Experiment: RC Circuits

OBJECTIVES

- Measure the potential across a capacitor as a function of time as it discharges and as it charges.
- Measure the 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.

MATERIALS

- Windows-based PC
- LabPro Interface w/ Logger *Pro*
- Vernier Voltage Probe
- connecting wires
- double-throw switch (optional)
- 330-μF non-polarized capacitor
- 1000-Ω, 560-Ω resistors
- DC power supply
- Pasco Electric Circuit Board

INTRODUCTION

As a capacitor charges the accumulation of electric charge within the capacitor is related to the increase in electric potential across the plates:

$$\Delta q = C\Delta V$$

where *C* is the proportionality constant (called the *capacitance),* measured in the unit of the farad, F (1 F = 1 C/V), that describes the physical properties of the system to accumulate electric charge.

At any time (t), the potential difference (ΔV or V(t)) across the capacitor is proportional to the total charge *q* residing on either of the capacitor's plates. We express this with

$$\Delta V = V(t) = \frac{q}{C}.$$

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.

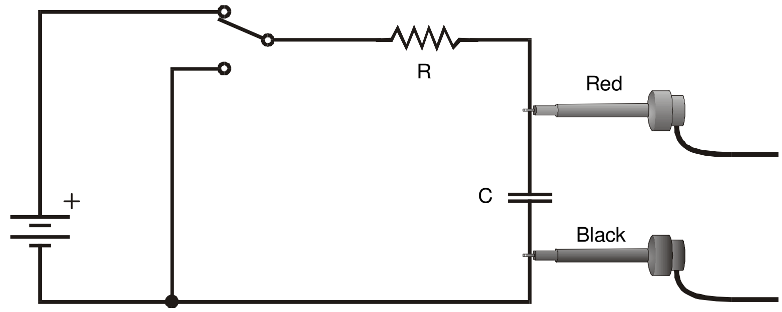


Figure 1

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.

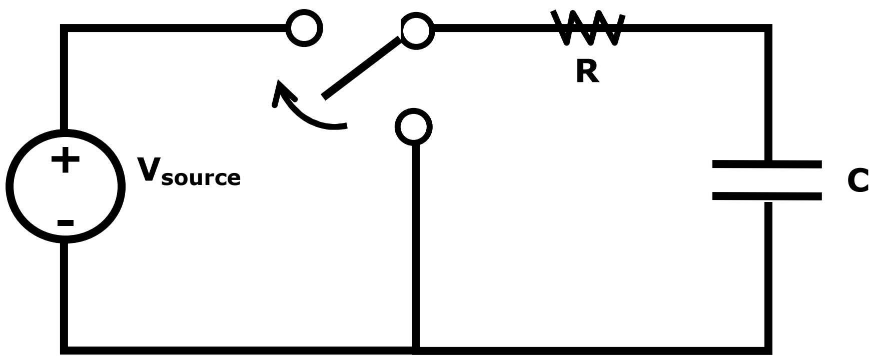
PRELIMINARY QUESTIONS

1. Consider a candy jar, initially with 1000 candies. Once each hour you take 10% of the candies in the jar.

a. Sketch a graph of the number of candies for a few hours.

b. How would the graph change if instead of removing 10% of the candies, you removed 20%? Sketch your new graph.

2. An uncharged 0.5 F capacitor is connected in series with a 50 Ω resistor. A 12 V power supply is connected to this circuit.



a. When the switch is thrown, the power source drives current through the circuit charging the capacitor. Sketch the capacitor voltage vs time and resistor voltage vs time graphs for the charging circuit.

b. Sketch the current vs time graph for this circuit.

c. How much charge is stored in the capacitor when it is completely charged?

d. The switch is then switched to the opposite position so that the power supply is no longer connected to the circuit and the capacitor discharges. Sketch the capacitor voltage vs time and resistor voltage vs time graphs for the discharging circuit.

e. Sketch the current vs time graph for this circuit.

PROCEDURE

1. Connect the circuit as shown in Figure 1 above with the 330μF capacitor and the 1-kΩ resistor. Record the values of your resistor and capacitor in your data table, as well as any tolerance values marked on them.

2. Connect the Differential Voltage Probe to Ch 1 to the LabPro interface and attach the probes across the capacitor, make certain to match the leads to the appropriate ends of the capacitor (positive to positive & negative to negative).

3. Start up LoggerPro then open the "Capacitors" experiment file.

4. Charge the capacitor for 15 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.

5. Begin data collection. As soon as graphing starts, throw the switch to its other position to discharge the capacitor.

6. Fit the graph, *only the region corresponding to the discharging capacitor*, to an exponential function. Be sure to select the "Time Offset" box in the Graph Fit window.

7. Record the fit parameter values in your data table *(Note: the C used in the curve fit is not the same as the C used to stand for capacitance)*. Compare the fit equation to the mathematical model for capacitor discharge proposed in the introduction,

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

8. Cut-and-paste the graph into Word then select "Store Latest Run" to store your data. You will need this data for later analysis.

9. Since the capacitor is discharged, now observe the charging process. Collect data for the charging capacitor.

10. This time you will compare your data to the mathematical model for a capacitor charging,

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

    Select the data beginning *after* the potential has started to increase by dragging across the graph. In the graph fit window, select "Time Offset" then fit the graph to the "Inverse Exponential function":

$$y = A(1 - e^{-Cx}) + B$$

11. Cut-and-paste the graph into Word.

12. Record the value of the fit parameters in your data table. Compare the fit equation to the mathematical model for a charging capacitor.

13. Hide your first runs by choosing Hide Run ▸ Run 1 from the Data menu. Remove any remaining fit information by clicking the gray close box in the floating boxes.

14. Repeat the experiment with a resistor of lower value, say 560-Ω. How do you think this change will affect the way the capacitor discharges? Repeat Steps 4 – 13.

DATA TABLE

	Fit parameters						Time constant
Trial	**A**	**B**	**C**	**1/C**	**R (Ω)**	**C (F)**	**RC (s)**
Discharge 1							
Charge 1							
Discharge 2							
Charge 2							

15. Print out the graphs.

ANALYSIS

1. For each trial, calculate and record the time constant (RC) of the circuit used; that is, the product of resistance in ohms and capacitance in farads. (Note that 1ΩF = 1 s).

2. Calculate and record the inverse of the fit constant *C* for each trial. How does this value compare with the corresponding time constant of your circuit?

3. Note that resistors and capacitors are not marked with their exact values, but only approximate values with a tolerance. If there is a discrepancy between the two quantities compared in question 2, can the tolerance values of R & C explain the difference?

4. What was the effect of reducing the resistance of the resistor on the way the capacitor discharged?

Optional:

5. One way to analyze a graph of this type, is to plot the the logarithm of the voltage, ln(V) vs t. Create a calculated data column to calculate ln(V) and plot it vs. time.

6. Fit this graph to a linear function. What is the significance of the slope of the plot of ln(*V*) *vs.* time for a capacitor discharge circuit?