LAKE FOREST COLLEGE
Department of Physics

Physics 115 **Experiment #7: Capacitors and RC Circuits v2** Spring 2025

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Table:

Preliminary Instructions
Create a folder for you and your lab partner on Teams. Save a copy of these instructions for each student to that folder. Include your name in the filename. As you edit this document put your text in a different color. Save one copy of the *Excel* template with both your and your partner's name included in the filename.

Pedagogical purpose
Study series and parallel combinations of capacitance. Study the time dependent behavior of the voltage across a capacitor in a circuit containing a capacitor and a resistor.

Experimental Purpose
Test the predictions for equivalent capacitance of capacitors connected in series and parallel. Test the prediction for the voltage across a capacitor as a function of time in discharging and charging RC circuits.

Background
A capacitor is a device that stores energy in the form of separated charge. Like resistors, capacitors can be combined in series or parallel, and the combination has an equivalent capacitance. The rules for combining capacitors are switched compared to the rules for resistors.

$$C_{\text{series}} = \frac{1}{\frac{1}{C_1}+\frac{1}{C_2}};\ C_{\text{parallel}} = C_1 + C_2$$

Using Kirchhoff's loop rule and some mathematics, we can derive the expressions given below for the potential difference (voltage) across a charging and discharging capacitor as a function of time. The circuits presented here are not exactly the same as those presented in our textbooks, but they deal more gracefully with the "bounce" of real switches. In both cases used here, the circuit is activated by opening the switch. OPEN = wires not connected; CLOSED = wires connected.

Procedure:

Part I: Combinations of capacitors

1. Use the Fluke PM6303A RCL meter to measure the capacitance of two individual capacitors. The nominal capacitances are $C_1 = 1.0\ \mu\text{F}$ and $C_2 = 0.22\ \mu\text{F}$. The capacitance accuracy of the RCL meter is 0.25% of the reading + 1 count in the least significant digit. Example: $\delta C_1 = (0.0025)(996.5\ \text{nF}) + 0.1\ \text{nF} = 2.6\ \text{nF} = 0.0026\ \mu\text{F}$. Use this for the absolute uncertainty in the measured values.

2. Calculate the parallel and series equivalent capacitances and their uncertainties. Some formulas for calculating the uncertainty of the series combination have been prefilled in the Excel template.

3. Measure the total capacitance of the series and parallel combinations using the RCL meter. Compare these measurements to the predictions using the ratio test. **Insert Part I tables here. Include a table caption.**

nominal 1.0 μF & 0.22 μF	measured	
	C_1 (nF)	C_2 (nF)
value	221.5	966.4
abs unc	0.65	2.5
rel unc (%) (no units)	0.30%	0.26%

calculated				
$C_{parallel}$ (μF)	$1/C_1$ (1/nF)	$1/C_2$ (1/nF)	$1/C_{series}$ (1/nF)	C_{series} (nF)
1.188	0.004515	0.001035	0.005549	180.2
0.0040	0.000013	0.0000027	0.000016	0.52
0.33%	0.30%	0.26%	0.29%	0.29%

measured	
$C_{parallel}$ (μF)	C_{series} (nF)
1.190	180.4
0.0040	0.55
0.33%	0.31%

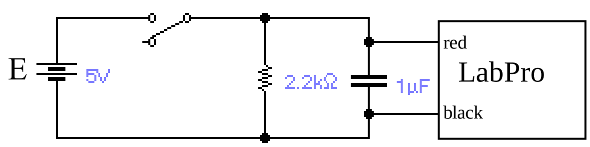
	measured	abs unc	calculated	abs unc	ratio test
C_{parallel} (μF)	1.190	0.0040	1.188	0.0	0.26
C_{series} (nF)	180.4	0.55	180.2	0.52	0.19

Table 1. Capacitor Measurements. The C_1 had a nominal capacity of 0.22μF and C_2 had a nominal capacity of 1.0μF. The capacities of the capacitors in series was calculated using the equation $C_{eq}=(1/C_1 + 1/C_2)^{-1}$. The capacities of the capacitors in parallel was calculated using the equation $C_{eq} = C_1+C_2$. The actual capacities were measured by a Fluke PM6303A RCL meter. The absolute uncertainly of the measured values was calculated by adding 1 lowest significant digit to 0.25% of the overall value. The measured capacities agreed with the calculated capacities according to the ratio test.

Part II: Discharging *RC* circuit

Discharging Circuit

$V_C = \mathcal{E} e^{-t/RC}$



4. Use a resistor of $R = 2.2\ \text{k}\Omega$ and a capacitor of $C_1 = 1.0\ \mu\text{F}$ (nominal values). Measure the resistance of the resistor using a handheld Fluke 75 DMM. Determine its absolute uncertainty as in Experiment 5. Use the measured value and its uncertainty from above for the capacitance.

5. Based on your measured values, calculate the predicted time constant $\tau_{\text{pred}} = RC$ in milliseconds and its absolute uncertainty.

6. Connect the charging circuit shown above. Close the switch. Set the voltage of the power supply to $\mathcal{E} = 5.00\ \text{V}$.

7. Connect the voltage probe to LabPro and open the RC circuit *LoggerPro* file on the desktop.

8. Zero the sensor by temporarily connecting the red and black EZ hooks together and selecting EXPERIMENT → ZERO.

9. Set the timing by selecting EXPERIMENT → DATA COLLECTION. In the Collection tab, set the Duration to 10 milliseconds and the Sampling Rate to 50 samples/millisecond. Under the Trigger tab, check the Triggering box and set it to DECREASING ACROSS 4.90 V. This places the Logger Pro software in “trigger mode”: after “Collect” is pressed, the program will wait unit the voltage drops below a preset value (in this case 4.90 V) before starting to take data.

10. Press “Collect” and OPEN the switch to discharge the capacitor.

11. Fit the data to an exponential (ANALYZE → CURVE FIT, $y = Ae^{-Ct} + B$ →TRY FIT). Here, C is a fitting parameter and not the capacitance.

12. Increase the font size of the parameters box and **paste the graph of the data here. Include a graph caption.**

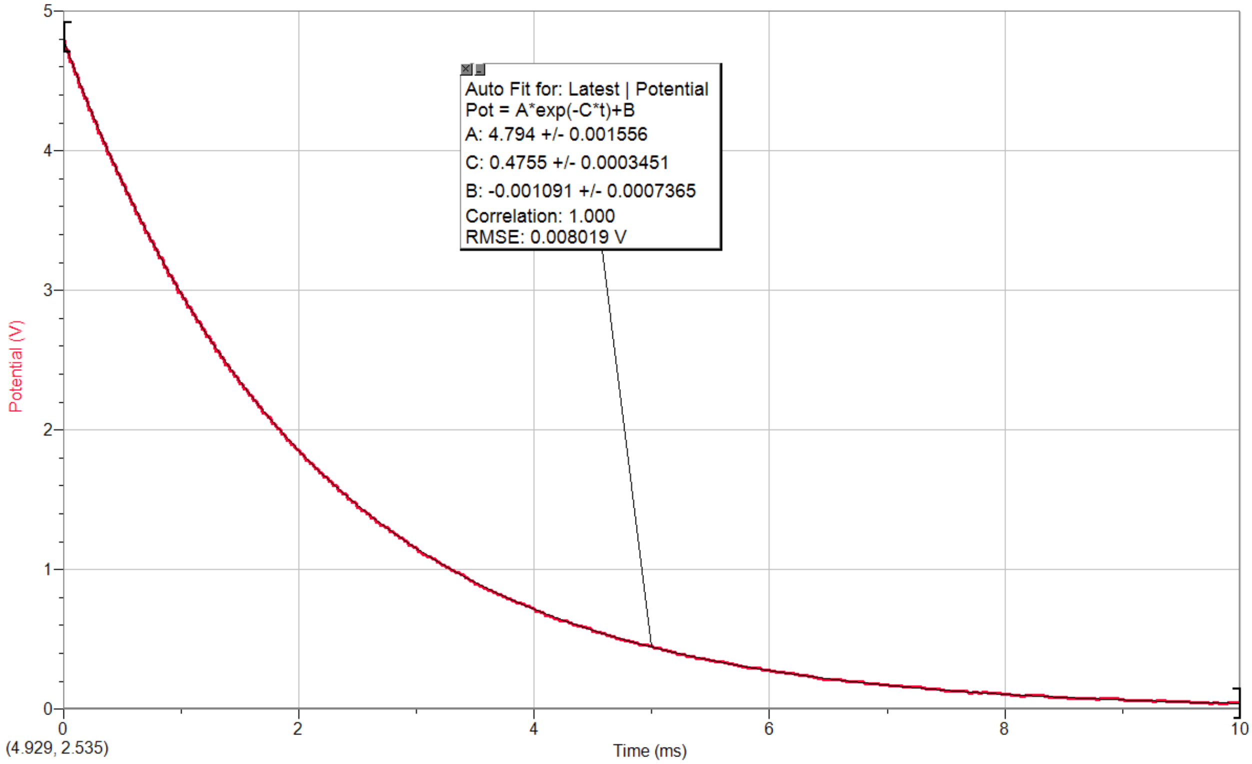


Figure 1. Discharging Circuit Graph. This graph shows the change in voltage (V) over time (ms) of a RC circuit as it discharges. The circuit starts at 5.00V at t = 0ms and decreases towards 0.0V as the capacitor discharges. The data collection started when the switch of the circuit was opened. The C value of the graph represents the value of 1/τ.

13. Convert the fit parameter C_{fit} and its uncertainty to the time constant τ ($\tau = 1/C_{fit}$) and its uncertainty. Compare this measured time constant to your predicted value of τ using the ratio test. **Insert Part II tables here. Include a table caption.**

Part II	Discharging Circuit					
nominal	measured		calculated	measured		
2.2 kΩ &	R	C	τ_{pred}	C_{fit}		$\tau_{fit} = 1/C_{fit}$
1.0 μF	(Ω)	(nF)	(ms)	(1/ms)		(ms)
value	2171	966.4	2.098	0.4755		2.103
abs unc	12	2.5	0.017	0.00035		0.0015
rel unc (%) (no units)	0.55%	0.26%	0.81%	0.073%		0.073%

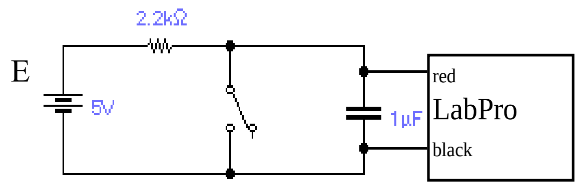
	measured	abs unc	calculated	± abs unc		ratio test
τ (ms)	2.103	0.0015	2.098	0.017		0.27

Table 2. Discharging Circuit Calculations and Comparison. The circuit was made with a capacitor, a resitor, and a switch. The τ_{pred} values comes from the equation $\tau = RC$. The C_{fit} value and absolute uncertainly came from a fitted curve on LoggerPro. The measured and calculated values agree according to the ratio test.

<u>Part III: Charging *RC* circuit</u>

Charging Circuit

$$V_C = \mathcal{E}\left(1 - e^{-t/RC}\right)$$



14. Use the same resistor and capacitor from the discharging experiment and connect the charging circuit shown above.

15. Reset the triggering mode. Under the triggering tab set it to INCREASING ACROSS 0.10 V. Now after "Collect" is pressed, the program will wait unit the voltage increases past 0.10 V before starting to take data.

16. Press "Collect." The data will accumulate when the switch in the circuit is OPENED.

17. Fit the data to an inverse exponential (ANALYZE → CURVE FIT, $y = A\left(1 - e^{-Cx}\right) + B$ → TRY FIT). Again, here, C is a fitting parameter and not the capacitance.

18. Increase the font size of the parameters box and **paste the graph of the data here. Include a graph caption.**

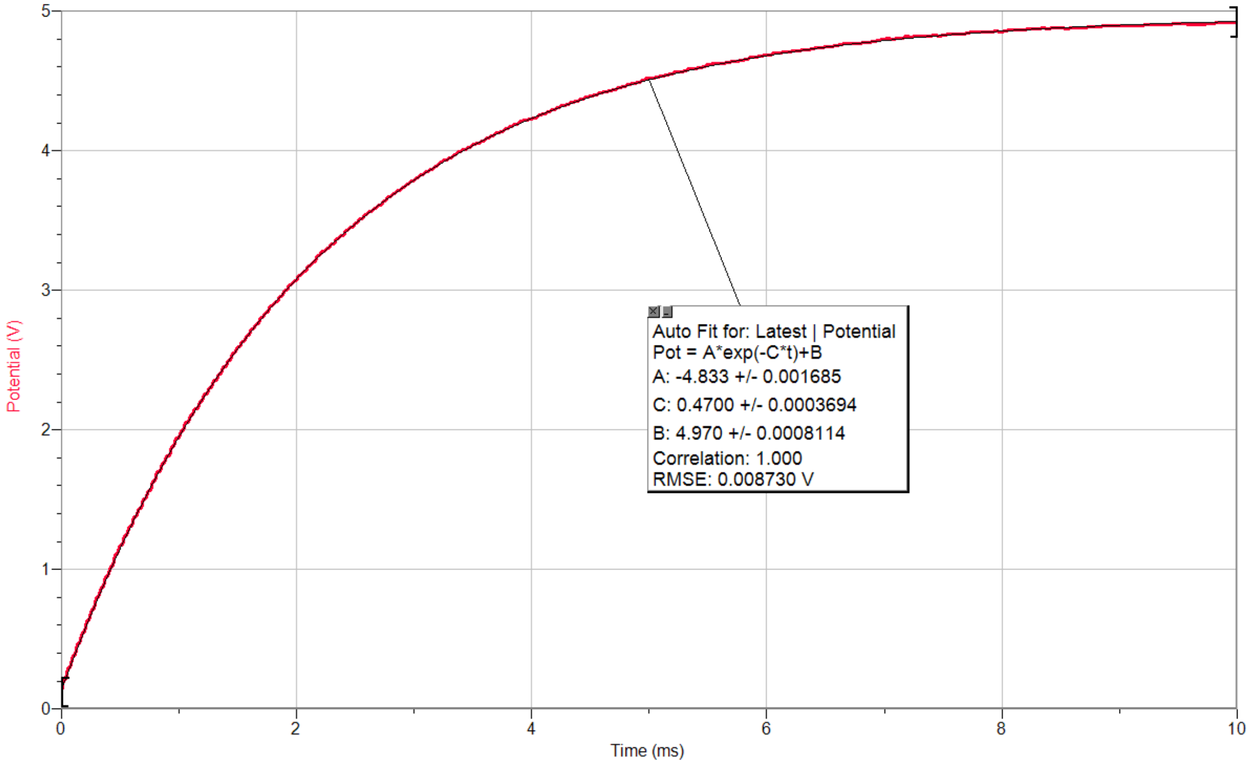


Figure 2. Charged Circuit Graph. This graph shows the change in voltage (V) over time (ms) of a RC circuit as it discharges. The circuit starts at 0.0V at t=0ms and increases toward 5.0V as the capacitor charges. The data collection started when the switch of the circuit was opened. The C value of the graph represents the value of 1/τ.

19. Convert the fit parameter C_{fit} and its uncertainty to the time constant τ and its uncertainty. Compare this measured time constant to your predicted value of τ (which is the same as in part II) using the ratio test. **Insert Part III tables here. Include a table caption.**

Part III — Charging Circuit

nominal	measured		calculated	measured	
2.2 kΩ & 1.0 μF	R (Ω)	C (nF)	τ (ms)	C_{fit} (1/ms)	$\tau_{fit} = 1/C_{fit}$ (ms)
value	2171	966.4	2.098	0.4700	2.128
abs unc	12	2.5	0.017	0.00037	0.0017
rel unc (%) (no units)	0.55%	0.26%	0.81%	0.079%	0.079%

	measured	abs unc	calculated	abs unc	ratio test
τ (ms)	2.128	0.0017	2.098	0.017	1.6

Table 3. Charged Circuit Measurements. The circuit was made with a capacitor, a resitor, and a switch. The τ_{pred} values comes from the equation $\tau = RC$. The C_{fit} value and absolute uncertainly came from a fitted curve on LoggerPro. The measured and calculated values agree according to the ratio test although there is more of a difference between the values then there was in the discharging circuit.

Discussion questions:

20. For two series capacitors with $C_2 < C_1$, which of the following is accurate? **Select one.**

(a) $C_{eq} < C_2 < C_1$

(b) $C_2 < C_{eq} < C_1$

(c) $C_2 < C_1 < C_{eq}$

21. For two parallel capacitors with $C_2 < C_1$, which of the following is accurate? **Select one.**

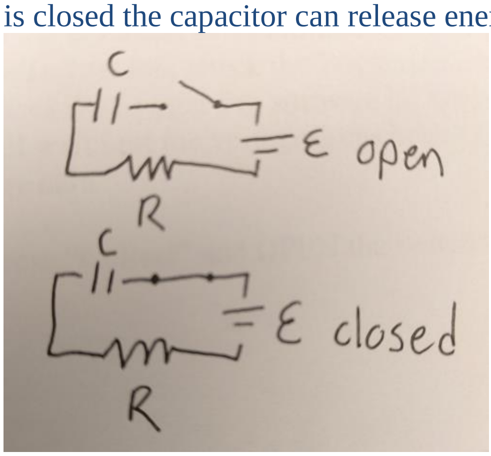
(a) $C_{eq} < C_2 < C_1$

(b) $C_2 < C_{eq} < C_1$

(c) $C_2 < C_1 < C_{eq}$

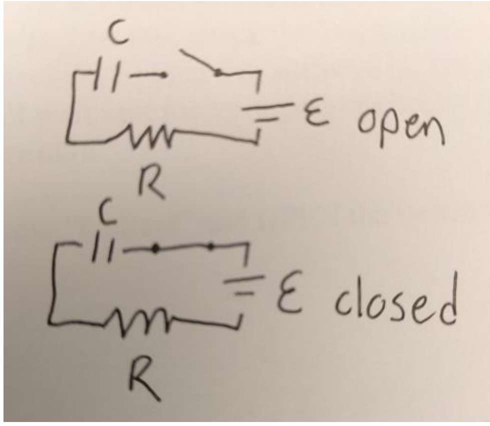
22. **Explain how the discharging circuit functions.** That is, how does having the switch closed charge the capacitor to a voltage of E? What path does the current follow when the switch is opened and how does this discharge the capacitor? (Two sketches of the circuit will be necessary here, one for the switch closed and one for the switch open.)

When the circuit is open the charge goes into the capacitor, storing energy in it. When the circuit is closed the capacitor can release energy into the circuit, discharging it.



23. **Explain how the charging circuit functions.** That is, how does having the switch closed make the voltage across the capacitor equal to zero? What path does the current follow when the switch is opened and how does this charge the capacitor? (Two sketches of the circuit will be necessary here, one for the switch closed and one for the switch open.)

When the switch is closed then the voltage can travel though the capacitor but when the switch is open the charge builds in the capacitor, charging it.



24. **Write an analysis of the experiment here.**

Analysis

25. **Write a brief conclusion here.**

When a capacitor with a capacity of 221.5±0.7nF and a capacitor with a capacity of 966.4±.5nF are in parallel, they have a combined capacity of 1.188±0.004μF but when they are series, they have a combined capacity of 180.2±0.52nF. These values can be accurately calculated using the equations $C_p = C_1 + C_2$ and $C_s = (1/C_1 + 1/C_2)^{-1}$. The calculated values and the measured values agree according to the ratio test.

When a capacitor disharges, it starts at the max voltage $V = \varepsilon$ and decreases towards 0. When a capacitor is charged, it starts a 0 and increases toward the max voltage $V = \varepsilon$. There is an asymptote at 0 and ε respectively. The calculate τ value of 2.098±0.017ms agrees with the measured discharge values of 2.103±0.002ms and the measured charged values of 2.128±0.002ms according to the ratio test. The discharge τ and the charge τ do not agree according to the ratio test.

Final remarks
Adjust the formatting (pagination, margins, size of figures, etc.) of this report to make it easy to read. Save this report as a PDF document. Upload it to the course Moodle page. Ensure that your Excel file, Logger Pro file, and all pictures are saved to the Team.

Clean up your lab station. Put the equipment back where you found it. Remove any temporary files from the computer desktop. Make sure that you logout of Moodle and your email, then log out of the computers. Ensure that the laptop is plugged in. Check with the lab instructor to make sure that they received your submission before you leave.