The RLC Series Circuit with an AC Source

Your Name _____

Partners' Names _____

_____

Obtained reasonable experimental results?	yes	☐
Answered questions?	yes	☐
Cleaned your table?	yes	☐

Introduction

Ohm's law and RC circuit labs use a steady current. However, this lab uses a different power supply, which is alternating current (AC). The previous electronics labs use a direct current (DC) power supply. For example, a cell battery is one of the DC power supplies and the home outlet provides the AC in our daily lives.

The voltages of the AC power supply changes as a sine or cosine function, but we can also obtain the equivalent DC voltage from this, which is called the root-mean-square voltage of the AC source. The relationship is given as:

$$V_{RMS} = \frac{V_{max}}{\sqrt{2}}$$

where V_{RMS} is the root-mean-square voltage to be measured by a multimeter and V_{max} is the maximum voltage of the AC source to be found by an oscilloscope.

The circuit elements, such as resistors and capacitors, connected to an AC source respond differently. For a series circuit with a resistance, capacitance, and inductance (solenoid), each circuit element reacts "resistively" to the power supply. The resistance changes only the amplitude, but the inductance and capacitance shift the phase of the AC source in time either in positive or negative directions. For this time shift, reactance plays a large role related to the frequency of the AC power supply. The inductive reactance, X_L, and the capacitive reactance, X_C, are given as follows:

$$X_L = 2\pi f L; \quad X_C = \frac{1}{2\pi f C}$$

where L, C, and f, are inductance, capacitance, and frequency, respectively. The total "resistive" property toward AC voltage is called impedance ("general resistance"). That is:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Even though the power supply is AC, it can still hold Ohm's law. Therefore, we can have

$$I = \frac{V}{Z} = \frac{V}{\sqrt{R^2 + (X_L - X_C)^2}}$$

As you can see from above, when $X_L = X_C$, the current, I, takes the maximum value. This is known as the resonance frequency:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The resonance frequency is used for tuning radio and other electric applications.

Objectives:
- To learn a property of the AC power supply (root-mean-square and peak voltages)
- To test Ohm's law for an AC circuit (reactance and impedance)
- To find the maximum possible current of the AC circuit (resonance frequency)

1. Alternating current (sinusoidal power supply):

① Open DataStudio and click "Create Experiment." Then, make the following environment with the picture instruction.
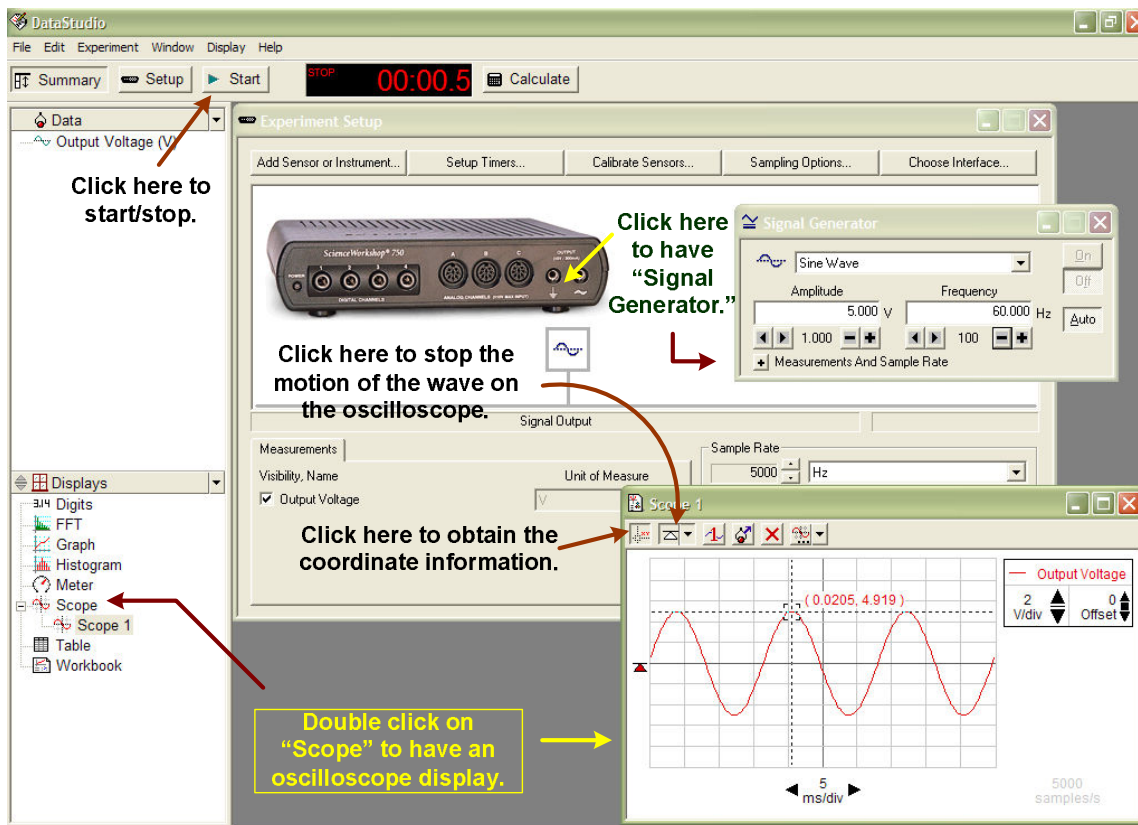
② Choose one of the amplitudes, such as 5 V. Use a proper frequency (like 60 Hz to 120 Hz).

③ Find the maximum amplitude of the AC voltage (value of the y-axis) using the "smart tool" as shown in the above figure.

Maximum voltage V_{max} = _____ (   ) ⇐ units

④ Since AC voltage varies with time, some type of average value is used, which is called root mean square, V_{RMS}, (quadratic mean). A multimeter measures V_{RMS}, so set up as shown in the picture and use voltage mode to read the above AC voltage.

RMS voltage V_{RMS} = _____ (   ) ⇐ units

⑤ The relationship between V_{max} and V_{RMS} is $V_{max} = \sqrt{2}\, V_{RMS}$. Use V_{RMS} measured above and calculate V_{max}.

Select $\tilde{V}$ to measure the AC voltage.
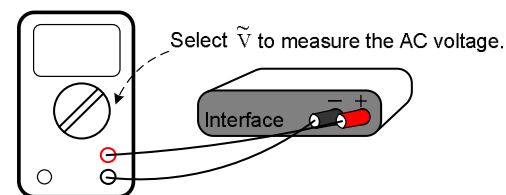
Theoretical V_{max} = _____ (   ) ⇐ units

Question: Is this close to the measured V_{max}?

2. RLC series circuit

- **Theoretical calculation**

① You use a circuit module as shown. This implements an RLC series connection.

② Each value of the circuit elements is given as follows: R (resistance) = 100 Ω, L (inductance) = 10 mH, and C (capacitance) = 0.1 μF.

③ You will use the AC voltage as 5.0 V as the amplitude and the frequency, f = 2000 Hz.

④ Calculate the inductive reactance, X_L and the capacitive reactance, X_C with the given reference values. (Don't forget the units.)

$X_L = 2\pi f L$	$X_C = \frac{1}{2\pi f C}$

⑤ Calculate the impedance. (Don't forget the units.)

$$Z = \sqrt{R^2 + \left(X_L - X_C\right)^2}$$

⑥ Calculate the theoretical current and voltages across the inductor and capacitor. These will be verified with the experimental values. Use Z in ⑤.
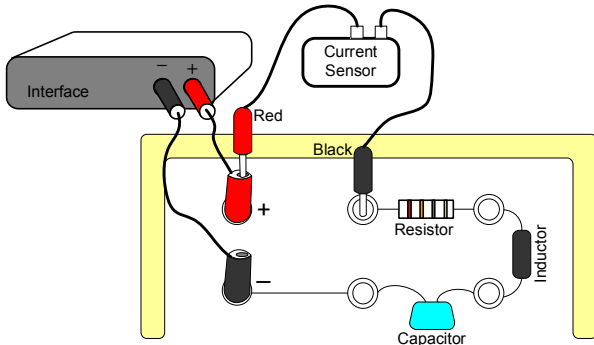
Table I: Theoretical Values (Calculate each one of the following. Don't forget the units.)

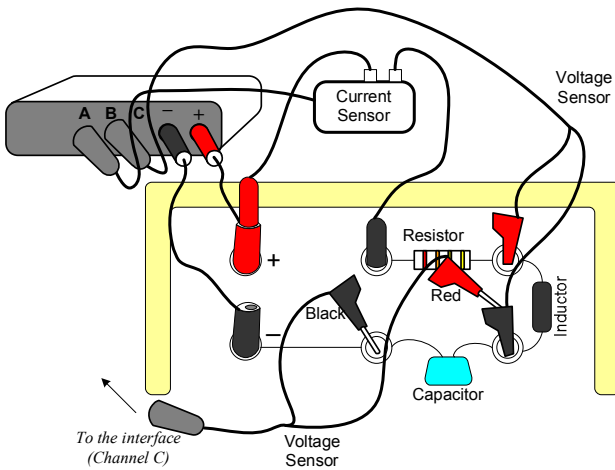| 1	2	3
$I = V / Z =$	$V_L = I X_L =$	$V_C = I X_C =$
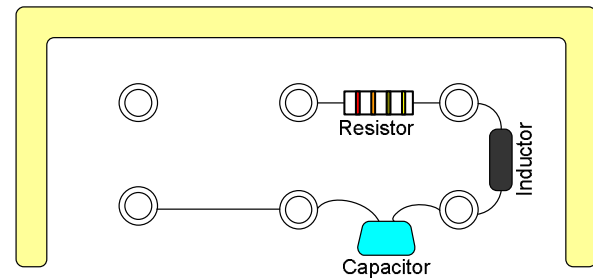
- **Experimental measurements**

① Set up the circuit as shown: The two terminals are going into the voltage source and ground in the interface.

Interface

+

Current
Sensor

Red

Black

Interface

+

−

Resistor

Capacitor

Inductor

② A current sensor will be connected as shown. Remember that the current sensor has to be a series connection with the circuit. Also, the current going through a series connection is equal in every circuit element.
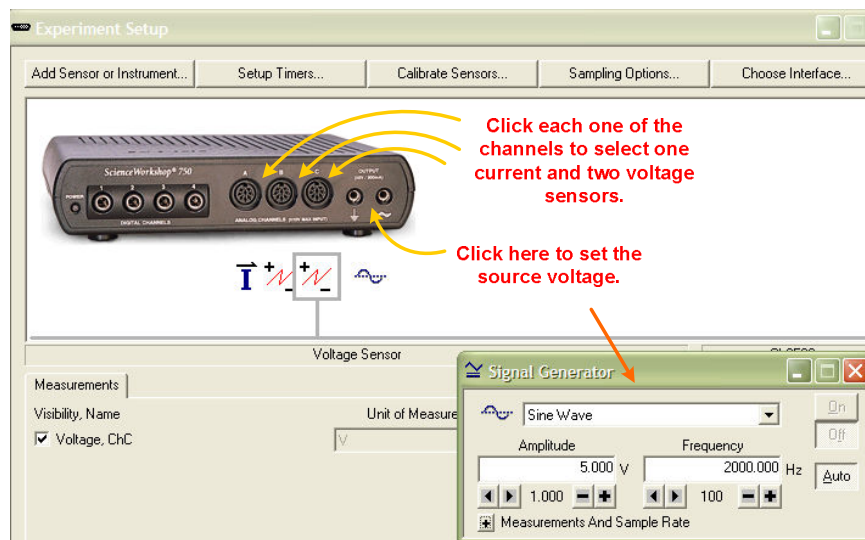
Resistor

Inductor
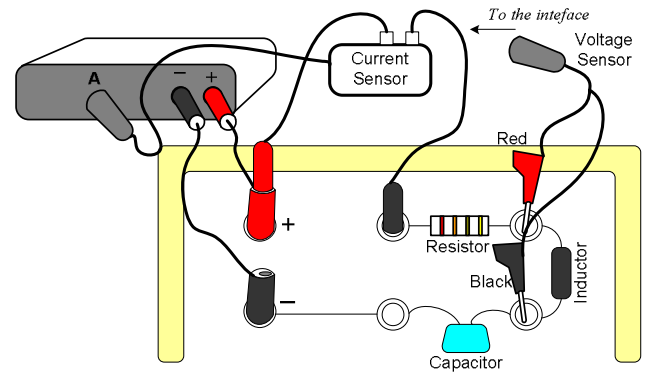
Capacitor

③ To measure the voltage across inductor, a voltage sensor has to be connected as shown: Make sure which should be a red or black terminal.

To the inteface

Voltage
Sensor

Current
Sensor

A

+

−

Red

Resistor

Black

Inductor

Capacitor

A B C − +

Current
Sensor

Voltage
Sensor

+

Resistor

Red

Black

−

Inductor

Capacitor

*To the interface
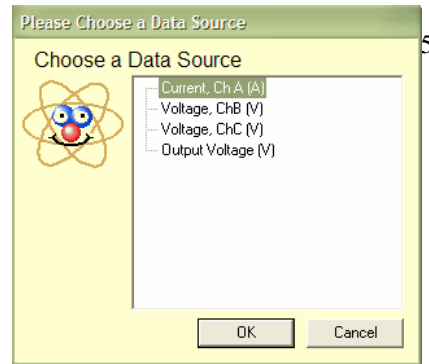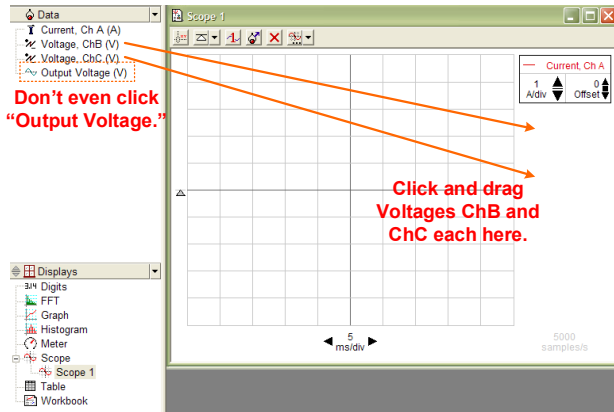(Channel C)*

Voltage
Sensor

④ For the voltage across capacitor, connect the voltage sensor as shown in the figure.

⑤ Now, start up DataStudio. Click "Create Experiment" and select current sensor, voltage sensors for analogue channels, A, B and C.

⑥ Also, click the voltage source. Select "Sin Wave", "5.0 V", and "2000 Hz."

Experiment Setup

Add Sensor or Instrument... | Setup Timers... | Calibrate Sensors... | Sampling Options... | Choose Interface...

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Click each one of the channels to select one current and two voltage sensors.

Click here to set the source voltage.

Voltage Sensor

Measurements

Visibility, Name   Unit of Measure

☑ Voltage, ChC   V

Signal Generator

Sine Wave

Amplitude   Frequency

5.000 V   2000.000 Hz   Auto

◄ ► 1.000 − +   ◄ ► 100 − +

⊞ Measurements And Sample Rate

On
Off

⑦ Display "Scope", click OK with "Current, Ch A (A)."

Please Choose a Data Source

Choose a Data Source

- Current, Ch A (A)
- Voltage, ChB (V)
- Voltage, ChC (V)
- Output Voltage (V)

OK   Cancel

⑧ The other analogue channels for the voltage sensors will be displayed as shown in the figure. Drag them to just under Current ChA.

⑨ Use "Trigger" to stop the motion. To find each values for current and voltages, use "Smart Tool" as illustrated.
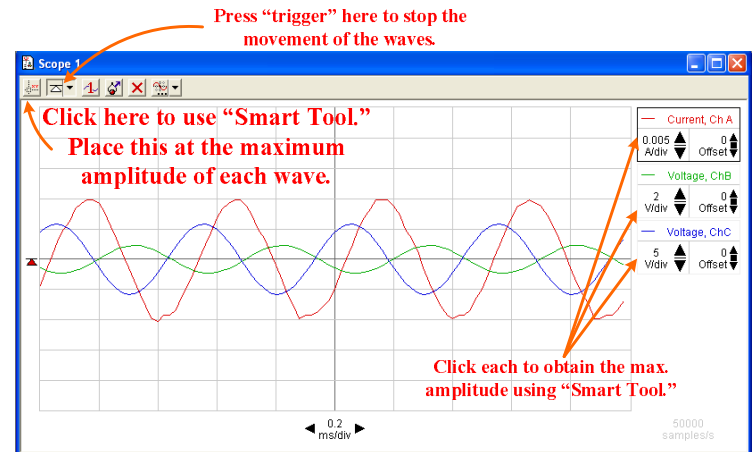
Hint: The current sensor may not detect a very small current. Use a multimeter as shown.

Replace the current sensor with a multimeter.
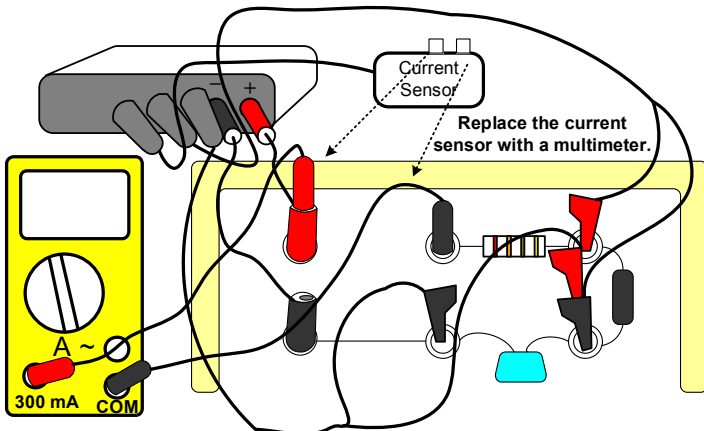
The current displayed in the multimeter is the root mean square, so multiply by $\sqrt{2}$ to obtain the peak current.

Press "trigger" here to stop the movement of the waves.

Click here to use "Smart Tool." Place this at the maximum amplitude of each wave.

Click each to obtain the max. amplitude using "Smart Tool."

Table II: Theoretical Values

	1	2	3
Measured values from DataStudio (See also the hint above.)	I	V_L	V_C
Theoretical values from Table I			
The percent difference $\dfrac{\|\text{Measured} - \text{Theoretical}\|}{\frac{1}{2}\left(\text{Measured} + \text{Theoretical}\right)}$			

2 Resonance frequency

- Qualitative experiment

  ① Set the A/Div, V/Div, and ms/Div as 0.02 A/Div, 5 V/Div (both inductor and capacitor), and 0.2 ms/Div, respectively.
  ② Change the frequency in "Signal Generator" from 2000 Hz with 100 Hz increment up to around 5000 Hz.

  Describe how the voltages across inductor and capacitor changes. How about the current? Is there a maximum value? Which values is increasing or decreasing by increasing the frequency?

- Quantitative experiment

  As for an RLC series AC circuit, when the current becomes maximum with respect to frequency change. This is utilized as tuning signals. Using Ohm's law for the AC circuit, we can have:

  $$f = \frac{1}{2\pi\sqrt{LC}}$$

  This is known as resonance frequency. The qualitative experiment above depicts this property.

  Calculate the resonance frequency. (The L and C are given in the second part.)

  ① Use a multimeter instead of the current sensor. The wires will be connected to the correspondent terminals as shown. The mode of the multimeter has to be A ~, which is for the measurement of the alternating current.
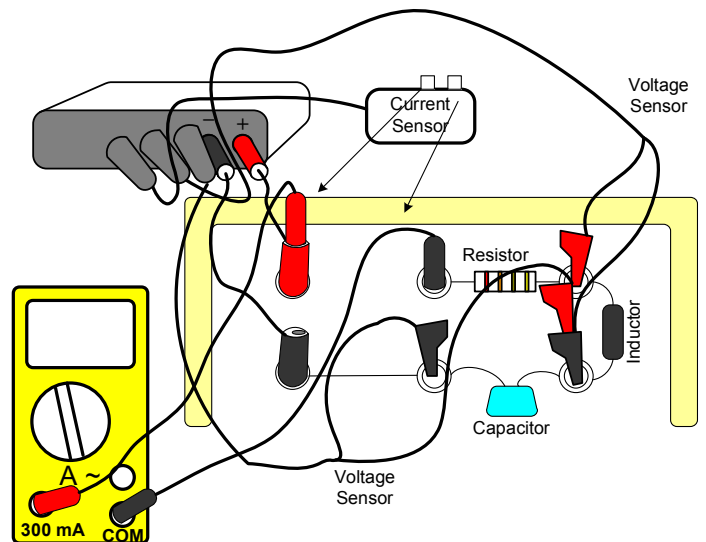

  ② Start 4000 Hz for the source frequency. The increment for this is 100 Hz. Increase

the frequency and look at the current measured with the multimeter. Record the value right before the <u>current going down</u>.

③ Change the increment into 10 Hz and increase the frequency so you can find when you have the maximum current. [Note that you will do this with the following hint. However, you may have to go back a little more to find the maximum current when you keep getting smaller current. <u>Please imagine what is going on! Don't just believe things without thinking.</u>]

Hint: You are trying to find the maximum current by changing frequency. After you find the "frequency right before the current going down", you decrease the step size of frequency to approach the closest maximum current as shown in the figure below.
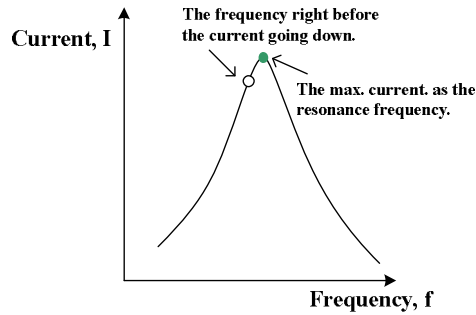
The frequency you select	The current you observe in the multimeter
(The frequency right before the current going down.)	
Increase this by 10 Hz from the above frequency value. ⇩	

④ What is the resonance frequency from the above result?

Experimental resonance frequency _____ (   ) ← units

Calculate the percent difference between theoretical and experimental.

The % difference _____