CAPACITORS: RC CIRCUITS

OBJECTIVE

To experimentally explore the time-dependent relationships between charge, capacitance and potential in a resistor-capacitor (RC) circuit

EQUIPMENT

Computer, Vernier Circuit Board with batteries or Vernier Computer interface, 10 μF non-polarized capacitor, Logger Pro, 100 kΩ and 47 kΩ resistors, two C or D cells with battery holder, single-pole - double-throw switch and connecting wires

THEORY

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.

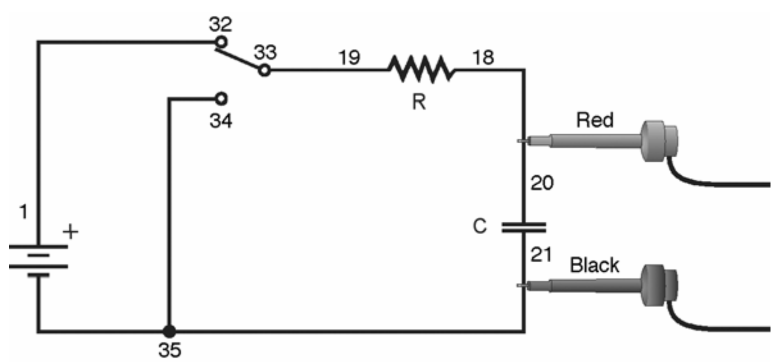

Figure 1

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.

PROCEDURE

1. Connect the circuit as shown in Figure 1 above with the 10 μF capacitor and the 100 kΩ resistor. Record the values of your resistor and capacitor in your data table, 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.

2. 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.

3. Open the file in the “27 Capacitors” file in the *Physics with Computers* folder.

4. 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.

5. Click ▶ Collect 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.

6. 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*exp(–Ct) + B. Click Try Fit, and inspect the fit. Click OK to return to the main graph window.

7. 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. 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?

8. 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.

9. The capacitor is now discharged. To monitor the charging process, click ▶ Collect. As soon as data collection begins, throw the switch the other way. Allow the data collection to run to completion.

10. 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. Click the Curve Fit button, , and from the function selection box, choose the Inverse Exponent function, A*(1 – exp(–Ct)) + B. Click Try Fit and inspect the fit. Click OK to return to the main graph.

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

12. 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.

13. 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? Rebuild your circuit using the 47 kΩ resistor and repeat Steps 4 – 11.

14. Complete the data table by calculating the time constant of the circuit used and the inverse of the fit constant *C* for each trial. (Note that 1Ω F = 1 s).

Name ____ **Date** ____________

Partners ____

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DATA TABLE

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

ANALYSIS

1. Compare the inverse of the fit constant *C* to the calculated time constant. What is the percent error in each case?

2. 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 above, can the tolerance values explain the difference?

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

4. 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 OK to see the new plot.

5. Explain the significance of the slope of the plot of ln(V) vs. time for a capacitor discharge circuit.

6. Try two 10 μF capacitors in parallel. Predict what will happen to the time constant. Repeat the discharge measurement and determine the time constant of the new circuit using a curve fit.

7. Try two 10 μF capacitors in series. Predict what will happen to the time constant. Repeat the discharge measurement and determine the time constant for the new circuit using a curve fit.