Experiment 21
RC Time Constants

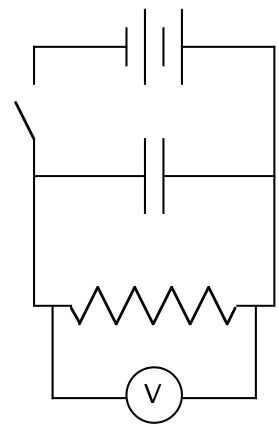
Figure 21-1
Capacitor discharging

Advanced Reading:
University Physics Vol.2 by OpenStax, Chapter 10 Section 5

Equipment:
1 universal circuit board
1 680KΩ resistor
1 1.8MΩ resistor
4 jumpers
1 47μF 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:

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 680KΩ 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 1.8MΩ. **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 time 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. Show that the product of RC has the units of seconds (t=RC).

2. 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 0.1volts and a 10V initial voltage, show that 5 RC time constants is a good estimate for the capacitor being totally discharged.

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.

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-line.

PHYS222
Results
RC Time Constant Experiment

Part 1 Results

680 K ohm Resistor and 47 μF capacitor

Method	**RC time (τ) (sec)**	**% diff** (w.r.t. ideal Voltmeter)	**2xRCtime(2τ) (sec)**	**% diff** (w.r.t. ideal Voltmeter)
Color code (0.680M Ω x47 μ F)				
R_{DMM} times C_{DMM} (ideal voltmeter)		**xxxxxxxxx**		**xxxxxxxx**
R_{eq} times C_{DMM} (real voltmeter)				
Cartesian plot				
Semi-log plot				**xxxxxxxx**

Part 2 Results

1.80 M ohm Resistor and 47 μF capacitor

Method	**RC time(τ) (sec)**	**% diff** (w.r.t. ideal Voltmeter)	**2xRCtime(2τ) (sec)**	**% diff** (w.r.t. ideal Voltmeter)
Color code (1.80 M Ω x 47 μ F)				
R_{DMM} times C_{DMM} (ideal voltmeter)		**xxxxxxxxx**		**xxxxxxxx**
R_{eq} times C_{DMM} (real voltmeter)				
Cartesian plot				
Semi-log plot				**xxxxxxxx**