**Experiment 3**

**Capacitors**

This experiment uses the computer simulation, “Capacitor Lab”, found on the website: phet.colorado.edu. Once you have downloaded the simulation there are three tabs located at the top of the window: “Introduction”, “Dielectric”, and “Multiple Capacitors”.

**Part 1**

**Charge and Potential Difference**

**A. Plate Area: 100.0 mm2**

The tab for “Introduction” should be open when you first download the simulation. On the battery there is a slide button to adjust the voltage supplied to the capacitor. On the capacitor there are green arrows that allow you to adjust the separation between the capacitor plates and to allow you to adjust the area of both plates.

Adjust the slide button on the battery. As you do this note the indication of charges collecting on each of the two plates. Set the slide button back to 0 volts. On the right of the window there is a list of Meters. Click on the Voltmeter. You now have a virtual voltmeter to measure the potential difference between two points of the circuit. Place the red probe on the wire above the top plate, and the black probe on the wire below the bottom plate. Now, slowly increase the slide button on the battery. You are now able to measure the potential difference of the plates.

The plate separation is initially set to 10.0 mm, while the plate area is initially set to 100.0 mm2. In this first set of data keep the separation and area set to these initial values.

The relationship for the amount of charge collected on one of the plates (an equal amount of charges collects on both plates, but one plate has positive charges, while the other has negative charges) is dependent upon the potential difference placed across the plates.

(equation 1)

The total charge Q is directly proportional to the voltage V. V is multiplied by a proportionality constant to make the relationship an equality. This proportionality constant is the capacitance of the capacitor. When plotting the total charge Q as a linear function of the voltage V, the capacitance C is the slope of the line.

In the Meters section of the simulation, click on the “Plate Charge” to get a reading of how much charge is on the top plate. Starting with 0 volts, record the amount of charge on the top plate for various voltage values, ending with 1.5 volts as your last entry on the table located on the Excel worksheet for this experiment.

Plot this data and determine the slope of the trend line. Make sure that your slope value is in Scientific Notation and has at least 4 decimal places.

Again, in the Meters section of the simulation, click on the “Capacitance” meter and record this value in the Excel worksheet. Compare this with the slope value using the percent error equation.

**B. Plate Area: 400.0 mm2**

Use the green arrow for the Plate Area and increase the area to 400.0 mm2. Take data as you did in part A and plot the data and determine the slope of the trend line.

When you are finished determining the slope, click on the “Capacitance” meter and record this value on the Excel worksheet. Compare this with the slope value using the percent error equation.

**Part 2**

**Determining the Dielectric Constant**

Often times a material is placed between the plates to increase the capacitance of a capacitor when it is manufactured. Click on the “Dielectric” tab near the top of the simulation window. On the right of the window you will see a drop down menu for selecting a dielectric material. Your lab instructor will inform you in lab which dielectric material to use.

Notice in the simulation that you can slide the dielectric material to different positions between the plates. Slide the dielectric material fully between the plates for this part of the experiment. Have the plate area equal to 100.0 mm2 and set the voltage on the battery to 1.5 volts.

For this part of the experiment you will vary the separation between the plates, effectively changing the thickness of the dielectric as you do so. By changing the separation between the plates, the capacitance of the capacitor will change. The relationship for this is:

(equation 2)

Where k is the dielectric constant, ϵo is the permittivity of free space (8.85x10-12 F/m), A is the area of one of the plates (assumed both plates are the same size), and d is the separation distance between the plates.

Click on the “Capacitance” meter to “measure” the capacitance of the capacitor as you change the plate separation. Fill in the table on the Excel worksheet for various separations, starting with 5 mm and ending with 10 mm. Make sure that you convert millimeters to meters for the separation. Plot the capacitance as a function of the separation and fit the proper trend line style to the data points (this will not be a linear fit). Use the constant value from the trend line fit to determine the dielectric constant k. Your lab instructor will describe this more fully in lab. Compare what you determined for the dielectric constant with the value of k in the simulation.

**Part 3**

Choose the “Multiple Capacitors” tab near the top of the simulation window for this part of the experiment.

**A. Capacitors in Parallel (circuit)**

In the “Circuits” section choose “3 in Parallel”. Adjust the battery to 1.5 volts. Your lab instructor will tell you what capacitance values to adjust C1, C2, and C3.

Use the voltmeter to measure the potential difference for each of the capacitors. Place the red lead on the wire just above the top plate, and the black lead on the wire just below the bottom plate. Record these values on the Excel worksheet.

Determine the charge on each of the capacitors, recording these on the Excel worksheet. Notice that all of the capacitor’s top plates are connected to the same wire coming from the battery. All of the charges on the top plates have been distributed between these top plates. Add up the charges for each plate together and record this on the Excel worksheet. Now, click on “Stored Charge” in the Meters section of the simulation. Record this in the Excel worksheet and compare this value with the sum total of charges of the plates.

Capacitors in a circuit which are in parallel to each other can be combined mathematically and represented by a single capacitance value. This relationship is:

(equation 3)

Where the three dots mean a continuation of any more capacitors that are in parallel. Using the capacitance values for the three capacitors given to you by your lab instructor determine mathematically the total capacitance and record this in the Excel worksheet. This total capacitance capacitor contains the total charge of all three capacitors. Determine the total capacitance using the total charge and the potential difference and record this in your worksheet. Click on the “Total Capacitance” meter and record this on the worksheet. Compare the total capacitance found using equation 3 with the “Total Capacitance” value using the percent error equation.

**B. Capacitors in Series (circuit)**

In the “Circuits” section of the simulation, choose “3 in Series” for this part of the experiment. Again, your lab instructor will tell you the capacitance values for these three capacitors. Record these values in your worksheet.

Adjust the battery to 1.5 volts.

Measure the voltages across each of the individual capacitors using the voltmeter. Record these values on the Excel worksheet. Mathematically determine the charge on each of the capacitors and record these values on the worksheet. Click on “Stored Charge”, record this and compare to the charges you determined.

Capacitors that are connected in a single line, one to the next, are in “Series” with each other. These can be combined mathematically and represented by a single capacitance value. This relationship is:

(equation 4)

Where the three dots mean a continuation of any more capacitors that are in series. Using the capacitance values for these three capacitors, given by your lab instructor, determine mathematically the total capacitance and record this on the Excel worksheet. Each capacitor shows to have the same amount of charge when in a series configuration, but a different potential difference. Adding up these potential differences will equal the potential difference of the battery. Using this single charge value and the potential difference of the battery determine the total capacitance, again. Record this in your worksheet. Compare the capacitance determined using equation 4 with the “Total Capacitance” value from the simulation using the percent error equation.

**C. Combination of Capacitors in Series and Parallel (circuit)**

In the “Circuits” section choose “2 in Parallel; 1 in Series” for this part of the experiment. Your lab instructor will give you the capacitance values for these capacitors.

Use the voltmeter to “measure” the potential differences of each of these three capacitors and record these on the worksheet.

Mathematically determine the charge on each of the three capacitors and record these on the worksheet.

Since this is a combination of Series and Parallel, both equations for Series and Parallel will need to be used.

C1 is in “Series” with the “Parallel” combination of C2 and C3. Combine the parallel combination of C2 and C3 first to determine their equivalent, single capacitance value. This equivalent, single capacitance value for C2 and C3 can then be combined in “Series” with C1 to result in the over-all combination of all three capacitors. Record this total capacitance value on the worksheet. Click on the “Total Capacitance” meter and record this on the worksheet. Compare your mathematically determined total capacitance with the “Total Capacitance” meter reading using the percent error equation.

**Results**

For each of the parts, how well do the mathematically determined total capacitance values compare to the “Total Capacitance” meter value. Use the percent error equation for these comparisons.

**Questions for Discussion**

1. In part 1 the capacitance of the capacitor was determined for a particular area of the plates, and again for an increased area of the plates. By what factor was the area increased, and how does this compare to the two capacitances found?
2. Capacitors are said to store electric charge. How do you determine the total charge, or net charge of the entire capacitor?
3. In part 3B, a series combination of 3 different capacitance capacitors show to have the same amount of charge upon them. In part 3A the 3 different capacitors in a parallel combination do not have the same charge upon them. Describe why this occurs for both setups.
4. In the online simulation you were able to fully place a dielectric material between the two plates of the capacitor. By placing the dielectric material between the two plates the capacitance of the capacitor changes. By keeping the distance between the two plates at 10 mm, the area of the plates at 100 mm2, and having the material of the dielectric to have a dielectric constant equal to 5 (the dielectric constant for air is ≈1), write an equation that shows by how much the capacitance will change if you only place the dielectric material halfway between the two plates.