

Experiment 21

RC Time Constants (FALL 2020)

Advanced Reading:
Openstax- University Physics-Vol 2
Chapter 10, section 10-5

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., $2RC$).

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

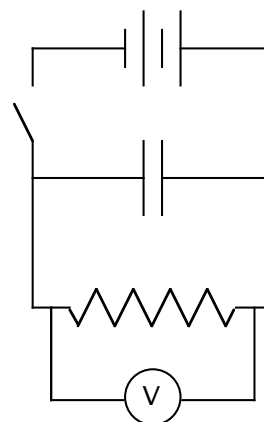


Figure 21-1
Capacitor discharging

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 exponential curve and then extended down (vertically) to a point on the x (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 the relationship $V = V_0 e^{-t/RC}$

we see that

$$\ln V = \ln V_0 - t / RC \quad \text{or} \quad \ln V = -t / RC + \ln V_0 .$$

Graphing natural log of voltage vs. time on a semi-log plot yields a straight line with *slope of minus $1/RC$ & a y-intercept of $\ln V_0$* , 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 .

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**).

Print the graph. Be sure and use **“Print Graph” and not “Print”**.

Using a straightedge locate the $1/e$ and the $1/e^2$ points (on the y axis) and the *defined times* for the discharge curves and label *these times on the x axis of the graph*.

5. Next, graph voltage versus time for each RC circuit on a semi-log graph, with the natural log of voltage (**i.e., ln voltage**) on the logarithmic (Y) axis and time on the linear (X) axis. **Note that y axis has no units.**

Go to **Data/New Calculated Column/**. Rename column from **“calculated column”** to **“ln voltage”**. 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 **“ln voltage”** 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. Print graph(s).

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. In theory, the time to fully discharge a capacitor would approach infinity, but in practice five RC time constants is usually enough.

Assuming that the DMM you used has a resolution of 0.1 volts and a 10V initial voltage, show that 5 RC time constants is a good estimate for the capacitor being totally discharged.

2. 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.

There are many good websites to show you how to plot and how to (linearly) fit your data.

Semi-log paper can also be found on the PHYS222 lab website.

3. Show how you calculated the equivalent resistances of each resistor when they are (individually connected in parallel) to a 10 M ohm voltmeter. Use the (resistor) resistances you measured with the DMM ohmmeter.

You will find that the (equivalent) resistance of each resistor (with voltmeter attached) is reduced.

By what fraction were they both affected? Is this what you would expect? Why? **Show all work.**

One way to avoid this effect is to use a more expensive voltmeter. What is the resistance of a ‘high precision’ voltmeter? See top of page 468 of text.