the capacitor is charged to the same potential difference for each trial. (You can check the "constant efficiency" assumption in the lab.)

EXPLORATION



WARNING: A charged capacitor can discharge quickly producing a painful spark. **Do not** handle the capacitors by their electrical terminals or handle connected wires by their metal ends. **Always discharge a capacitor with a wire when you are finished using it.** To discharge a capacitor, use an insulated wire to briefly connect one of the terminals to the other.

Take the capacitor with the smallest capacitance. Give the capacitor plates a potential difference of 6 volts by connecting the "+" terminal of the capacitor to the "+" terminal of the battery and the "-" terminal of the capacitor to the "-" terminal of the battery.

NOTE: DO NOT reverse the polarity of the connection by connecting the battery's "+" terminal to the capacitor's "-" terminal or vice versa. Doing so would irreversibly change the capacitor's capacitance.

Disconnect the capacitor from the battery. Explain how you can use the DMM to tell if the capacitor is fully charged or fully discharged. Explain what you mean by fully charged. Try charging for different amounts of time. Determine how long it takes the capacitor to fully charge.

Connect the block to the motor with the string. Without touching the capacitor leads to anything else connect one lead to one terminal of the motor and the other lead to the other terminal of the motor. Which direction does the motor spin? Does the direction that the motor spins depend on how you connect the motor and the capacitor? Decide the best way to connect the motor and the capacitor.

How far is the block pulled along the track? Try it for the largest capacitor as well. Does the efficiency appear to be constant? If not, can you make it more constant, or will you have to average over several trials, or is the assumption of constant efficiency simply not realized by this system? Choose a range of capacitors to give you a good range of distances.

Write down your measurement plan.

MEASUREMENT

Measure the distance that each fully charged capacitor pulls the block. Be sure to take more than one measurement for each capacitor.

ANALYSIS

Graph the distance the block is pulled versus the capacitance of the capacitor. Show the estimated measurement uncertainty on your graph.

CONCLUSION

Did your results match your predictions? Explain any differences.

How efficient is this energy transfer? Define what you mean by efficient. How good was the assumption of constant efficiency for this situation?

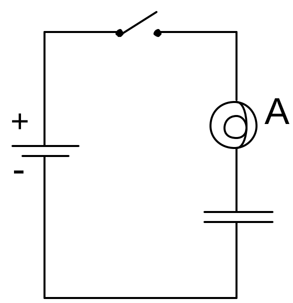
You have heard that energy is always conserved. Is it appropriate to say that energy was conserved in this situation? Why or why not?

EXPLORATORY PROBLEM #2
SIMPLE CIRCUITS WITH CAPACITORS

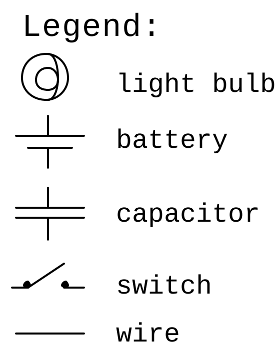
You and your friend are trying to determine if you can use a capacitor to extend the lives of batteries in circuits. You suggest that you try a simple circuit with a capacitor, originally uncharged, connected to a battery through a switch. To monitor the output energy, you put a light bulb in series with the capacitor. Your friend believes that when the switch is closed the capacitor charges up and the bulb gets brighter and brighter until the brightness levels off. The bulb then stays on until the switch is opened. Do you agree?

EQUIPMENT

You can build the circuit shown below out of wires, bulbs, capacitors and batteries. Use the accompanying legend to help you build the circuits. You will also have a stopwatch and a digital multimeter (DMM).



Circuit I

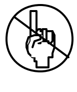


PREDICTION

Restate the problem. Do you agree with your friend? If not, describe what you think the behavior of the circuit will be. Give your reasoning. Explain what is going on in each component of the circuit.

Sketch a qualitative graph of the bulb's brightness vs. time.

EXPLORATION



WARNING: A charged capacitor can discharge quickly producing a painful spark. **Do not** handle the capacitors by their electrical terminals or connected wires by their metal ends. **Always discharge a capacitor with a wire when you are finished using it.** To discharge a capacitor, use an insulated wire to briefly connect one of the terminals to the other.

Examine each element of the circuit **before** you build it. How do you know if the battery is "good"? Is the capacitor charged? Carefully connect the two terminals of the capacitor to ensure it is uncharged.

After you are convinced that all of the circuit elements are working and that the capacitor is uncharged, build the circuit but do not close it yet.

NOTE*:* Be sure that the polarity of the capacitor's connection is correct -- that the part of the circuit connected to the battery's "+" terminal is connected to the capacitor's "+" terminal, and the part of the circuit connected to the battery's "-" terminal is connected to the capacitor's "-" terminal. Reversing the polarity would irreversibly change the capacitor's capacitance.

Now, close the circuit and observe how the brightness of the bulb changes over time.

From your observation of the bulb's brightness, how does the charge flowing through the bulb change over time? You can check this using the DMM set for current (Amps). See Appendix D for the use of the DMM. Using a mental model of the capacitor as two parallel plates separated by a short distance, how does the charge accumulated on each plate of the capacitor change over the same time? Can you measure this with the DMM? Use conservation of charge to explain what you observe.

From what you know about a battery, how does the potential difference (voltage) across the battery change over time? Check this using the DMM set for potential difference (Volts). From your observations of the brightness of the bulb, how does the potential difference across the bulb change over time? Check this using the DMM. What can you infer about the change of voltage (change of potential difference) across the capacitor over time? Can you check with a DMM? Use the concept of conservation of energy to explain what you observe.

After a few moments, open the circuit. Is the capacitor charged or uncharged? To determine if the capacitor is charged, carefully (and safely) remove the battery from the circuit and reconnect the circuit without the battery. With only the capacitor and bulb (no battery) in the circuit, does the bulb light? Use the result to answer the following questions. Was the capacitor charged before you closed the circuit? Was the capacitor still charged long after the circuit was closed? Use conservation of charge and conservation of energy to explain your results.

CONCLUSION

Was your friend correct about how the brightness of the bulb changed?

Sketch a qualitative graph of the brightness of the bulb as a function of time after you complete the circuit consisting of the *initially discharged* capacitor, battery and light bulb. How does this compare to your prediction? Sketch a qualitative graph of the charge on the capacitor as a function of time for this situation.

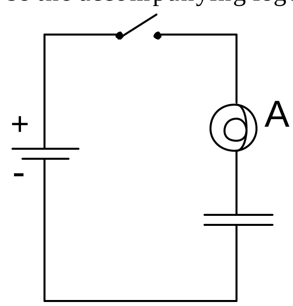
Sketch a qualitative graph of the brightness of the bulb as a function of time after you complete the circuit consisting of the *initially charged* capacitor, NO battery and light bulb. Sketch a qualitative graph of the charge on the capacitor as a function of time for this situation. Describe how this graph relates to the changing potential difference across the capacitor, and to the changing amounts of charge on each plate of the capacitor.

EXPLORATORY PROBLEM #3
CAPACITANCE

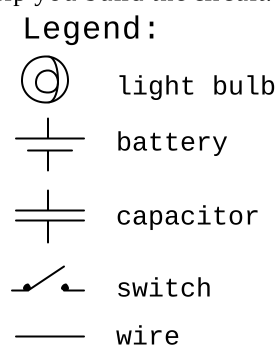
You have a part time job as a special effects technician at a local theater. As part of the theatrical production, the play's director wants a light bulb to dim very slowly for dramatic effect. You design a simple, inexpensive circuit to automatically accomplish this task: a battery, a switch, a light bulb, and a capacitor in series. You have been asked to demonstrate different rates of dimming for the light bulb so the director can select the one that best fits the performance. You need to determine how to adjust the amount of time it takes for the light bulb to go out by varying the capacitance. To make a proper comparison you make sure that the capacitor is initially uncharged.

EQUIPMENT

You have the materials to build the circuit below. You will also have a stopwatch and a digital multimeter (DMM). Use the accompanying legend to help you build the circuit.



Circuit I



PREDICTION

Restate the problem. What is the variable you will be measuring and what is the variable you will be controlling? How do you think they will depend on one another? Give your reasoning. Explain what is going on in each component of the circuit.

Sketch a graph of the time it takes for the light bulb to turn completely off as a function of the capacitor's capacitance.

EXPLORATION

WARNING: A charged capacitor can discharge quickly producing a painful spark. **Do not** handle the capacitors by their electrical terminals or connected wires by their metal ends. **Always discharge a capacitor before you use it and after you are finished using it.** To discharge a capacitor, use an insulated wire to briefly connect one of the terminals to the other.

Examine each element of the circuit **before** you build it. How do you know if the battery is "good"? Be sure the capacitors are uncharged.

After you are convinced that all of the circuit elements are working and that the capacitor is uncharged, connect the circuit but do not close it yet.

NOTE*:* Be sure that the polarity of the capacitor's connection is correct -- that the part of the circuit connected to the battery's "+" terminal is connected to the capacitor's "+" terminal, and the part of the circuit connected to the battery's "-" terminal is connected to the capacitor's "-" terminal. Reversing the polarity would irreversibly change the capacitor's capacitance.

Now, close the circuit and observe how the brightness of the bulb changes over time. How long does it take for the bulb to turn off?

From what you know about a battery, how does the potential difference (voltage) across the battery change over time? Check this using the DMM set for potential difference (Volts). From your observations of the brightness of the bulb, how does the potential difference across the bulb change over time? Check this using the DMM. What can you infer about the change of voltage across the capacitor over time? Can you check with a DMM? Use the concept of potential difference to explain what you observe.

Develop a measurement plan that will allow you to determine the time it takes a bulb to turn off as a function of capacitance. You will want to decide how many different capacitors you need to use, how many time measurements to take for each capacitor, what you mean by the light bulb being "off," and how to ensure that the capacitor is uncharged before you make each measurement.

MEASUREMENT

Follow your measurement plan. Be sure to record your estimated uncertainty for each measurement.

ANALYSIS

Graph the time it takes for the light bulb to turn off, as a function of capacitance, with the capacitor initially uncharged.

CONCLUSION

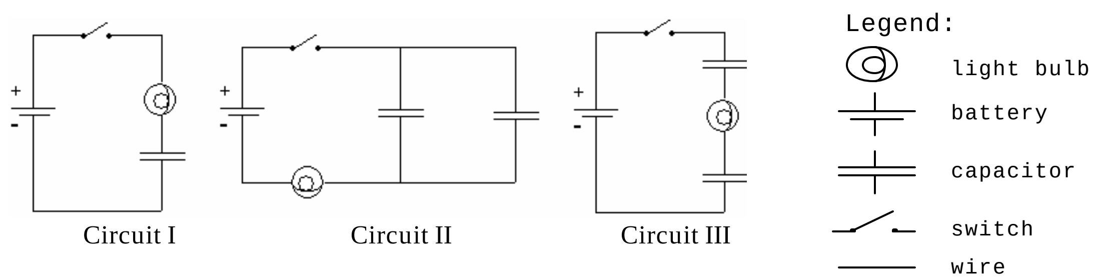
How did your measurement compare with your prediction? Using conservation of charge, conservation of energy, and the model of a capacitor as two plates separated by a short distance, explain how the capacitance affects the time it takes for the bulb to turn off.

PROBLEM #4
CIRCUITS WITH TWO CAPACITORS

You recently purchased a used camera with an electric flash. After taking a roll of pictures you are disappointed that the flash isn't bright enough. You look in the camera and notice that the flash works by allowing a battery to slowly charge a capacitor, and then quickly releasing the capacitor's stored electrical energy through a light bulb when a photo is taken. You think that the problem with your camera may be that not enough energy is stored in the capacitor to properly light the flash bulb. You have another capacitor with different capacitance, but aren't sure if you should connect it in series or in parallel with the original capacitor in order to store the most energy. You make an educated guess, and decide to test your prediction with circuits consisting of one or two initially uncharged capacitors, a battery, and a light bulb. You plan to measure the amount of time the bulb stays lit for one capacitor and for each of the possible arrangements of two capacitors, reasoning that if capacitors in a circuit can store more energy, they will take longer to fully charge.

EQUIPMENT

You will build the circuits shown below out of wires, *identical* bulbs, two *different* capacitors, and batteries. You will also have a stopwatch.



Note: Some of the light bulbs in the lab may be of different kinds and have different resistances. To find identical light bulbs look for markings and check to see that the color of the plastic bead separating the filament wires is the same.

PREDICTION

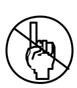
Restate the problem. What quantity do you wish to compare across the three situations; use physics to decide how they will compare? Which quantity will you be measuring directly; describe qualitatively how it is connected to the quantity of interest?

WARM-UP QUESTIONS

Read: Fishbane Chapter 25 Section 3.

1. Draw a picture of each arrangement of the capacitors, light bulb, and battery. On each picture, label the capacitance of each capacitor. (Remember that you will have only have capacitors with different capacitances.) Also, label the electric potential difference across each circuit element and the charge stored on the plates of each capacitor.
2. Decide on the physics principles you will use. For a circuit, conservation of charge is usually useful, as is conservation of energy. What is the relationship between the total energy stored in each circuit and the energy stored on each capacitor in that circuit?
3. For each capacitor, determine an equation that relates its stored energy, the charge collected on its plates, and its capacitance.
4. For each capacitor, write an equation relating the charge on its plates, the potential difference across the capacitor, and its capacitance.
5. *After the current stops flowing* through the circuit, do the two capacitors in Circuit II have the same amount of stored charge? Circuit III? At that time, what is the potential difference across the bulb in each circuit? At that time, what is the relationship between the potential difference across the battery and the potential difference across each capacitor?
6. The target quantity is the energy stored in the capacitors of each circuit. To determine which circuit stores more energy in the capacitors, you must calculate the energy stored in terms of quantities you can easily find, such as the potential difference across the battery and the capacitance of each capacitor.
7. From the previous steps, you can find the total energy stored in the capacitors in each circuit in terms of the potential difference across the battery and the capacitance of each capacitor. Now compare them to determine which is largest. *Check your equations by making the comparison when both capacitors have the same capacitance. Does the result make sense?*
8. What assumptions must you make to relate the total energy stored in the capacitors for each configuration to the time the light bulb remains lit after each circuit is closed?

EXPLORATION



WARNING: A charged capacitor can discharge quickly producing a painful spark. **Do not** handle the capacitors by their electrical terminals or connected wires by their metal ends. **Always discharge a capacitor before you use it and when you are finished using it.** To discharge a capacitor, use an insulated wire to briefly connect one of the terminals to the other.

Make sure all of your capacitors are uncharged before starting the exploration. Examine each element of the circuit **before** you build it. How do you know if the battery and the bulb are "good"? Connect Circuit I to use as a reference.

NOTE*:* Be sure that the polarity of the capacitor's connection is correct in each circuit -- that the part of the circuit connected to the battery's "+" terminal is connected to a capacitor's "+" terminal, and the part of the circuit connected to the battery's "-" terminal is connected to a capacitor's "-" terminal. Reversing the polarity would irreversibly change each capacitor's capacitance.

Close the circuit and observe how the brightness of the bulb changes over time. How long does it take for the bulb to turn off?

Connect Circuit II using the capacitor from Circuit I along with a capacitor with a different capacitance. *Do not close the circuit yet.* Do you think the bulb will light when the circuit is closed? Record your reasoning in your journal. *Now, close the circuit.* Record your observations and explain what you saw using conservation of charge and the concept of potential difference. Does the order that you connect the two capacitors and the bulb in the circuit matter? Try following one capacitor with the other capacitor and then the bulb. Try switching the two capacitors.

When the brightness of the bulb no longer changes, how are the the potential differences across the circuit elements related? Check this using the DMM, set for potential difference (Volts). Use the concept of energy conservation to explain what you observe.

Connect Circuit III using the two capacitors you used in Circuit II. *Do not close the circuit yet.* Do you think the bulb will light when the circuit is closed? Record your reasoning in your journal. *Now, close the circuit.* Record your observations and explain what you saw using conservation of charge and the concept of potential difference. Use the DMM to check the relationship between the potential differences across the elements of this circuit. Explain what you observe.

Develop a plan for measuring the time that it takes for the bulbs in Circuits I, II, and III to turn off, if they light at all.

MEASUREMENT

Use your measurement plan to record how long it takes for the light bulb to go off for each circuit. Use "0 seconds" for any bulbs that did not light. What are the uncertainties in these measurements?

ANALYSIS

Rank the actual time it took each bulb to turn off. Do all the bulbs initially light? Do all the bulbs eventually go off?

CONCLUSION

How did your initial ranking of the time it would take for the bulbs to go out compare with what actually occurred? Use conservation of charge, conservation of energy, and the concept of potential difference to explain your results.

Compare the reasoning you used in the exploration section to predict whether the bulbs would light in each circuit to the understanding you now have. If your reasoning has changed, explain why it changed.

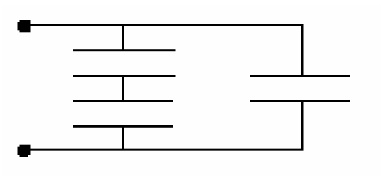
☑ CHECK YOUR UNDERSTANDING

For each of the arrangements of identical capacitors shown below:

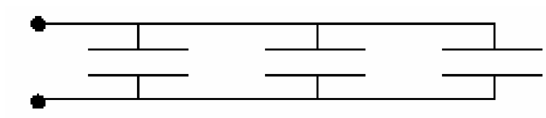
1) Rank them in terms of the amount of time they can light a light bulb. Assume that the leads shown have been connected to a 6 Volt battery and then removed from the battery and connected to a light bulb.

2) Calculate the potential difference between the terminals of each capacitor. Assume that the leads shown have been connected to a 6 Volt battery and that the capacitance of each capacitor is 10 μC.

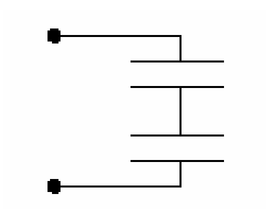
3) Calculate the amount of energy stored in each capacitor and the total energy stored in each arrangement of capacitors. Assume that the leads shown have been connected to a 6 Volt battery and that the capacitance of each capacitor is 10 μC



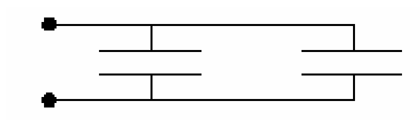
Arrangement 1



Arrangement 2



Arrangement 3



Arrangement 4

TA Name:___________________________

PHYSICS 1302 LABORATORY REPORT

Laboratory III

Name and ID#: ____

Date performed: ____________ Day/Time section meets: ______________________

Lab Partners' Names: ____

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Problem # and Title: ____

Lab Instructor's Initials: ________

Grading Checklist	Points*
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up questions completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.