Course and Section________ Names ______________________________

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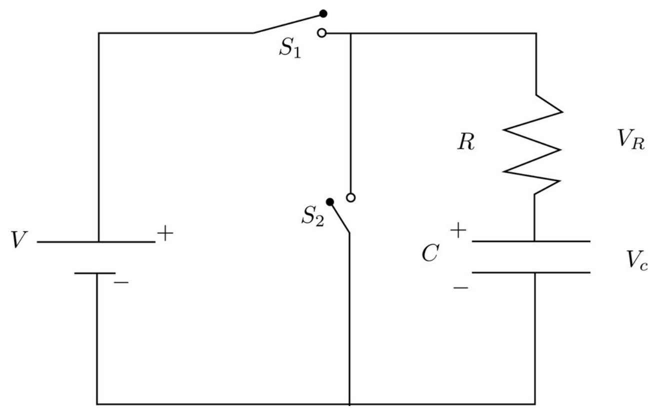
RC CIRCUIT SIMULATION

Introduction

In this simulation you will study the behavior of the current and voltages of a RC circuit.



In the diagram above we display an RC circuit. When we close the switch S_1 leaving the switch S_2 open, the capacitor is **charged** through the resistor by the constant voltage source. The voltages across the capacitor and resistor change exponentially with time. The voltage across the capacitor and the resistor are given as,

$$V_C(t)=V\left(1-e^{-t/\tau}\right) \qquad V_R(t)=V\,e^{-t/\tau}\ ,$$

where *V* is the applied voltage and τ=RC is the time constant.

Once the capacitor is charged we can open the switch, S_1 and then close the switch S_2 . The capacitor will now **discharge** through the resistor, the voltages across the capacitor and resistor in this case are given by,

$$V_C(t)=V\,e^{-t/\tau} \qquad V_R(t)=-\,e^{-t/\tau}\ ,$$

where *V* is the initial voltage across the capacitor.
The rate at which the capacitor charges or discharges is characterized by the time constant $\tau = RC$.
When **charging**, *RC* is the time that it takes for the capacitor voltage to increase from zero voltage to 0.632 times the charging voltage, since at $t = \tau = RC$

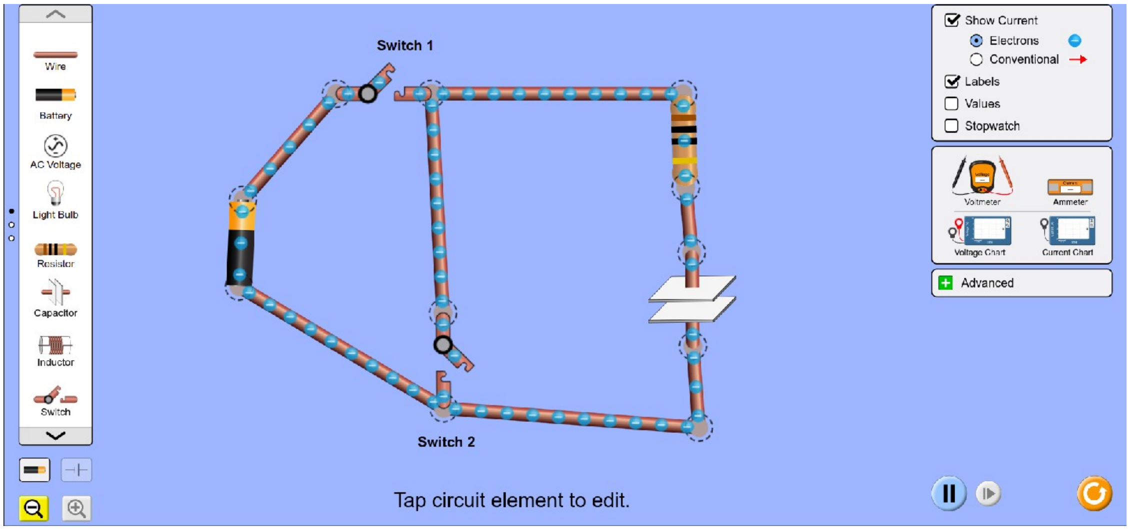
$$V_C(t)=V\left(1-e^{-1}\right) = V(1 - 0.368) = 0.632V, \quad or \quad 63\% \text{ of V}$$

Similarly, when **discharging**, *RC* is the time for the voltage to drop to 0.368 times its initial value, since at $t = RC$

$$V_C = V e^{-1} = 0.368V, \quad or \quad 36.8\% \text{ of V}$$

1 – Setup

Open the link (https://phet.colorado.edu/en/simulations/circuit-construction-kit-ac). Run the simulation and select "Lab" on the right. Opening this software you will see a blank canvas.



This simulation let you construct circuits. The circuit elements are displayed on the left side and can be dragged into the blue canvas. The numerical values of the circuit element, as resistance, capacitance, etc can be modified clicking on the element. Use the Voltmeter and the Ammeter and relative charts to take measurement and display graphs. To do so drag the meter into the blue canvas and move the red/black probes.

Create in the circuit simulator the RC circuit shown on the first page. It does not need to looks exactly like it, just match the connections as shown in the circuit in the figure above. Choose the following values for the resistor, the capacitor and the battery:
$R = 50\Omega$, $C = 0.2\text{F}$, $V = 5\text{V}$.

2 – Charging a Capacitor

Preliminary Questions: Suppose you have an RC circuit with R = 50Ω, C = 0.2F, hooked up to a battery with V = 5V. We are going to charge the capacitor.
1. Using the equations above what is the time constant τ? (s)
2. When t = τ what is the value of the voltage? (V)
3. What percentage of the battery voltage is the voltage across the capacitor at this time?
4. When t = 2τ what is the value of the voltage? (V)
5. What percentage of the battery voltage is the voltage across the capacitor at this time?
6. By what percentage of the battery voltage did the voltage across the capacitor change from t = τ to t = 2τ?
7. Is the following statement true: During charging, the capacitor gains the largest fraction of its final voltage during the time t = τ to t = 2τ.

To begin make sure your capacitor is discharged. That is the potential difference or voltage across the capacitor is zero. You can use the voltmeter to check that it is zero. If it is not zero we can discharge the capacitor by closing switch 2 and opening switch 1. Once the voltage is zero leave switch 1 open and open switch 2.

Since this is a simulation it also gives you the option to right click on the capacitor and choose discharge or charge capacitor. If you choose to do this for your setup make sure both switches are open so the capacitor will remain in the charged/discharged state until you are ready.

You are going to time the charging of the capacitor, i.e. the time and it takes for the capacitor to reach a specific value *Vc*. This can be done with your own stopwatch or the stopwatch in the simulation (it is much easier to use your smartphone as the stop watch). When your ready, start you first measurement *Vc* = 0.5V and repeat (or it might be more convenient to use the lap function on your stopwatch).

Make a copy of the the table below to collect your data (no need to turn it in). The voltage increases faster at the beginning.

Vc	0.5V	1.0V	1.5V	2.0V	2.5V	3.0V	3.5V	4.0V	4.5V	5.0V
Time										

<u>Plot *Vc* as a function of time.</u>

8. Looking at the plot, at about what time did the voltage reach 63% of its total voltage? (s)
9. Assume you do not know the value of the capacitor *C*, calculate *C* from the knowledge of *R* and time constant found in question 1. (F)
10. What is the percent error between the calculated values and the exact value of *C*?

<u>Plot in a semi-log format.</u>

If you solve $V_C(t)=V(1-e^{-t/\tau})$ for $e^{-t/\tau}$ and take the natural log of each side, then you can plot $y=\ln(1-V_C/V)$ vs and $x=t$. Draw a single line of best fit through your data.

11. Write your result as $y = m\, x$, what is the value of *m*? (1/s)
12. Using your plot and the result from question 4, what value of τ do you find? (s)
13. Again assuming we do not know the capacitance solve for C using your fitted value of τ and the known value of R. (F)
14. What is the percent error between the calculated value and the exact value of C?

3 – Discharging a Capacitor

Preliminary Questions: Suppose again you have an RC circuit with R = 50Ω, C = 0.2F, hooked up to a battery with V = 5V. This time we will discharge the capacitor.

15. Is the time constant τ different when we discharge a capacitor?
16. When t = τ what is the value of the voltage? (V)
17. What percentage of the battery voltage is the voltage across the capacitor at this time?
18. When t = 2τ what is the value of the voltage? (V)
19. What percentage of the battery voltage is the voltage across the capacitor at this time?

20. By what percentage of the battery voltage did the voltage across the capacitor change from t = τ to t = 2τ?
21. Is the following statement true: During discharging the capacitor loses the largest fraction of its initial voltage during the time t = τ to t = 2τ.

Repeat the set of measurements taken above but now you discharge the capacitor rather then charge it. The capacitor needs to be fully charged before you start. If you have not changed anything your capacitor should be charged from the previous step at 5V. If not you can open both switches and right click on the capacitor and select the charge option.

When you are ready, leaving switch 1 open, close switch 2 and begin timing the discharge of the capacitor as it discharges from 5V to 0V. Make a copy of the the table below to collect your data (no need to turn it in). The voltage increases faster at the beginning.

Vc	4.5V	4.0V	3.5V	3.0V	2.5V	2.0V	1.5V	1.0V	0.5V	0.0V
Time										

Plot *Vc* as a function of time.
22. Looking at the plot at about what time did the voltage reach 36.8% of its total voltage? (s)
23. Assume you do not know the value of the resistor R, calculate R from the knowledge of C and the time constant found in question 1. (Ω)
24. What is the percent error between the calculated values and the exact value of R?

Plot in a semi-log format.
If you solve $V_C(t)=V e^{-t/\tau}$ for $e^{-t/\tau}$ and take the natural log of each side, then you can plot $y=\ln(V_C/V)$ vs and $x=t$. Draw a single line of best fit through your data.
25. Write your result as $y = m x$, what is the value of m ? (1/s)
26. Using your plot and the result from question 11, what value of τ do you find? (s)
27. Again assuming we do not know resistance solve for R using your fitted value of τ and the known value of C. (Ω)
28. What is the percent error between the calculated value and the exact value of R?

4 – Non-Ohmic Materials

(this is a continuation about the topics discussed in the Resistor Simulation)
Ohm's Law states a particular relationship between the voltage applied actors a material and the amount of current which passes though it.

$$I=\frac{1}{R}V$$

This relation is linear in the sense that if you double the voltage also the current will double as the resistance stays constant. This is not true for all the materials. For example some material have a resistance which increases with the temperature (Joule Heating).

29. As you turn on a light switch, does the resistance of a light bulb stay constant ?
30. Do you expect a light bulb to follow the Ohm law?

Suppose we have a light bulb connected to a battery. We vary the voltage and measure the current passing through the bulb. Our measured data is recorded in the table below with the voltage in Volts and the current in mA.

V	1	2	3	4	5	6	7	8	9	10
I	2.61	5.07	7.46	10.8	12.6	14.3	15.6	16.2	16.7	16.9

Make a plot of I vs V (Use Excel or Libreoffice Calc or whatever you prefer)
31. It the relation between current and voltage in the table above linear?
32. Is the relation linear when the temperature of the bulb is low (i.e. the bulb is cold)?