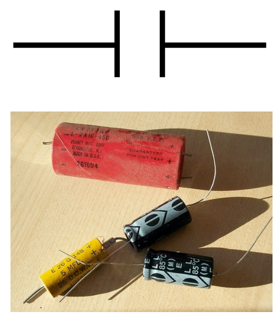
PH102 Capacitors Lab

Introduction

In this experiment we will determine how voltages are distributed in capacitor circuits and explore series and parallel combinations of capacitors. The capacitance is a measure of a device's ability to store charge. Capacitors are passive electronic devices which have fixed values of capacitance and negligible resistance. The capacitance, C, is the charge stored in the

$$C = \frac{Q}{\Delta V}$$

device, Q, divided by the voltage difference across the device, ΔV:



(top) Circuit diagram symbol for a capacitor. (bottom) Various real-life capacitors.

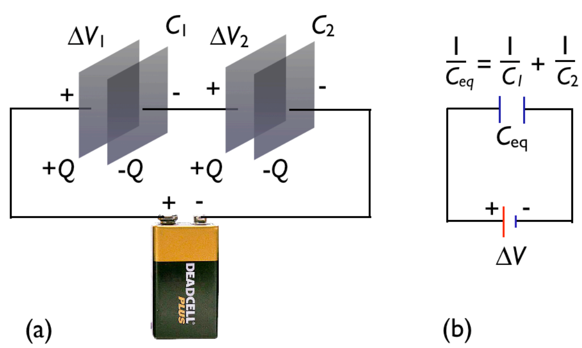
The SI unit of capacitance is the farad, 1 F = 1 C/V. Capacitance can be calculated from the geometry of a device. For most practical devices, the capacitor consists of capacitor plates which are thin sheets of metal separated by a dielectric (insulating) material. For this reason, the schematic symbol of a capacitor is has two vertical lines a small distance apart (representing the capacitor plates) connected to two lines representing the connecting wires, as shown below at left. Also shown is what your capacitor might look like, at right.

Sometimes the sheets are rolled up in a spiral to increase the overall area while keeping the device compact - this is why your capacitors are cylindrical. In any case, so long as the device consists of two parallel conductors much larger than their separation, the capacitance is:

$$C = \frac{\kappa \epsilon_0 A}{d}$$

Here κ is the dielectric constant of the spacer material, ϵ_0 is the permittivity of free space, A is the surface area of the metal sheets, and d is the thickness of the dielectric. The capacitors used in this lab mostly use mylar sheet as a dielectric, with κ = 3.2 and a thickness d~10μm.

Series Capacitors



Two capacitors in series. (a) Schematic illustration. (b) Equivalent circuit diagram.

There are two ways to connect two passive (no polarity) components in an electronic circuit: in series or in parallel. In a series connection, the components are connected at a single point, end to end as shown at right. **For a series connection, the charge on each capacitor will be the same.** Conservation of energy dictates that the total potential difference of the voltage source will be split between the two capacitors - if both capacitors are identical, each would have half the voltage of the source. Consider the leftmost plate of C_1 and rightmost plate of C_2 in the figure above. Since they are connected directly to the battery, they must have the same magnitude of charge, +Q and -Q respectively.

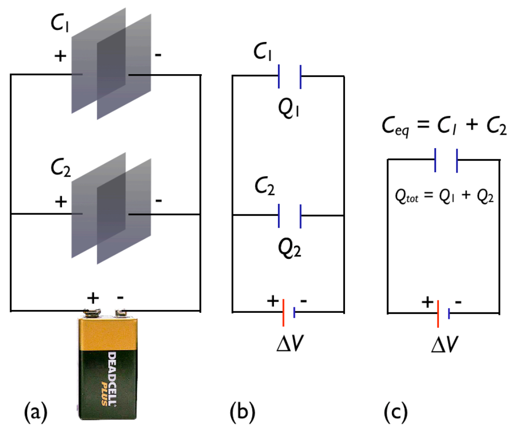
Since the middle two plates (the right plate of C_1 and the left plate of C_2) are not connected to the battery at all, so together *they must have no net charge*. On the other hand, the left and right plates of the same capacitor have to have the same magnitude of charge, so this means all plates have a charge of either +Q or -Q stored on them. All the right plates have charge -Q, and all the left plates have a charge +Q.

In class, we calculated the equivalent capacitance, C_{eq}, for two capacitors in series, based on conservation of energy:

$$\frac{Q}{C_{eq}} = \Delta V_{\text{source}} = \Delta V_1 + \Delta V_2 = \frac{Q}{C_1} + \frac{Q}{C_2} \qquad \Longrightarrow \qquad \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$

Parallel Capacitors

In the parallel case, the components are connected at both ends as shown below. When the capacitors are first connected, electrons leave the positive plates and go to the negative plates until equilibrium is reached - when the voltage on the capacitors is equal to the voltage of the battery. The internal (chemical) energy of the battery is the source of energy for this transfer. In this configuration, both capacitors charge independently, and the total charge stored is the sum of the charge stored in C_1 and the charge stored in C_2. We can write the charge on each capacitor easily to calculate the total charge, which will give us an expression for the equivalent capacitance of our pair:



Two capacitors in parallel. (a) schematic illustration. (b) Circuit diagram. (c) Circuit diagram with equivalent capacitance.

$$\begin{aligned} Q_1 &= C_1 \Delta V \\ Q_2 &= C_2 \Delta V \\ Q_{\text{total}} = Q_1 + Q_2 &= C_1 \Delta V + C_2 \Delta V = (C_1 + C_2)\,\Delta V \\ \Longrightarrow \quad C_{eq} &= C_1 + C_2 \end{aligned}$$

The key point **for capacitors in parallel is that the voltage on each capacitor is the same.** One way to see this is that they are both connected to the battery by the same perfect wires, so they must have the same voltage. This is true, in general, so long as we have perfect textbook wires. It follows readily that the equivalent capacitance of a parallel combination is always more than either of the individual capacitors.

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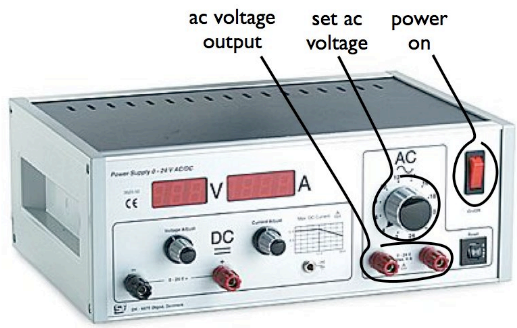
You will need:

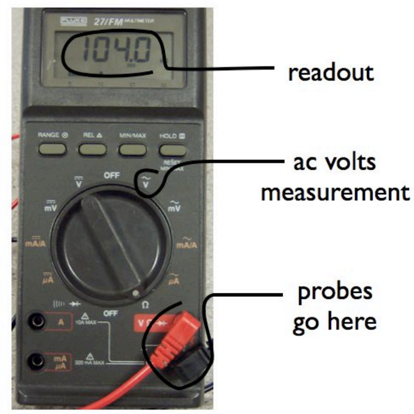


A Pasco ac/dc power supply (at left)

A Fluke handheld digital multimeter or "DMM" (below, shown in resistance mode)

Several banana plug wires (shown below)

A few capacitors (see above)



Procedure *(refer to the diagram at the end of this procedure)*

1. Turn on the power supply and set the AC voltage[1] between 5 and 10 V. Measure this voltage with the digital volt meter (DMM) and record it below:

V_3 = ____________________V

2. Connect two capacitors in series from ground, with the connecting point at the meter, V_2. Measure V_2 (relative to ground) with the DMM and record it below.

V_2 (measured) = ____________________V

3. Compute the expected value of V_2 using the measured value of the power supply voltage, the values of the capacitors C_1 and C_2 with the equations above (the DMM is measuring the voltage across C_2).

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1 NOTE: Since we used AC, the measured voltage is actually the rms voltage, $\Delta V = I/\omega C$, where I is the rms current and ω is the angular frequency. We don't measure I or ω here, and the analysis is the same. This is covered in more detail in the chapter on AC circuits.

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V_2 (expected) = ____________________V

% difference = |measured - expected|/measured x 100 % = ___________

4. Connect a third capacitor, C_3, in parallel with C_2. What is the equivalent capacitance of C_2 and C_3?

C_{eq} = __________ mF. Measure and compute the voltage across the equivalent capacitance.

V_{eq} (measured) = ____________V, V_{eq} (expected) = __________V,

% difference = ___________

5. Now remove the third capacitor, C_3, and replace it with a different capacitor. What is the equivalent capacitance now?

C_{eq} = __________ mF. Measure and compute the voltage across the equivalent capacitance.

V_{eq} (measured) = ____________V, V_{eq} (expected) = __________V,

% difference = ___________

6. Now connect all three capacitors in series as C_{eq}. What is the equivalent capacitance now?

C_{eq} = __________ mF.

Measure and compute the voltage across the equivalent capacitance.

V_{eq} (measured) = ____________V, V_{eq} (expected) = __________V,

% difference = ___________

7. This method can be used to find an unknown capacitance. Replace C_2 with the unknown value capacitor and determine its capacitance by measuring V_2 and using the equations above.

V_2 = ____________V , C_2 = __________ mF.

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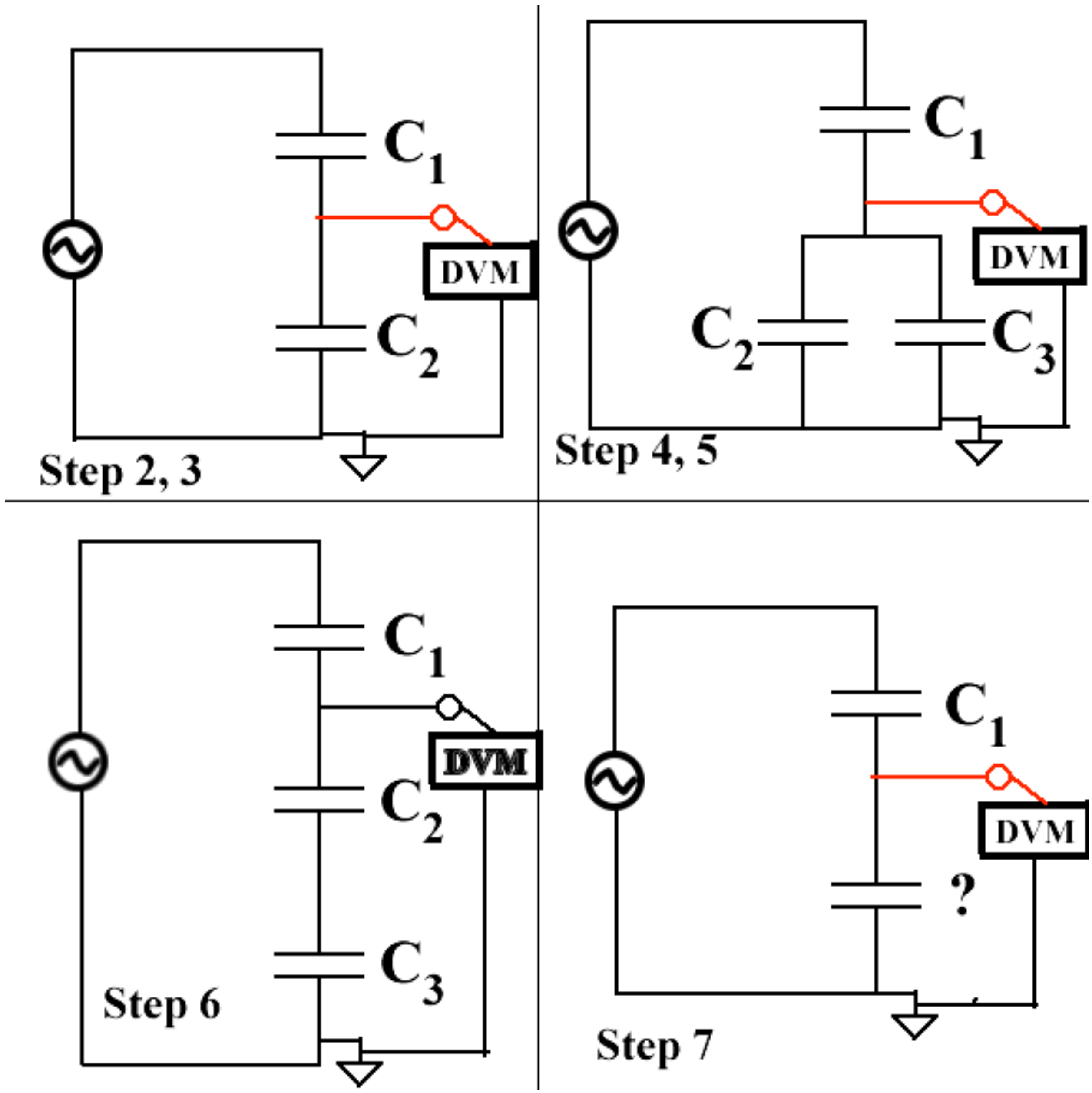

When you are finished:

- put away the wires, power supply, multimeter, and wires
- clean up your lab table
- turn in your report with all group member's names included