

Capacitors

Goal: To study the behavior of capacitors in different types of circuits.

Lab Preparation

A capacitor stores electric charge. A simple configuration for a capacitor is two parallel metal plates. The amount of charge stored is proportional to the voltage difference V between the plates. The charge stored on one plate is

$$Q = CV$$

where Q is the charge stored, C is the capacitance, and V is the voltage. An equal amount of opposite charge is induced on the other plate. The capacitance depends on the area and separation of the plates and any material (called a dielectric) between the plates.

Figure 1(a) shows typical symbols used to represent capacitors in electrical schematics. Attaching a capacitor to a battery stores charge on the capacitor plates as in Figure 1(b). Connecting a resistor to the capacitor as in Figure 1(c) can drain the stored charge.

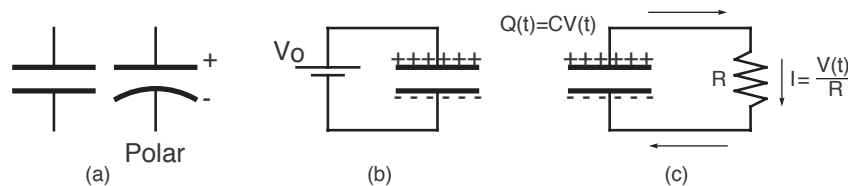


Figure 1

When a capacitor is discharged through a resistor R the voltage across the resistor is $V_R = IR$. The same voltage appears across the capacitor, $V_C = Q/C$. The capacitor acts like a poor battery that "dies" quickly by giving up all its stored charge. The charge on the capacitor at a given time is given by

$$Q = Q_0 e^{-\frac{t}{RC}}$$

where Q_0 is the charge stored on a capacitor initially. Since $V_C = Q/C$, the voltage across the capacitor also decays following the same form

$$V = V_0 e^{-\frac{t}{RC}}$$

where $V_0 = Q_0/C$. A typical exponential decay is shown in Figure 2a.

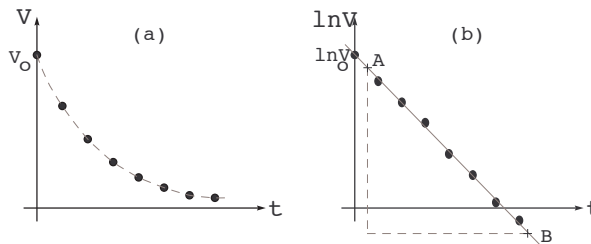


Figure 2

The product RC is called the time constant of the circuit and is often denoted as τ . When an amount of time equal to one time constant has elapsed from the start of the discharge ($t = \tau$), the voltage will have dropped to $V_0 e^{-1} \approx 0.37V_0$.

When the $\ln V_C$ is plotted against time (Figure 2b), a straight line graph is expected with the slope of the line equal to $-1/\tau$ (or $-1/RC$). To see that the slope of the $\ln V_C$ vs. time graph is $-1/\tau$, you take the natural logarithm of $V = V_0 e^{-\frac{t}{RC}}$. This yields the following:

$$\ln V_C = -\frac{1}{RC} t + \ln V_0.$$

This is the standard form of a linear equation, $Y = mX + b$. Thus we find $Y = \ln V_C$, slope $m = -1/RC$, $X = t$, and $b = \ln V_0$.

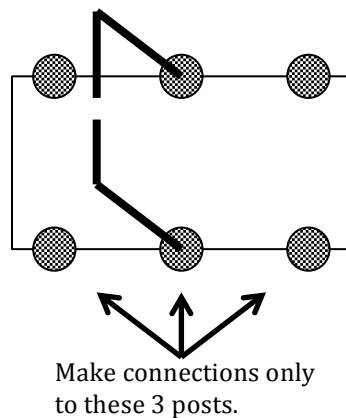
Equipment

Capacitors will obviously be used in this lab. The value stated on a capacitor is more likely to be a rough estimate of its true capacitance. Normally the value is $\pm 20\%$ or worse. You should always make sure your capacitor has no charge stored on it before an experiment. You can discharge it by simply connecting a wire from the + side to the - side.

For resistance in this lab a decade resistance box will be used. You can set the dials to different multiples of different resistances.

Voltages and currents will be measured using the computer. Make sure you follow the instructions on the screen when opening a program. You will also want to be sure to zero the voltmeter and ammeter probes before using them.

A double-throw switch will be used in this lab. We will only be connecting to one side of the switch as shown in the top view picture of the switch below.



Procedure

I. Exponential discharge in an RC circuit

- A. Wire up the circuit shown in Figure 3, but have your lab instructor check your circuit before closing the switch. For the switch you will use one side of a double-throw switch. The resistance R is set on a variable decade resistance box and should be set at $1000\ \Omega$. Use the capacitor with the larger capacitance labeled on. It is important that the capacitor is connected with its + terminal to the + side of the battery/voltage supply. Connecting them with reversed polarity can damage or destroy the capacitors.

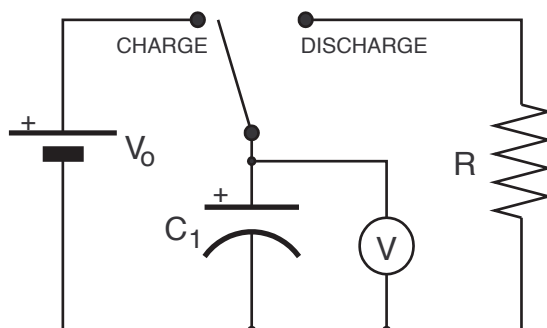


Figure 3

Use the computer to measure, V_o , the voltage drop across the capacitor. Start by opening up the "RC-discharge" file. Before connecting the voltage measuring leads from the computer interface to the circuit, connect the red and black wires directly to each other to short the leads. The voltage readout should be nearly zero. If the voltage readout is not $0.000 \pm 0.006\text{V}$ you should "zero" the reading (under "Experiment" choose "Zero"). Once zeroed, connect the voltage leads to the capacitor as indicated in Figure 3.

Put the double-throw switch in the charging position and wait for the voltage reading to give a steady reading for a minimum of 15 seconds. Record this initial voltage, V_o .

Simultaneously start data collection on the computer and flip the switch to the discharge position. Allow the measurements to continue until the capacitor voltage has dropped below 0.10 V , or for 200 seconds, whichever ever comes first.

- B. Make a quick estimate of the decay time constant τ by looking at the graph of V_c (voltage across the capacitor) versus time and determining how long it takes for V_c to drop from its initial value of V_o to about $.37V_o$. Use the "examine" tool button to help you. Record your value.

- C. A better way to determine the time constant τ is by examining a plot of $\ln V_C$ versus time. Determine and record the slope by carrying out a linear fit to the data (be careful not to use poor data points in this linear fit). Use the slope to determine the time constant τ .

Temporarily disconnect the decade box from your circuit and use a digital multimeter to measure the true value of the discharge resistor. Use this value of R and τ to find the capacitance, C .

Store the data (under "Experiment" choose "Store latest run") so it can be compared with the next measurements.

- D. Repeat the process above with the decade resistance box set to $500\ \Omega$. Once again, make sure you charge the capacitor for 15 seconds first and then simultaneously start data collection and flip the switch to discharge the capacitor. Repeat calculations to find τ and C . Once again, store the data.
- E. Repeat the entire process one more time with the decade resistance box set to $200\ \Omega$. Print out a V_C vs. t graph and a $\ln V_C$ vs. t graph with all 3 different resistance settings shown on each graph (so two graphs with 3 plots on each one). Label the curves with their proper resistance settings once printed.
- F. Find the average of your three capacitance calculations.
- G. With the decade resistance box set to $1000\ \Omega$ repeat the procedure above with the capacitor of lower nominal value. Calculate the capacitance, C_2 . You do not need to do $500\ \Omega$ or print out graphs here.

II. Charging the capacitor

- A. Use the "RC-Charge" file for this part of the experiment. Build the circuit shown in Figure 4. Use the larger capacitor and decade resistance box set to $R = 20\ \Omega$. The ammeter is a current probe sensor connected to the computer. The discharge side of the double-throw switch is now simply a short circuit to allow you to rapidly discharge the capacitor completely.

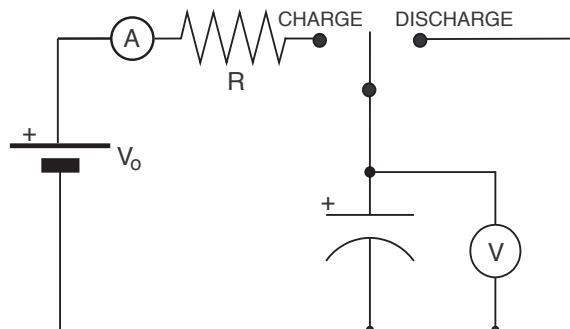


Figure 4

Discharge the capacitor fully - for at least 30 seconds. With the capacitor fully discharged and still shorted, so that both $V_C = 0$ and $I_C = 0$, zero both sensors.

- B. Before collecting charging data predict the initial current that you expect to flow once the switch is thrown to the charging position. Show a supporting calculation of your predicted I_0 . What do you expect the V_C vs. t and I_C vs. t graphs to look like? Sketch them qualitatively in your report before measuring.
- C. Start data collection and after a couple seconds flip the switch to the charging position (the collecting will trigger automatically when the capacitor begins to charge). Allow the charging process to go for 50 s (you do not have to hit stop - it will automatically stop). Record the initial current. Check to see if the initial current is close to your predicted value and if your plots look like your predicted graphs. Store the data.
- D. Repeat the process above for $R = 80 \Omega$. Print out the graph (use the landscape setting) window documenting your measurements for both trials on one page.

***When finished with your lab clean up your lab station. Make sure you put all wires away.**

Homework

Series combination. Suppose your two capacitors were hooked up in series as shown in Figure 5 below.

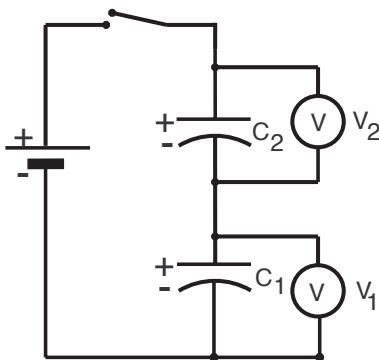


Figure 5

1. Will the charge on each capacitor be the same or different?
2. Will the voltage on each capacitor be the same or different?
3. What is the equivalent capacitance of the circuit? Use the values of capacitance you determined in your experiment.
4. Using V_0 from part IA, determine the charge on each capacitor.
5. Determine the voltages V_1 and V_2 across each capacitor.