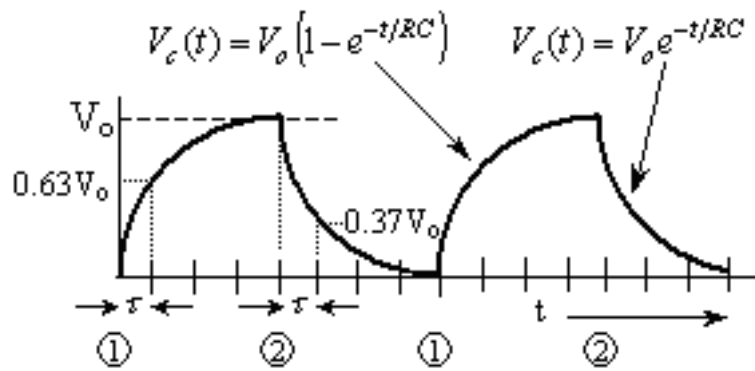
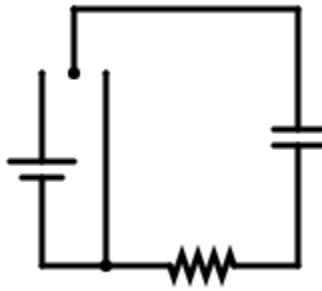


The RC Circuit



Produced by the Physics Staff at Collin College

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Purpose

In this experiment, you will both charge and discharge capacitors in an RC circuit. We will explore how the charging and discharging times depend on the resistance and capacitance in the circuit.

Equipment

- Computer with Internet Access
- Online Circuit Simulator: <http://falstad.com/circuit/>

Theory

When you connect a battery or power supply to an uncharged capacitor, the charge does not instantaneously appear on the capacitor plates. The charge on (and voltage across) the capacitor increases exponentially from zero. Similarly, the charge on (and voltage across) the capacitor decreases exponentially toward zero when you discharge it.

As with all properties that change at an exponential rate, the rate of change of the charge (or voltage) on a capacitor at any point in time is proportional to the amount of charge (or voltage) already present at that time. And like all exponential curves, both the half-life of the measured property (the time required for the property to change to half — or double — its value) and its time constant (the time required for the property to change to $1/e$ of its initial or final value) are constant. The values of the half-life and of the time constant depend on the values of C and R in the circuit.

Figure 1 shows a capacitor, a resistor, a switch, and a battery (power source) connected in series. Assume initially that the switch is open and there is no charge on the capacitor. When the switch is closed at time $t = 0$, current begins to flow in the circuit.

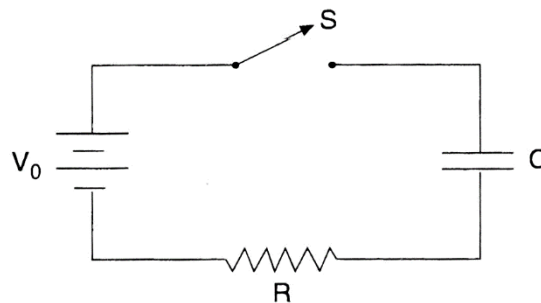


Figure 1

Kirchhoff's second rule states that the sum of all the voltage drops across the components of a loop (or series circuit) is zero. The voltage across the capacitor is q/C ; the voltage across the resistor is IR ; and the battery has a voltage V_0 . Assume that the voltages across the other circuit components (wires and switch) are negligible. Setting the sum of all the voltage drops to zero, you get

$$V_0 - q/C - IR = 0 \quad \text{Equation 1}$$

Since the current cannot flow across the capacitor, charge must accumulate on the two capacitor plates. The time rate of change or accumulation of charge is, of course, the current I , so

$$dq/dt = I \quad \text{Equation 2}$$

Eliminating I from equation (1) by using its value in equation (2), you get

$$V_0 - q/C - R(dq/dt) = 0 \quad \text{Equation 3}$$

Equation (3) is a differential equation for the charge on the capacitor as a function of time. Solving this equation, you get

$$q(t) = Q(1 - e^{-t/RC}), \quad \text{Equation 4}$$

where $Q = C \cdot V_0$ is the charge on the capacitor after an infinite time. This means that the voltage across the capacitor is

$$V_C(t) = V_0(1 - e^{-t/RC}), \quad \text{Equation 5}$$

where $V_C = q/C$. To find the current, divide the voltage across the resistor $V_R = V_0 - V_C$ to get

$$I(t) = V_R/R = (V_0/R)e^{-t/RC} \quad \text{Equation 6}$$

Note from Equations (4) and (6) that the initial charge on the capacitor is zero. This is consistent with the requirement that the capacitor be uncharged initially. The initial current (at $t = 0$) is V_0/R . This is the current that would flow if you replaced the capacitor with a short piece of wire. After an infinite time, the charge on the capacitor is Q , and the current in the circuit is zero.

The denominator in the exponent of Equations (4), (5), and (6) is RC . This factor is called the time constant τ_c of the series RC circuit. After a time equal to τ_c , the current in the circuit is reduced to $1/e$ (36.8%) of its initial value. This is true for all values of time: if you measure the current at any time while the capacitor is charging, the current at a time τ_c later will be 36.8% of the value you measured.

Another way of expressing the rate of current decrease is the half life of the circuit. The half life, τ_h , is the time for the current to be reduced to 50% of its value. The half life is related to the time constant by

$$\tau_h = \tau_c \ln 2 \qquad \text{Equation 7}$$

The half-life is the time for the capacitor to discharge from any given charge to half that charge, or the time required to charge a capacitor to one half the voltage of the power source.

Procedure

The basic procedure is to connect an uncharged capacitor, a resistor and a voltage source in series and measure the rate at which the voltage across the capacitor increases. However, we can also characterize the RC circuit by observing the decay of the voltage on a charged capacitor.

You will observe the discharge of a capacitor through a resistor. You will first charge the capacitor with a DC voltage, and then use a double-throw switch to disconnect the voltage source across the capacitor. You will measure V_C during both the charging and discharging of the capacitor, but you will record your measurements only for the discharge. You will start a stop watch when V_C has an arbitrary value; then stop the stop watch when V_C drops to half that value.

Building the Circuit

1. Open the circuit simulator by going to the following website: <http://falstad.com/circuit/>. A sample circuit is running when the page opens.
2. Click the Circuits pulldown menu then hover over the Basics submenu. Click Capacitor. This will automatically load our basic RC circuit.
3. Right click on the resistor and choose Edit. This will allow you to set the resistance. For now, set the resistance to 10 k Ω by typing '10k' into the textbox.
4. Right click on the capacitor and choose Edit. Set the capacitance to 330 μ F. The 'u' notation in the textbox indicates 'micro'.
5. Right click on the Battery and choose Edit. Set the Voltage to 4.5 V.
6. The graph at the bottom of the screen is the "Scope" and displays the voltage across the capacitor in green and the current in the circuit in yellow. You will notice that to the right of the graph is a time value and that time is passing but very slowly. You can alter the flow of time here by adjusting the red and grey slider in the upper right of the screen labelled Simulation Speed. You can also pause the flow of time entirely by clicking the Run/Stop button.

Data Collection

1. Charge the capacitor by closing the switch to the left such that the Capacitor charges through the Resistor. Let the capacitor charge until the voltage across it is at least 4 volts. You can adjust the simulation speed.
2. Move the switch to the right position so that the Capacitor discharges through the Resistor. If you sped up the simulation speed, you may want to slow it back down and be ready to push the Run/Stop button.
3. When the voltage across the capacitor reaches 3 volts, record the value for t found to the right of the Scope Display in Table 1.
4. When the voltage reaches 1.5 volts, stop the watch and record the value for t in Table 1. Calculate and record the measured time of the half-life, τ_h in Table 1 as $\tau_h = t_f - t_i$.
5. Calculate and record the measured time constant τ_C of the RC circuit in Table 1 as $\tau_C = \tau_h / \ln(2)$.
6. Calculate and record both the theoretical time constant and theoretical half-life of the circuit using $\tau_C = RC$ and $\tau_h = \tau_C \ln(2)$. Record these values in Table 1.
7. Calculate and record the percent error in your experimental value of the time constant and half-life for this combination of capacitor and resistor. Given that this is a simulation, the percent error should be extremely low. Record these in Table 1.
8. Right click on the Resistor and choose Edit. Set the resistance to 22 k Ω and repeat steps 1 – 7. Record all results in Table 2.
9. Right click on the Resistor and choose Edit. Set the resistance to 10 k Ω . Right click on the Capacitor and choose Edit. Set the capacitance to 1000 μF . Repeat steps 1-7 and record all results in Table 3.
10. Right click on the Capacitor and choose Edit. Set the capacitance to 2200 μF and repeat steps 1 – 7. Record all results in Table 4.
11. Right click on the Resistor and choose Edit. Set the resistance to 22 k Ω and repeat steps 1 – 7. Record all results in Table 5.