RC Circuit

Name:	Teammates:

Introduction

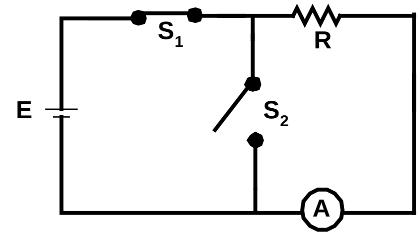


Fig 1: An example of a complete circuit

All of the circuits that we have studied so far have all been in a steady state, i.e. the current was constant. Circuits in this regime operate on the basis of two things: a constant potential difference to provide a steady stream of electrons and a conducting path. In all of these circuits there is at least one continuous path from positive end of the power supply to the negative end (see Fig 1 for an example.)

When like in Fig 2, there is a gap in the circuit there can be no path for the electrons to flow from one end of the battery to the other. In this case, the circuit cannot maintain a steady state. Instead, when the gap is small enough to allow for electrostatic forces to operate across the gap, a non-steady flow of charges in the circuit will occur. The flow will continue until a potential difference equal to the applied potential difference is built across the gap. An example of a small enough gap is the gap present in capacitors. The gap presented by open switch like the one shown in Fig 1 and Fig 2 will not enable any charge flow.

The purpose of this lab is to study the non-steady current due to a circuit made up of a capacitor and resistor, often called an RC circuit.

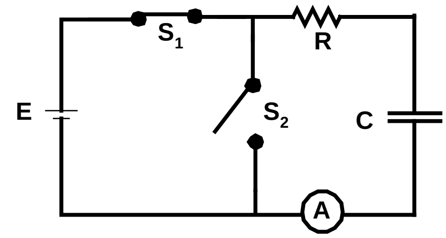


Fig 2: A circuit including two gaps.

Theory

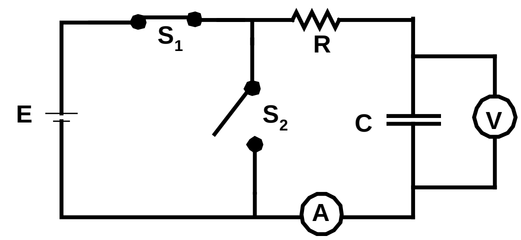


Fig 3: Circuit for charging the capacitor

An RC circuit consists of a voltage source connected in series with a resistor and a capacitor. Two switches in the circuit allow us to control how currents in the circuit. When switch S1 is closed (Fig 3) with the voltage supply connected, the potential difference as a function of time, $V_C(t)$, across an initially uncharged capacitor is given by:

$$E - V_C(t) – R\, i(t) = 0$$

where i(t) is the time dependent current in the circuit, E is the potential difference provided by the voltage source, R is the resistance in the circuit, C is the capacitance in the circuit, and t is time measured from the instant the switch is closed.. By using differential equation calculus, it can be shown that this leads to:

$$V_C(t) = E\,(1 - e^{-t\,/\,RC}) \qquad \text{(Equ. 1)}$$

The voltage across the resisto $V_R(t)$ is simply given by:

$$V_R(t) = E - V_C(t) = E\,(e^{-t\,/\,RC})$$

Since from Ohm's law we know that: $V_R(t) = R\, i(t)$

$$i(t) = V_R(t)/R = (E/R)\,(e^{-t\,/\,RC})$$

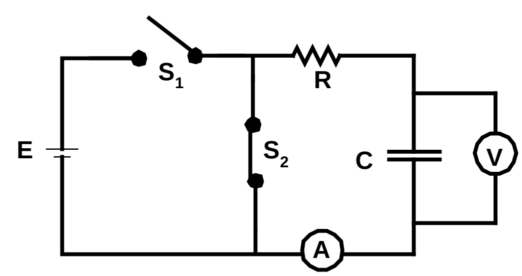


Fig 4: Circuit for discharging a capacitor

To discharge the capacitor, the voltage source is removed from the circuit, and the charged capacitor is allowed to discharge through the resistor. Fig 4 shows one possible configuration. In this configuration, the voltage across the capacitor as a function of time after discharge is

$$V_C(t) = V_o\, e^{-t\,/\,RC} \qquad \text{(Equ. 2)}$$

where V_o is the potential difference across the capacitor at the time discharge begins (which is equal to E if the capacitor was allowed to gain a full charge), and t is time measured from the instant that discharge begins.

It can also be shown that

$$i(t) = (-V_o/R)\,(e^{-t\,/\,RC})$$

Note that in both cases, the current follows a simple exponential function. Now with a little manipulation it can be shown that:

$$\ln[i(t)/I_o] = -t / RC$$

ln is the natural log function, and $I_o = (V_o/R)$. A graph of the $\ln[i(t)/I_o]$ versus time should produce a straight line.
In this experiment the potential difference across the capacitor for the charging case will be measured as a function of time and the relationship between the various voltages and currents analyzed.

Procedure

For this experiment, you will need two resistors (both are provided in duplicates), a known capacitor, a masked capacitor, the Vernier power supply and probes, a circuit board and wires. The circuit to be constructed should look like the diagram in Fig 5. We will use the Vernier LabPro interface as both the power supply and the voltage measuring device.

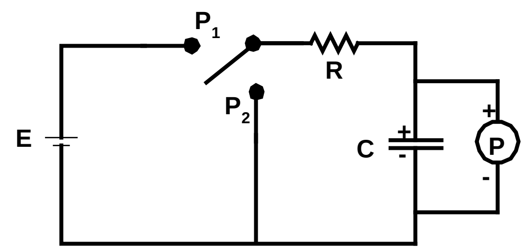
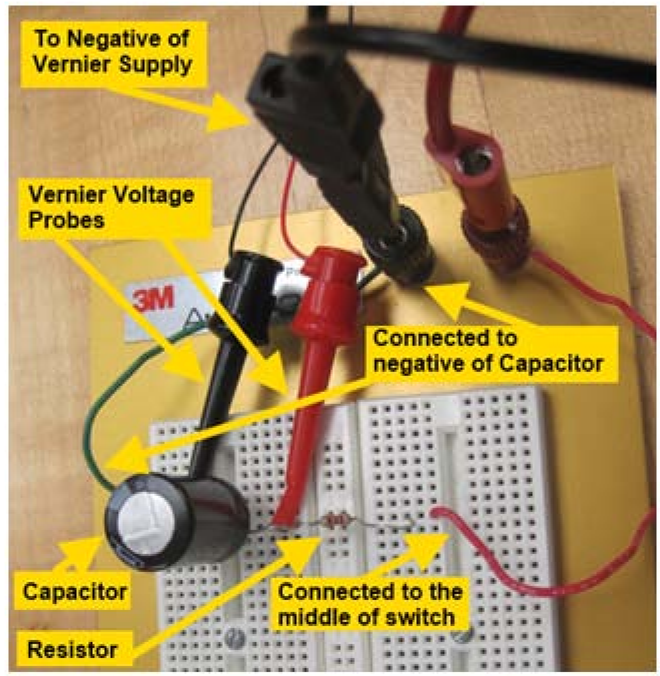
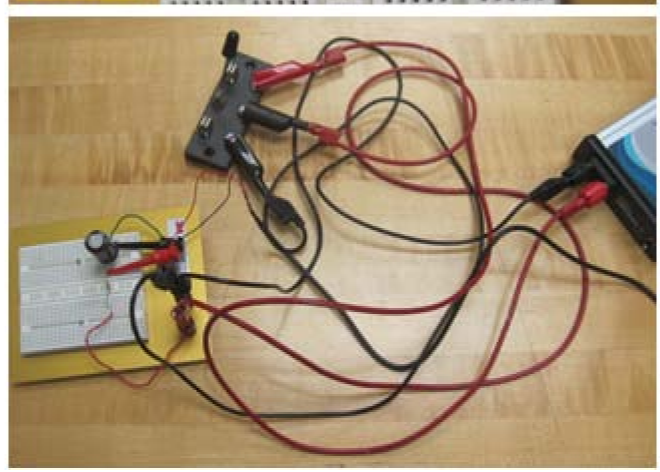


Fig. 5: Circuit Set up

It is important that the connection going to negative terminal of both the power supply part and the Vernier voltage probe should be the same.

It is also important that the negative of the capacitor is connected to the negative of the power supply.





Furthermore, in the starting position, the switch should be open, like shown in the figure.

1. Read the value of the capacitance for the known capacitor off the case and use the utility at this website http://physci.kennesaw.edu/physlets/dig/resistors.htm to figure out the resistance of both resistors:

   Resistor 1 = ____ Ω   Resistor 2 = ____ Ω

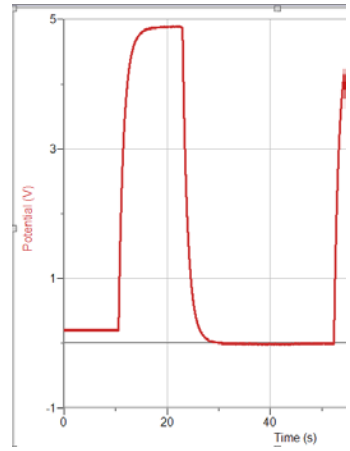
   Capacitor = ____ F

2. Note that the capacitor has one of the leads marked as either positive or negative. Which of the capacitor leads is the negative one? (long or short)
3. To see how a breadboard is wired, check the following: http://science.kennesaw.edu/physics/breadboard.htm. Our board is made up of 5 strips, four wide one and one thin one. The five holes in the wide strips are connected along the width. The holes for the narrow strip are connected along the length. The breadboard allows us to connect the components (resistors and diodes) without the use of wires.
4. Connect the larger of the two resistors, the known capacitor, and switch (in the open position) as shown in Figs 5, 6 and 7. Make sure that the capacitor is connected to the negative terminal of the Vernier power supply. Connect the Vernier voltage probe across the capacitor, with the negative terminal of the probe on the negatives side of the capacitor.

5. Ask your instructor to verify the circuit before proceeding.

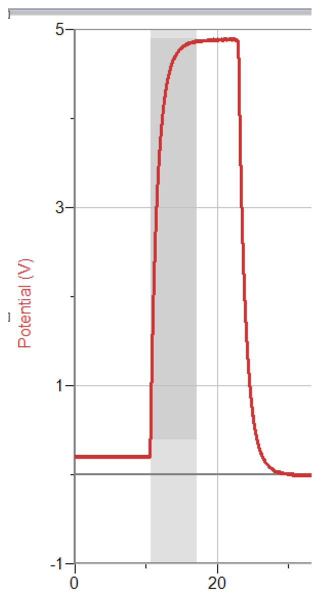
6. Locate the capacitor.mcbl file in the "Vernier" folder on the computer desktop, then open it.
   - In case the software does not recognize the power amplifier, disconnect the amplifier, press the connect button, connect the amplifier, then press no if prompted to disable the DC output.
7. We are now ready to investigate the voltage across the capacitor in the charging scenario. Press the green "collect" button on the LoggerPro software.

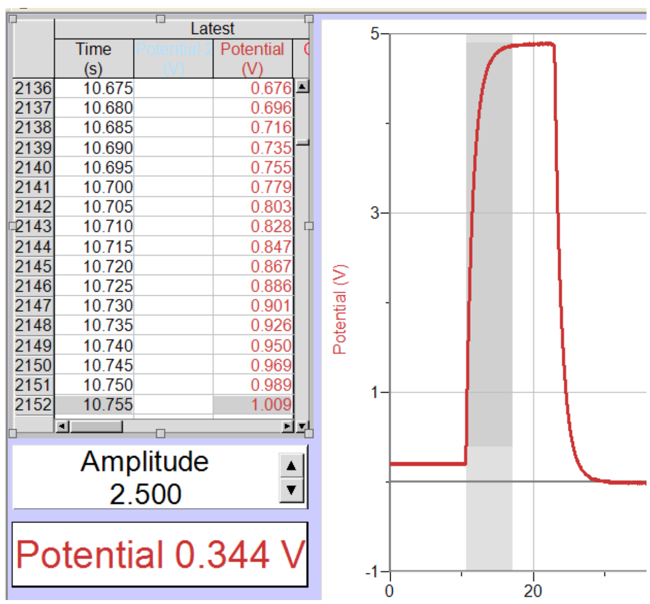
8. With the LoggerPro software running, move the Switch into position (P1) allowing current to flow into the RC portion of the circuit. The computer will collect voltage data for a few minutes.
9. When you notice no change in the voltage values, the capacitor is fully charged. Note the value of the maximum voltage.
10. With the capacitor now fully charged, **immediately** move the Switch to position (P2) to allow the capacitor to discharge through the resistor.
11. When the voltage has tapered off, repeat steps 8-10 to make sure you are collecting consistent data. Your graph should look like the following:

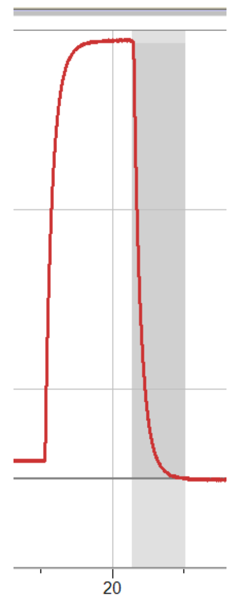


12. Once you are satisfied that you have collected good data, open the switch (middle position) and unplug the connection to the power. If the software stops collecting data before you finish collecting acceptable data, press the “collect” button again while being careful not to allow the software to delete the data you have already collected.

13. Your task now is to export your data to Microsoft Excel and analyze it. After starting Microsoft Excel, highlight the portion of the graph you want to export. Refer to the following figures for guidance:







14. Notice that the portion highlighted is a darker shade of grey then the rest of the graph. Once you highlighted the data, position your cursor over the data table and press your left mouse button.
15. Now press the CTRL-C key combination to copy the data to your computer clipboard.
16. Move to Excel, select where you want to paste the data and press the CTRL-V key combination.
17. Repeat steps13-16 for the discharge data.

18. For each resistor capacitor combination (you should have two unique resistor values, a known capacitor and an unknown capacitor) repeat steps 7-17.

19. For each time in the **charging data sets**, calculate $\ln(E - V_C(t))$. A tutorial is available next to the lab handout to show you how to use Excel to make the calculations and to graph the data.
20. Plot $\ln(E - V_C(t))$ versus time. Fit the graph to a linear trend. (To do this, position the cursor over the data points, press the right mouse button and select “Add Trendline”. Select “Linear”, and select “Display equation on chart” option. Press OK.) Record the slope in the following table.

Charging Data:

Data Run	Resistance (R)	Capacitance (C)	Slope	-1/Slope	RC
Resistor 1, known capacitor					
Resistor 2, known capacitor					
The larger of the Resistors, unknown capacitor		unknown			unknown

21. For each time in the **discharging data sets**, calculate ln(V_C(t))
22. Plot ln(V_C(t)) versus time and fit the graph with a best-fit line. Record the slope.

Discharging Data:

Data Run	Resistance (R)	Capacitance (C)	Slope	-1/Slope	RC
Resistor 1, known capacitor					
Resistor 2, known capacitor					
The larger of the Resistors, unknown capacitor		unknown			unknown

23. Save your data, shut-off the power, dismantle your circuit and return everything to the proper boxes.

24. Answer the following questions.

A. How does the size of the resistor affect the RC time constant? What do you expect to happen if the resistor you use is *larger*? Smaller?

B. How did the time it takes for the capacitor to charge relate (compare) to the RC time constant?

C. How did the time it takes for the capacitor to discharge compare to the time it takes for the capacitor to charge?

D. What are the theoretical slopes for each of your runs?

Data Run	Resistance (R)	Capacitance (C)	Slope (charging)	Slope (discharging)
Resistor 1, known capacitor				
Resistor 2, known capacitor				

E. How do these theoretical slopes compare to the slopes you have measured earlier?

F. For the known capacitor, compute the average capacitance from the *RC* circuit (from the values you have calculated above). Does this average agree with the value you can get from the slope data?

G. Based on all the data you have collected, what is your best value for the masked capacitance?