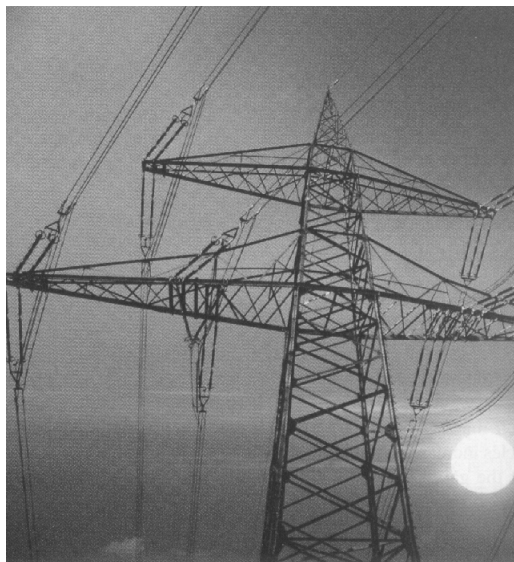


Name: _____
Partners: _____

PHYSICS 221 LAB #6: CAPACITORS AND AC CIRCUITS



The electricity produced for use in homes and industry is made by rotating coils of wire in a magnetic field, which results in alternating current. This lab deals with time varying electrical currents and voltages.

OBJECTIVES

1. Observe and make measurements for the charging and discharging of a capacitor.
2. Measure how the reactances of capacitors and inductors vary with the frequency of an AC current.
3. Observe the phenomenon of electric resonance.

OVERVIEW

In a circuit with a DC power supply (voltage V_0), a resistor (R), and a capacitor (C), the voltages across the capacitor is given by

$$V(t) = \begin{cases} V_0 [1 - \exp(-t/RC)] & \text{charging} \\ V_0 \exp(-t/RC) & \text{discharging} \end{cases}$$

where t is measured from the moment when the capacitor starts charging or discharging. The time for the voltage across the capacitor to increase or to decrease is related to the capacitive time constant, $t=RC$ ($1 \Omega \cdot F = 1 \text{ s}$). After that much time, the voltage has either increased to 63% of its final value (charging) or decreased by 63% from its initial value (discharging).

For alternating current circuits, meters measure the root-mean-square (rms) values of the current and the voltage, which are

$$I_{rms} = I_0 / \sqrt{2} \quad \text{and} \quad V_{rms} = V_0 / \sqrt{2}$$

where I_0 and V_0 are the amplitudes of the sinusoidally varying current and voltage. The rms voltage across a resistor is related to the rms current by

$V_{rms} = I_{rms}R$. The capacitive reactance of a capacitor, $X_C = \frac{1}{2\pi fC}$, is a measure of its ability to impede the flow of charge in a circuit. The inductive reactance of an inductor, $X_L = 2\pi fL$, is a measure of its ability to impede current flow through it. Both of these reactances change with the frequency of the alternating current. The rms voltage across a capacitor or inductor is related to the rms current by $V_{rms} = I_{rms}X$. Some useful relations between units are $1 \Omega = \frac{1}{\text{Hz} \cdot \text{F}} = 1 \text{ Hz} \cdot \text{H}$.

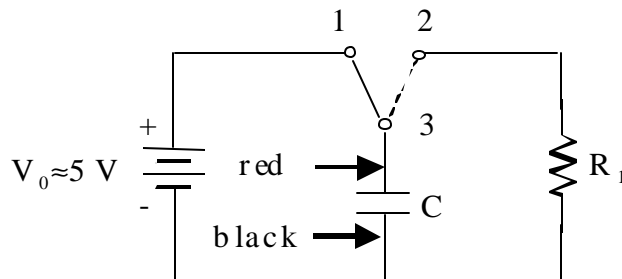
For a circuit that contains an inductor, a resistor, and a capacitor in series, the total impedance of the circuit is $Z = \sqrt{R^2 + (X_L - X_C)^2}$. Resonance will occur at the frequency for which the reactances of the inductor and the capacitor are equal and the impedance is as small as possible so the amplitude of the current is the largest.

PART ONE: : Charging and Discharging Capacitors (RC Circuits)

1. Use the multimeter to measure the resistance of the “330-kΩ” resistor (orange-orange-yellow-gold stripes).

$R_1 = \underline{\hspace{2cm}}$

2. Set up the circuit shown below with the capacitor and the “330-kΩ” resistor to make measurements for discharging of the capacitor. Your instructor will give you instructions about how to make the connections on a breadboard. The wires coming from the switch are numbered. The arrows show how the probe from the LabPro should be attached to the capacitor.



3. Open the file **Capacitor** (in Physics Experiments / Physics 220 – 221/ Capacitors...) and make sure the voltage probe is plugged into CH1. Clip the red end to the side of the capacitor by the switch and the black end to the other side, as shown above. Turn the power supply on. Flip the switch to the position marked “1” so that the capacitor will start out charged. **Warning:** Be sure you flip the switch *all* the way because it has an intermediate, disconnected position.
4. Press the “Collect” button and the program will start taking data once the voltage starts decreasing. Flip the switch to the position marked “2” and the capacitor will start discharging.

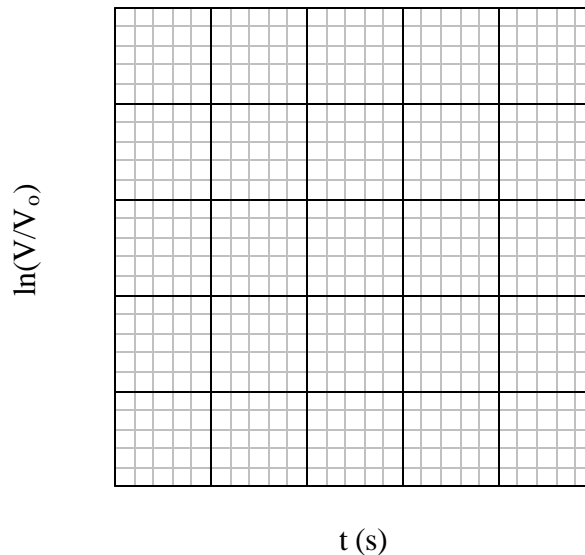
5. In order to interpret the data, it is useful to take a natural logarithm of the voltage.

$$V(t) = V_0 e^{-t/RC} \quad \ln(V/V_0) = \frac{-t}{RC}$$

A plot of $\ln(V/V_0)$ vs. time should be a straight line. Select "Examine" under the **Analyze** menu, then move the cursor around to get voltages at 5 times (including $t = 0$). Take the natural logarithm to fill in the third column of the table. Note: V_0 is the *maximum* voltage value.

t (seconds)	V (Volts)	$\ln(V/V_0)$
0	$V_0 =$	

6. Plot $\ln(V/V_0)$ vs. the time below and find the slope of the line.



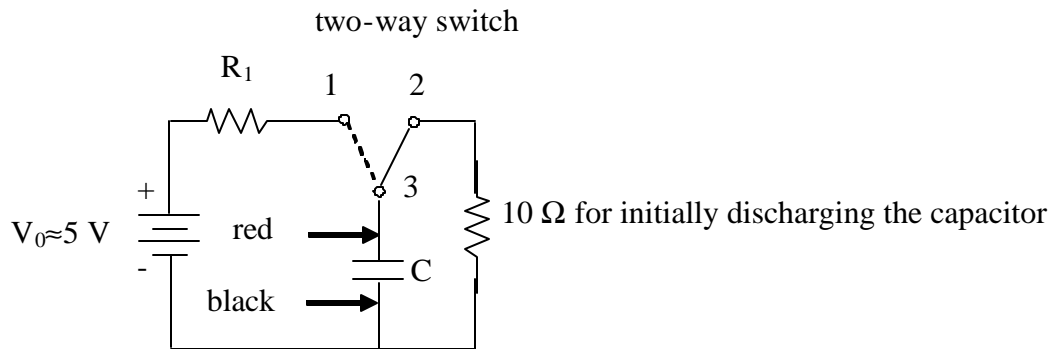
slope = _____

7. Using the slope, find the capacitive time constant. Show your work.

$\tau =$ _____

Question: According to their packages, the capacitors are supposed to be within 20% of the value printed on them. Using the measured values of the resistance and the capacitive time constant, calculate the capacitance. Is this within 20% of $10\ \mu\text{F}$?

8. In order to make measurements for the charging of a capacitor, set up the circuit shown below. The arrows show how the probe from the LabPro should be attached to the capacitor. You will be using a capacitor marked $10\ \mu\text{F}$. The color code on the $10\text{-}\Omega$ resistor is brown-black-black-gold.



9. Turn on the power supply. Flip the switch to the position marked “2” so that the capacitor will start out uncharged.
10. Press the “Collect” button and the program will start taking data once the voltage starts increasing. Flip the switch to the position marked “1” and the capacitor will start charging.
11. As shown below, a plot of $\ln\left(1 - \frac{V}{V_0}\right)$ vs. time should be a straight line. Use the program to get data at 5 times (including 0). Take the natural logarithm to fill in the third column of the table.

$$V(t) = V_0(1 - e^{-t/RC}) \quad V_0 - V(t) = V_0 e^{-t/RC} \quad \ln\left(1 - \frac{V(t)}{V_0}\right) = \frac{-t}{RC}$$

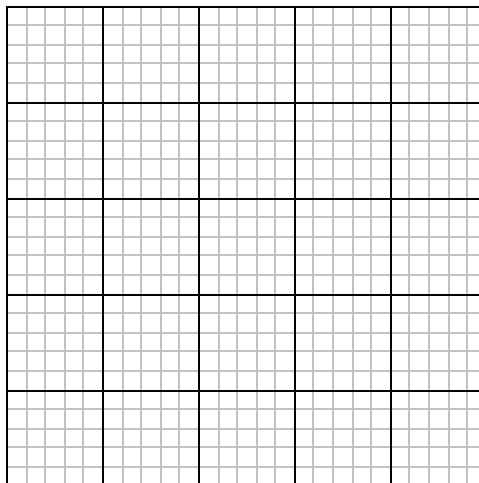
Select “Examine” under the **Analyze** menu, then move the cursor around to get the voltage when the capacitor is fully charged (V_0) and voltages at 5 times. Also, calculate the values for the third and fourth columns of the table.

$$V_0 = \underline{\hspace{2cm}} \text{ (maximum voltage eventually reached)}$$

t (seconds)	V (Volts)	(V/V_o)	ln(1-V/V_o)

12. Plot $\ln\left(1 - \frac{V}{V_o}\right)$ vs. the time below and find the slope of the line.

$$\ln\left(1 - \frac{V}{V_o}\right)$$



t (s)

slope = _____

13. Using the slope, find the capacitive time constant. Show your work.

$\tau =$ _____

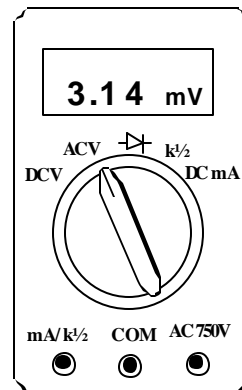
Question: Are the measured values of the time constant for charging and discharging consistent with each other?

PART TWO: Reactances of Inductors and Capacitors

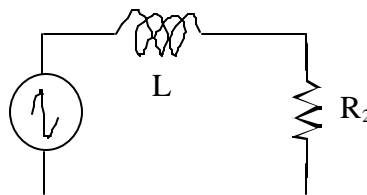
- Use the multimeter to measure the resistance of the “1-kΩ” resistor (brown-black-red-gold stripes).

$R_2 =$ _____

- To use a multimeter like the one pictured to the right as an AC voltmeter, turn the dial to “ACV”. Plug one wire in the “COM” socket and the other into the “AC 750V” socket. The wires from the voltmeter should be connected at the two points in a circuit between which you want to know the rms voltage.



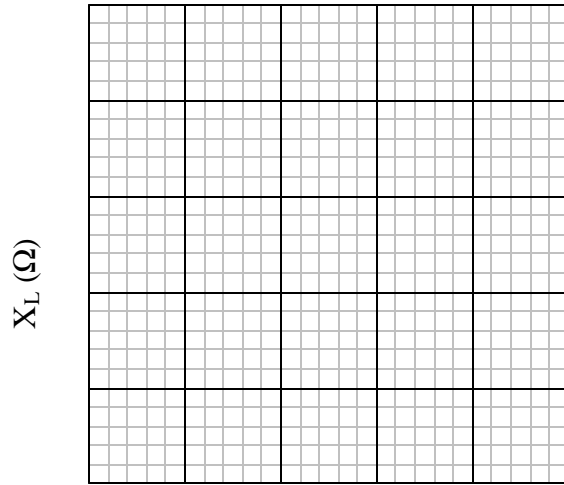
- Connect the “1-kΩ” resistor and a 7-mH inductor in series with a function generator. Connect one AC voltmeter across the resistor and another across the inductor.



- Turn on the function generator and adjust the amplitude to about half of its maximum value, then do not change it.
- Measure the rms voltages across the resistor (V_R) and inductor (V_L) for 5 frequencies (f) from 100 to 500 Hz. Fill in the first three columns of the table below.

f (Hertz)	V_R (Volts)	V_L (Volts)	I (Amps)	X_L (Ohms)

- Use the resistance (R_2) and the rms voltage across the resistor to calculate the rms current (I) for each frequency. Fill in the fourth column of the table.
- Use the rms voltage across the inductor and the rms current to calculate the reactance of the inductor (X_L) for each frequency. Fill in the fifth column of the table.
- Plot the reactance of the inductor (from the table above) versus the frequency below.

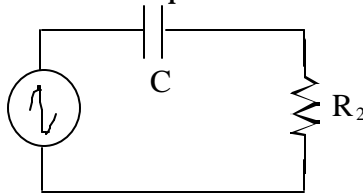


f (Hz)

Slope = _____

Question: Is the value of the slope of the line what you expect? Show your work.

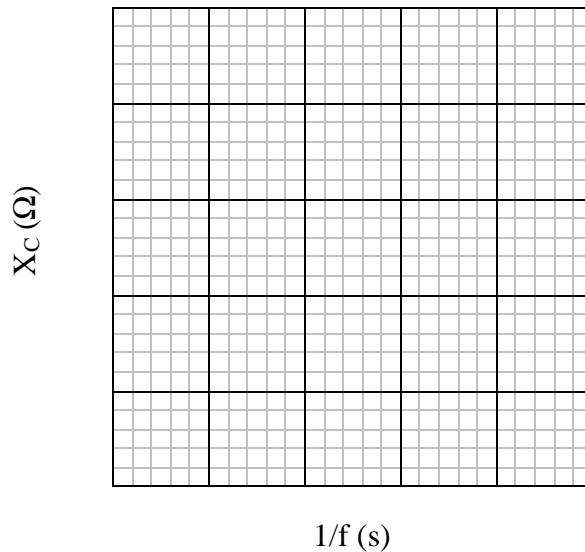
9. Connect the “1-kΩ” resistor and the capacitor from Part One in series with a function generator. Make sure the function generator is set to produce a sine wave. Connect one AC voltmeter across the resistor and another across the capacitor.



10. Turn on the function generator and adjust the amplitude to about half of its maximum value, then do not change it.
11. Measure the rms voltages across the resistor (V_R) and capacitor (V_C) for 5 frequencies (f) from 100 to 1000 Hz. Fill in the first three columns of the table below.

f(Hz)	1/f (s)	V_R (Volts)	V_C (Volts)	I (Amps)	X_C (Ohms)

12. Use the resistance (R_2) and the rms voltage across the resistor to calculate the rms current (I) for each frequency. Fill in the fourth column of the table.
13. Use the rms voltage across the capacitor and the rms current to calculate the reactance of the capacitor (X_C) for each frequency. Fill in the fifth column of the table.
14. Plot the reactance of the capacitor (from the table above) versus the inverse of the frequency below.

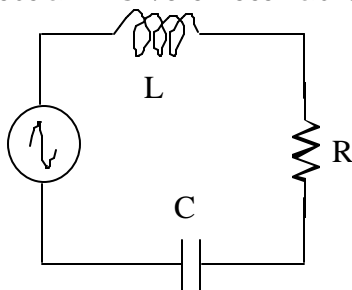


Slope = _____

Question: Is the value of the slope of the line what you expect? Show your work.

PART THREE: Electrical Resonance (LRC Circuits)

1. Connect the 7-mH inductor, the 10-Ω resistor, and the 10-μF capacitor in series on the breadboard. Attach a function generator as shown below. Connect an AC voltmeter across the resistor.

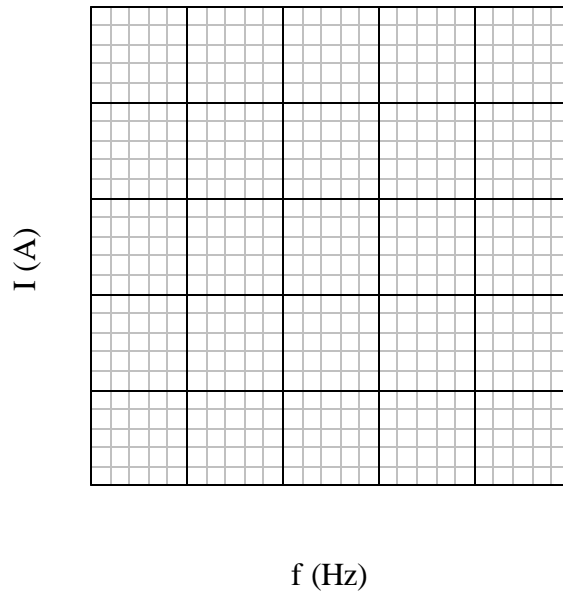


2. Pull out the amplitude knob of the function generator. Turn the power on and adjust the amplitude to about half of its maximum value.
3. Measure the rms voltages across the resistor (V_R) for ten frequencies (f) from 50 to 2000 Hz. Record more measurements in the frequency range where the voltage increases dramatically. Fill in the first two columns of the table below.

f (Hertz)	V_R (Volts)	I (Amps)

4. Use the rms voltage across the resistor to calculate the rms current in the circuit (I) for each frequency. Fill in the third column of the table.

5. Plot the rms current versus the frequency of the function generator. Estimate the resonant frequency (f_0) from the graph.



$f_0 =$ _____

Question: How does the measured value of the resonant frequency compare with the theoretical prediction? Show your work.