RC & RLC circuits

The purpose of this lab is to Investigate RC and RLC circuits. You will measure and record the voltage as the function of time as the capacitor is discharged in an RC circuit and also record the oscillations in an RLC circuit. We will determine time constants and oscillation frequencies.

Equipment

1. LabQuest 2
2. Differential voltage probe
3. Inductor with iron core
4. Circuit board

INTRODUCTION: RC circuits

In previous labs you have examined the effect that resistors have on the electric potential and current in DC circuits. ("DC" stands for "Direct Current". We will also study the "Alternating Current" or "AC".) In such circuits, if you flip a switch the electric potential and current reach a steady state almost instantaneously. When there is a capacitor (or an inductor) in the circuit, the development of a steady state takes time. In this experiment, you will study the transient state that occur when a capacitor is discharged through a resistor.

A capacitor is an electrical element that stores electrical charge. Assume that the switch SW2 in Figure 1 has been in position **a** for long time, long enough to let the capacitor to reach its maximum charge, $V=V_0$, the voltage of the battery. If SW2 is switched to position **b** at time $t=0$, the capacitor will discharge trough the resistor R. The voltage V in the capacitor will decrease at,

$$V = V_0 e^{-t/\tau} \qquad (1)$$

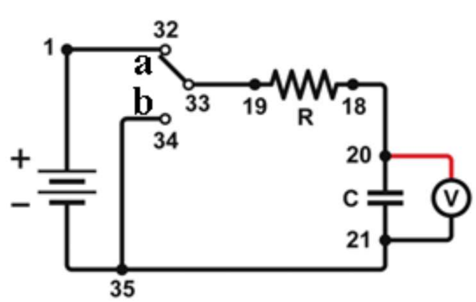
where τ is the time constant of the RC circuit,

$$\tau = RC \qquad (2)$$

Here C is the capacitance of the capacitor measured in the SI unit of Farad [F] and R is the resistance measured in Ohm (Ω).

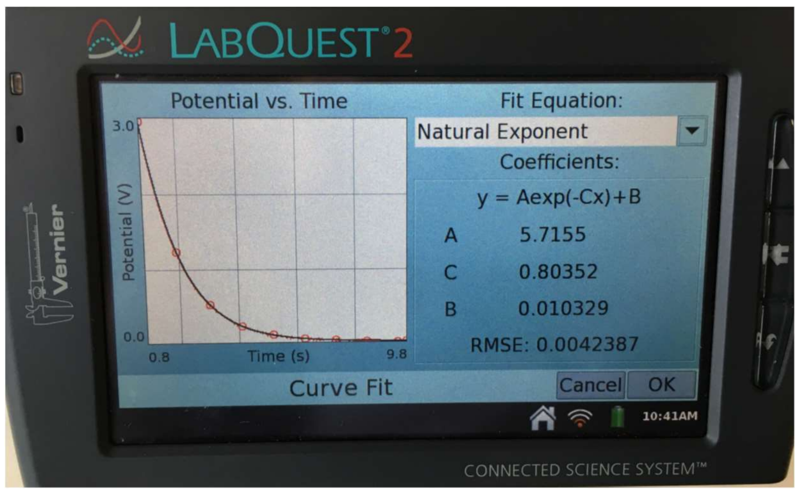
PROCEDURE:

1. Using the Vernier Circuit Board, construct a series circuit with batteries, 100kΩ resistor, capacitor, and a double-throw switch, as shown in Figures 1. The numbers represent the terminals on the circuit board. (There is no need to connect terminals 1 and 35 to the battery; that connection has been made on the circuit board.)



2. Connect the Differential Voltage Probe to the interface. Change the data-collection rate to 200 samples per second and the data-collection duration to 10 seconds.
3. Connect the leads of the voltage probe to the terminals of the capacitors shown in the Figure.
4. Move the switch to position "a" so that the battery charges the capacitor. Consider the charging to be complete when the potential reading stabilizes.
5. Start data collection, wait a second, then move the switch to "b" to discharge the capacitor.
6. Examine the graph of potential vs. time in the graph meter. Increase the duration, if necessary, to capture the essential details of the discharge. Store the run.
7. Use the 47kΩ (terminals 16-17) resistor instead of the 100kΩ. Predict how the potential vs. time graph during discharge would differ from that in your first run. Charge the capacitor, test your prediction, and store the run.
8. Perform another run as you did in Step 7 with the 22kΩ resistor. Store the run.

Evaluate the data:



1. Examine the potential vs. time graph for your first run. Select the region of the graph where the potential is changing and try the natural exponent curve fit. (highlight the area, click "Graph", click "Zoom in", click "Analyze", click "Curve fit", select "Natural exponential").
2. The figure shows a successful fit to the data (the red line and red dots represent the data; the black line is the fit). If the black line does not match the data, repeat the measurement. Record the parameter C in the Table 1.
3. You may want to take a photo of your successful fit and use it in the final lab report.
4. The parameter C of the curve fitting routine is NOT the capacitance, but it is one of the 3 parameters (A, B and C) used by LabQuest to obtain the best fit. The equation LabQuest is using is

$$y = Ae^{-Cx} + B \qquad (3)$$

   Comparing this to Eq. (1), you can see that the potential V corresponds to y in Eq (3), the time t corresponds to x and V_0 corresponds to the parameter A. You can calculate τ, the time constant from the experiment, from the parameter C. How?
5. Record the experimental time constant in Table 1.
6. Repeat this process for your additional runs.

TABLE 1

	C parameter (fitted curve)	Time constant from experiment
Run 1 (R=22kΩ)		
Run 2 (R=47kΩ)		
Run 3 (R=100kΩ)		

7. Calculate the time constants from the resistors and the capacitor using Eq. (2) and record the values in Table 2.

TABLE 2

	R [kΩ]	ΔR [kΩ]	C [F]	ΔC [F]	RC [s]	ΔRC [s]
Run 1	**22**					
Run 2	**47**		**10×10^{-6}**			
Run 3	**100**					

8. The tolerance for each resistor and the capacitor is ±10%, use this to calculate the error for R and C. Then, use equation E.7 from Lab Uncertainty manual to find the error for *RC*.

$$\frac{\Delta(RC)}{RC} = \sqrt{\left(\frac{\Delta R}{R}\right)^2 + \left(\frac{\Delta C}{C}\right)^2}$$

Are the experimental values for RC consistent with their expected values?

INTRODUCTION: RLC Circuits

An inductor is an electrical element that exhibits an induced voltage when the current is changing. Inductors are made by winding a wire into a coil. The induced voltage is linearly related to the rate of change of the magnetic flux and therefore the inductance can be increased if we place an iron core into the coil (since the iron increases the magnetic flux).

An inductor, a capacitor and a resistor in series is called and "RLC circuit". If exposed to an abrupt change of voltage, the voltage and the current in an RLC circuit will oscillate. We will study this oscillation.

If the switch in Figure 2 has been in position **a** for long time, the capacitor is fully charged. If SW2 is switched to position **b** at time **t=0**, the capacitor starts to discharge, but the inductor develops a voltage to prevent a sudden change of current. As the current increases, the magnetic field in the inductor increases as well. When the capacitor is fully discharged, the inductor maintains the current and re-charges the capacitor in the opposite direction. This process repeats itself with the frequency

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad (4)$$

Here *C* is the capacitance (in units of Farad, F) and *L* is the inductance (in units of Henry, H). In each cycle of the oscillation a fraction of the energy is dissipated in the resistor, and eventually the amplitude of the oscillation decays to zero. In our experiment we do not need to add a resistor to the circuit, since the coil that is used for the inductive element has a resistance as well.

PROCEDURE:

1. Set up the circuit as shown in Figure 2. (The inductor is not on the circuit board.) Place the iron core into the inductor.
2. Change the data-collection rate to 10,000 sample/sec and the data-collection duration to 0.05 seconds.
3. Enable triggering and set it to CH 1, 0.1V, collect 100 data points before trigger.
4. Connect the leads of the voltage probe to the capacitor.
5. Start data collection. You should see a note on the screen : "Waiting for CH 1 …."

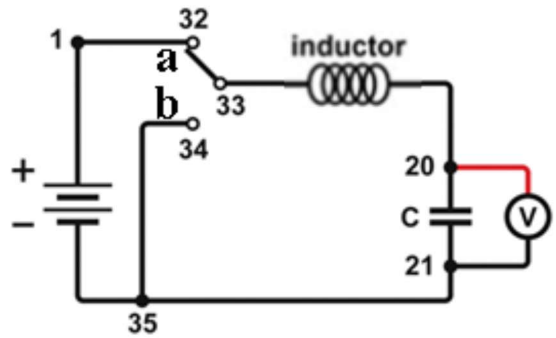
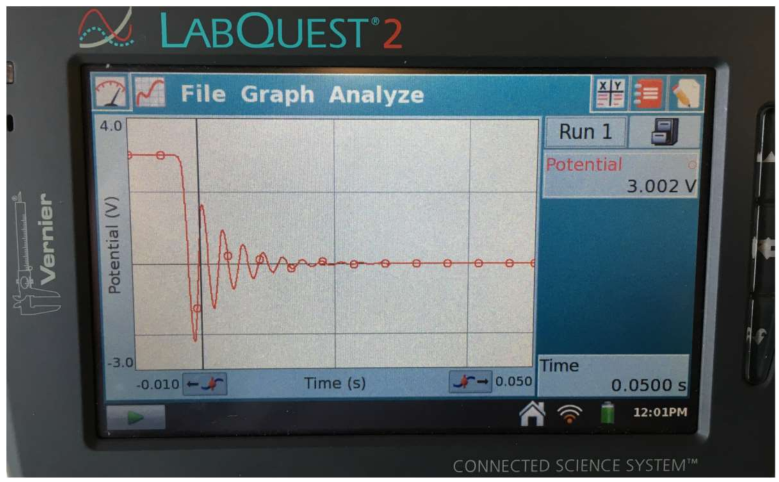


Figure 2

6. Flip the switch to position **b**. If the triggering is set up correctly the data will be recorded, and you will see something similar to the screen shot. Store the run.
7. Remove the iron core and repeat the measurement.
8. (If the LabQuest freezes up in "Waiting for CH 1…." Mode select "Home", "System" and reboot.)



Evaluate the data:

1. Examine the graph from your first run (with the iron core in the coil). Determine the period of the oscillation (Note: far the largest source of error in this measurement is the uncertainty of the value of the capacitor, ±10%. Therefore you do not need to worry about the error of the quantities you read out of the screen.) Record the period T.
2. Use $f = 1/T$ to calculate the frequency and record it.
3. Re-arrange Eq. (4) so that you express the inductance, and determine the inductance. We will call this L_1. Record the value. The relative error of this value is the same as the relative error of the capacitance.
4. Repeat the same for the second set of data, taken without the iron core. Record the value of the inductance, L_2.
5. **What is the ratio L_1/ L_2?**