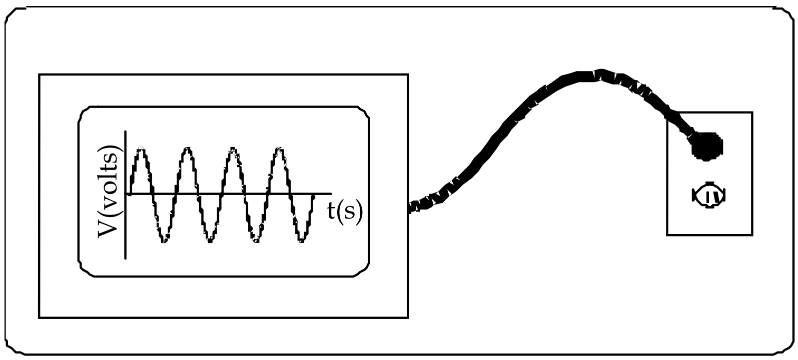
Name ___________________________ Date ____________ Partners_________________________________

Lab 9 - INTRODUCTION TO AC CURRENTS AND VOLTAGES

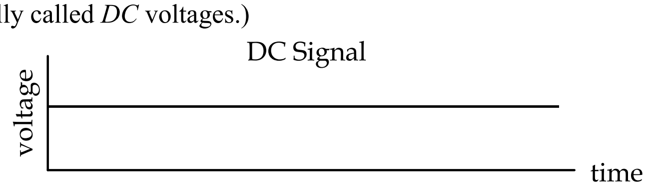


OBJECTIVES

- To learn the meanings of *peak voltage* and *frequency* for AC signals.
- To observe the behavior of resistors in AC circuits.
- To observe the behaviors of capacitors and inductors in AC circuits.
- To understand the meanings of *phase*, *amplitude*, *reactance*, and *impedance* in AC circuits.

OVERVIEW

Until now, you have investigated electric circuits in which a battery provided an input voltage that was effectively constant in time. This is called a *DC* or *Direct Current* signal. (A steady voltage applied to a circuit eventually results in a steady current. Steady voltages are usually called *DC* voltages.)



Signals that change over time exist all around you, and many of these signals change in a regular manner. For example, the electrical signals produced by your beating heart change continuously in time.

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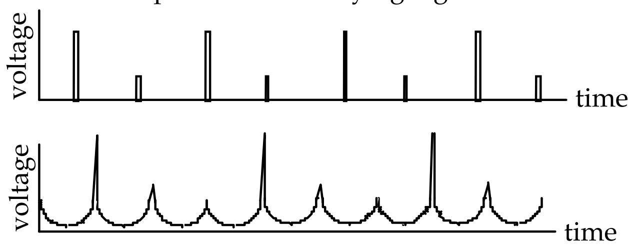
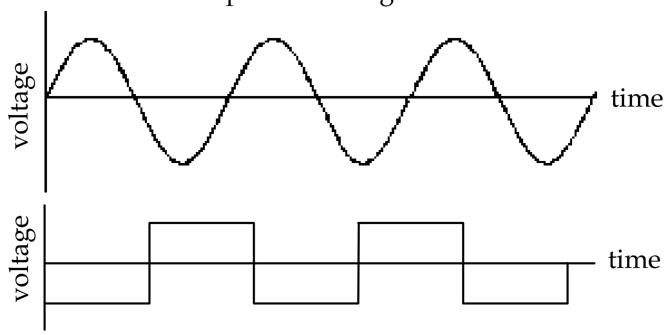
Examples of Time-Varying Signals



There is a special class of time-varying signals. These signals can be used to drive current in one direction in a circuit, then in the other direction, then back in the original direction, and so on. They are referred to as *AC* or *Alternating Current* signals.

Examples of AC Signals



In Investigation 1, you will discover how a time-varying signal affects a circuit with a resistor. In Investigation 2, you will discover how inductors and capacitors influence the current and voltage in various parts in an AC circuit.

INVESTIGATION 1: AC SIGNALS AND RESISTANCE

In this investigation, you will consider the behavior of resistors in a circuit driven by AC signals of various frequencies.

You will need the following materials:

- current probe and voltage probe
- 100 Ω resistor
- multimeter
- 7 alligator clips leads
- internal signal generator of *Data Studio*

Comment: • Phase difference between i(t) and v(t) at 20 Hz, 30 Hz and 40Hz.
• Change in impedance between 20 Hz, 30 Hz and 40Hz.
(R1 = R2 = 100W, signal amplitude = 6 volts)

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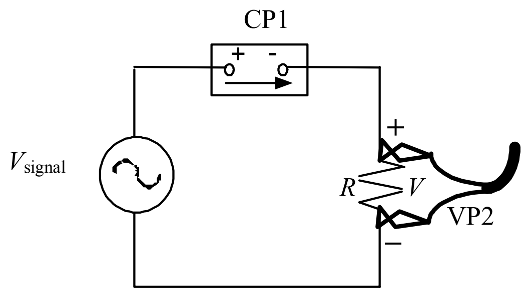
Activity 1-1: Resistors and Time-Varying (AC) Signals.

Consider the circuit in Figure 9-1 with a signal generator and resistor.



R = 100 Ω

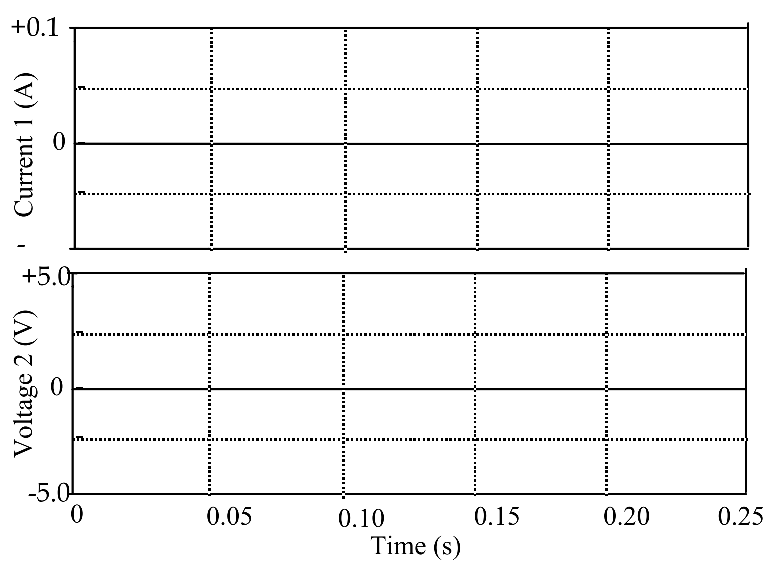
V_{signal} = 5V (amplitude)

f = 20 Hz

Figure 9-1: Resistor circuit with AC input signal.

Question 1-1: What is the relationship between the input signal, V_{signal}, and the voltage measured by the voltage probe, V? (**Hint**: remember that CP1 has a very small resistance compared to R.)

Prediction 1-1: On the axes that follow, sketch, with *dotted* lines, your *quantitative* prediction for the input signal, V_{signal} vs. t and the current through the resistor, I vs. t. (**Hint:** consider Ohm's Law). You know the signal voltage and frequency from Figure 9-1, so try to put in correct values.



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Test your predictions.

1. Open the experiment file called **Resistor with AC L9A1-1**.
2. Connect the circuit in Figure 9-1. We are using the internal signal generator of *Data Studio* interface. The controls should appear on the computer screen.
3. Set the signal generator to 20 Hz and 5 volts amplitude (+5 V maximum and -5 V minimum).
4. **Begin** graphing. When you have a good graph of the signal, **stop** graphing. Expand the graph to look at the same range (0.25 s) as above.
5. **Print** one set of graphs for your group report. Do not erase data.
6. On the graph of voltage vs. time, identify and label a time or two when the current through the resistor is maximum. Depending on the way you hooked up the voltage probe across the resistor, you may have current and voltage in or out of phase. If out of phase, you may want to switch the voltage probe and repeat.
7. On your graph of current vs. time, identify and label a time or two when the voltage across the resistor is maximum.

Question 1-2: Does a voltage maximum occur at the same time as a current maximum, or does one maximum (current or voltage) occur before the other? Explain.

Question 1-3: Use the **Smart Tool** to find the period (time from one peak to the next), *T*, of the voltage. (**Hint:** determine the time period for ten peaks and divide by 10.) Show your calculation.

T:______s

Question 1-4: The period of a signal is the inverse of the frequency ($T = 1/f$). Is your measurement of period consistent with the frequency setting on the signal generator? Show your calculation.

8. Use your graph to complete Column I in Table 9-1. To obtain information from the graph, you can use the **Smart Tool** or you

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can select several cycles by highlighting them, and then use the **statistics feature** to find the maximum values for the voltage and current.

9. Set the frequency of the signal generator to 30Hz. Check that the amplitude is still 5 V. **Graph** *I* and *V* as before. Use the **analysis feature** to complete Column II in Table 9-1.

10. Set the frequency of the signal generator to 40 Hz. Check that the amplitude is still 5 V. **Graph** I and V as before, and complete Column III in Table 9-1.

Table 9-1

Comment: For this table and the subsequent analysis to be useful, Vp-p (signal) must be at least approximately equal to the battery voltage.

Some options are:
1) make sur e that happens.
2) Eliminate column 1 from the table (This makes the whole first part of the lab not as pertinent and I don't like that option)
3) avoid the need to make the voltages equal by adding a step which requires the students calculate effective resistance. This adds even more length to the lab which isn't appealing to me.

Column I	Column II	Column III
f = 20Hz	**f = 30Hz**	**f = 40Hz**
At maximum voltage, current is (circle one): maximum, minimum, zero and increasing, zero and decreasing, nonzero and increasing, nonzero and decreasing, other	**At maximum voltage, current is** (circle one): maximum, minimum, zero and increasing, zero and decreasing, nonzero and increasing, nonzero and decreasing, other	**At maximum voltage, current is** (circle one): maximum, minimum, zero and increasing, zero and decreasing, nonzero and increasing, nonzero and decreasing, other
max. voltage (V_{max}) = ______	max. voltage (V_{max}) = ______	max. voltage (V_{max}) = ______
max. current (I_{max}) = ______	max. current (I_{max}) = ______	max. current (I_{max}) = ______
$R = V_{max} / I_{max}$ = ________	$R = V_{max}/I_{max}$ = ________	$_{max}/I_{max}$ = ________

Question 1-5: Based on the calculations in Table 9-1, what can you say about the resistance of *R* at different frequencies (does its value appear to increase, decrease, or stay the same as frequency increases)? Explain your answer.

Question 1-6: When the input signal is 30 Hz or 40 Hz, does a maximum positive current through *R* occur before, after, or at the same time as the maximum positive voltage across *R*?

Note: Do *not* disconnect this circuit, you will be using a very similar one in Investigation 2.

Comment: In this investigation you discovered that the resistance of a resistor does not change when the frequency of the AC signal applied to it changes. In Investigation 2, you will examine the behavior of capacitors and inductors with AC signals applied to them.Investigation 2: AC Signals with Capacitors and Inductors

INVESTIGATION 2: AC SIGNALS WITH CAPACITORS AND INDUCTORS

In AC circuits, the behavior of circuit elements like inductors and capacitors is in some ways similar to the behavior of resistors. With a resistor in a DC circuit, the resistance determines how much current will flow through it when a voltage is applied to it, according to Ohm's Law.

In AC circuits there is a quantity called *impedance* associated with each circuit element that acts like the resistance in Ohm's Law. In fact, the peak voltage V_{max} is related to the peak current, I_{max} by the relationship $I_{max} = V_{max}/Z$, where Z is the impedance.

For a resistor, the impedance is just the same as the resistance. You have seen in the last investigation that the impedance of a resistor does not change as the frequency of the applied signal changes. In this investigation you will learn about the impedance of a capacitor and an inductor and how these depend on the frequency of the applied AC signal.

You will need the following materials:

- current probe and voltage probe
- multimeter
- 47 μF capacitor
- 800 mH inductor
- 7 alligator clip leads
- internal signal generator

Activity 2-1: Capacitors and AC Signals

In this investigation we want to find out whether the impedance of a capacitor changes when the frequency of the applied signal changes.

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You will investigate this by measuring the behavior of a capacitor when signals of various frequencies are applied to it. Specifically, you will look at the amplitude and the phase of the current through it and the voltage across it. (See the *Comment* that follows for an introduction to phase.)

Comment: When the peak current through and voltage across a circuit element always occur at the same instant the current and voltage are said to be *in phase.* In Activity 1-1, you observed the AC current-voltage characteristics of a resistor. The current and voltage are *in phase* for a resistor.

When the peak current occurs at a different instant than the peak voltage, there is a *phase difference,* or the current and voltage are said to be *out of phase*. The phase difference can be expressed in degrees, radians, or fractions of a period.

Consider the circuit shown in Figure 9-2.

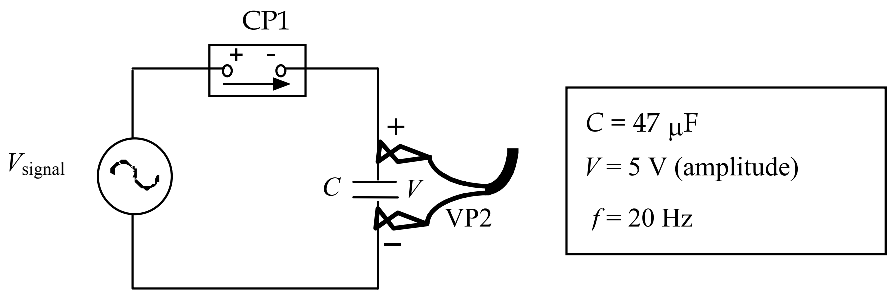

Figure 9-2: Capacitor circuit with AC input

Prediction 2-1: Suppose that you replaced the signal generator with a battery and a switch. The capacitor is initially uncharged, and therefore the voltage across the capacitor is zero. If you close the switch, which quantity reaches its maximum value first: current in the circuit or voltage across the capacitor? As charge builds up on the capacitor, and the voltage across the capacitor increases, what happens to the current in the circuit? Explain.

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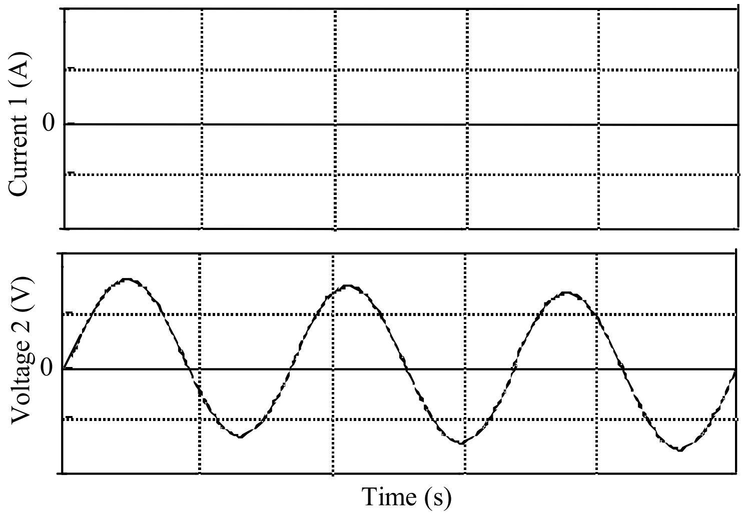
Prediction 2-2: The actual AC voltage applied to the circuit in Figure 9-2 by the signal generator is shown on the axes that follow. Use your answers from the above questions to sketch with *dashed* lines your prediction for the current as a function of time.



Test your predictions.

1. Open the experiment file called **Capacitor L9A2-1**.
2. Connect the circuit in Figure 9-2.
3. Set the signal generator to 20 Hz and amplitude of 5 volts (+5 V maximum and –5 V minimum).
4. **Begin** graphing. When you have a good graph of the signal, **stop** graphing.
5. **Print** one set of graphs for your group report.
6. On the graph of voltage vs. time, identify and label a time or two when the current through the capacitor is maximum.
7. On your graph of current vs. time, identify and label a time or two when the voltage across the capacitor is maximum.
8. Clearly mark one period of the AC signals on your graphs.

Question 2-1: Does your measured current graph agree with your predicted one? If not, how do they differ?

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Comment: One way you can determine the phase difference between two sinusoidal graphs with the same period is by measuring the time difference between two neighboring peaks from each graph and dividing that time difference by the period. This will give you the phase difference as a fraction of a period. For example, if the time difference between two peaks is 0.5 s and the period of the signals is 2.0 s, then the phase difference is 0.25 or 1/4 period. Phase difference can also be stated in degrees or radians by simply multiplying the phase difference in periods by 360^o or 2π radians. Continuing with the example, the signals are 90^o or $\pi/2$ radians out of phase.
The signal that reaches its peak value first is said to *lead* the other.
The impedance of a capacitor, X_C, is called the *capacitive reactance*. The relationship between the peak voltage (V_{max}) across the capacitor and peak current (I_{max}) through the capacitor is $V_{max} = I_{max} X_C$.

Question 2-2: For the capacitor with an input signal of 20 Hz, does a current maximum occur before, after, or at the same time as the maximum voltage?

Question 2-3: What do you predict the phase difference between current and voltage will be? Hint: $\tan\phi = \dfrac{X_L - X_C}{R}$ for your calculation. Put your result in the table.

9. Use the various analysis features to help you fill in Column I in Table 9-2. Determine the experimental phase difference.
10. Set the frequency of the signal generator to 30 Hz. Check that the amplitude is still 5 V. **Graph** I and V as before. Use the **analysis feature** to complete Column II in Table 9-2.

Question 2-4: What can you say about the magnitude of the reactance of the capacitor at 20 Hz compared to the reactance of the capacitor at 30 Hz? Explain based on your observations.

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Question 2-5: What can you say about the phase difference between current and voltage for a capacitor at 20 Hz compared to the phase difference at 30 Hz? Explain based on your observations.

Table 9-2

Column I	Column II
f = 20Hz	F = 30Hz
At maximum voltage, current is (circle one): maximum, minimum, zero and increasing, zero and decreasing, nonzero and increasing, nonzero and decreasing, other	**At maximum voltage, current is** (circle one): maximum, minimum, zero and increasing, zero and decreasing, nonzero and increasing, nonzero and decreasing, other
max voltage (V_{max}) = ______	max voltage (V_{max}) = ______
max current (I_{max}) =_______	max current (I_{max}) =_______
$X_C = V_{max}/I_{max}$ = _______	$X_C = V_{max}/I_{max}$ = _______
Calculate $X_C = 1/\omega C$ ___________	Calculate $X_C = 1/\omega C$ ___________
Calculated phase diff:______ Experimental phase diff:_____ Current leads or voltage leads?	Calculated phase diff:______ Experimental phase diff:_____ Current leads or voltage leads?

Comment: For this table and the subsequent analysis to be useful, Vp-p (signal) must be at least approximately equal to the battery voltage.

Some options are:
1) make sur e that happens.
2) Eliminate column 1 from the table (This makes the whole first part of the lab not as pertinent and I don't like that option)
3) avoid the need to make the voltages equal by adding a step which requires the students calculate effective resistance. This adds even more length to the lab which isn't appealing to me.

Does the impedance of an inductor change when the frequency of the applied signal changes? Is there a phase difference between the current and voltage for an inductor? These questions will be answered in the following activity.

Activity 2-2: Inductors and AC Signals

Consider the circuit shown in Figure 9-3.

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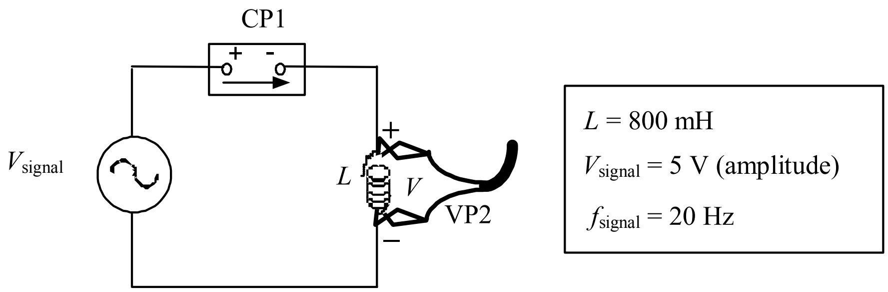

Figure 9-3: Inductor circuit with AC input

Prediction 2-3: Suppose that you replaced the signal generator with a battery and a switch. The inductor initially has no current through it. If you close the switch, which quantity reaches its maximum value first: current in the circuit or voltage across the inductor? (**Hint**: recall that when the current through an inductor is changing, the induced voltage across the inductor opposes the change.) As the current builds up in the circuit, what happens to the induced voltage across the inductor? Explain.

Prediction 2-4: At the instant the current reaches its maximum value for this circuit, what do you predict the magnitude of the induced voltage will be--maximum, minimum or zero? Why?

Prediction 2-5: The actual AC voltage applied to the circuit in Figure 9-3 by the signal generator is shown on the axes that follow. Use your answers from the above questions to sketch with *dashed* lines your prediction for the current as a function of time on the following graph.

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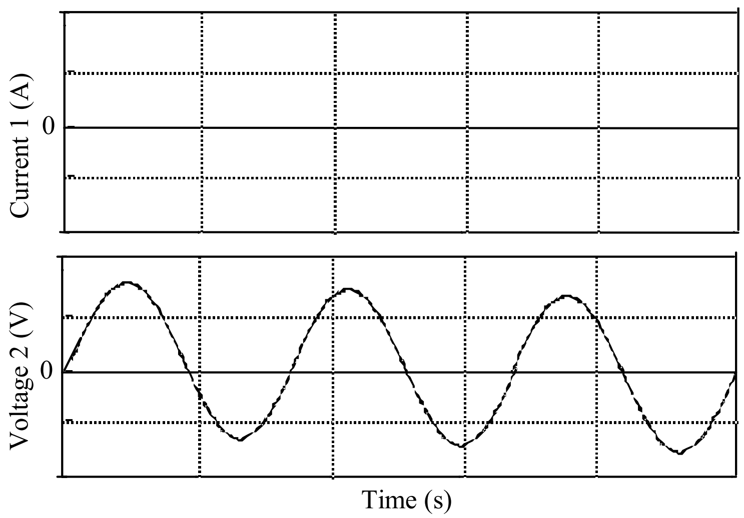

Test your predictions.

1. Open the experiment file called **Inductor L9A2-2**.
2. Connect the circuit in Figure 9-3.
3. Set the signal generator to 20 Hz and amplitude of 5 volts (+5 V maximum and -5 V minimum).
4. **Begin** graphing. When you have a good graph of the signal, **stop** graphing.
5. **Print** one set of graphs for your group report.
6. On the graph of voltage vs. time, identify and label a time or two when the current through the inductor is maximum.
7. On your graph of current vs. time, identify and label a time or two when the voltage across the inductor is maximum.
8. Clearly mark one period of the AC signals on your graphs.

Question 2-6: Does your measured current graph agree with your predicted one? If not, how do they differ?

Question 2-7: For the inductor with an input signal of 20 Hz, does a current maximum occur before, after, or at the same time as the maximum voltage? Explain.

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Comment: The impedance of an inductor, X_L, is called the *inductive reactance*. The relationship between the peak voltage (V_{max}) across the inductor and peak current (I_{max}) through the inductor is $V_{max} = I_{max} X_L$. (**Note**: since you are using a *real* inductor, it has some non-zero resistance. This will actually make your inductor act like a series combination of a resistor and ideal inductor.)

9. Use the analysis features to fill in Column I in Table 9-3. Show your calculation of the phase difference for 20 Hz in the space below the table. Determine it also for 30 Hz, but you do not need to show your work.

Question 2-8: What do you predict will be the phase difference for this inductor at 30 Hz?

10. Set the frequency of the signal generator to 30 Hz. Check that the amplitude is still 5 V. **Graph** I and V as before. Use the analysis features to complete Column II in Table 9-3.

Table 9-3

Column I	Column II
f = 20Hz	f = 30Hz
At maximum voltage, current is (circle one): maximum, minimum, zero and increasing, zero and decreasing, nonzero and increasing, nonzero and decreasing, other	**At maximum voltage, current is** (circle one): maximum, minimum, zero and increasing, zero and decreasing, nonzero and increasing, nonzero and decreasing, other
max voltage (V_{max}) = ______	max voltage (V_{max}) = ______
max current (I_{max}) =_______	max current (I_{max}) =_______
$X_L = V_{max}/I_{max}$ = _______	$X_L = V_{max}/I_{max}$ = _______
Calculate X_L = tan $\phi = X_L/R$ = ______	Calculate X_L = tan $\phi = X_L/R$ = _______
Calculated phase diff:____ Experimental phase diff:_____ Current leads or voltage leads?	Calculated phase diff:____ Experimental phase diff:_____ Current leads or voltage leads?

Comment: For this table and the subsequent analysis to be useful, Vp-p (signal) must be at least approximately equal to the battery voltage.

Some options are:
1) make sur e that happens.
2) Eliminate column 1 from the table (This makes the whole first part of the lab not as pertinent and I don't like that option)
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Question 2-9: What can you say about the magnitude of the reactance of the inductor at 20 Hz compared to the reactance of the capacitor at 30 Hz? Explain based on your observations.

Question 2-10: What can you say about the phase difference between current and voltage for an inductor at 20 Hz compared to the phase difference at 30 Hz? Explain based on your observations. Were the phase differences what you expected? Do you think the fact that the inductor you used has a significant resistance plays a role?

Summary: The impedance (resistance) of a resistor does not change as the AC signal frequency is changed. The responses of a capacitor and an inductor are considerably different. As you have observed, as the frequency of the AC signal increases, the reactance of a capacitor decreases, while the reactance of an inductor increases. The actual equations for capacitive and inductive reactance are:

$$X_C = \frac{1}{2\pi fC} \quad \text{and} \quad X_L = 2\pi fL$$

Here, C is the capacitance, L is the inductance, and f is the frequency of the AC signal in Hz.

Question 2-11: Go back to Tables 9-2 and 9-3 and compare your experimental reactances with theoretical reactances, which you may now calculate with the equations above. How well do they agree? Is this reasonable?

Question 2-12: Do the reactance equations above make intuitive sense? Answer this by considering DC circuits (i.e. $f = 0$) in the steady state(i.e. after things settle down), and then by considering what happens at high frequencies.

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