

Experiment 21

RC Time Constants

Advanced Reading:
(Serway & Jewett 8th Edition)
Chapter 28, section 28-4.

Equipment:
1 universal circuit board
1 680K Ω resistor
1 1.8M Ω resistor
4 jumpers
1 47 μ F capacitor
1 Kelvin DMM leads
1 power supply
1 stopwatch

Objective:

The objective of this experiment is to measure the time constants for two RC circuits and to determine the effect of a voltmeter on the circuit.

Theory:

A circuit containing a resistor connected in series with a capacitor is called a RC circuit. When a charged capacitor discharges through a resistance, the potential difference across the capacitor decreases exponentially. The voltage across the capacitor in this case is given by:

$$V = V_0 e^{-t/RC} \quad \text{Equation 1}$$

where V_0 is the potential difference across the capacitor at time $t=0$.

The RC time constant (represented by τ) is defined as the time it takes for the voltage to drop to 37% of its original value (i.e., when the voltage is $1/e$ of its original value, e being the irrational number 2.718...). This is the case when $t=RC$. The time that it takes for V_0 to drop to 13.5% of the original voltage [since $(1/e)(1/e) = 1/e^2 = 0.135$] is two times the RC time (i.e., $2RC$).

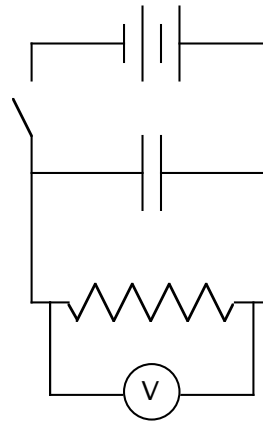


Figure 21-1
Capacitor discharging

If voltage vs. time is graphed on Cartesian coordinates, the result is an exponential decay curve. From this curve it is possible to determine:

1) the time constant, by locating the **$1/e$ point** when the voltage V_0 has dropped to 37% of its original value.

From this $1/e$ point (i.e., voltage value) a horizontal line is drawn to the curve and then extended down (vertically) to a point on the $x(\text{time})$ -axis. This time is the RC time.

2) two times the RC time, by locating the **$1/e^2$ point** when the voltage V_0 has reached 13.5 % of its original value. Use the same procedure as above.

From $V = V_0 e^{-t/RC}$ we get $\ln V = \ln V_0 - t / RC$
or $\log V = \log V_0 - t / RC \log e$.

Graphing voltage vs. time on a semi-log plot yields a straight line with *slope of minus $1/RC$* , so that the value of the time constant can be determined.

Procedure:

1. Construct the circuit that appears in figure 21-1 using the 680K Ω resistor. **Note: The capacitors have a polarity. They must be placed in the circuit with the negative side of the capacitor on the negative side (black pole) of the power supply).**
2. After having the circuit approved by your lab instructor, turn on the power supply and charge the capacitor until it reads 10 volts. Disconnect the wire from the power supply and begin monitoring the voltage in **5 second intervals** for the first 20 seconds, **10 second intervals** until 60 seconds and **twenty second intervals** until you reach a total time of 120 seconds. Record these voltages and times in your lab notebook. **You should prepare a data table before you start.**
3. Repeat steps 1 and 2 for the 1.8M Ω . and for the unknown resistor if you have one. **Please note that your twenty second intervals should extend to 220 seconds.**
4. Graph voltage versus time on Cartesian coordinates using **Graphical Analysis**. You will now determine the equation of your plotted data. Go to **Analyze/ Automatic curve fit** and choose exponential curve fit (**Exp**). Go to **file/page setup** and change size from 100% to 80%. Print the graph. Using a straightedge locate the $1/e$ and the $1/e^2$ points and the *defined times* for the discharge curves and label them on the graph.
5. Next, graph voltage versus time for each RC circuit on a semi-log graph, with voltage on the logarithmic (Y) axis and time on the linear (X) axis. Go to **Data/New Calculated Column/**. Rename column from “**calculated column**” to “**C*log of potential**” and add units. Next go to “**functions**” and high light “**ln()**”. Then go to “**variables (column)**” and high light “**Y**” (or whatever you named your previous Y column). Redraw the graph by clicking on the “Y” (label of graph) next to the y-axis and selecting “**log of potential**”

column. Determine the slope of the line by using the automatic curve fit and choosing a Linear fit. The slope of this line is equal to $1/RC$. Calculate the RC time constants from the slopes for each of the RC circuits.

6. Measure the resistance of your resistors with the ohmmeter. Your instructor will give you the DMM values of your capacitor. Calculate the RC time values using the DMM values. See Theory.
7. You have now determined the RC time constant for each resistor by three different methods. (DMM, Cartesian and semi-log plots). Calculate the percent difference between the DMM values and the average experimental values obtained from the experiment.
8. Calculate the percent difference between the $1/e^2$ time obtained from the Cartesian plot and the DMM $1/e^2$ time value. Please note that two times the RC value is the $1/e^2$ time.

Questions/Conclusions:

1. Show that the product of RC has the units of seconds ($t=RC$).
2. If an RC circuit had a time constant of 20 seconds, how long would it take for the circuit to discharge to $1/e^5$ of its original value?
3. Discuss the effect of the DMM (i.e., the voltmeter) on your circuit and on the RC time compared to an ideal voltmeter.
4. You are to manually plot **one set of data only** (either the 620K Ohm or 1.8 M resistor data) **on a sheet of semi log paper**. You should then manually fit a line to your data. Lastly, determine the slope of your linear fit. **Show all work**. Compare your fit to the computer fit. Go to the website below for questions about semi log plots, to download paper and how to determine the slope. See panel 6.

<http://www.physics.uoguelph.ca/tutorials/GLP/>