Lab 5

RC Circuits

What You Need To Know:

The Physics In the previous two labs you've dealt strictly with resistors. In today's lab you'll be using a new circuit element called a *capacitor*. A capacitor consists of two small metal plates that are separated by a small distance. This is evident in a capacitor's circuit diagram symbol, see **Figure 1**. When a capacitor is hooked up to a circuit, charges will accumulate on the plates. Positive charge will accumulate on one plate and negative will accumulate on the other. The amount of charge that can accumulate is partially dependent upon the capacitor's *capacitance*, C.

With a charge distribution like this (i.e. plates of charge), a uniform electric field will be created between the plates. [You may remember this situation from the Equipotential Surfaces lab. In the lab, you had set-ups for two point-charges and two lines of charge. The latter set-up represents a capacitor.] A main function of a capacitor is to store energy. It stores its energy in the electric field between the plates.
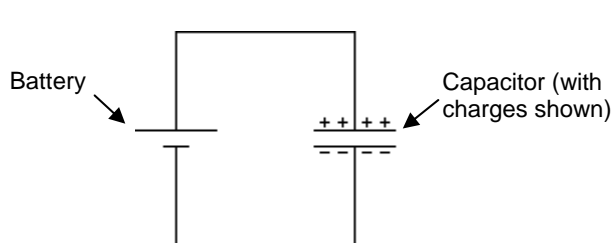

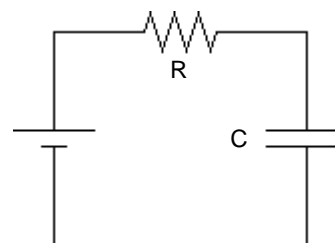
FIGURE 1 - Battery/Capacitor

FIGURE 2 - RC Circuit

If you hook up a battery to a capacitor, like in **Figure 1**, positive charge will accumulate on the side that matches to the positive side of the battery and vice versa. When the capacitor is fully charged, the voltage across the capacitor will be equal to the voltage across the battery. You know this to be true because Kirchhoff's Loop Law must always be true. Convince yourself of this, it's important later. The capacitor will reach its maximum voltage almost instantaneously because there is nothing in the circuit to slow down the current flow. If we now put a resistor in series with the capacitor, see **Figure 2**, it will slow down the flow of current. It will now take a longer time for the capacitor to "charge up".

If you make a graph of the voltage across the capacitor, V_c, versus time, t, as it is charging up, it would look like the graph in **Figure 3**. This is an exponential curve.

FIGURE 3

Voltage vs. Time
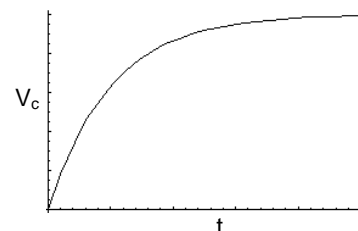
The equation that determines the exponential graph in **Figure 3** is as follows …

$$V_C = V_{MAX}(1 - e^{-t/RC})$$

(Charging)

V_C is the voltage across the capacitor (in volts, V)
V_{MAX} is the maximum capacitor voltage (in volts, V)
R is the resistance of the resistor (in ohms, Ω)
C is the capacitance of the capacitor (in farads, F)
t is the time (in seconds, s)

Due to the fact that the equation is exponential, it will take an infinite amount of time for the capacitor to charge to its maximum voltage. You can see this in the graph. This is too long to wait, so instead we talk about the time it takes the capacitor to reach *half* of its maximum value. This is called the *half-life*. The equation for the half-life is as follows …

$$t_{1/2} = RC \ln 2$$

$t_{1/2}$ is the half-life (in seconds, s)
R is the resistance (in ohms, Ω)
C is the capacitance (in farads, F)

Eventually the capacitor will be sufficiently charged, as shown after a long time in **Figure 3**. If we remove the battery and replace it with a wire, then the capacitor will want to discharge. This is because there is no longer anything forcing the capacitor to hold its charge. There is a different equation for V_C when the capacitor is discharging (you'll see this later in the lab), but the half-life equation holds for charging and discharging.

In today's lab you will be measuring the half-life for the RC circuit shown in **Figure 4**. You will be finding the half-life in three different ways: using a direct measurement, using a graph, and using the computer. Finally, there will be a fourth section in which you will have to apply what you've learned thus far in the lab.
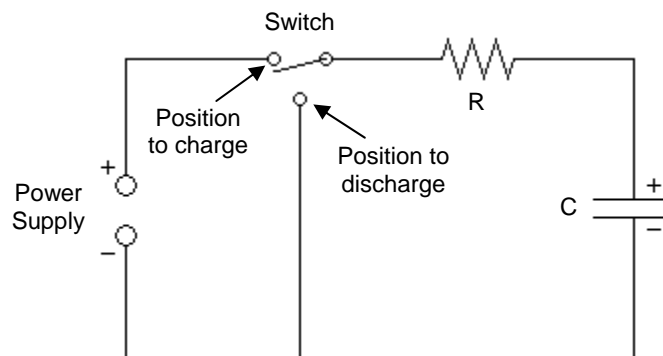
What You Need To Do:

FIGURE 4 – RC circuit

Part 1 – Half-life By Stopwatch   The first way you are going to measure the half-life of your circuit (**Figure 4**) is by using observation and a stopwatch.

A) If not already done, hook up the circuit to the power supply using OUTPUT1.

B) Flip the switch on the circuit board to **Discharge**. **Helpful Hint:** If you ever want to quickly discharge the capacitor, use the small extra wire with clip ends. Just touch the ends on either side of the capacitor. You don't even have to clip them on, just touch them to the wires. The capacitor will quickly discharge through the wire, instead of the resistor.

C) Make a chart in your lab report like **Chart 1** below. NOTE: You won't be plugging in any numbers into the grayed out areas.

	Half-Life (Charging)	Half-Life (Discharging)	Average Half-Life	Calculated Half-Life	% Error
Part 1					
Part 2					
Part 3					

CHART 1

D) Turn on the power supply and set it to 5 V.

E) Turn on the voltmeter and set it up so that it is measuring the voltage across the capacitor. You can leave it in the 20 V range for the entire lab.

F) You will be using the stopwatch on the table. Make sure you know how to use it. You can also use a timer on your own cell phone (or whatever). [This might actually be a better idea since the stopwatches are ancient and some don't work all that well.]

G) Start your timer as you flip the switch to **Charge** and measure the time it takes to get to half of the maximum voltage of 5 V. Record this value in the chart.

H) Let the capacitor continue to charge all the way to 5 V even though you have your data. It may take a minute or two. As long as it gets into the 4.9 V region it's fine.

Color Band Chart

BLACK	0
BROWN	1
RED	2
ORANGE	3
YELLOW	4
GREEN	5
BLUE	6
VIOLET	7
GRAY	8
WHITE	9
RED	2%
GOLD	5%
SILVER	10%

I) Now you are going to measure the half-life again but in a different way. Start your timer as you flip the switch to **Discharge** and measure the time it takes to get to half of the maximum voltage of 5 V. Record this value in the chart.

J) Sketch a graph of what you think the voltage of the capacitor versus time will look like.

Question 1 Why should you get the same half-life for the charging and discharging cases? Base your answer on examining your graph and the one in **Figure 3**.

K) Average your two half-life values and place this value in your chart.

L) Use the color band chart to determine the resistance of your resistor. Record this value. Also record the value of the capacitance of the capacitor. [It is written on the side of the capacitor in μF.]

M) Using the two values from **L)**, calculate the half-life of the circuit.

N) Find the percent error of your measured value to the calculated value. Show all of your work for this and place the value in the chart.

Question 2 What are some sources of error that would make the percent error high?

Part 2 – Half-life By Linearization In the Physics 225 Lab you did a lab on the 1st day called **Graphical Analysis**. In this part of the lab you are going to be measuring the half-life of the circuit using the method you learned last semester in **Graphical Analysis**. Your TA should go through an example of this process to refresh your memory.

Time	Voltage
10	
15	
20	
…	
75	

CHART 2

A) Flip the switch to **Charge** and let the capacitor charge up. While you wait, make a chart like **Chart 2.** Have the time start at 10 s and go up to 75 s in increments of 5 s.

B) Once the capacitor is fully charged, flip to **Discharge** and while the capacitor is discharging, write down the capacitor voltage for the times listed in the chart. This can be a little hectic, so work as a team. One person should monitor the stopwatch and the other should write down the data.

C) Open the software on the desktop of the computer called **Graphical Analysis**. Use this to make a plot of your data as V_C vs. t. Once plotted, make a rough sketch in your lab report.

D) The graph you just made should look the same as the one you drew in **Part 1 – J** (they are both for a discharging circuit). If this is not the case then you may want to amend your answer to **Question 1** since your answer is based on an incorrect graph.

Notice that the line in your graph is not linear. You now are going to go through a process to linearize the graph so that you can glean some data from it. It is very similar to what your TA described to you.

E) The equation below is for a discharging capacitor. In its present form it is a non-linear equation. Transform this equation so that it can be interpreted as linear, (i.e. y = mx + b). On your paper note what "y" will represent, what "m" will represent, what "x" will represent, and what "b" will represent.

$$V_C = V_o e^{-t/RC}$$
(Discharging)

V_C is the voltage across the capacitor (in volts, V)
V_o is the initial capacitor voltage (in volts, V)
R is the resistance of the resistor (in ohms, Ω)
C is the capacitance of the capacitor (in farads, F)
t is the time (in seconds, s)

F) Add a new column to **Chart 2**. Head the column with whatever you calculated to represent "y". Using the previous data you took, do the calculations for *your* "y" and place them in this column. Many people do this part wrong and use the entire linearized equation. *This is wrong.* You only use what you got for your "y" to calculate the numbers you put in the chart.

G) Use **Graphical Analysis** to make plot of "y" vs. time. [Make sure you erase the other data first.] You have now forced the original graph to be linear. Sketch the graph on your paper.

H) Press the "R=" button to calculate the slope of the line. The slope will be given in a small screen.

I) Use the expression you got for "m" and set it equal to the value for the slope. From this equation, calculate the value of RC.

J) Use this RC value to calculate the half-life using the half-life equation and place the value in the chart.

Question 3 Is this new half-life value better or worse than the value you calculated in **Part 1**? Explain why you think so in either case.

Part 3 – Half-life By Computer Now you are going to use the Logger Pro software on the computer to measure the value 'RC' directly by using both the charging case and discharging case.

CHARGING

A) Close out of **Graphical Analysis** and bring up **RC Circuits** on the desktop. If you cannot find the software then ask your TA, a certified PC expert.

B) Detach the voltmeter cables from the circuit. Attach the voltage probe, coming from the LabPro [blue box on top of the computer], across the capacitor. Make sure the red cable attaches to the positive side of the capacitor.

C) Make sure the switch is set to **Discharge**. At the top of the computer screen, the potential should read zero. If not, then either wait for it to discharge or just use the extra wire to dissipate the charge.

D) Push the **Collect** button. Wait 2 seconds and then flip the switch to **Charge**. The computer will monitor the voltage across the capacitor and plot it out on the graph as the voltage increases. Let it charge up so that it fills the screen.

E) Use the mouse to *highlight* the region of the graph where it is charging. Push the Curve Fit button, it looks like **f(x)=** .

F) Scroll down and choose INVERSE EXPONENT from the list in the lower left, then push **TRY FIT**. Check to see if it's a good fit and then click OK. If it's not, then grab your TA.

G) In the little window that points to the curve, there is a value labeled "C". **This is not the capacitance.** It is equal to 1/**RC**. Use this to calculate **RC** and then calculate the half-life. **Show your work.** Place this value in the chart.

DISCHARGING

A) Make sure the switch is set to **Charge** and the capacitor is sufficiently charged.

B) Push **Collect**, erase the old data, wait 2 seconds and then flip the switch to **Discharge**. Let it fill the graph.

C) Use the mouse to *highlight* the region of the graph where it is discharging. Push the **Curve Fit** button again. Choose NATURAL EXPONENT from the list this time, then **TRY FIT**, check it, and then OK.

D) Use the "C" value and calculate the half-life like you did before. Now, **average** these two half-life values. **Show your work.** Place these values in the chart.

Question 4 Notice that the three half-life values you measured in **Parts 1 – 3** are all somewhat similar. Notice also that they are not very similar to the half-life value you calculated with the given values of **R** and **C**. Explain this behavior. HINT: Both the voltmeter and the LabPro have an "internal resistance".

Part 4 – Voltage Across the Resistor Disconnect the voltage probe from the capacitor and attach it across the resistor with the red probe on the side of the resistor closer to the switch. Push **Collect**, wait 2 seconds, and then flip the switch to **Charge**.

Question 5 Why does the graph for the voltage of the resistor look the way it does on the computer screen? In your explanation you must use Kirchhoff's Loop Law.

Part 5 – Clean Up Please detach the voltage probe from the circuit, flip the switch to **Discharge**, and turn off your power supply and voltmeter. Thanks!

What You Need To Turn In:

Turn in all the data you took. Make sure you showed all the work for any half-lives and such. All questions must be answered in the sections where they are asked.