

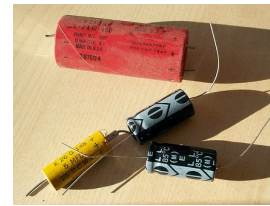
PH102 Capacitors Lab

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

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

The SI unit of capacitance is the farad, $1 \text{ F} = 1 \text{ C/V}$. 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.



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

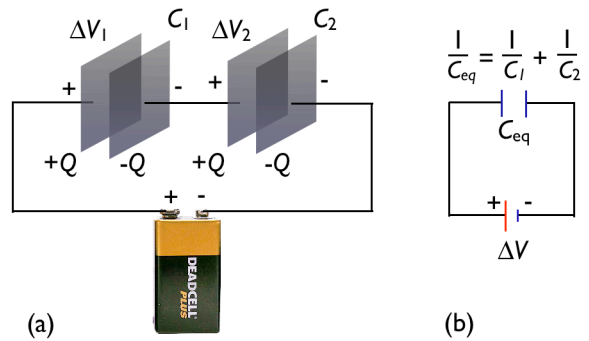
Sometimes the sheets are rolled up in a spiral to increase the overall area while keeping the device compact - this is why your capacitors are cylindrical. In any case, so long as the device consists of two parallel conductors much larger than their separation, the capacitance is:

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

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 $\kappa = 3.2$ and a thickness $d \sim 10 \mu\text{m}$.

Series Capacitors

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.



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

Since the middle two plates (the right plate of

PH102 Capacitors Lab

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:

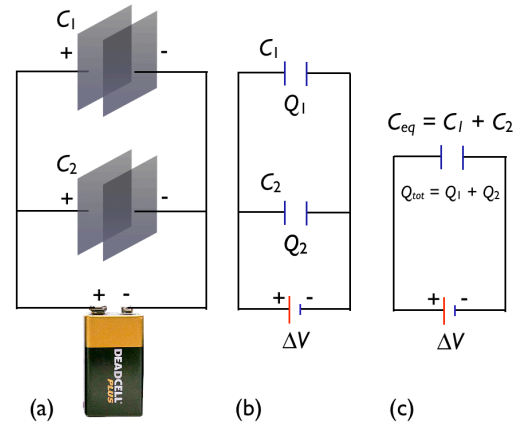
$$\frac{Q}{C_{eq}} = \Delta V_{source} = \Delta V_1 + \Delta V_2 = \frac{Q}{C_1} + \frac{Q}{C_2} \quad \Rightarrow \quad \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$

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:

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

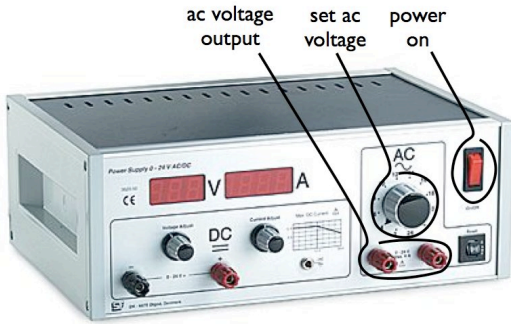
The key point for capacitors in parallel is that the voltage on each capacitor is the same. One way to see this is that they are both connected to the battery by the same perfect wires, so they must have the same voltage. This is true, in general, so long as we have perfect textbook wires. It follows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



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

PH102 Capacitors Lab

You will need:

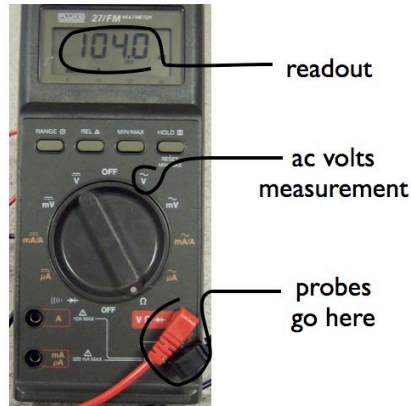


A Pasco ac/dc power supply (at left)

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

Several banana plug wires (shown at left below)

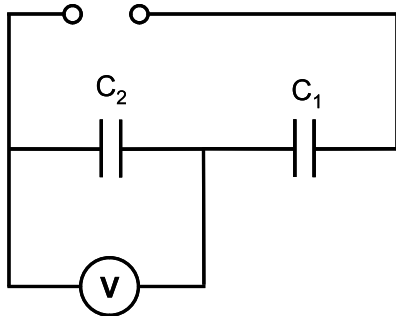
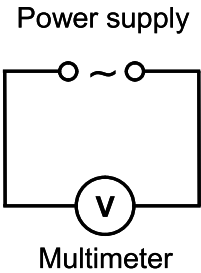
A few capacitors (see above)



Procedure

1. Turn on the power supply and set the AC voltage to 10 V. Measure the actual output voltage with the multimeter and record it below:

$$V_{\text{output}} = \text{_____} \text{ V}$$



2. Connect two capacitors in series. Measure V_2 (across C_2) and record it below.

$$V_2 \text{ (measured)} = \text{_____} \text{ V}$$

3. Compute the expected value of V_2 using the measured V_{output} and the known values of C_1 and C_2 with equations 3 and 4. If you are not sure of the values of C_1 and C_2 , measure them with the meter at the front of the room.

$$V_2 \text{ (expected)} = \text{_____} \text{ V}$$

$$\% \text{ difference} = |\text{measured} - \text{expected}| / \text{measured} \times 100 \% = \text{_____}$$

PH102 Capacitors Lab

4. Repeat the procedure for C_1 .

$$V_1 \text{ (measured)} = \underline{\hspace{2cm}} \text{ V}$$

$$V_1 \text{ (expected)} = \underline{\hspace{2cm}} \text{ V}$$

$$\% \text{ difference} = |\text{measured} - \text{expected}| / \text{measured} \times 100 \% = \underline{\hspace{2cm}}$$

5. Connect a third capacitor in parallel with C_2 . Compute the equivalent capacitance of C_2 and C_3 .

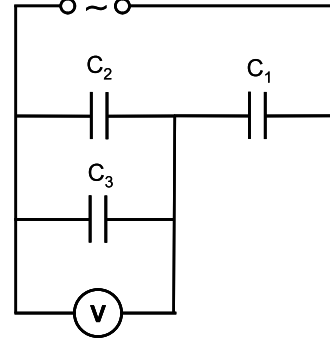
$$C_{eq} = \underline{\hspace{2cm}} \mu\text{F}.$$

Measure and compute the voltage across the equivalent capacitance.

$$V_{eq} \text{ (measured)} = \underline{\hspace{2cm}} \text{ V,}$$

$$V_{eq} \text{ (expected)} = \underline{\hspace{2cm}} \text{ V,}$$

$$\% \text{ difference} = \underline{\hspace{2cm}}$$



6. Without changing the arrangement of capacitors you have, measure and compute the voltage across C_1 . Has it changed since you connected C_3 ?

$$V_1 \text{ (measured)} = \underline{\hspace{2cm}} \text{ V}$$

$$V_1 \text{ (expected)} = \underline{\hspace{2cm}} \text{ V}$$

7. Now place all three capacitors in series. Compute the equivalent capacitance of C_2 and C_3 .

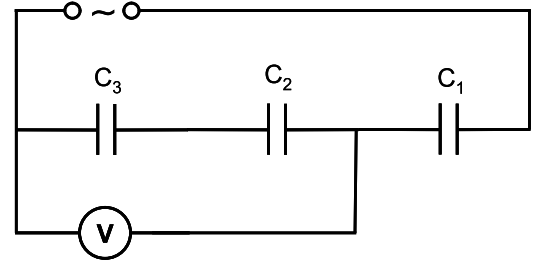
$$C_{eq} = \underline{\hspace{2cm}} \mu\text{F}.$$

Measure and compute the voltage across C_2 and C_3 .

$$V_{eq} \text{ (measured)} = \underline{\hspace{2cm}} \text{ V,}$$

$$V_{eq} \text{ (expected)} = \underline{\hspace{2cm}} \text{ V,}$$

$$\% \text{ difference} = \underline{\hspace{2cm}}$$



8. Now connect only C_2 and C_3 in series (i.e., remove C_1). Compute the equivalent capacitance.

$$C_{eq} = \underline{\hspace{2cm}} \mu\text{F}.$$

Measure and compute the voltage across C_2 and C_3 separately.

$$V_2 \text{ (measured)} = \underline{\hspace{2cm}} \text{ V,}$$

$$V_2 \text{ (expected)} = \underline{\hspace{2cm}} \text{ V,}$$

$$\% \text{ difference} = \underline{\hspace{2cm}}$$

$$V_3 \text{ (measured)} = \underline{\hspace{2cm}} \text{ V,}$$

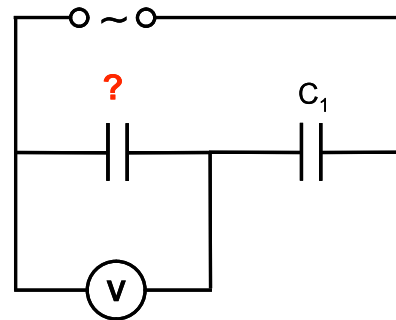
$$V_3 \text{ (expected)} = \underline{\hspace{2cm}} \text{ V,}$$

$$\% \text{ difference} = \underline{\hspace{2cm}}$$

PH102 Capacitors Lab

9. The methods above can be used to find an unknown capacitance. Place C_1 in series with an unknown capacitor and determine its capacitance by measuring its voltage.

$$V_? = \text{_____ V,} \quad C_? = \text{_____ } \mu\text{F.}$$



10. Measure your unknown capacitor with the meter at the front of the room. How well did you do?

$$C_? \text{ (measured)} = \text{_____ F,}$$

$$C_? \text{ (expected)} = \text{_____ F,}$$

$$\% \text{ difference} = \text{_____}$$

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