Objective

RC circuits charge and discharge in regular predictable ways. The fact that we can tailor a circuit to charge/discharge at whatever rate we want is the basis of electronic timing. In this lab we will determine what properties of a circuit effect the rate at which capacitors discharge, what properties of a capacitor effect its capacitance, and what the equivalent capacitance is for several capacitors connected together.

Overview of the Experiment

Power Supply. This makes a variable electric potential difference across its red and black terminals. Set the voltage to 10 V for safety.

DMM (Digital Multimeter). When the dial is set to “ V ”, this measures the voltage across its “com” and “ HzΩ” terminals. When the dial is set to “Ω” this measures the capacitance between “com” and “ HzΩ” terminals.

Stopwatch. Use this to measure the time that passes between events.

Switch. This type of switch is known as a “knife switch” – to open and close a circuit.

Capacitors. Devices for storing electric charge.

Part 1 – Parallel Plate Capacitors:

A parallel plate capacitor is just two flat pieces of metal with an insulator (also called a “dielectric material”) sandwiched between them. In this part of the lab you will make your own capacitors out of aluminum foil and a readily available dielectric material (paper). You can easily craft plates of a wide variety of sizes and shapes out of aluminum foil by hand. By choosing the number of layers of dielectric between the plates, the plate separation can also be controlled.

Dielectric Materials: The electrons in a dielectric are not free to move across the material because they’re stuck to the nuclei of their host molecules. However, the distribution of electrons around a molecule can change. In other words, electrons can be pushed or pulled from one side of their host molecules to the other as long as they stay close to the nuclei.
Checkpoint 1: Discuss with your group and write down answers to the following questions. Then come up with experiments to test your hypotheses. Have your TA check your answers and your procedure before proceeding.

Suppose you have made a capacitor as was just described.

1) How might its capacitance depend on the area of the plates?

2) How might its capacitance depend on the plate separation?

3) How might its capacitance depend on the dielectric material?

4) Explain why electrically neutral dielectrics, such as small bits of paper, are attracted to charged objects.

5) What factors (or components) affect the speed while a capacitor charges or discharges?

Conduct the experiment –

Using the aluminum foil, paper, connecting wires and digital meter, build a capacitor. Use the Digital meter to observe the capacitance value. When the dial is set to “ incarcerated capacitors” and “Hz/Ω” terminals, this measures the capacitance between “com” and “terminals.” In your lab notebook, write down your observations for capacitance dependence on area of plates, plate separation.

Note – Suggestion is to initially have area of foil nearly equal to size of one page and plate separation as one page.

Checkpoint 2: Show your TA your experimental observations for part-1 of the experiment.

Part 2 – Equivalent Capacitance:

When several capacitors are connected in series or in parallel they effectively form a new capacitor with a new capacitance. In this part we examine why that is.

Checkpoint 3: To answer the questions below it may help to assume the capacitors have the parallel plates.

1) When two capacitors (C1 and C2) are connected in parallel, is their combined equivalent capacitance greater than, less than, or equal to their individual capacitances? Why?

2) When two capacitors (C1 and C2) are connected in series, is their combined equivalent capacitance greater than, less than, or equal to their individual capacitances? Why?

3) In your note book draw a circuit diagram that you plan to build to measure the equivalent capacitance of the two capacitors for parallel and series configurations.

Come up with experiments to test your hypotheses on equivalent capacitance. Have your TA check that they're reasonable before proceeding.
Conduct the experiment –

Plan your experiment to determine the capacitance of two capacitors \( C_1 \) and \( C_2 \) which are mounted on a wooden board.

Tips for using the DMM to measure capacitance directly –
- When the dial is set to “ \( \pm \)”, this measures the capacitance between “com” and “HzVO” terminals.
- Once it’s connected to your capacitor, the DMM may take a few seconds to measure capacitance.
- Watch for the prefix (e.g. \( M, \ m, \ \mu, \ n \)) of the units as you make your measurements.
- If your DMM is reading zero for a capacitor, try swapping the terminals it’s attached to.

Plan your experiment to determine the equivalent capacitance of \( C_1 \) and \( C_2 \) for parallel and series configuration.

Checkpoint 4: Show your TA your experimental data and analysis of part-2 of the experiment for individual capacitance \( C_1 \) and \( C_2 \) as well as for parallel and series configurations.

Part 3 – RC Decay:
Whenever the rate of change of a quantity is proportional to the quantity itself, it results in an exponential behavior. For example, if each algae cell on the surface of a pond bifurcates into two algae cells every hour, the number of algae cells increases exponentially with time.

![Figure 1: A basic RC circuit. The voltmeter is contained within the dotted box and \( R_m = 10 \, M\Omega \) is its internal resistance.](image)

Mathematical analysis shows that, in a circuit like the one in Figure 1, the time it takes for a discharging capacitor to reach 36.8% of its initial voltage is:

\[
\tau = CR
\]

where \( C \) is the capacitor’s capacitance (in Farads) and \( R \) is the total resistance of the circuit (in Ohms).

The quantity \( \tau \) is called the circuit’s time constant.

Example – Time constant is how long it takes to discharge from initial voltage of 10 V to 3.68 V. Or – You can set to any initial voltage, and measure time to discharge to \( (1/3)^{rd} \) its initial value.
Checkpoint 5: Discuss with your group and write down answers to the following questions. Then come up with experiments to test your hypotheses. Have your TA check your answers and your procedure before proceeding.

1) Suppose the capacitor in Figure 1 is completely discharged. Now the switch is closed.
   a) What happens to the voltage across it?
   b) What happens to the number of electrons on the negative plate? On the positive plate?

2) Suppose the capacitor in Figure 1 is fully charged. Now the switch is opened.
   a) What happens to the voltage across it?
   b) What happens to the electrons stored on the capacitor’s negative plate?

3) How does time constant depend on the capacitance? On the resistance?

Conduct the experiment –
Determine time constant –
- On the DMM when the dial is set to “V”, this measures the voltage across its “com” and “HzVΩ” terminals.
- Use one of the capacitors (C1 or C2).
- Connect the DMM across the capacitor (not power supply)
- Given that Resistance of the DMM as $R_m = 10 \, \text{M}\Omega$.
- Set the initial voltage of the power supply to 10 V.
- Build the circuit and measure the time constant.

Explore the behavior of discharging voltage in RC circuit –
- For the above set up, create a data table in your lab notebook.
- Conduct the experiment and record all the data.
- In your lab notebook, plot a graph of voltage (V) vs. time (t)
- Indicate “τ” on your graph.

Checkpoint 6: Show your TA your experimental data, graph and analysis of part-3 of the experiment for time constant in RC decay.

Show your TA all the experimental data, analysis, and graphs for all parts of the experiment.

Results, Analysis & Discussion

Perform your proposed experiments and examine the data you get. Do the data support or refute your hypotheses – questions 1 to 5 in check point #1? How can you tell?

Lab Report – due one week after the lab

The procedure you followed should be clearly written and all the analysis should be included. You can include the computer plotted graphs. Make sure you address the questions posed at the beginning of this handout, your expectations before conducting the experiment and use your experimental data to support your conclusions. Your conclusion should indicate whether or not you were able to confirm your expectations.