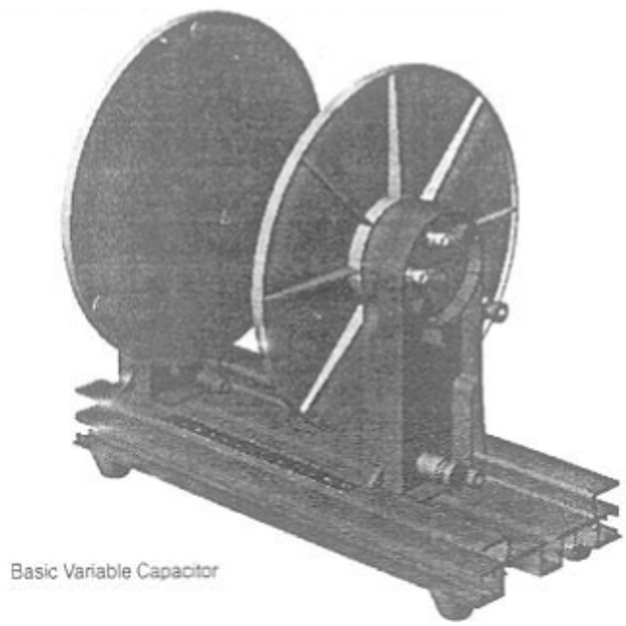

Physics 261

The Capacitor

Figure 1: A large parallel-plate capacitor used in parts 1 and 2 of this laboratory exercise.

Introduction

A pair of conductors, narrowly separated by an insulator (or dielectric, such as air, paper, or plastic), can store charge or, equivalently, the energy associated with an electric field. Such an apparatus is called a **capacitor**, because of its storage capacity. When each conductor is connected to a pole of an *emf* source, one to the positive pole, the other to the negative, net charge on each increases, positive in the one case, and an identical quantity of negative in the other, until the potential difference between the conductors is the same as that of the *emf* source. The amount of charge Q accumulated depends, therefore on this potential difference V, but also on the geometry of the capacitor:

$$Q = CV, \qquad [1]$$

where C is the geometry-dependent proportionality constant known as **capacitance**. The capacitance is given in units of charge per unit potential difference, or, in standard international units, coulombs per volt, a ratio given the name farad and the symbol **F**. Since one coulomb is a great deal charge, a farad is a very large unit. Values of capacitors found in typical circuits range from picofarads (pF) to microfarads (μF).

Investigations

A simple parallel plate capacitor consists of two parallel metal plates separated by a distance d. The capacitance of these plates at a distance is given by

$$C = \kappa \varepsilon_0 \frac{A}{d}$$

where κ is the dielectric constant, ε_0 is the permittivity of free space (8.85 x 10^{-12} $C^2/N\ m^2$) and A is the cross sectional area of the plates

Equipment:

On the first page is an image of the large parallel plate capacitor used in this experiment. The last page of this write up contains information for use in assigning and propagating uncertainties for the capacitance meter. Two wires will be provided to connect the capacitor plates to the meter. A meterstick will be employed to measure the diameter of the parallel plates to calculate the radius of the plates. The measuring tape affixed to the apparatus should be used to measure the distance between the two plates. Upon careful inspection it should be noted that one plate has white spacers glued on it. Be sure to address how this fact is handled when measuring the distance 'd' and when adding differing dielectric materials.

Procedure:

- Students should first examine the equipment and ensure that the plates are parallel, if not, make a parallel as possible using the adjustment knobs on the one plate.
- Students should then ensure that the meter is zeroed for the pF scale they will be using.
- Next, students need to determine the Co or the capacitance value that is NOT dependent upon the plate distance but intrinsic to the materials used such as the wires to connect the meter to the plates. Students should discuss and present a method used to determine this Co value in the lab report. Other capacitors of constant value as well as wires are supplied for students to determine this Co value.
- Now, students will likely measure the change in capacitance as the distance of the plates is changed. Note that because of the (predicted) nonlinear relationship between C and d, measurements of uniform distance will not sufficiently cover the data set. Students may need to go back and take extra values to sufficiently cover the distances from 0.25cm to 4cm. Data taken beyond 4cm will see smaller changes in the C value and therefore not needed to fit the graph of C vs. d.
- Make a graph of C vs. d. Are the data linear? If not, add an appropriate trendline fit, ensure the fit equation can be read on the graph to determine the relationship between C and d and discuss results.

- Now, repeat experiment AT THE DISTANCES selected above for the 1st graphed data set. Re-measure the associated capacitance values at least 5 times to explore the precision of the experimental technique. Make sure to re-measure all distances then repeat the process 5 times Do **NOT** simply measure the same distance 5 times then go on to the next distance. NOTE: THE STUDENT PLACING THE PARALLEL PLATE AT SPECIFICED DISTANCES SHOULD NOT BE LOOKING AT THE CAPACITANCE METER WHILE DOING SO. THIS COULD LEAD TO ADJUSTMENTS THAT ARE MISREPRESENTING THE PRECISION OF THE MEASUREMENTS.
- Students should create a table showing the positions and multiple runs of capacitance at these distances. Since the distances are all the same for each run – they only need to be 1 column of distance measurements shown in the table.
- Find the standard deviation of the capacitance at each distance location. How does the size of the standard deviation compare with the associated measured capacitance values? (Hint: How Large is the stdev compared to the measurement as a percentage?) Do you think the procedure and equipment are providing precise values, discuss. Do you see indications of significant random uncertainties in these data sets?
- Finally, calculate the predicted capacitance values at the distances chosen and discuss accuracy of your data to the predicted capacitances calculated.
- Now, change the material between the plates from air to Plexiglass or rubber. How does this impact the measured capacitance? Is this expected from the model equation? Discuss. (Students may access the list of dielectric constants with link found in lab folder on Blackboard.) Note that if the distance is kept constant that one may write the ratio of $C_{dielectric}/C_{air}$ such that the dielectric constant can be calculated directly from the capacitance values. This can be repeated for various distances of dielectric between the plates.
- Students may note that small spacers exist on one of the parallel plates. Measurements can be made of their thickness and students can calculate the impact of these spaces on the dielectric capacitance results above using predictive equations. Note that the air and dielectric materials are in series with each other between the parallel plates. Make proper calculations and discuss your new results to the predicted dielectric constants. Did the air significantly change the measured dielectric constants' values?

Supplement: How to use the Capacitance meter

In making capacitance measurements the capacitor must be completely removed from the circuit. The C_x probe should be connected to one end of the capacitor (red) and the COM probe (black) should be connected to the other end. Turn the rotary switch to the F (farad) area and select the appropriate range.

The CR50 meterman also has a zero adjust for capacitance, make sure to zero out the meter before measurements.

Different ranges will offer different levels of precision – denoted in the table below. Note that each range value shown is the maximum value the range can measure. If one was to measure a value known to be in the pF or nF range – using the 0-20mF dial would measure this as 0.0mF as a 1nF is 10^6 times smaller than 1mF. Therefore, selecting an appropriate range to measure is important.

Finally, not that if the meter is reading '1.' this means that the value that is being measured is <u>larger</u> than the range's maximum value. To measure the value the dial must be moved to a larger range until a value is shown. The greatest precision will always occur at the lowest value range dial a measurement can be read from.

Capacitance	**Precision**	**Test Frequency**
0-200pF	± 0.5% + 0.6pF	820 Hz
0-2000pF to 0-2 µF	± 0.5% + 1 lsd*	820 Hz
0-20 µF	± 0.5% + 1 lsd*	82 Hz
0-200 µF	± 0.5% + 1 lsd*	8.2 Hz
0-2mF	± 1.0% + 1 lsd*	8.2 Hz
0-20 mF	± 1.5% + 1 lsd*	8.2 Hz
Protection: 0.1A/250		

*lsd =least significant digit (place)