Capacitors Module Student Guide

Activity 1: Dielectric Permittivity of Air (30 minutes)

The unit of capacitance is the Farad, F, named after Michael Faraday. One Farad is equal to one Coulomb/Volt. As you will demonstrate shortly, one Farad is a very large capacitance for a conventional capacitor. Thus actual capacitances are often expressed in smaller units with alternate notation:

- microfarad: $1\ \mu\text{F} = 10^{-6}\ \text{F}$
- nanofarad: $1\ \text{nF} = 10^{-9}\ \text{F}$
- picofarad: $1\ \text{pF} = 10^{-12}\ \text{F}$

This experiment uses data taken by a capacitance meter. The meter is hooked to two parallel metal plates separated by an air gap. The theoretical capacitance for such a capacitor is given by:

$$C = \varepsilon \frac{A}{d}$$

Where A is the area of each plate, d is there separation distance, and ε is the dielectric permittivity of the insulating material separating the two conducting plates. When using SI Units, dielectric permittivity is measured in F/m.

Professor Harlow has measured the diameter of the circular plates to be 17.70 ± 0.05 cm. He has made the following measurements for separation distance, d, and Capacitance C. (These are also available in a Google Sheet at https://docs.google.com/spreadsheets/d/1gHEi4s_eUD3_goIPGhPUauleGzlrvIHkBfUSfd8ecWc/edit?usp=sharing):

d [mm] ± 0.5 mm	C [pF] ± 2 pF
1.8	131
2.7	88.6
3.5	63
5	46
6	39.7
7	31.2
8.5	27.7

A. What is the area of each circular metal plate, A, in m^2?
B. Convert d and C into SI units, and make a plot of A/d on the horizontal axis versus C on the vertical axis. The horizontal axis should have units of [m] and the vertical axis should have units of [F].
C. Fit a straight line through the data of your graph from part B. There are many ways of doing this. One may be to simply print the graph and use a ruler to

sketch a straight line which seems to pass through or nearest most of the points. You should be able to estimate the slope and the uncertainty of the slope. The slope of your graph from part B should be equal to the dielectric permittivity of air in $\mathrm{F/m}$. Should a straight line fit through the data necessarily pass through zero? Based on your fit, what is your measurement for ε for air for these data?

D. Compare your value to the vacuum permittivity of $\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F/m}$. Is your measurement for permittivity of air consistent with the vacuum permittivity, or is your measurement significantly different from ε_0?

Activity 2: Dielectric Permittivity of Textbook Paper (25 minutes)

When a solid or liquid insulating material is placed between the conducting parallel plates of a capacitor, it tends to increase the permittivity by a factor:

$$\kappa = \frac{\varepsilon}{\varepsilon_0}$$

where $\kappa > 1$, and $\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F/m}$. κ is a dimensionless parameter called relative permittivity. There are tables of measured values of κ for various materials. For example, water has quite a high relative permittivity of about 80.

Professor Harlow has taken two square metal plates of side length 15.20 ± 0.05 cm, and placed them overlapping each other, separated by a certain number of sheets of paper in the textbook for this course. For each separation he measured the capacitance of the plates, below. (These are also available in a Google Sheet at https://docs.google.com/spreadsheets/d/1J5jmWd1YuNOJ3ZRrCmHAvSTYn7fD5LlkS-2XO0XKVjY/edit?usp=sharing):

Sheets between	C [pF] ± 2 pF
5	1391
10	854
15	586
20	471
25	384
30	332
35	292
40	262
45	233

He also measured that 620 sheets have a total thickness of 36.4 ± 0.5 mm.

A. What is the area of each square metal plate, A, in m^2?
B. What is the thickness of one sheet of paper in your textbook, in m?

C. Compute the separation, d , in m, and convert C into SI units, and make a plot of A/d on the horizontal axis versus C on the vertical axis. The horizontal axis should have units of $[\mathrm{m}]$ and the vertical axis should have units of $[\mathrm{F}]$.
D. Fit a straight line through the data of your graph from part C. You should be able to estimate the slope and the uncertainty of the slope. The slope of your graph from part B should be equal to the dielectric permittivity of air in $\mathrm{F/m}$. Based on your fit, what is your measurement for ε for textbook paper for these data?
E. What is the relative permittivity, κ, for the paper in your textbook, based on your data?