

RC Circuits (Remote Version)

Safety and Equipment

- Computer with modern HTML5 web browser
- Two online resistor-capacitor simulations from The Physics Aviary:
 - <https://www.thephysicsaviary.com/Physics/singlepage.php?ID=380> (Charging)
 - <https://www.thephysicsaviary.com/Physics/singlepage.php?ID=52> (Discharging)

Introduction

When a DC voltage source is connected across an uncharged capacitor, the capacitor starts charging quickly. The only thing opposing the flow of current is any resistance in the circuit. But, as the capacitor fills, the potential of each plate gets closer to the potential of the corresponding terminal of the power supply. The drop in potential difference between a terminal of the power supply and a plate of the capacitor reduces the flow of current. This makes the rate of charging decrease as time passes. At first, the capacitor is easy to charge because there is very little charge on the plates and potential difference between a plate and a terminal is large. But as the charge accumulates on the plates, it becomes more difficult for the power supply to move additional charges onto the plates because the plates already have a charge of the same sign as the terminals on them. As a result, the capacitor charges exponentially, quickly at the beginning and more slowly as the capacitor becomes fully charged. The charge on the capacitor at any time is given by:

$$Q(t) = Q_{max}(1 - e^{-t/\tau})$$

The voltage across the capacitor is proportional to the amount of charge on the capacitor:

$$V_{cap} = \frac{Q}{C}$$

The voltage across the capacitor at any time is given by:

$$V(t) = V_{max}(1 - e^{-t/\tau})$$

Where V_{max} is the maximum voltage of the capacitor, and τ is the capacitive time constant ($\tau = RC$, where R is resistance and C is capacitance). The time constant describes the rate of the charge of the capacitor. The greater the time constant the longer it takes to charge the capacitor and vice versa.

NOTE: Taking the extreme limits, notice that when $t = 0$, $V(0) = 0$ which means there is not any charge on the plates initially. Also notice that when t goes to infinity, V approaches V_{max} . For any finite t , the voltage is less than V_{max} , which means it takes an infinite amount of time to completely charge the capacitor.

Objective:

- Experimentally determine the time constant of the R-C circuit.
- Investigate how a resistance affects the rate of charging of a capacitor

Part #1. Data Recording

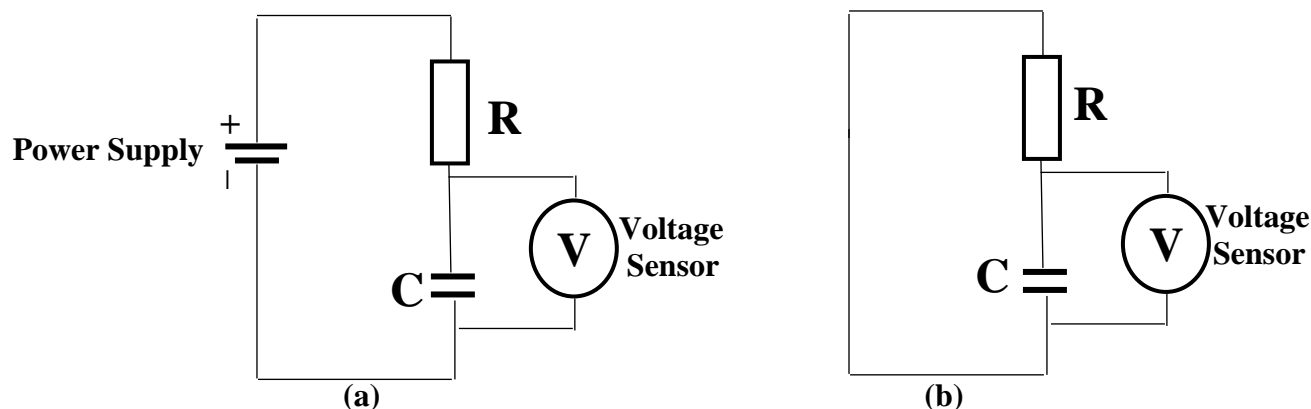


Figure 2. Schematic diagram of RC circuit for (a) charging and (b) discharging of the capacitor

1. **Charging:** Open the Charging a Capacitor in a DC Circuit (Lab) simulation from the Physics Aviary (<https://www.thephysicsaviary.com/Physics/singlepage.php?ID=380>) and click on the circuit diagram. (Note: In the simulation, the current is drawn as the direction of **electron flow**, not the direction of the **conventional current** I . That means it's backwards from what we're doing.)
2. When you start the simulation, it will set up a charging circuit with an 8.0 V battery, a 50 μF capacitor, a random resistance, and a switch to pause and restart the simulation.
 - While the switch is open (disconnected), the simulation is paused. The resistor voltage shows as zero (because $I = 0$ is the resistor current), and the capacitor's voltage is paused.
 - Clicking on the switch closes it. While the switch is closed (connected), the simulation runs quickly. The resistor and capacitor display live voltages, and the value of current is also shown.
 - A clock counts how long the capacitor has been charging.
3. Create a simple table to record the Charging Time and Capacitor Voltage. **Record the resistance and capacitance values** as part of the caption. You'll need these to form your conclusions.

Time (s)	Capacitor Voltage (V)
0	0
:	:
:	:

Table. Time and voltage recorded while (charging/discharging) a capacitor. This circuit had a resistance of _____ and Capacitance of _____. (Adjust caption for each specific data set.)

4. Discharge the capacitor by tapping on Discharge Capacitor.

5. Start the simulation by clicking on the switch. You should see the capacitor voltage start at a low value and build up toward the battery voltage.
6. Watch the capacitor voltage, and pause the simulation at approximately one volt intervals, up to 7 V. Try to be within 0.1 V of each voltage value. If you overshoot your target voltage too much, you can click Discharge Capacitor to run the simulation again. At each pause, record the Charging Time and the Capacitor Voltage.
7. When you have a set of values, reload the simulation to get a different resistance, and repeat the measurements to obtain another set of data points for charging the capacitor. This data series will have different times and slightly different voltages, so it will have to be a separate Table. Put it on the same spreadsheet, though, so you can graph the two series together.
8. **Discharging:** Open the RC Circuits (Lab) simulation from the Physics Aviary (<https://www.thephysicsaviary.com/Physics/singlepage.php?ID=52>) and click on the circuit diagram.
9. When you start the simulation, it will set up a discharging circuit, with a 1000 μF capacitor, a random resistor, and multimeters set up for measurement. Here are the controls:
 - Click on the resistor or capacitor to see the resistance or capacitance. You can also change them, which resets the simulation.
 - Click on Charge Cap to charge the capacitor to 9.0 V to start the simulation. It will be paused.
 - When paused, click on “Resume” to make the simulation run.
 - While running, click on “Pause” to make it pause.
 - Pause and click on a voltmeter to display the resistor voltage. This is also equal to the capacitor voltage, because they are connected in parallel. (They are connected by the red wire, and by the black wires. The ammeter acts like part of the black wire.)
10. Click on the resistor and change its value. Pick a resistor with an orange third band. Record the resistor colors and decode them (look up Resistor Color Code online).
11. Create a table to similar to the table above, except this time you will be discharging capacitor. **Record the resistance and capacitance values** as part of the caption.
12. Click Charge Cap to charge the capacitor. Take a voltmeter reading for 0.0 s.
13. Run the simulation and take time and voltage measurements approximately every 1 V. In this simulation, you can’t watch the voltage, so you’ll have to guess at what time to pause the simulation. Each point should be close (within 0.5 V) of the desired voltage. If you overshoot a voltage, you can Charge Cap to start over. Record the actual voltages, not just what you were shooting for. The last point can be for 2 V; you don’t have to wait until it gets to 1 V.
14. Change the resistance, charge the capacitor, and record another series of values in a separate table. Don’t forget to record and decode the second resistor’s color code.

Part #2. Analyzing the Data

1. Plot the data collected **during charging** of the capacitor as *two series* of V vs. t *on the same chart*. See https://youtu.be/1XvChT_15kA if you don’t know how.
2. Compare two graphed series and describe how the value of the resistance affects the rate of charge of the capacitor. Include this in the abstract.
3. Plot the data collected **during discharging** of the capacitor as *two individual V vs. t charts*. (It’s easier to interpret trendlines when the data is in separate charts.)
4. Fit each plot with an exponential function and display the equation of the trend line on the graph. Format the trendline equations so that each displays at least 4 decimal places in the exponent.
5. Edit the trendline equations to use physics variables, i.e. replace y with V and x with t in the equation.

- Determine the time constant, τ , from each trendline equation. [**HINT:** The voltage across the capacitor during discharge varies by: $V(t) = V_{\max}e^{-t/\tau}$, so the number in your exponent corresponds to $1/\tau$.] Record your analysis in a Table like the one below.
- Compare the time constants as calculated from experiment to the ones calculated from theory ($\tau = RC$).
- Describe how the value of the resistance affects the rate of discharge of the capacitor. Include this in the abstract.

RC Circuit	Trendline equation	Time Constant from Experiment	Time Constant from Theory
xx Ω resistor, 1000 micro-F capacitor			
yy Ω resistor, 1000 micro-F capacitor			

Table. Experimental results of the discharging capacitor where time constant was calculated from a trendline equation and from RC .

Requirements for the Formal Report:

The report must contain a **Header** at the top (Title of Lab, Authors, and Date)

The **Abstract** is a summary of the Main Body, so write it last. Place Abstract at the top of the report. Don't forget to summarize the discussion (with results) and conclusions!

The **Main Body** of the report must address the following:

- The Introduction should have the objectives of the lab and background information about RC Circuits. Describe the purpose of an RC Circuit, and provide an example of an RC Circuit. Include the theoretical equations for charging and discharging an RC circuit.
- The Methods should describe broadly what was done, using what tools, and what was measured/recorded.
- The Discussion should incorporate the following:
 - Analysis of the length and rate of charge/discharge for each resistor during charging and discharging. Is the length of charge similar for each resistor? Is the length of discharge similar for each resistor? How does each resistor alter the rate of charge? How does each resistor alter the rate of discharge? Overall, what impact does the resistor have on charging and discharging?
 - Analysis of the time constants based on measured and calculated data. How does resistance affect the time constant? Are the measured time constants similar to the theoretical time constants for each resistor? Explain differences between the measured and theoretical time constants.
 - The lab instructions contain several imperatives in Part 2 that will guide you with the Discussion based on the tables and graphs.
- Conclusions based on the quantitative results.

The **Data Section** must contain the following:

[Each graph and table should be labeled and captioned including the circuit component values.]

- 1 Graph w/ two sets of charging data (DO NOT fit trendlines)
- 2 Graphs w/ each set of discharge data (Fit trendlines to each discharge graph)
- 1 Summary Table with trendline equations and time constants.