E: Capacitors

GOAL.
- To measure capacitance with a digital multimeter.
- To make a simple capacitor.
- To determine and/or apply the rules for finding the equivalent capacitance for capacitors connected in parallel and for capacitors connected in series.
- To discover the effect of connecting a capacitor in a circuit in series with a resistor or bulb and a voltage source.
- To mathematically explore how the potential across a capacitor and the current through it change with time in a circuit containing a capacitor, a resistor, and a voltage source.

EQUIPMENT.
- 2 sheets of metal, same size (various size pairs)
- a "fat" textbook or phone book
- digital capacitance meter with clip leads
- ruler with a centimeter scale
- 4 different capacitors (each 20-100 μF)
- alligator clip leads
- 6-V battery (or power supply)
- #40 bulb (6 V) and socket
- 2 capacitors (each about 25 000 μF)
- single-pole–double-throw switch
- 2 20 Ω resistor
- computer-based interface
- Current and Voltage probes
- Experiment configuration file: **CapacitorDecay.cmbl**

1. Building a Capacitor
Imagine that you are stuck at home, can't leave the house, and in order to complete your physics assignment, you need a capacitor. How would you go about making one? Explain.

You can make a capacitor out of aluminum foil and some kind of insulating spacer, such as paper. Make a capacitor and then measure its capacitance.

  1. Measure the capacitance of your capacitor? _____

- P 1.1: **Predict** what will happen if you increase the distance between the aluminum sheets.

  2. Increase the distance between the sheets. **Measure** the capacitance. _____

- Q1.1: Did the capacitance change? If so, how did it change?

- P 1.2: **Predict** what will happen if you decrease the area of your capacitor.

  3. Decrease the area of your capacitor. **Measure** the capacitance. _____

- Did the capacitance change? If so, how did it change?

NOTE: Some of the capacitors we use are polar capacitors and have +/- marked on the terminals. Another common marking is to have arrow pointing to the negative terminal.
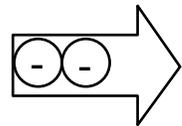
2. Capacitors in Parallel and Series

Although capacitors are made with many different capacitances, you might not find the capacitance you want. Therefore, it is useful to combine capacitors to produce a new equivalent (or effective) capacitance.
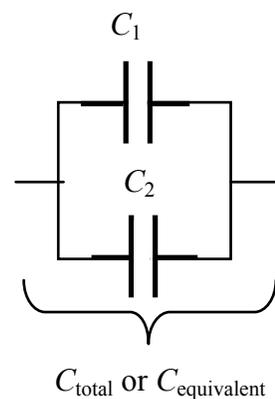
Parallel
  4. Choose two of your capacitors (in the range 20-100 µF). Measure the capacitance using a digital capacitance meter. Record the capacitances below.

        The capacitance of C_1 = _____

        The capacitance of C_2 = _____

  5. Connect the two capacitors together in parallel using connecting pieces, as shown.
  6. Measure the equivalent capacitance of the combination of C_1 and C_2 in parallel: _____

  7. Connect 3 and then 4 capacitors in parallel and measure their equivalent capacitances.

        3 capacitors _____   4 capacitors _____

- Produce an algebraic law that relates the equivalent capacitance to the individual capacitances for capacitors connected in parallel.
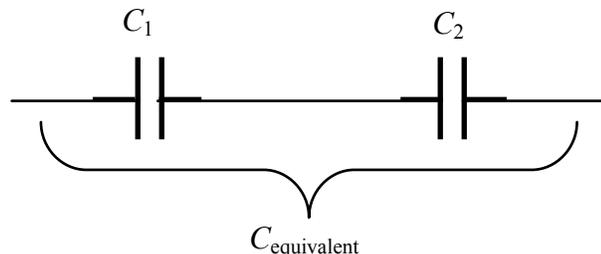
<u>Series</u>

8. Measure, or be sure you know the individual capacitance values for two capacitors.

> The capacitance of C_1 = _____

> The capacitance of C_2 = _____

9. Connect your chosen capacitors as shown.

10. Using the digital capacitance meter, measure the capacitance of the combination of your two capacitors in series. **Measure quickly.**

> Combined capacitance of C_1 in series with C_2: _____

11. Connect 3 or 4 capacitors in series and measure the equivalent capacitance.

> Combined capacitance of 3 capacitors in series: _____

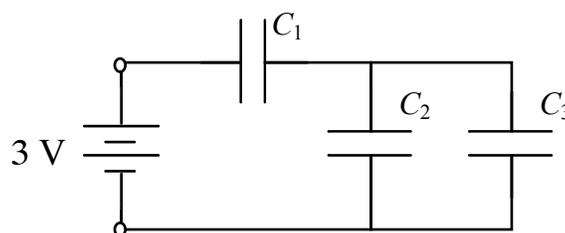> Combined capacitance of 4 capacitors in series: _____

Q2.1: Are your results consistent with $\dfrac{1}{C_{equivalent}} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + ...?$

3. Combinations of Capacitors

12. Choose three capacitors (all roughly the same) and record each capacitance below.

> C_1=_____ C_2=_____ C_3=_____

Consider the following circuit with capacitors arranged as shown.

13. For the capacitors you chose calculate the potential difference across each capacitor. (Also put your results in the table below.)

> ΔV_{C1}=_____
> ΔV_{C2}=_____ ΔV_{C3}=_____

Show your work here:

14. You are going now to build the circuit and measure the voltage across each capacitor. Before doing it though, make sure that every capacitor is discharged (short circuit it with a cable). Then complete the following table.

	Calculated	Measured	% difference
ΔV_{C1}			
ΔV_{C2}			
ΔV_{C3}			

4. Charging and Discharging Capacitors

Capacitor and bulb
Consider this circuit using a 25 000 µF capacitor with a battery, bulb and switch.
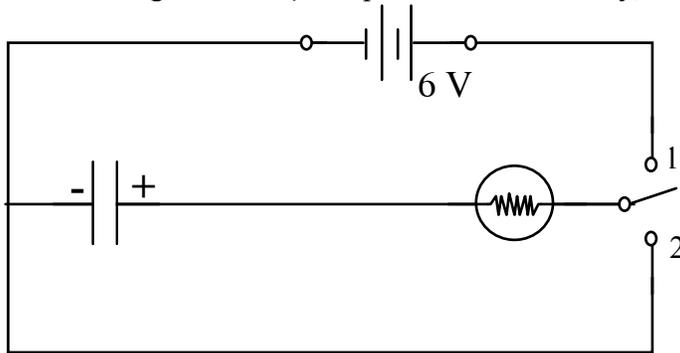
Single pole, double throw switch

15. Draw the equivalent circuit when the switch is in position 1.

16. Draw the equivalent circuit when the switch is in position 2.

Suppose the switch is moved to position 1.
- P4.1: On the left axes **predict** the bulb brightness as a function of time.

Suppose the switch is now moved from position 1 to position 2.
- P4.2: On the right axes **predict** the bulb brightness as a function of time.

brightness	brightness
time	time
Switch in position 1	Switch in position 2
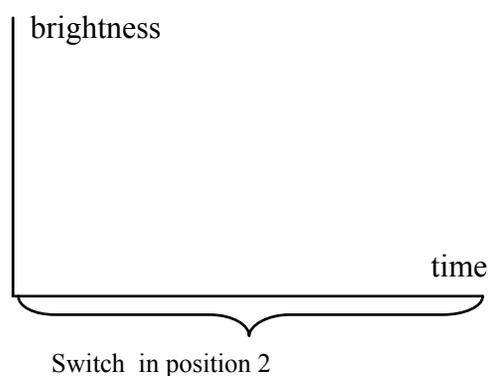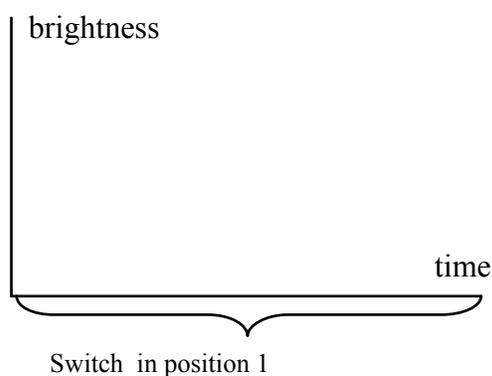
Build the following circuit using a 25 000 µF capacitor and appropriate current and voltage probes.
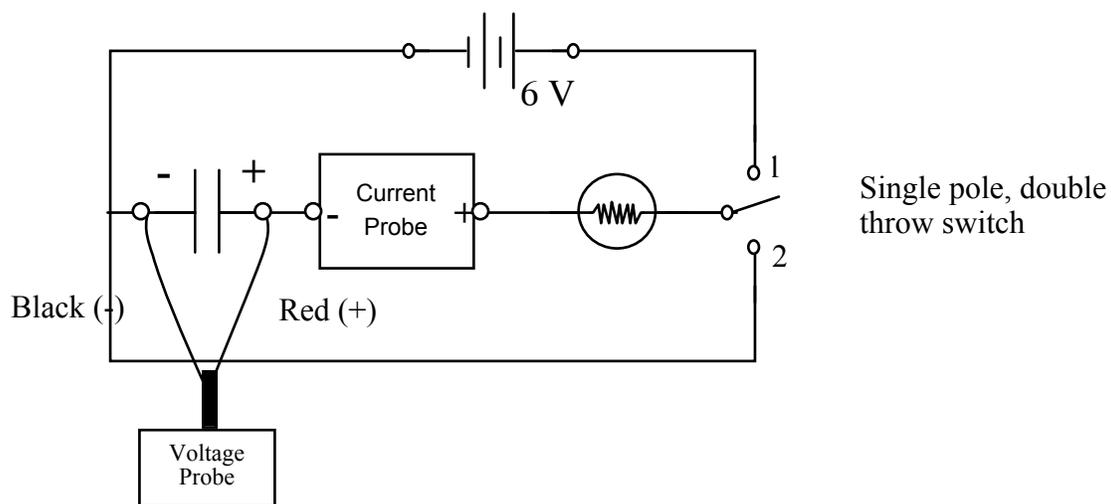
17. Open the file **CapacitorDecay.cmbl**.

18. **Zero** the current and voltage probes.
19. Move the switch to position 2. Now begin collecting data. Move the switch to position 1. When the graph stops changing, move the switch to position 2.
20. Print out your graph. Title it "Activity 3: Capacitor-bulb decay."
21. On your graph label the times when the switch was in position 1 and when it was in position 2.

- Q4.1: Are the predictions you made in P4.1 and P4.2 consistent with your current vs. time graph? Explain.

Capacitor and Resistor

We've seen in previous experiments that the resistance of a light bulb varies with the current/voltage. In order to be more quantitative, we will now replace the bulb with a resistor.

22. Replace the light bulb with a 20 Ω resistor.
23. **Zero** the current and voltage probes.
24. Move the switch to position 2. Begin collecting data. Move the switch to position 1. When the graph stops changing, move the switch back to position 2.
25. Store your data for later using the Store Latest Run command in the Experiment menu.

The **time constant** is defined as the amount of time it takes for the potential difference across a capacitor to decay to 37% of some initial value. Experimentally you can measure the time constant by choosing a time and measuring the starting voltage at that time. Then find the time when the voltage has dropped to 37% of that starting value.

26. Determine the time constant experimentally using the data on your graph.

$\Delta V_0 =$ _____ @ $t_0 =$ _____

$\Delta V_1 (= 0.37 \Delta V_0) =$ _____ @ $t_1 =$ _____

Time constant $= t_1 - t_0 =$ _____ (Put in table below.)

The actual shape of the potential difference across the capacitor vs. time is an exponential curve and is given by the following equation: $\Delta V(t) = \Delta V_o e^{-\frac{t}{RC}}$.

- Q4.2: Using the equation above, show that if $t=RC$, then $\Delta V(t = RC) = 0.37 \Delta V(0) = 0.37 \Delta V_0$.

27. Use the curve-fitting feature to fit your data to an exponential curve. Make sure you only select the portion of the data you are interested in fitting.

28. Print out your data along with the curve fit. Title the graph "Activity 4: Capacitor-Resistor decay."

- Q4.3: Is your data exponential? If so, determine from your fit the value of RC and write it in the table below.

Determination of RC	From time needed to decay to 37% of starting value (t_1-t_0)	From the exponential fit	"Direct" measurement: use meter for R and labelled C, then calculate RC.
RC			

- Q4.4: Do the results for RC obtained via the different methods agree with each other?

5. Two capacitors in parallel

Now we put an identical capacitor in parallel with the capacitor in the last section, so that we have the following circuit.
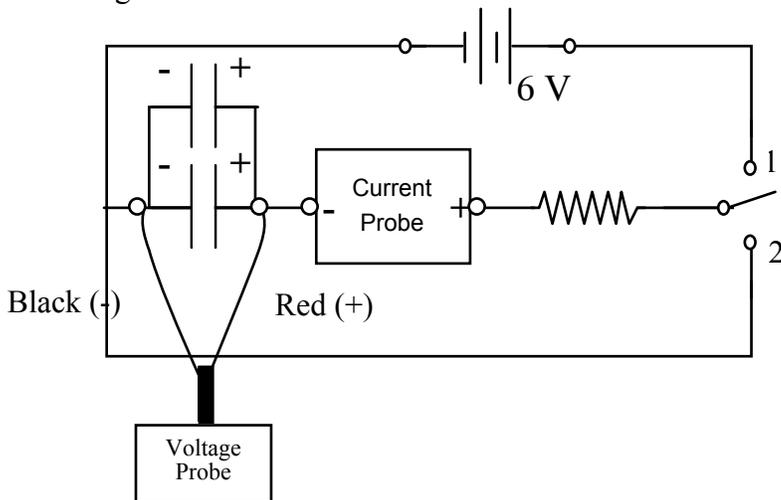
- P5.1: **Predict** the shape of the ΔV vs. t graph for the situation where the second capacitor is added in parallel. For comparison, using a dotted line, also draw the ΔV vs. t graph for the one-capacitor circuit.

  29. Place a second capacitor in parallel with the original capacitor.
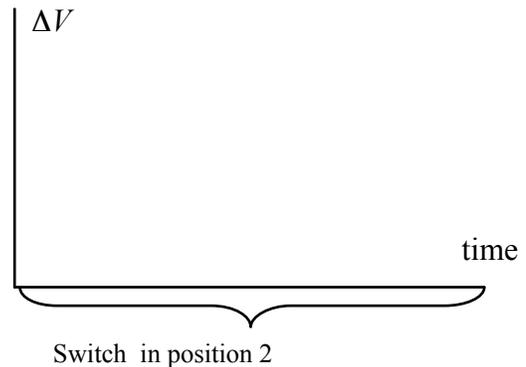 30. **Zero** the current and voltage probes.
  31. Move the switch to position 2. Begin collecting data. Move the switch to position 1. When the graph stops changing, move the switch to position 2. Store your data for later comparison by using the Store Latest Run command in the Experiment menu.
- Q5.1: Does the shape of the ΔV vs. t curve match your prediction? If not, explain how it is different.


  32. Determine the time constant either by a) using the data on your graph and finding the time for the potential difference to decrease to 37% of the starting voltage, or b) fitting your data to an exponential and using the fit. Show your work.

- Q5.2: How is the time constant for two capacitors in parallel different from a single capacitor?

6. Two capacitors in series

Now we put a second capacitor in series with the capacitor from before, so that the circuit is as shown.
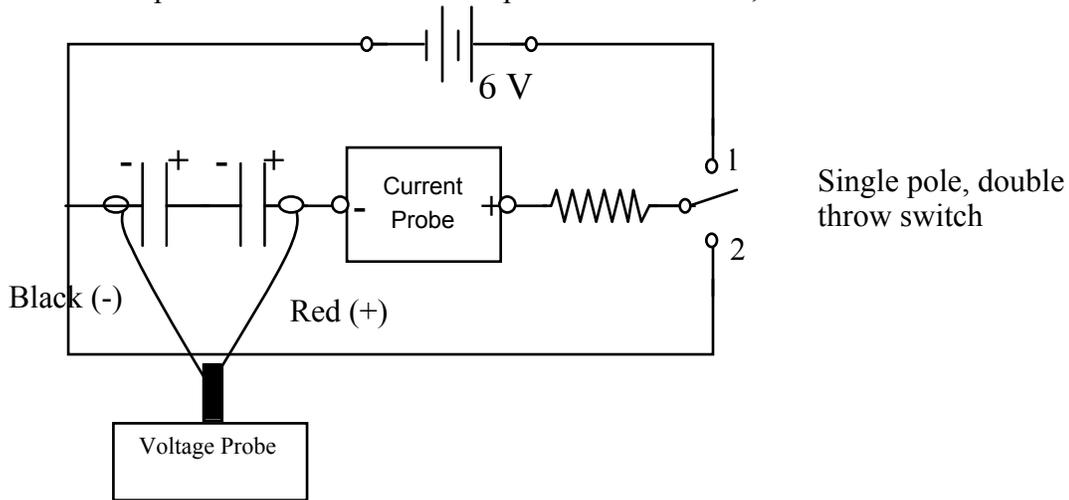
- P6.1: **Predict** the shape of the ΔV vs. t graph for the situation where the second capacitor is added in series. For comparison, using a dotted line, also draw the ΔV vs. t graph for the one-capacitor circuit.

  33. Place a second capacitor in series with the original capacitor.
  34. **Zero** the current and voltage probes
  35. Move the switch to position 2. Begin collecting data. Move the switch to position 1. When the graph stops changing, move the switch to position 2.
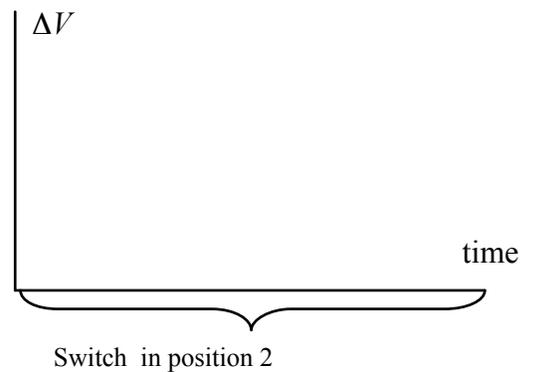
Print your graph. Label the three curves. Title the graph "Activity 6: Two capacitors."

- Q6.1: Does the shape of the ΔV vs. t curve match your prediction? If not, explain how it is different.

  36. Determine the time constant either by a) using the data on your graph and finding the time for the potential difference to decrease to 37% of the starting voltage, or b) fitting your data to an exponential and using the fit.

- Q6.2: How is the time constant for two capacitors in series different from one capacitor?

7. Capacitors and Resistors
Consider the following circuit where $R_1 = R_2 = 3\ \Omega$.

<u>Predict</u> the short time and long time behavior of the
currents and voltages in different parts of the circuit.
Be quantitative!
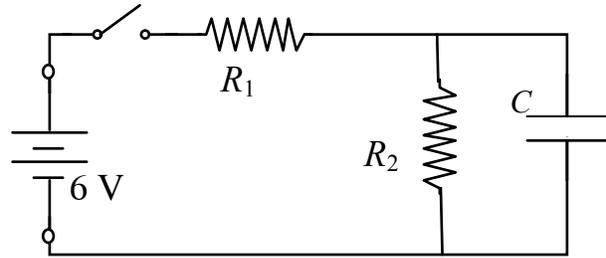
"Short" time behavior

Predict the current through R_1, I_1, just after the switch is closed.	Predict the potential difference across R_1, ΔV_1, just after the switch is closed.
Predict the current through R_2, I_2, just after the switch is closed.	Predict the potential difference across R_2, ΔV_2, just after the switch is closed.
Predict the current through the capacitor branch, I_C, just after the switch is closed.	Predict the potential difference across C, ΔV_C, just after the switch is closed.

"Long" time behavior

Predict the current through R_1, I_1, after the switch has been closed a long time.	Predict the potential difference across R_1, ΔV_1, after the switch has been closed a long time.
Predict the current through R_2, I_2, after the switch has been closed a long time.	Predict the potential difference across R_2, ΔV_2 after the switch has been closed a long time.
Predict the current through the capacitor branch, I_C, after the switch has been closed a long time.	Predict the potential difference across C, ΔV_C, after the switch has been closed a long time.

37. Now build the above circuit, but use $R_1 = R_2 = 20\ \Omega$ and $C = 25\ 000\mu F$.
38. Use CURVOLT to measure the current through and the potential across R_1. Store the data for later comparison.
39. Measure the current through and the potential across R_2. Store the data for later comparison.
40. Measure the current through and the potential across C. Store the data for later comparison.
41. Label each of your curves and print your graph. Title it "Activity 7."

- Does the behavior of your data match your predictions (ignore the numerical values)? If not, describe any differences.

Capacitance Post Lab

In the following circuit the switch has been open for a long time.
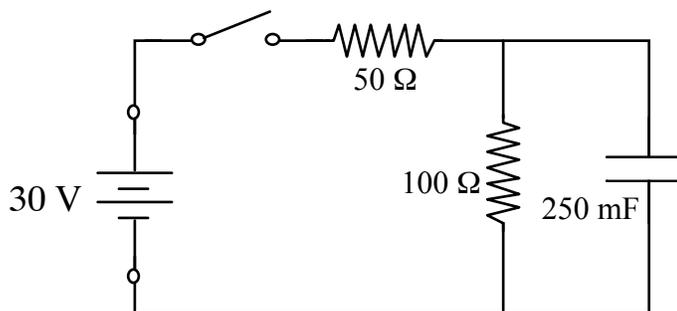
a) Before the switch is closed, what is the potential difference across the capacitor? Explain.

b) After the switch has been closed for a long time, what is the potential difference across the capacitor? Explain.

c) The switch has been closed a long time and it is then opened. How long does it take the potential difference across the capacitor to become 10% of its original value? Explain.

d) When the switch is opened in part c), what is the potential difference across the 50 Ω resistor? Explain.