

Lab 7:

RC Circuits

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INTRODUCTION & REVIEW

The charge q on a capacitor's plate is proportional to the potential difference V across the capacitor. We express this relationship with

$$V = \frac{q}{C},$$

where C is a proportionality constant known as the *capacitance*. C is measured in the unit of the farad, F, (1 farad = 1 coulomb/volt).

If a capacitor of capacitance C (in farads), initially charged to a potential V_0 (volts) is connected across a resistor R (in ohms), a time-dependent current will flow according to Ohm's law. This situation is shown by the RC (resistor-capacitor) circuit below when the switch is closed.

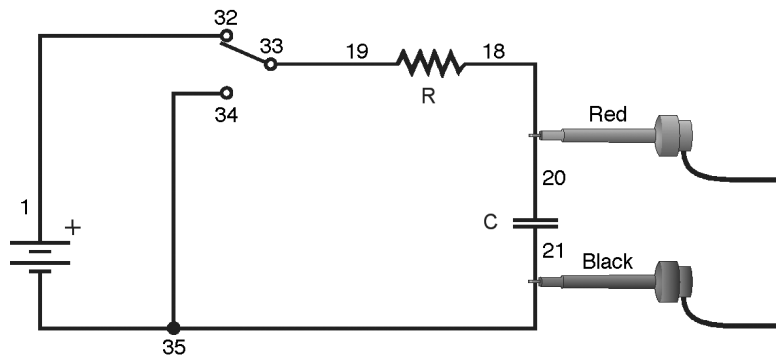


Figure 1

As the current flows, the charge q is depleted, reducing the potential across the capacitor, which in turn reduces the current. This process creates an exponentially decreasing current, modeled by

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

The rate of the decrease is determined by the product RC , known as the *time constant* of the circuit. A large time constant means that the capacitor will discharge slowly.

When the capacitor is charged, the potential across it approaches the final value exponentially, modeled by

$$V(t) = V_0 \left(1 - e^{-\frac{t}{RC}} \right)$$

The same time constant RC describes the rate of charging as well as the rate of discharging.

OBJECTIVES

- Measure an experimental time constant of a resistor-capacitor circuit.
- Compare the time constant to the value predicted from the component values of the resistance and capacitance.
- Measure the potential across a capacitor as a function of time as it discharges and as it charges.
- Fit an exponential function to the data. One of the fit parameters corresponds to an experimental time constant.

MATERIALS

Computer
Vernier computer interface
Logger *Pro*
Vernier Voltage Probe

Vernier Circuit Board with batteries, or
Various resistors and
capacitors
Single-pole, double-throw switch
connecting wires


PRELIMINARY QUESTIONS

- *** 1. Consider a candy jar, initially with 1000 candies. You walk past it once each hour. Since you don't want anyone to notice that you're taking candy, each time you take 10% of the candies remaining in the jar. Sketch a graph of the number of candies for a few hours.
- *** 2. How would the graph change if instead of removing 10% of the candies, you removed 20%? Sketch your new graph.

PROCEDURE (Choose Only One of the Following: Discharge or Charge)

Discharge:

1. Create the simple "RC" circuit (depicted on the first page of this lab). Informally experiment with it (using different combinations of resistors and capacitors) until you can reliably and reproducibly observe a vivid demonstration of the following :
Throwing the switch causes your L.E.D. to burst on intensely and then decay to full darkness.
2. Connect the circuit as shown in Figure 1 above with a capacitor and resistor of your choice. Record the values of your resistor and capacitor in your data table (once you've found a functioning combination), as well as any tolerance values marked on them. If you are using the Vernier Circuit Board, the terminal numbers are shown on the schematic to help you to connect the circuit.
3. Connect the Voltage Probe to Channel 1 of the computer interface, as well as across the capacitor, with the red (positive lead) to the side of the capacitor connected to the resistor. Connect the black lead to the other side of the capacitor.
4. Open the file in the "24 Capacitors" file in the *Physics with Vernier* folder. (It helps to find the folder first then select the file)
5. Charge the capacitor for 30 s or so with the switch in the position as illustrated in Figure 1. You can watch the voltage reading at the bottom of the screen to see if the potential is still increasing. Wait until the potential is constant.
6. Click to begin data collection. As soon as graphing starts, throw the switch to its other position to discharge the capacitor. Your data should show a constant value initially, then decreasing function.

- To compare your data to the model, select only the data after the potential has started to decrease by dragging across the graph; that is, omit the constant portion. Click the Curve Fit button , and from the function selection box, choose the Natural Exponent function, $A \cdot \exp(-Ct) + B$. Click , and inspect the fit. Click to return to the main graph window.
- *** Record the value of the fit parameters in your data table. **Notice that the C used in the curve fit is not the same as the C used to stand for capacitance.** This is extremely unfortunate and confusing but there is nothing we can do about what letters are used by a piece of software. Compare the fit equation to the mathematical model for a capacitor discharge proposed in the introduction,

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


How is fit constant C related to the time constant of the circuit, which was defined in the introduction?

- *** Print or sketch the graph of potential vs. time. Choose Store Latest Run from the Experiment menu to store your data. You will need these data for later analysis.

Charge:

- The capacitor is now discharged. To monitor the charging process, click . As soon as data collection begins, throw the switch the other way. Allow the data collection to run to completion.
- This time you will compare your data to the mathematical model for a capacitor charging,

$$V(t) = V_0 \left[1 - e^{-\frac{t}{RC}} \right]$$

Select the data beginning *after* the potential has started to increase by dragging across the graph. Check the time offset curve fit box. Click the Curve Fit button, , and from the function selection box, choose the Inverse Exponent function, $A \cdot (1 - \exp(-Ct)) + B$. Click and inspect the fit. Click to return to the main graph.

- *** Record the value of the fit parameters in your data table. Compare the fit equation to the mathematical model for a charging capacitor.
- Hide your first runs by choosing Hide Data Set from the Data menu. Remove any remaining fit information by clicking the upper left corner in the floating boxes.
- Now you will repeat the experiment with a resistor of lower value. How do you think this change will affect the way the capacitor discharges?

DATA TABLE

Trial	Fit parameters				Resistor	Resistor Uncertain	Capacitor	Capacitor Uncertainty	Time constant
	A	B	C	1/C	R (Ω)	%	C (F)	%	RC (s)
Discharge 1									
Charge 1									
Discharge 2									
Charge 2									

ANALYSIS

- *** In the data table, calculate the time constant of the circuit used; that is, the product of resistance in ohms and capacitance in farads. (Note that $1\ \Omega\ F = 1\ s$).
- *** Calculate and enter in the data table the inverse of the fit constant C for each trial. Now compare each of these values to the time constant of your circuit. How is the fit parameter A related to your experiment?
- *** Resistors and capacitors are not marked with their exact values, but only approximate values with a tolerance. Determine the tolerance of the resistors and capacitors you are using. If there is a discrepancy between the two quantities compared in Question 2, can the tolerance values explain the difference?
- *** What was the effect of reducing the resistance of the resistor on the way the capacitor discharged?
- *** How would the graphs of your discharge graph look if you plotted the natural logarithm of the potential across the capacitor vs. time? Sketch a prediction. Show Run 1 (the first discharge of the capacitor) and hide the remaining runs. Click on the y -axis label and select $\ln(V)$. Click to see the new plot.
- *** What is the significance of the slope of the plot of $\ln(V)$ vs. time for a capacitor discharge circuit?