Capacitors

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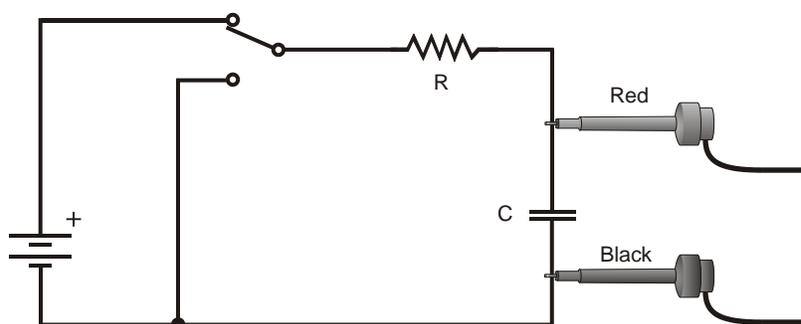

Figure 1

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.

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.
- Fit an exponential function to the data. One of the fit parameters corresponds to an experimental time constant.

MATERIALS

CBL interface	10-µF non-polarized capacitor
TI Graphing Calculator	47- and 22-kΩ resistors
PHTSICS program	9V battery with battery clip
TI Voltage Probe	single-pole, double-throw switch
connecting wires	

PROCEDURE

1. Connect the circuit as shown in Figure 1 above with the 10-μF capacitor and the 47-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 Voltage Probe to the Channel 1 input on the CBL interface. Connect the clip leads on the Voltage Probe 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. Use the link cable to connect the TI Graphing Calculator to the interface. Firmly press in the cable ends.

3. Turn on the calculator and start the PHYSICS program.

    a. Select SET UP PROBES, 1:ONE probe, 7:MORE, 3:VOLTAGE [ENTER].

4. Choose 2:COLLECT DATA and select 1:MONITOR to determine the maximum voltage stored on the capacitor that your battery produces.

    a. Charge the capacitor for 10 seconds with the switch in the position as illustrated in Figure 1.
    b. Watch the reading on the calculator screen and note the maximum value reached. You will need this value in a later step.
    c. Press + to go back then 5:RETURN TO MAIN MENU.

5. Set up the interface for triggering. In this mode you will not have to manually synchronize data collection and the capacitor discharge. Instead, the interface will wait for the voltage to reach a certain level before collecting data.

    a. Select 4:TRIGGERING.
    b. Select 2:CHANNEL 1.
    c. Select DECREASING from the TRIGGER TYPE menu.
    d. Enter 90% of the maximum voltage you observed in Step 4. Note that you can enter an expression at the calculator's prompt for a trigger level. That is, you can press 0.9 $\boxed{\times}$ (maximum voltage) $\boxed{\text{ENTER}}$ where (maximum voltage) is the maximum voltage observed in Step 5.
    e. Enter "0" for prestore in percent.

6. Set up the calculator and interface for data collection.

    a. Select 2:COLLECT DATA from the main screen.
    b. Select 2:TIME GRAPH from the SELECT MODE menu to collect motion data as a function of time.
    c. Enter "0.01" as the time between samples in seconds
    d. Enter "50" as the number of samples.

7. Select ENTER to begin data collection. Wait a moment, and throw the switch to charge the capacitor, then switch to its other position to discharge the capacitor. The interface will wait for the measured voltage to reach the trigger value before collecting data. After data collection is complete, a graph of potential *vs.* time will be displayed.

8. Press ENTER to return to the main screen.

9. Next, fit the exponential function $y = A\,e^{-B*x}$ to your data.

   a. Select 3:ANALYZE from main screen.
   b. Select 1:CURVE FIT from ANALYZE menu.
   c. Select 7:MORE to select 2:EXPONENT (L_1, L_2) from the CURVE FIT menu.
   d. Record the value of the fit parameters in your Data Table.
   e. Press ENTER to view the fitted equation along with your data.

10. **Include the graph** in your report of potential *vs*. time. (Connect a USB cable and take a screen shot and save as .jpg file)

11. Repeat the experiment with the 22-kΩ resistor in place of the 47-kΩ resistor. How do you think this change will affect the way the capacitor discharges? Rebuild your circuit using the 22-kΩ resistor and repeat Steps 7 – 10.

12. Measure the resistance of each resistor and measure the capacitance with an ohm meter; enter in data table.

DATA TABLE

Trial	Fit parameters			Resistor	Capacitor	Time constant
	A	B	1/B	R (Ω)	C (F)	RC (s)
Discharge 1						
Discharge 2						
Measured values	R1 (Ω)		R2 (Ω)		C (F)	

ANALYSIS

1. In the Data Table, calculate the time constant of the circuit used; that is, the product of resistance in ohms and capacitance in farads. (Show that 1 Ω·F = 1 s).

2. 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 are the fit parameters A and B related to the time constant of the circuit, which was defined in the introduction?

3. From the fit parameter B, calculate and enter in the Data Table 1/B for each trial. Compare each of these values to the time constant of your circuit.

4. Note that resistors and capacitors are not marked with their exact values, but only approximate values with a tolerance. Ask your instructor 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?

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