

Capacitance & Capacitor Networks

Apparatus: Two 12" by 12" aluminum plates, 1 sheet poster board, 1 sheet PVC (1/8" thick), 1 sheet poster board, breadboard, jumper wires, single battery in battery holder, banana cables, alligator clips, 1 LCR meter, 1 handheld DMM, 1 variable capacitor (mounted), 3 capacitor circuits set up at front of class, calipers, protractors

Goals:

1. Determine the effective dielectric constant of poster board & PVC sheet.
2. Plot capacitance versus angle for variable capacitor (comparing theory to experimental values).
3. Build several capacitor networks. Compare theoretical voltages to experimental voltages.

Part 1:

Look up the theoretical formula for capacitance of a parallel plate capacitor.

Look up how adding a dielectric material between the parallel plates should affect the equation for capacitance.

Create a parallel plate capacitor with the aluminum plates using the PVC sheet as the dielectric material.

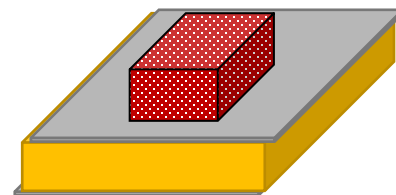
Note: you will likely need to offset the plates slightly as shown in the figure at right.

The offset is required to allow a small strip of metal on each side.

The small strip of metal allows you space to connect to both the upper & lower plate without making accidental contact to both plates simultaneously.

TIP: in lab, let the bottom plate hang slightly off the table to allow for a clip to be used.

Place a brick on top of the upper plate to ensure there is no air gap between the plates and the PVC.



WATCH OUT! The area of the capacitor is the area of overlap...not the entire area of a single metal plate. The thickness of the dielectric is also the plate spacing. Nominal thickness from the manufacturer is 1/8-inch but don't trust this number; measure the thickness directly with calipers. Ensure the calipers are zeroed before measuring! When you measuring paper thickness, it may help to measure the thickness of 10 sheets of paper then divide by 10.

Measure capacitance with the LCR meter.

Note: you may need to let the LCR meter run for several seconds until the reading stabilizes.

Determine an experimental value of the dielectric constant from the meter reading.

Repeat the experiment using poster board as the dielectric.

Compare both experimental values to values found on the internet using a percent difference.

According to some web surfing I found these values.

You might search around for others.

Notice the values given have quite a bit of variability.

Material	κ	Source
Paper	2-2.5	http://www.ydic.co.jp/english/technology/table_E.html#Anchor_p
PVC	4	https://www.doeet.com/content/eee-components/passives/what-is-a-dielectric-constant-of-plastic-materials/
Paper	2.3	https://www.engineeringtoolbox.com/relative-permittivity-d_1660.html
PVC	3.18	http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/diel.html

When you are done with Part 1 you should have:

- two experimentally determined values of dielectric constant
- two accepted values from the internet (with website reference)
- a % difference for each value.

Part 2:

A variable air capacitor can be made using semi-circular plates as shown at right.

The plates are grouped into two sets.

In the first set, all N plates have radius R and are spaced distance d apart.

All plates in the first set are connected together by a conducting rail not shown in the figure.

The second group of plates have the same radius and spacing.

The second group is designed such that each plate of the second group lies exactly halfway between the plates of the first group (see upper figure at right).

All plates in the second group are also connected together by a rail not shown in the figure.

Determine a theoretical expression for the capacitance in terms of θ , R , N , & d .

Consider the sketch at right using $N = 4$ (the larger number of plates is N).

Using that value of N , count the number of cap's in parallel created by the interlacing process.

Make a sketch using $N = 5$ and confirm your formula correctly determines the number of caps.

Repeat as necessary until you see the pattern for how N relates to the number of capacitors in parallel.

Use that information/pattern to write your general formula in terms of N ...

The *standard* form for such an answer would probably use *radians* for θ .

The standard form uses radians which are dimensionless quantity.

Since we are planning to *present* data, write your formula so it uses *degrees* for θ .

Not much different, but you'll end up with a ratio in your formula.

One of the quantities in your ratio will have units of degrees.

In general, make clear what units you are using for θ in any work you present to others...

Now consider an actual capacitor made in this fashion (see lower figure at right).

Count the number of plates and measure the radius.

Measure capacitance in 15° increments for all angles between 0° & 180° (use LCR meter).

Normally we use axis increments in multiples of 1, 2, or 5.

Angles (in degrees) obey different conventions.

For angular plots, 15° increments hit all the major angles (30° , 45° , etc).

Tabulate and plot both experimental & theoretical capacitance versus angle.

From your theoretical formula, hopefully you notice the slope of this plot should be linear.

From your derived capacitance formula, notice the slope of the plot of C versus θ is inversely proportional to d .

Measure the diameter of the semi-circular plates (calipers might be a good idea here).

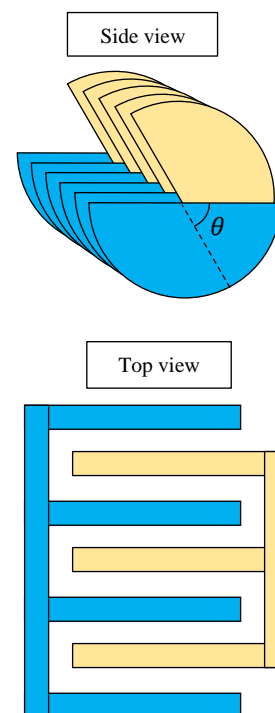
Use this information and the slope of the plot to determine an estimate for plate spacing.

Compare this to a visual inspection of the plate spacing.

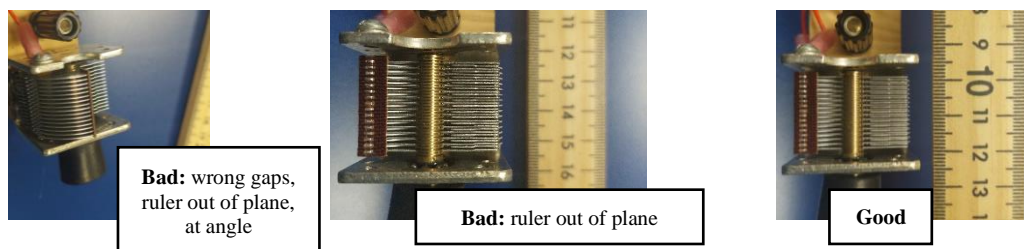
Tip: set the capacitor to maximum overlap, put a ruler next to it (in same plane as the capacitor gaps) and take a close-up photo.

Look at the photo on-screen & zoom in really close to get a better feeling for the plate spacing.

More on this on the next page...

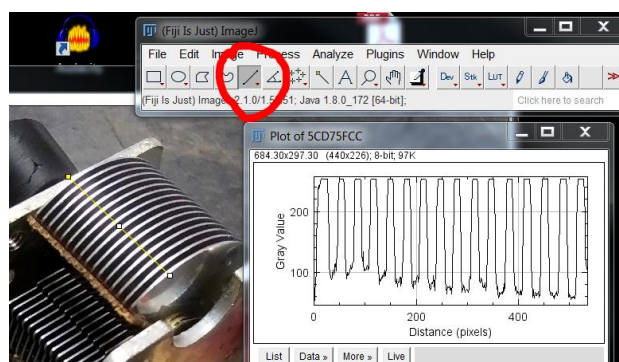


Part 2 (cont.): I feel it is good practice to learn how to use technology to get measurements from your image. Lab computers have the free image processing software Fiji. (<https://imagej.net/software/fiji/downloads>). You have a calibrated image...an image with an object of known size in it (ruler). From this you could calibrate pixel size to real life size in mm (similar to what was done in Tracker). The photos below show a terrible photo, a bad photo, then a good photo as you go left to right. In the *rightmost* photo below the ruler is in focus because it is in the same plane as the closed capacitor gaps.



Open the software and use it to open your image. Use the “Straight” tool (circled in figure) and draw a line across your object of known size. I will call this your calibration line. Under the “Analyze” tab, click “Set Scale”. Type in the know size of the calibration line in mm.

Now draw a new line (again using the “Straight” tool) across the parallel plates (see image below). Under the “Analyze” tab, execute the “Plot Profile” option. Hopefully you end up with a plot like similar to the one shown in the figure.



Note: I deliberately forgot to use a calibration line so my horizontal axis is in units of pixels (you should use mm).
Note: my picture above is measuring the wrong gap sizes!!!

What have you done?

The calibration line and “Set Scale” tells the computer the conversion factor from pixels to mm. The “Plot Profile” shows image intensity versus distance. Since the plates themselves are highly reflective, the peaks in the plot correspond to regions where metal is present. The gaps between the peaks must correspond to plate spacing.

Use the calibrated pixels plot to determine an average plate spacing. Let us call this the *experimental* spacing. Compare this plate spacing to the plate spacing determined from your C versus θ plot with a % difference. Again, assume the value d obtained from the slope of the plot of C versus θ is the *theoretical* spacing.

When you are done with Part 2 you should have:

- derivation of the theoretical capacitance as a function of θ , R , N , & d
- a plot showing C versus θ (proper formatting & trendline displaying both the equation & the R^2 value).
- work showing a calculation of the *theoretical* value of plate spacing (using *slope* of plot)
 - We know $C = \text{slope} \times \theta$ where *slope* contains the constant d .
 - Use the trendline of the experimental data to determine *slope*
 - Then use *slope* (and plate diameter) to find the constant d .
 - Using the slope gives an average all data and also provides a visual for others.
- a screen shot (print out) of your work processing the image use to determine *experimental* plate spacing
- a comparison of the two plate spacing values using % difference

Part 3:

Your instructor will build three capacitor circuits based on the schematics shown on the next page.

Your goal is to make sketches of those circuits with numerical values of each capacitance, the theoretical voltage across each capacitor (assuming a battery voltage of $\mathcal{E} = 10.0 \text{ V}$), as well as the actual measured values of voltage across each capacitor.

I have found it convenient to use large capacitors in this experiment (not sub-microfarad ceramic caps).

Because our large capacitors cannot be measured with the LCR meters, we must use *nominal* values.

Each capacitor has a nominal value stated on it somewhere.

WATCH OUT!!! Unless otherwise specified, lower case “m” & uppercase “M” imply the prefix $\mu = 10^{-6}$!!!

Label the smallest capacitance C_1 and the largest C_3 .

Measure the battery voltage and record that value \mathcal{E} .

Consider the circuit schematics shown on the next page.

Assume the measured battery voltage \mathcal{E} and each LCR measured capacitance are exact values.

Use these values to predict theoretical voltages across each capacitor in the circuits shown on the next page.

Now actually build the circuits and measure the voltage across each cap with a DMM.

Put a sketch of each circuit on your page and label the battery voltage \mathcal{E} with the *measured* value of voltage.

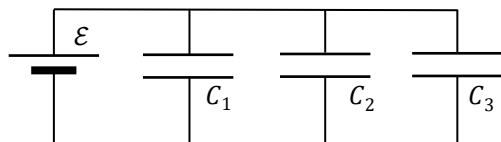
You want your sketch to be large enough such that you can label each capacitor with four things:

- Battery voltage & nominal value of each capacitance
- Theoretical voltage (computed from measured value of \mathcal{E} and measured values of C 's)
- Experimental voltage (measured with the DMM)
- % difference (no need to show work for this calculation)
- As you do your computations, don't freak out if you get large percent differences. The default manufacturer tolerance on capacitance values is 20%!

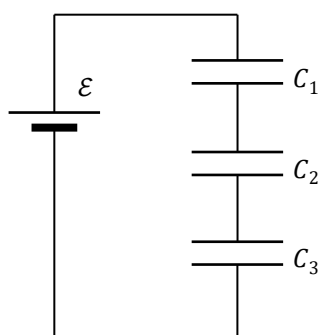
When you are done with Part 3 you should have a completed sketch of all three circuits showing:

- Nominal value of capacitance
- Theoretical voltage (computed from measured value of \mathcal{E} and measured values of C 's)
- Experimental voltage (measured with the DMM)
- % difference (no need to show work for this calculation)

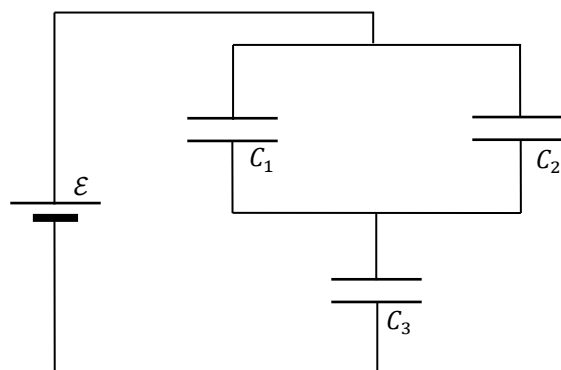
Circuit 1



Circuit 2



Circuit 3



Conclusions:

1a) In part 1, suppose you accidentally used the entire plate area (instead of overlapping area) to compute the dielectric constant. Would this error make the percent difference more positive, more negative, or cause no change? Explain your reasoning.

1b) Percentage-wise, which would the error described in question 1a) affect more: your measurement of κ_{paper} or your measurement of κ_{PVC} ? Would it affect both the same amount?

2a) Suppose the aluminum plates were slightly warped instead of perfectly flat (as is probably the case in the real world). Would this error make the percent difference more positive, more negative, or cause no change? Explain your reasoning.

2b) Percentage-wise, which would the error described in question 1a) affect more: your measurement of κ_{paper} or your measurement of κ_{PVC} ? Would it affect both the same amount?

3) In Part 2 (variable capacitor) your theoretical equation predicts zero capacitance when $\theta = 0^\circ$. However, when measured, the capacitance in real life is non-zero? Explain this discrepancy. Why do we have some residual capacitance in real life when $\theta = 0^\circ$?

To turn in:

- Each student is expected to submit a single pdf file. Include a lab title, your name (indicated as author), partners names, lab time should appear centered on of the first page. Making a title for real scientific work is an important skill but not something I want to talk about for this report...keep it simple.
- Intro *for part 1 only*. **Start each new section on a new page.** Read the Lab Manual Appendices for style guidelines and worked examples. Don't write a lot, write about one paragraph but follow the guidelines carefully. I am most interested in seeing if you can read and follow the instructions in those guidelines.
 - Did you use first person (do not use *I* or *we*)?
 - No bulleted lists.
 - Equations centered on own line (preferably numbered for ease of reference)
 - Variables immediately before or after first use in an equation
 - Variables NOT re-defined at each subsequent use.
- Start each new section on a new page.
- Data & calculations for each part as stated at the bottoms of pages 1, 3, & 4.
 - **Start each new section on a new page.**
 - I am ok with data, derivations, calculations, and results being all mixed together in today's lab.
- Conclusion questions
 - **Start each new section on a new page.**
 - Use a numbered list. While not standard for a real report, I want to find your answers quickly.
 - First person ok (ok to use *I* or *we*).
 - Use full sentences.
 - Phrase answers in a manner which makes clear what question was asked (but don't write out the questions). In other words rephrase the question in your answer.