How Do We Sense, Think, and Move? -- Lab #7
Zap! Storing and Moving Electric Charge

Task #1 - Getting Started

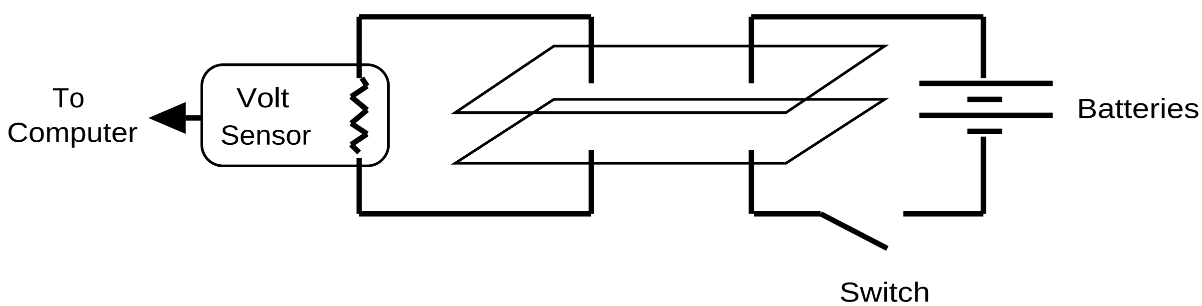
Most of the properties of electrical signals – whether within the nervous system of the human body or within the electrical wires in the walls of your house – are related to potential differences across two different places and the movement of charge from one place to another. While these systems are often complex, you can begin to understand them if you develop simple models of their behavior.

To begin this process, you will investigate the properties of an electrical system and begin to develop models of the behavior of this system during today's lab.

Description of the System: Two charge holders (parallel plates of aluminum sheet metal, also known as a parallel-plate capacitor)

Available Equipment: Source of electrical potential energy (D cell batteries)
Electrical connections (wires and alligator clips)
Electrical potential measuring device (MBL volt sensor)

Basic Equipment Setup:



Before you begin your investigations, verify that the following setup has been done correctly.

- Set the two metal sheets so that they are directly on top of each other with the little plastic spacers in the middle to keep them separated.
- Use the two wooden boxes to support the stacked metal sheets above the table.
- Attach an alligator clip to each of the metal sheets. Be careful that each clip is only touching one sheet! No part of the clip should be touching both of the sheets at the same time. This is important!!
- Attach the two leads of the MBL sensor to the metal sheets. Attach the black lead to the bottom sheet and the red lead to the top sheet.
- Open up the file " Lab#7 MBL - Elec Potential".

You know that electric charges exert forces on one another. Since like charges repel one another, work must be done on charges to put an excess of one kind of charge on an object (like a metal sheet, for example). This work is stored in the system as electric potential. It is convenient to measure the ratio of the total energy of the system divided by the total charge of the system. Hence the unit for electric potential has the units of joules (energy) divided by coulombs (charge).

$$\text{Electric Potential} = \frac{\text{energy}}{\text{charge}} = \frac{joules}{coulomb}$$

One joule / coulomb is named a "volt" (after an early electrician, no doubt).

Experiment #1 - Trying out the volt sensor …

You will measure the electric potential of the sheet attached to the red lead in relation to the electric potential of the sheet attached to the black lead. That is,

$$\text{Electric Potential} = \Delta V = V_{\text{Upper sheet}} - V_{\text{Lower sheet}}$$

Leaving the switch open, record a set of electric potential vs. time data for these two metal sheets (the computer has been set to record data for 5 seconds).

1. Sketch this graph in your logbook. Using the data, describe the electrical potential difference between these two sheets.

Experiment #2 - Trying out the batteries …

Using a lead with banana plugs and an alligator clip, attach the "negative" end of the 4 D-cell batteries to the key switch and the key switch to the bottom plate.

"Low" or "Negative" or "-"
end of the battery

"High" or "Positive" or "+"
end of the battery

Attach another lead from the other end of the batteries to the upper plate. Your experimental setup should now look like the setup pictured on the first page.

Read all of the following directions before you collect data:

- Start recording data for the system.
- After about 2 seconds have passed, press down on the key switch and hold it down.
- Keep the switch "closed" until the computer stops collecting data (after a total of 5 s).
- Let go of the key switch (it should pop open).
- Sketch this graph in your logbook. Answer questions 2 – 4 based on the data you collected.

2. What was the effect of connecting the batteries to the upper <u>and</u> lower plates (when you closed the switch)? How did the graph change? Knowing that typical D cell batteries are usually rated as "1.5 volts," does this change make sense? Explain.

3. Based on what you know about the behavior of charges and the definition given here of electric potential, what kinds of charge do you think ended up on the upper metal sheet? The lower metal sheet? Explain your reasoning.

4. Draw a careful sketch of your equipment (batteries, metal sheets, wires, and MBL sensor). Based on your answer to question #3, also draw in pluses (+ + +) and minuses (- - -) to represent the presence of net positive charge and net negative charge.

You might want to check your reasoning with another lab group before you continue on.

Task #2 - Moving Electric Charge

The metal sheets you used in the previous activity are often called "parallel plates." Due to their ability to hold electric charge they are called a parallel plate capacitor. When you connect a battery across two such plates, you can refer to this as "charging up the plates." Once the plates are "charged up," you can use this collection of charge to study the behavior of charges.

Research Question #1: How long does it take for electric charge to move from one location to another?

In the following experiment, you will use the energy of the batteries to put an excess of charges on the two plates of the capacitor. After the plates are charged up, you will disconnect the battery by opening the switch. The two plates will be connected electrically through a device (the volt sensor) that will enable you to measure the motion of the charges from one plate to the other.

5. Discuss the following prediction questions with your group. Record your predictions after your discussion (to be graded only for completeness).

   - How do you expect the motion of the charges to depend upon the number of excess charges that you put on each plate?
   - What other variables might influence the speed with which charges move?
   - Based on your intuition and your graph from the previous activity, how long do you think it will take the charges to move between the plates so there is no longer any difference between the two plates?

Experiment #3 - Four Batteries

Collect a set of data by completing the following procedure:

- Charge up the plates by holding down the key switch.
- One person should start recording data. Once data is being collected, the other person should let go of the key switch.
- The capacitor will now discharge through the volt sensor.
- Stop recording data once the electric potential has returned to zero.
- Use the "zoom" tool to inspect the resulting decay curve. If the curve is smooth, then you are ready to move on.
- If there are spikes and bumps in the decay curve, then try repeating the experiment. Be careful not to jiggle the plates during the experiment. Also, be sure that each alligator clip only touches one plate.

You might want to check your data with another lab group before you continue on.

Data Analysis – Building a Mathematical Model

Once you have collected a "good" set of data, you are ready to analyze it. Since you want to answer the question of how long it takes the charge to move from one location to another, you will want to measure a meaningful time. But what is a meaningful time…?

As you probably recall, the decay curve for this system has a shape very similar to the decay curve you found for light intensity as a function of number of filters (Lab #2). In that experiment, you examined how many filters it took to reduce the intensity by 50%. That same strategy may be useful here. That is, you should try to measure how much time it takes for the electric potential to be cut in half. We will call this time: $T_{1/2}$.

6. What mathematical function could describe the shape of your data? Explain.

In order to estimate values of $T_{1/2}$, use the *ScienceWorkshop* cursor tool to make careful measurements from the graph and a data table such as the following. Estimate $T_{1/2}$ three different times for this data.

Trial		*Electric Potential (V)*	*Time (s)*	*$T_{1/2} = T_B - T_A$ (s)*
1	*Point A*	V_A = 4.00		
	Point B	V_B = (0.5) V_A = 2.00		
2	*Point A*	V_A = 3.00		
	Point B	V_B = (0.5) V_A = 1.50		
3	*Point A*	V_A = 1.50		
	Point B	V_B = (0.5) V_A = 0.75		

7. Adjust the axes of the graph to clearly show the data of interest (the decay curve). Print one copy of this graph and write on it your best estimate of $T_{1/2}$ for this experiment. Explain why you feel this is the best value.

Research Question #2: How does the value of $T_{1/2}$ change if you change the energy supplied by the batteries?

You just experimentally measured a parameter that describes how quickly the charge moves from one plate to the other. Now you will repeat the experiment using two different (smaller) initial potential difference values.

8. How do you think the variable $T_{1/2}$ will change if you reduce this initial energy input? Explain your reasoning completely (for credit).

Experiment #4 - Three Batteries

Collect a set of data for three batteries by completing the following procedure:

- Move the alligator clip so you are only using three batteries (instead of four as you used in the last experiment).
- Charge up the plates by holding down the key switch.
- Collect a "good" set of data showing the decay curve for this new system.

From this data, estimate $T_{1/2}$ three different times. Be sure to record all relevant values and calculations in a table as you did previously.

9. Adjust the axes of the graph to clearly show the data of interest (the decay curve). Print one copy of this graph and write on it your best estimate of $T_{1/2}$ for this experiment.

Experiment #5 - Two Batteries

Collect a set of data for two batteries by completing the following procedure:

- Move the alligator clip so you are only using two batteries.
- Charge up the plates by holding down the key switch.
- Collect a "good" set of data showing the decay curve for this new system.

From this data, estimate $T_{1/2}$ three different times. Be sure to record all relevant values and calculations in a table as you did previously.

10. Adjust the axes of the graph to clearly show the data of interest (the decay curve). Print one copy of this graph and write on it your best estimate of $T_{1/2}$ for this experiment.

Distribute the printed graphs so that each person in your group has at least one sample data graph taped in their logbook.

11. How were the resulting data graphs similar and how were they different as you changed the number of batteries used for charging the plates? Explain.

12. What affect did changing the number of batteries used for charging the plates of the capacitor have on the time it takes the charges to move from one plate to the other? Explain.

13. Consider these variables:
    (a) initial electric potential, V_0
    (b) decay time, $T_{1/2}$
    (c) physical construction of the capacitor (its capacitance)
    (d) components in the circuit other than the capacitor.

    Based on your results for experiments #3 - #5,
    - Which variable(s) did you experimentally change?
    - Which variable(s) did you hold constant?
    - Which variable(s) changed as a result of the experimental conditions?
    - Which variable(s) did not change as a result of the experimental conditions?

Research Question #3: How does the value of $T_{1/2}$ change if you change the capacitor by putting a different material between the plates?

In the following experiment, you will investigate what happens if you change the physical parameters of the capacitor. There are many physical characteristics of the capacitor that you could change including the size of its plates, the distance between the plates, and the material between the plates. Since your lab time is limited, you will just investigate one of these possibilities.

14. Predict how the material between the capacitor plates might influence the speed with which charges move.

Experiment #6 - Four Batteries, Paper between the plates

Collect a set of data by completing the following procedure:

- Adjust the capacitor so that there is paper between the plates instead of air.
- Be sure to keep all other variables constant (such as the separation distance between the plates and the overlap of the two plates). You will need to flip over the top plate (with the plastic separators) so the plate can just rest on the paper.
- Verify that the circuit has remained intact and that each alligator clip is only touching one plate.
- Charge the plates by holding down the key switch.
- Collect a "good" set of data showing the decay curve for this new system.

From this data, estimate $T_{1/2}$ three different times. Be sure to record all relevant values and calculations in a table as you did previously.

15. Adjust the axes of the graph to clearly show the data of interest (that is, that shows the decay curve). Print one copy of this graph for each person in your group and write on it your best estimate of $T_{1/2}$ for this experiment.

16. How was this data graph similar and different to the data you collected in Experiment #3?

17. What effect did changing the material within the capacitor have on the time it takes the charges to move from one plate to the other? Explain.

    Quantify this effect by determining by what factor the decay time increased. That is, calculate the ratio: $\dfrac{T_{\frac{1}{2}paper}}{T_{\frac{1}{2}air}}$.

18. Consider these variables:
    (a) initial electric potential, V_0
    (b) decay time, $T_{1/2}$
    (c) physical construction of the capacitor (its capacitance)
    (d) components in the circuit other than the capacitor.

    Based on your results for Experiment #3 and #6,
    - Which variable(s) did you experimentally change?
    - Which variable(s) did you hold constant?
    - Which variable(s) changed as a result of the experimental conditions?
    - Which variable(s) did not change as a result of the experimental conditions?

Reminder… don't forget your accuracy and implication statements!