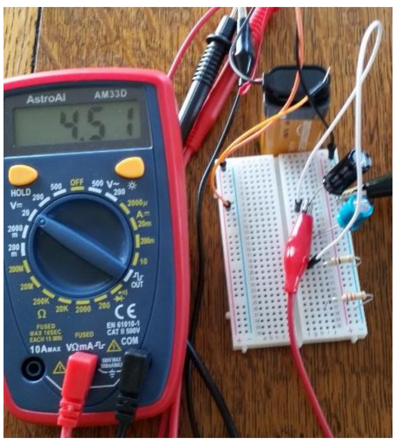
Physics 196 Lab 7: RC Time Constant

Equipment:

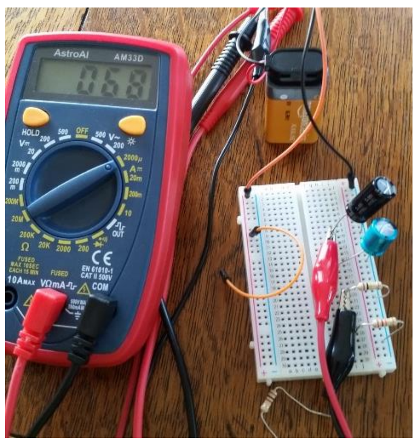
This week's experiment will use your hand's on kits. You will need the following:

Digital Multimeter with probes
1 x 9V battery with battery clip and female-male extenders
2 x alligator-alligator leads
Breadboard
2 x male-male jumper wires
1000 μF capacitor, 330 μF capacitor (For RC circuit)
100 kΩ resistor (brown-black-yellow), 22 kΩ resistor (red-red-orange) (For RC circuit)
1 kΩ resistor (brown-black-red) (for measuring current if DMM fuse is blown)

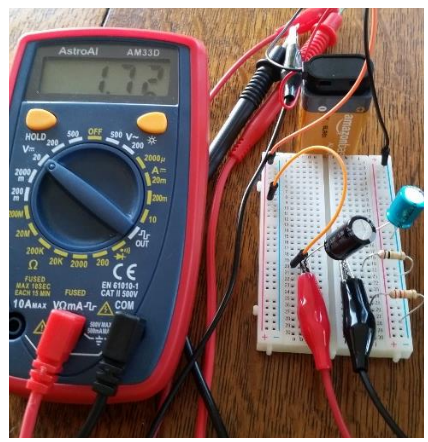
Layouts:



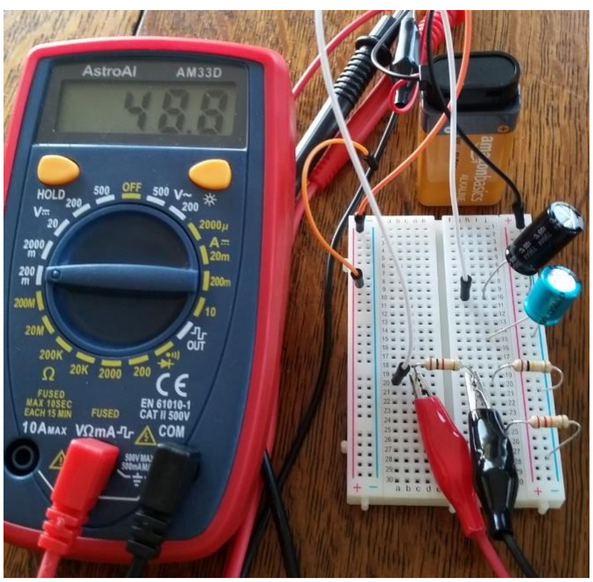
A. Capacitor voltage decay vs. time



B. Resistor Current decay vs. time



C. Capacitor voltage increase vs. time



D. Alternate way to measure current by measuring voltage across small resistor in series with large resistor.

Summary:

Students will use their hand's on kits to explore the RC time constant by observing the following:

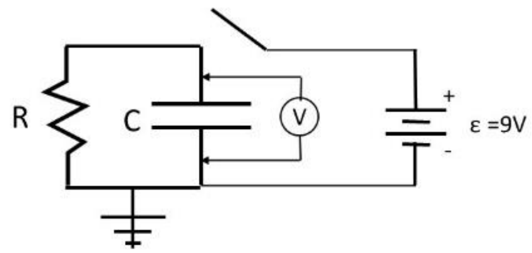
A. Voltage across a capacitor in an RC circuit decaying as a function of time after the capacitor has been charged by a battery: $V_C = V_0 e^{-t/RC}$ where V_C is the voltage drop measured across the capacitor, corresponding to its charge $Q = V_C C$.

B. Current through a resistor in an RC circuit decaying as a function of time after the capacitor has been charged by a battery: $I = (V_0/R)e^{-t/RC}$. (If the student's fuse is blown so the multimeter no longer measures current, an alternate method D is provided).

C. Voltage across a capacitor in an RC circuit increasing as a function of time while the capacitor is being charged, $V_C = V_0 (1-e^{-t/RC})$

Prelab: Tape the first page of the lab write-up (including materials, equipment photograph and summary) in your laboratory notebook. Calculate the RC time constants for the four possible combinations of resistors (one of 100 kΩ or 22 kΩ) and capacitors (one of 1000 μF or 330 μF) being used for the experiment.

Prepare a full page table in your lab notebook for data collection. (It will be most convenient if you put this table on a left page in the notebook, leaving room on the opposite right page for a graph). You will be measuring a voltage or current as a function of time from 0 to 330 s, every 10 s. All of the measurements in this table will be for a 1000 μF capacitor combined with a 100 kΩ resistor having an RC time constant of 100 s. There should be 34 rows below the column labels. There should be columns titled as follows: Time (s), Predicted Decay Voltage (V), Measured Decay Voltage (V), Measured Decay Current (μA), Measured Charging Voltage (V). Fill in the Time column with times from 0s to 330s every 10s.



Calculate the expected voltage across a capacitor as a funcition of time in a simple RC circuit as shown (R=100kΩ, C= 1000 μF, τ = RC = 100s) after the capacitor has been charged from a 9V battery, and then the battery is disconnected at time t=0. ($V_C = V_0\, e^{-t/RC}$). Do this calculation for 30 s increments and fill the values into the second column of the table (remember, you will skip two rows each time before filling in the next value).

On a second full page of your notebook, make a careful graph. (It will be most convenient if this is on the right hand page across from your data table.) Take your time, this same graph will be used to graph all of the data you take during this lab. Start about two rows left of the dark line on the notebook page, about 4 rows up from the bottom. Draw in an x-axis all the way across the page. Label this as time(s) and go from 0s to 330s across 33 grid squares. Label the time every 60 seconds. Draw a y axis at 0 s. On the left axis this will be labelled in Volts (V) going from 0V to 9.5V, with each square corresponding to 0.25V. (4 squares per volt, you need 38 squares vertically on the page). There will be an example in the lab video. Carefully plot in the points from your prelab calculation, with a lightly sketched curve connecting the points.

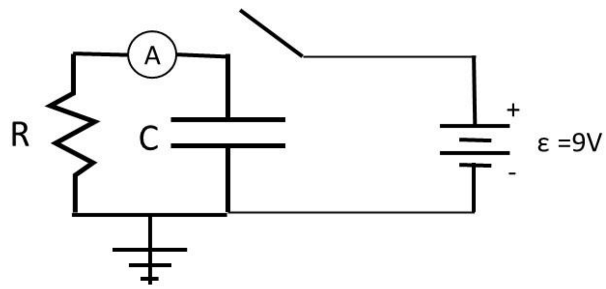
Lab:

Experiment A: Voltage Decay vs. time, R=100 kΩ, C=1000 μF

Attach a 9V battery from the + column to the – column on the breadboard. (Positive 9V on +, negative terminal on – representing a 0V circuit ground). Figure A shows both resistors and both capacitors inserted in the breadboard with one end in the ground column. (Note that the capacitors have the shorter lead, marked -, going into the 0V ground column). For the first few experiments you will only be using the 100 kΩ resistor and 1,000 μF capacitor. Connect the free ends of the capacitor and resistor (the ends not in the negative column) with a jumper wire. With the Digital Multimeter on the 20V setting, connect the black lead to the 0V ground end of the capacitor, and the red lead to the positive end of the capacitor. Insert a second jumper wire in the positive voltage column. Hold the other end of this wire to the positive end of the capacitor and observe the voltage on the DMM. The circuit diagram for this experiment is the same as the one shown in the prelab. The DMM should read somewhere near 9V. This is your starting voltage at time t=0. Record it in the data table column for Measured Decay Voltage. Now start a timer and disconnect the jumper wire used to charge the capacitor at the same time (t=0). Record the voltage reading on the Digital multimeter every 10 seconds for 330 seconds and record the values in the data column. After about 100 seconds (the RC time constant) the voltage should have deacyed to 1/e of its initial value. (about 0.368 x 9V = 3.31V). After about 200 seconds (2x RC time constant) it should have decayed to about e^{-2} of its initial value (about 0.135 x 9V = 1.22V) and after about 300 seconds (3 x RC time constant) it should have decayed to about e^{-3} of its initial value (about 0.050 x 9V = 0.45V). Carefully plot the data points on your graph (the same one from the prelab).

Experiment B: Current Decay vs. time, R=100 kΩ, C=1000 μF

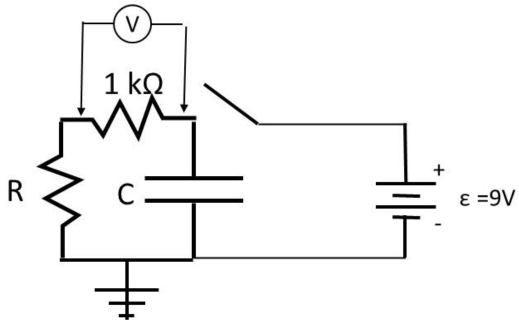
This experiment will be similar to Experiment A, except that you will measure the current going from the capacitor through the resistor instead of the Voltage.



To do this, simply replace the jumper wire between the positive ends of the resistor and capacitor with the digital multimeter on the most sensitive setting. (This is 2000 μA on my AstroAI meter). The red alligator clip should connect to the positive end of the capacitor, and the black alligator clip should attach to the negative end of the capacitor as in Photo B. Charge up the capacitor with the jumper from the 9V column, and then disconnect that at time t=0 and start reading the current. (Record the steady current before disconnecting the jumper as the value for t=0 in the data table column Measured Decay current). Record the current every 10 seconds for 330 seconds. The initial value should be somewhere around 9V divided by 100 kΩ, that is 90 μA. To plot the data points, put a second vertical axis on the right side of your graph which goes from 0 to 95 μA, with 2.5 μA per square (that is, 10 μA every 4 squares). 95 μA should line up vertically with 9.5V. Plot these points on the graph. You will want to use a different symbol than what you used for the voltage plot, because the points may be close to the same places on the graph. You should notice that the current decays in exactly the same way as the voltage.

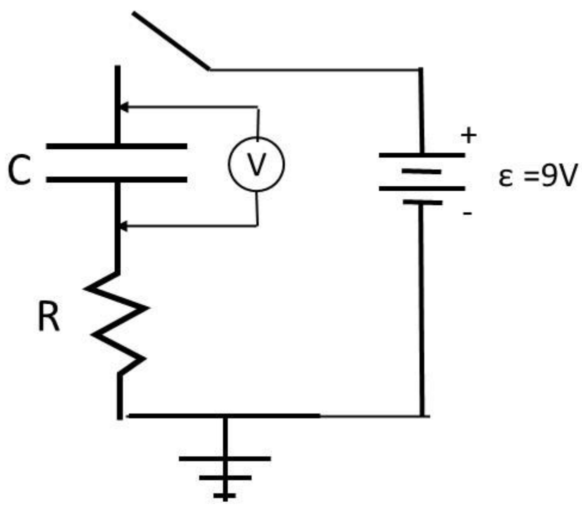
Some of you may no longer be able to measure currents with your DMM because the fuse needs to be replaced. If you place your 1 kΩ resistor in series with the 100 kΩ resistor as in photograph D (and the circuit diagram below), it should only have a 1% effect on the total resistance in the circuit, and thus the time constant. When the current decays and flows through this resistor, there will be a voltage V=IR with R = 1 kΩ. So if you measure the voltage across this resistor, 1 mV of voltage will correspond to 1 μA of current. Record the voltage as a function of time in your data table (mV). Then before plotting the data, convert it to μA. Make a note of what you are doing.

Even if you do not need to measure current this way, it is instructional to try the method out (without collecting the full data set).



Experiment C: Voltage vs. Time Charging the Capacitor, R=100 kΩ, C=1000 µF

This experiment will show the other shape of curve you encountered in class, where $V_C = V_0 (1-e^{-t/RC})$. The setup is shown in Photo C, and the circuit diagram is below:



For this experiment, it is necessary to start with the capacitor fully uncharged. With the battery jumper not connected, hold a jumper wire across the two terminals of the capacitor to "short it out" which will cause the voltage drop across the capacitor to be 0, and thus there will be no charge Q=CV. The Digital Multimeter should be on the 20V scale. Your first value in the data table for the column labelled Measured Charging Voltage should be 0V. Now at t=0, connect the jumper from the battery column to the positive end of the capacitor (using a hole in the breadboard). It will take time for the capacitor to charge up because the current has to flow through the resistor with the RC time constant. Record the voltage every 10 seconds for 330 seconds. Plot these points carefully on your graph. Make sure the shape of the plotted curve makes sense to you, and seems to agree with the formula at the beginning of the Experiment C description. Eventually the capacitor voltage should approach the battery voltage.

Experiment D: Time constants for different RC combinations.

So far you have used the 100 kΩ and 1000 µF capacitors giving a time constant of 100 seconds. (By the way, this is an extremely long time constant. In typical circuits time constants may be in the ns to ms range and are used as high pass filters (to block DC signals) or low pass filters (to block high frequency voltage spikes). In this experiment you will measure the time constants which you get with the 100 kΩ resistor coupled with the 330 μF Capacitor, the 22 kΩ resistor coupled with the 1,000 μF Capacitor, and the 22 kΩ resistor coupled with the 330 μF Capacitor and compare with your prelab predictions.

Look at your graph for Experiment A. Take the initial voltage value at t=0, and divide that by e. (Multiply by 1/e = 0.368). Draw a horizontal line on your graph at the calculated voltage (which should be around 3.3V depending on your battery). Draw a vertical line where this intersects your data from experiment A, and continue this down to the x-axis. This should give you the value of the time constant (around 100 seconds).

To get the time constant for the other RC configurations, simply hook the circuit up as in Experiment A with the different resistors and capacitors (one combination at a time) and time how long it takes to get to the voltage calculated in the previous paragraph (near 3.3V). This should be the time constant for that RC combination.

Have fun, and try to get a good understanding of the exponential RC decay curve. Be sure to write a complete description of the experiment in your lab notebook, including labelled experimental diagrams with electrical connections, procedures, results (including data table) and conclusions. If I were being thorough, I would also have you take the natural log of the voltage data, which should give a straight line when plotted against the time, with the slope corresponding to -1/RC. Think about why this would be the case (but you don't need to make the graph).