

LAB 5 - CAPACITORS AND RC CIRCUITS(TPL2)

Objectives

- To define capacitance.
- To discover how the charge on a capacitor and the electric current change with time when a charged capacitor is placed in a circuit with a resistor.
- To determine how total capacitance differs when capacitors are wired in parallel and when wired in series.

The Parallel Plate Capacitor

A capacitor consists of two conductors separated by an insulator. The choice of plate area, plate separation, and insulating material determines the "capacitance" of the capacitor. The typical method for transferring equal and opposite charges to the plates of a capacitor is to use a voltage source such as a battery or power supply to create a potential difference between the two conductors. Electrons will then flow off of one conductor (leaving positive charges) and on to the other until the potential difference between the two conductors is the same as that of the voltage source. The capacitance of a given capacitor is *defined mathematically as the ratio of the magnitude of the charge, Q , on either one of the conductors to the voltage, V , applied across the two conductors* so that:

$$C = \frac{Q}{V}$$

Thus, capacitance is *defined* as a measure of the amount of net or excess charge on either one of the conductors per unit voltage.

You can draw on some of your experiences with electrostatics to think about what might happen to a parallel plate capacitor when it is hooked to a power supply as shown in Figure 1. This thinking can give you an intuitive feeling for the meaning of capacitance. For a fixed voltage from a power supply, the net charge found on either plate is proportional to the capacitance of the pair of conductors. It is possible to calculate C

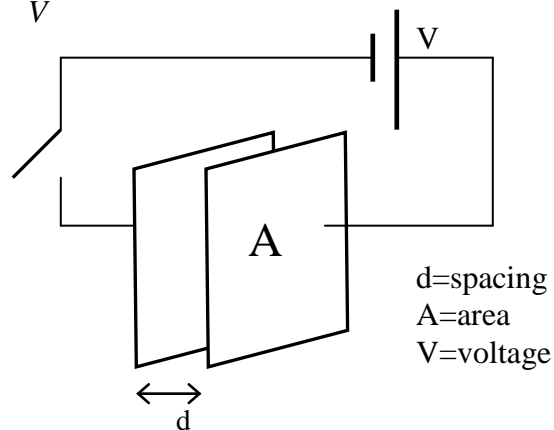


Figure 1 - A parallel plate capacitor with a voltage V

$$C = \epsilon A/d$$

Part 1 - Capacitor Discharging - Visual Method with Light bulbs

A capacitor will store charge when connected to a power supply. If the capacitor is disconnected from the voltage source, and then connected to a resistor (such as a light bulb), it will "**discharge**" through the resistor. There will be a current flow, which will *drop off with time*, as the capacitor loses its charge. (We could think of a charged capacitor as a very limited {short-lived} battery). Most capacitors used in electrical circuits contain microFarads of capacitance, so they don't store much charge. We will use a **1 Farad capacitor** (the light green capacitor), with our 5-volt power supply to store a relatively large amount of charge.

1. Circuit configuration. Set up the circuit below, using the power supply, the large 1 Farad capacitor, and the small light bulb. The wires shown are the banana plug wires, with alligator clips on some ends in the appropriate places. To the right of the second diagram, there is a location where a wire can be connected as illustrated to either charge or discharge the capacitor. Do not charge the capacitor yet.

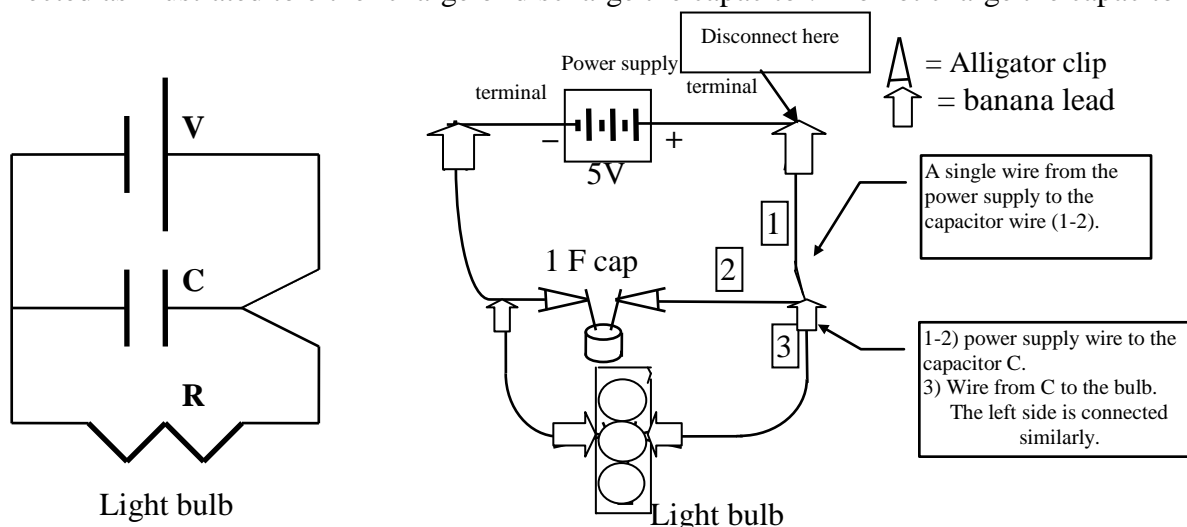


Figure 2 - Capacitor/bulb circuit diagram and wiring picture.

Predictions Answer on the Data/Question sheet.

- What will happen to the bulb when it is connected only to the charged capacitor?
- Will the brightness of the bulb remain steady, or change with time?

2. Charging the capacitor. In the above circuit, connect all wires to the capacitor and the light bulb as shown. Plug the top left lead into the power supply’s negative terminal. To charge the capacitor, plug the top right lead into the positive terminal of the power supply (Where it says “disconnect here”).

3. Discharging the capacitor. Disconnect the wire at the green, 5V, terminal of the power supply where indicated. This will discharge the capacitor through the light bulb (resistor).

Questions Answer on the Data/Question sheet.

- Describe what you observed of the brightness of the bulb, over time, after it was connected only to the capacitor.
- If your predictions did not match your observations, can you think of an explanation?

Preliminary activities



1. Prepare equipment. Connect the voltage probe to the analog adapter cable, this to the USBLink then to your laptop. It would also be very helpful to look at the online help page for this lab. Start the DataStudio software.

2. Load the experiment file. Download the Data Studio file **Lab05_Lab05_RC.ds** from the lab schedule webpage, and load it in DataStudio.

Part 2 - Simple RC circuit - voltage/current vs time

Quantitative Measurements on an RC System

The next task is to do a more quantitative study of your "RC" system. We will do this in two ways. The first involves measuring the voltage across a resistor that has been placed in a circuit with a capacitor. This will give us information about the current as a function of time, and the voltage across the capacitor as a function of time (since this is a simple series circuit). The goal here is to verify the mathematical relationship which best relates the voltage across the capacitor and time as the capacitor discharges. [The bulb would not be a good "constant-value" resistor as its resistance is temperature dependent; its resistance goes up when the current heats it.] For these more quantitative studies we will use a **2.2 kΩ (= 2200 ohm) resistor** in place of the bulb while attempting to discharge a **1000 μF capacitor** through it.

[NOTE: This small blue capacitor (1000 μF) must be connected in a particular way - there are arrows on the side of the capacitor pointing to one of its leads - that should be the negative terminal of the capacitor.]

1. Circuit connections. In your previous circuit, replace the large capacitor with the smaller one, and replace the bulb with the resistor as shown below:

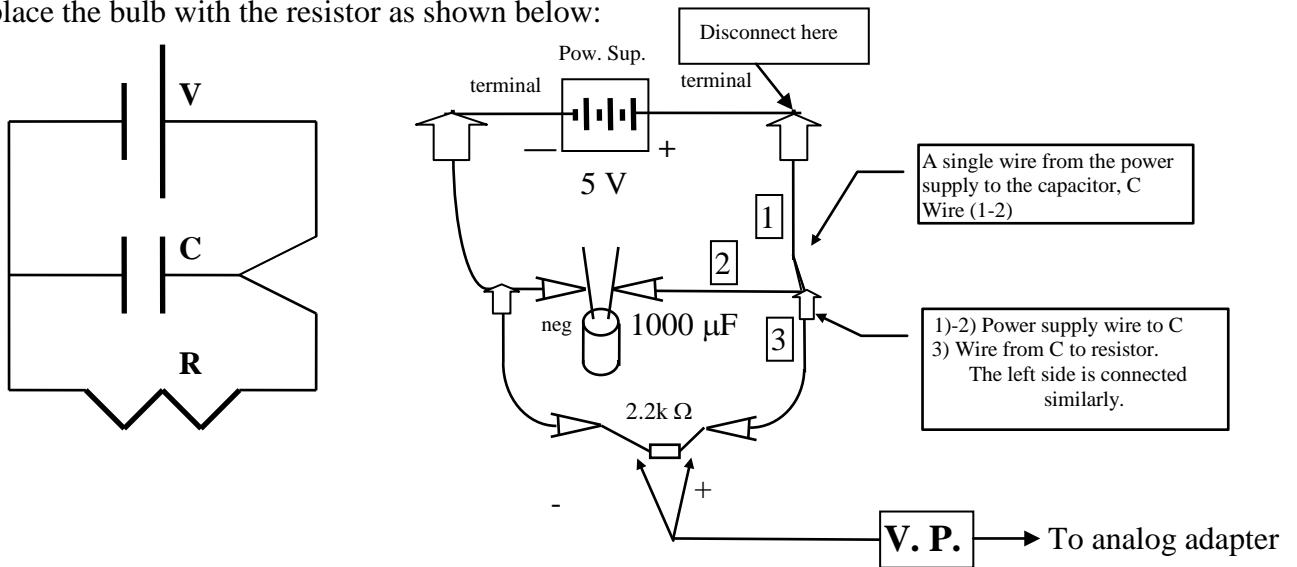


Figure 3 - Capacitor/resistor circuit diagram and wiring picture.

Prediction Answer on the Data/Question sheet

Based on your observations in the bulb section, what do you think will be the shape of the curve of voltage vs. time for the resistor?

2. Measuring voltage. To measure the voltage across the resistor (and thus the current through the system), connect the voltage probes (V.P.) across the resistor (the red lead should be closest to the positive lead of the power supply). The leads can just clip onto the wires of the resistor between the resistor and the alligator clips.

Making Voltage vs. Time measurements with DataStudio as a voltmeter

General procedure that we will follow in the next few steps:

- Charge the capacitor (for at least 10 seconds)
- Start graphing with DataStudio (see the online help page .. there is a “trigger” before the graph starts)
- Quickly disconnect the power supply (wire 1) ... so the capacitor discharges through the resistor
- Graph might stop by itself in about 15 seconds (we can change that if we wish)

3. Charging the capacitor. Use the same procedure as before to connect the wires and charge the capacitor.

4. Start graphing. Click START to graph the data. (The “trigger” condition won’t be met until after you start the discharge in the next step – but you should see a flickering datapoint indicator at around 4.7 volts on the voltage axis.)

5. Discharging the capacitor. Quickly disconnect wire 1 to discharge the capacitor. When the capacitor discharges through this resistor, it will happen within about a minute. But, the data rate is high enough that we can capture this decay curve very smoothly. You should see a graph similar to the one below:

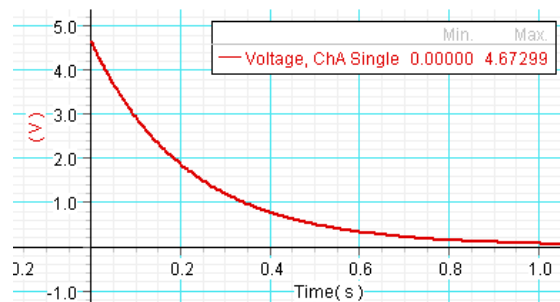


Figure 4 – Discharge graph for single capacitor and resistor. (Your time axis will be different!)



6. Rename/hide your single capacitor run. Name this single capacitor run (maybe “single?”), store and hide it.

Questions Answer on the Data/Question sheet.

- How did your prediction match your observation?

Part 3 - Calculating the Charge on the Capacitor

The main features of the previous graph match what we should expect: When the power supply is disconnected, and once the trigger condition is reached, the graph starts and the voltage begins to drop off. The charge on the capacitor is depleted as the current flows around the circuit. If the connection is not good, the start of the drop will not be sharp. *One other benefit to starting our graph after the decay has begun ... the initial disconnect of the power wire might not be “clean” – so the start of the decay might be a little “jagged” – we avoid it with our trigger. The beauty of the exponential decay is that it doesn’t matter where we start, there is a predictable decay from that point on.*

When the capacitor is charged by the power supply, there is a fixed amount of charge stored on each plate of the capacitor. From the capacitance relationship, we know that $Q=CV$. This will give us our first technique for calculating the amount of charge in our particular system.

1. Starting voltage. Using the Smart Tool, position the crosshairs on the very first data point. Record your value for this initial voltage on the Data/Question sheet.



2. Calculating charge on the capacitor. Calculate the charge on the capacitor. (This is actually the charge that was on the capacitor at that moment in time we just found above.) Show the calculation on the Data/Question sheet.

Now, there must be **another** way we can find the amount of charge on the capacitor. The graph that we made was the voltage across the resistor as a function of time. The resistor was chosen so that it would remain at a stable value, for the current in the system. Thus, our Voltage vs. time curve can be considered a Current vs. time curve (by dividing the voltage by the known resistance - we get the current!). What is the area under a current vs. time curve? (Current x time = charge ... **the area under the Current vs. Time curve is the charge that flowed during that time interval!**) DataStudio can automatically calculate the area under the curve (thus the integral of the curve). The curve we are looking at is really voltage vs. time; if we calculate the area, we will get volt-seconds as unit for the integral value. If we then divide by the resistance we will get the charge.

3. Selecting the area under the curve. Turn off the Smart Tool and go to the Statistics button, Σ , and select AREA at the bottom. The graph should automatically fill in – if not, click once near the data curve. The “area” value is the integral of the voltage vs time curve – record this value on the Data/Question sheet.

4. Calculating the charge. To calculate the charge, divide the integral value by the known resistance ($R = 2200$ ohms). Also calculate the % difference with the calculated charge value from Part 3.2. Show calculations on the Data/Question sheet.

Part 4 - Voltage vs Time Relationship

Remember how the bulb dimmed over time in Part 1. The quantity, $\tau = RC$, is a measure of the time required for the capacitor to discharge through the bulb or any resistor. Because this discharge is exponential in nature it is not possible to allow the voltage to drop to zero. An arbitrary value is selected for the low voltage in this discharge. It is 37% (or $1/e$) of the original voltage used. We will look at 2 ways to find this “time”.

1. Calculating the time constant. We have the values of the resistance (2200 ohms) and the capacitance (1×10^{-3} F), and can calculate the time constant on the Data/Question sheet.

2. Time constant from the decay curve. There is still one more way we can calculate the time constant! Starting from the initial voltage, we can look for the voltage value that is 37% of the maximum. Now, how much time passed between the maximum and the $0.37V_0$... the time constant! Now, we can use the Smart tool and the Delta tool to do this, but we have to make a slight modification to how we calculate. If we position the Smart Tool at the first data point, and use the Delta tool to drag down a bounding box, we should look for 63% of the main voltage to show up in the delta tool vertical range. (If the final voltage is 37%, then there must have been a drop of 63%!) Follow the directions on the Data/Question sheet to find the time for that 63% drop in voltage and record the time constant on the Data/Question sheet.

3. Clear fits/areas. If you haven't already done so, rename this run (maybe "single") and clear the area/fit results (to make the graph cleaner). We will want to compare this curve to series and parallel capacitor curves.

Question How close did the value of the time constant from these compare?

Part 5 - Series and Parallel RC circuits

You can observe and measure the equivalent capacitance for series and parallel combinations. For this study you can use two identical capacitors (each 1000 μF).

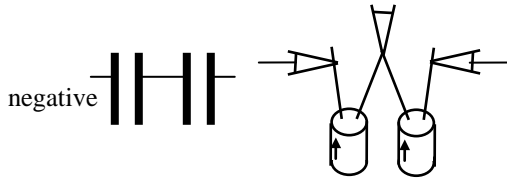


Figure 6 - Capacitors wired in series

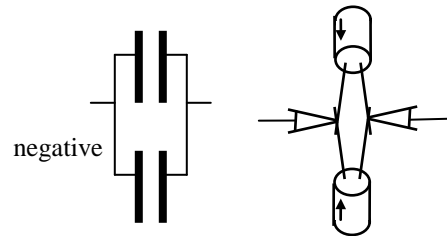


Figure 7 - Capacitors wired in parallel

We can go back to our original circuit, and use combinations of capacitors in series or parallel.

Capacitors in PARALLEL:

Predictions Answer on the Data/Question sheet.

- a) How will the amount of charge stored on each capacitor change by having two capacitors in parallel (as compared to only one capacitor in the circuit)?
- b) What will be the effect on the total capacitance of the system of putting two capacitors in parallel?

1. Measure voltage vs. time for two capacitors in parallel. Repeat the steps in Part 2 to measure the voltage vs. time information for two capacitors in parallel. Name the curve ("parallel"?). *[Here is a benefit of the "trigger" effect – this curve will start at almost exactly the same location as the single capacitor data run, thus we can easily compare one circuit to another since they all start discharging at about the same time.]*

2. Measurements from the voltage vs. time graph. Record the following information from the graph you obtain on the Data/Question sheet. (Repeat Parts 3.1 and 3.3 & 3.4)

Questions Answer on the Data/Question sheet.

- a) How does your $C_{\text{effective}}$ compare to the individual capacitance (1000 μF) of each element (is there a rough ratio between them)?
- b) What is the mathematical relationship relating the total capacitance of two capacitors in parallel to the individual capacitance?

For example, a graph is shown below with three different circuits: single capacitor, two capacitors in series, and two capacitors in parallel. Does this picture match the information you have gathered so far? (You don't have to duplicate this graph exactly ... it is for illustrative purposes.)

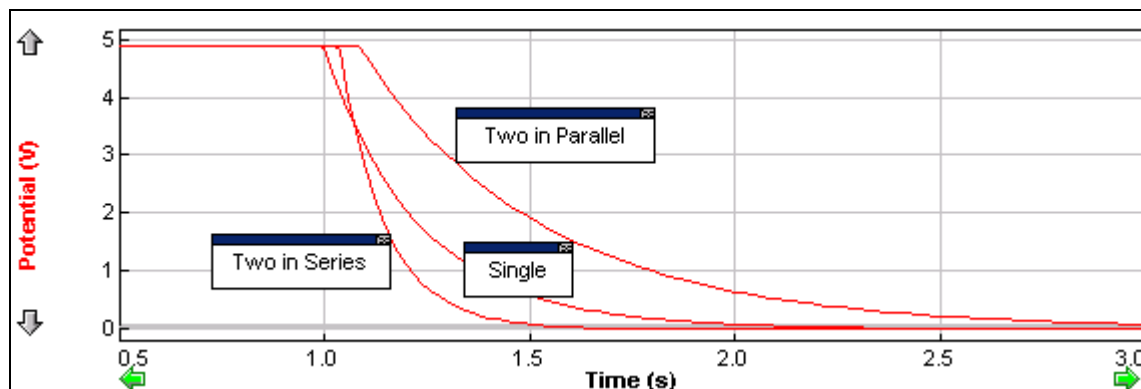


Figure 8 – Three capacitor circuits with nearly the same discharge start-time (This is an older style graph – yours should look similar.)

3. Rename this data run. Name the run (“parallel”) store and hide it.

Capacitors in SERIES:

Predictions Answer on the Data/Question sheet.

- a) How will the amount of charge stored on each of the capacitors change by having two capacitors in series (as compared to only one capacitor in the circuit)?
- b) What will be the effect on the total capacitance of the system of putting two capacitors in series?

1. Measuring voltage vs. time for two capacitors in series. Using the same procedure as before, take Voltage vs. time information using two capacitors connected in series.

2. Measurements from the graph. Record the following information from the graph you obtain on the Data/Question sheet.

Questions Answer on the Data/Question sheet.

- a) How does your Effective compare to the individual capacitance of each element (Is there a rough ratio between them)?
- b) What is the mathematical relationship relating the total capacitance of two capacitors in series to the individual capacitance?

(You should check these series and parallel relationships with your textbook for the lab report.)

3. Annotate and print a graph. Rename this last run (“series”). Show all the data runs (single, series, parallel), and scale the graph to show about 20 seconds (we want to emphasize the differences between the three). You want to print a copy of **ALL THREE RUNS ON THE SAME GRAPH** for the final report – if you don’t print in color, you might want to annotate the curves (either by hand or via DataStudio) to indicate which graph is which. See the [annotation help page](#) for tips. Save the experiment file when finished!

FINAL NOTE-TRANSFER ALL SAVED FILES TO YOUR OWN LAPTOP

DATA/QUESTION SHEET FOR LAB 5 - CAPACITORS AND RC CIRCUITS

Part 1 - Capacitor Discharging - Visual Method with Light bulbs

Predictions a) What will happen to the bulb when it is connected only to the charged capacitor?

b) Will the brightness of the bulb remain steady, or change with time?

3. Discharging the capacitor.

Questions a) Describe what you observed of the brightness of the bulb over time after it was only connected to the capacitor.

If your predictions did not match your observations, can you think of an explanation?

Part 2 - Simple RC circuit - voltage/current vs time

Prediction Based on your observations in the bulb section, what do you think will be the shape of the curve of voltage vs. time for the resistor?

6. Save data.

Questions How did your prediction match your observation?

Part 3 - Calculating the Charge on the Capacitor

1. Starting voltage.

Record that voltage here: $V_{\max} = \underline{\hspace{2cm}}$ volts

The capacitance of the capacitor: $C = \underline{1000} \mu\text{F} = \underline{1 \times 10^{-3}} \text{ F}$

2. Calculating charge on the capacitor.

$Q_2 = CV = \underline{\hspace{2cm}}$ coulombs (unit of Coulomb = Volt•Farad)

3. Selecting the area under the curve.

Area = $\underline{\hspace{2cm}}$ volt-seconds

$R = \underline{2200}$ ohms

5. Calculating the charge. To calculate the charge, divide the integral value (3.3 above) by the known resistance . Also calculate the % difference with the calculated charge value from section 3.2.

Charge = area/R = $Q_5 = \underline{\hspace{2cm}}$ coulombs

Calculate the % difference with previous calculation (beginning of this section) using $x_1 = Q_2$, $x_2 = Q_5$ and the %diff formula below.

$$\% \text{ diff} = \frac{|x_1 - x_2|}{\left(\frac{x_1 + x_2}{2}\right)} \times 100$$

% diff = $\underline{\hspace{2cm}}$ %

Part 4 - Voltage vs Time Relationship

1. Calculating the time constant. We also have the values of the resistance (2200 ohms) and the capacitance (1×10^{-3} F), and can calculate the time constant.

Time constant = $RC = \tau_{\text{theoretical}} =$ _____ second

2. Time constant from the decay curve. Position the Smart tool at the first data point, V_{max} . Calculate 63% of the V_{max} value. Drag the Delta tool (the lower right corner of the Smart tool) down along the curve until it shows that 63% value (the vertical number to the right of the box). Again, be sure you are on the curve. The number below the box is the time constant, τ_{measured} . Record below

$V_{\text{max}} =$ _____ volts (Part 3.1)

$(0.63) * V_{\text{max}} =$ _____ sec

Time constant = $\tau_{\text{measured}} =$ _____ sec

Calculate the %diff difference between $\tau_{\text{theoretical}}$ and τ_{measured} using the above %diff formula from Part 3.5.

% diff = _____ %

Question How close did the value of the time constant from these compare?

Part 5 - Series and Parallel RC circuits

Capacitors in PARALLEL:

Predictions a) How will the amount of charge stored on each of the capacitors change by having two capacitors in parallel (as compared to only one capacitor in the circuit)?

b) What will be the effect on the total capacitance of the system of putting two capacitors in parallel?

2. Measurements from the voltage vs. time graph.

V_{max} = _____ volts
 area = _____ volts-sec

R = 2200 ohms
 Q_p = area / R = _____ coulombs

If $Q_p = V_{max} C_{eff\ par}$, then for parallel capacitors: $C_{eff\ par} = Q_p / V_{max} =$ _____ F = _____ μ F

Questions a) How does your $C_{eff\ par}$ compare to the individual capacitance (1000 μ F) of each element [is there a rough ratio between them (twice, half)]?

b) What is the mathematical relationship relating the total capacitance of two identical capacitors, in parallel, to the individual capacitance?

Capacitors in SERIES:

Predictions a) How will the amount of charge stored on each capacitor change by having two capacitors in series (as compared to only one capacitor in the circuit)?

b) What will be the effect on the total capacitance of the system of putting two capacitors in series?

2. Measurements from the graph.

$V_{max} =$ _____ volts

$R = 2200$ ohms

area = _____ volts-sec

$Q_s = \text{area} / R =$ _____ coulombs

If $Q_s = V_{max} C_{eff\ ser}$, then for series capacitors: $C_{eff\ ser} = Q_s / V_{max} =$ _____ F = _____ μF

Questions a) How does your $C_{eff\ ser}$ compare to the individual capacitance of each element [Is there a rough ratio between them (twice, half)]?

b) What is the mathematical relationship relating the total capacitance of two identical capacitors in series to the individual capacitance?

(You should check these series and parallel relationships with your textbook for the lab report.)

Questions/Suggestions -> James Nolta - jnolta@LTU.EDU