EXPERIMENT 3
MEASUREMENT OF CAPACITANCE

I. THEORY

Capacitance is defined as the ratio of the charge of a capacitor to the potential difference across the capacitor:

$$C \equiv Q/V \tag{1}$$

unit of capacitance, the farad (F), is equivalent to one coulomb per volt. Convenient submultiples of the farad are the millifarad, the microfarad, the nanofarad and the picofarad. The correct abbreviation for micro- is the Greek letter μ. In practice, one often finds a 10 microfarad capacitor labeled 10 mF or 10 MF, although the abbreviations m and M should only be used for milli- or mega-, respectively.

If two parallel conducting plates of large area A are separated by a small distance d in vacuum, the theoretical capacitance is given by the equation

$$C_{vac} = \frac{\varepsilon_o A}{d} \tag{2}$$

in which ε_0 is the permittivity of free space (vacuum), with a numerical value of $8.85 \times 10^{-12}\ \mathrm{C^2/N \cdot m^2}$.

If a dielectric (insulating) material is placed between the plates, the capacitance increases. The dielectric constant, K, of the insulating material is defined by the equation

$$K \equiv C_{diel}/C_{vac} \tag{3}$$

It is evident that the dielectric constant of a material K is dimensionless. The dielectric constant for air is only very slightly greater than one, so the equation for a parallel plate capacitor in a vacuum, equation (2), will be used in this experiment when there is air between the plates of the capacitor.

When two or more capacitors are connected in parallel, the equivalent capacitance is given by the equation

$$C_{eq} = C_1 + C_2 + \cdots \tag{4}$$

When two or more capacitors are connected in series, the equivalent capacitance is given by the equation

$$1/C_{eq} = 1/C_1 + 1/C_2 + \cdots \tag{5}$$

See section IV of this experiment for diagrams of parallel and series connections.

The purpose of this experiment is to test the accuracy of the theoretical equation for a parallel plate capacitor and the formulas for the equivalent capacitance of capacitors in series and parallel and to measure the dielectric constant of bakelite. To do so we will measure the capacitance of a single capacitor and combinations of capacitors. This is done with the help of a capacitance meter.

When a combination of capacitors is connected to the meter, the meter will measure the equivalent capacitance of the combination.

II. LABORATORY PROCEDURE

1. Use the meter stick and caliper jaws to measure the diameters of the two plates of the air capacitor. Use care not to damage the smooth surfaces. Record both values.
2. Use the ratchet (the extension of the handle) of the micrometer to close the jaws with the correct amount of force. Record the zero correction of the micrometer. By convention, the zero correction is defined as positive if the instrument reads low. Each minor scale division of the micrometer is 0.01 mm.
3. Use the micrometer to measure the thickness of a sheet of bakelite, again using the ratchet to obtain the correct force of contact. One revolution of the handle opens or closes the jaws 0.5 mm. Record the reading of the micrometer; then apply the zero correction to obtain the thickness of the Bakelite sheet. Then find three scraps of bakelite having the same thickness as the sheet, within about 10%.
4. Use the three scraps of bakelite, well separated from each other, to hold the plates of the air capacitor apart.
5. Make a data table with two columns. Label one column capacitor system and the other measured capacitance. Your first capacitor system will be the ***air capacitor***.
6. Using two banana-to-spade cables, connect the air capacitor to the meter. You will not be using the “10 A” jack on the meter for this lab. The banana plugs should connect to the other two jacks on the meter called the “common” jack and the “positive input” jack. For measuring capacitance in this lab, it does not matter which jack is connected to which end of the capacitor system.
7. Turn the rotary switch to the ┤├ position. Record the displayed value as the capacitance of the system. The reading will have uncertainty in the third digit displayed; that will be your last significant figure.
8. Remove the scraps of bakelite from between the plates of the air capacitor, and replace them by the entire sheet of bakelite having approximately equal thickness. Apply some pressure to the top plate, in order to reduce air pockets. Maintain this pressure while taking the meter reading. Record the meter reading.
9. Replace the parallel-plate capacitor by the 1 nF (0.001 Mfd) capacitor of the capacitance box. Make certain that both binding posts of the test capacitor are tightened. Record the meter reading.
10. Repeat, using the 2 nF capacitor located just below the 1 nF capacitor. (The two 2 nF capacitors are only accurate to within ± 20% as manufactured, so they are not interchangeable.)

11. Repeat, using the 5 nF capacitor of the box.
12. Repeat, using every parallel combination of the 1, 2 and 5 nF capacitors. The combinations are 1 and 2; 1 and 5; 2 and 5; 1, 2 and 5. Use the same 2 nF capacitor that you used in step 10. See section IV for wiring diagrams. Make certain that all binding posts of the capacitors used are tightened.
13. Repeat, using every series combination of the same three capacitors. See section IV for wiring diagrams. The bus bar must be removed when all three capacitors are connected in series.
14. Turn the meter off and dismantle your circuit.

III. CALCULATIONS

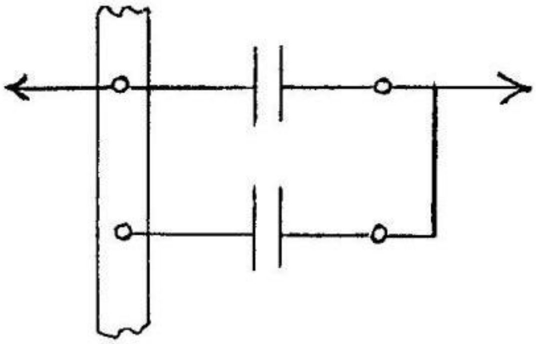
Express all values of capacitance in nF.

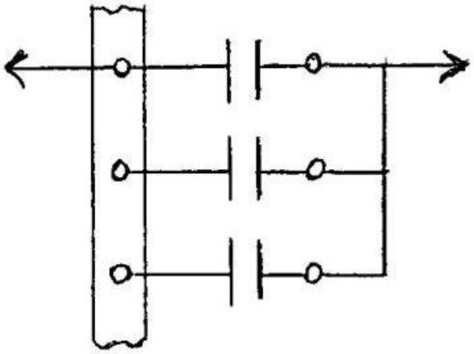
1. Calculate, in m^2, the area of one plate of the air capacitor. If the measured diameters were different, calculate the area of the smaller plate.
2. Apply the zero correction of the micrometer to the thickness of the bakelite sheet, if this was not done on the data sheet. Treating air and vacuum as interchangeable, calculate the theoretical capacitance of the air capacitor with (mainly) air between the plates. Find the percent difference between this theoretical value and the measured value of the capacitance.
3. Determine the dielectric constant of the bakelite used from the measured capacitance values of the parallel plate capacitors.
4. Make a table listing the nominal values of the 1, 2, and 5 nF capacitors along with the measured value of each.
5. For the four parallel combinations of capacitors, calculate the theoretical capacitance using the formula for equivalent capacitance and the ***measured capacitances*** of the individual capacitors. **DO NOT use the nominal values.** Make a table containing the columns: Capacitor Combination, Measured Capacitance, Theoretical Capacitance, and percent difference.
6. Repeat step 5 for the four series combinations of the three capacitors.
7. The meters we used in this experiment measure capacitance with an uncertainty of 3 %. This leads to a 3 % uncertainty in the calculated equivalent capacitances as well. Therefore, up to a 6 % difference can be expected between the Measured and Theoretical Capacitance for each of the series and parallel combinations. How do your percent differences in Calculations 4 and 5 compare to this 6 %? Are the formulas for series and parallel combinations of capacitors verified by your results?

IV. WIRING DIAGRAMS

1. Capacitors in Parallel

   The arrows indicate connection to the bridge circuit. The bus bar may be replaced by one or more wires if desired.





2. Capacitors in Series

   The bus bar MUST be removed when three capacitors are connected in series.