

Activity P52: LRC Circuit (Voltage Sensor)

Concept	<i>DataStudio</i>	<i>ScienceWorkshop</i> (Mac)	<i>ScienceWorkshop</i> (Win)
AC circuits	P52 LRC Circuit.DS	(See end of activity)	(See end of activity)

Equipment Needed	Qty	From AC/DC Electronics Lab (EM-8656)	Qty
Voltage Sensor (CI-6503)	1	Capacitor, 100 microfarad (100 μF)	1
Patch Cord (SE-9750)	2	Inductor Coil and Iron Core	1
<i>Graph paper (optional)</i>	1	Resistor, 10 ohm (10 Ω)	1
LCR Meter (SB-9754) (optional)	1	Wire Lead, 5 inch	1

What Do You Think?

The purpose of this activity is to study resonance in an inductor-resistor-capacitor circuit (LRC circuit) by examining the current through the circuit as a function of the frequency of the applied voltage. What will happen to the amplitude of the current in the LRC circuit when the frequency of the applied voltage is at or near the resonant frequency of the circuit?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

When a vibrating mechanical system is set in motion, it vibrates at its natural frequency. However, a mechanical system can be forced to vibrate at a different frequency. The amplitude of vibration, and hence the energy transferred to the system, depends on the difference between the natural frequency and the frequency of forced vibration. The amplitude becomes very large when the difference between the natural and forced frequency becomes very small. This is known as resonance and the natural frequency of the system is sometimes called the resonant frequency. At resonance, relatively little energy is required to get a large amplitude. One example of resonance is when a singer's amplified voice is used to shatter a glass.



Electrical resonance is analogous to mechanical resonance. The energy transferred to a system is a maximum at resonance.

The amplitude of the AC current (I_o) in a series LRC circuit is dependent on the amplitude of the applied voltage (V_o) and the impedance (Z).

$$I_o = \frac{V_o}{Z}$$

Since the impedance depends on frequency, the current varies with frequency:

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

where X_L = inductive reactance = ωL , X_C = capacitive reactance = $\frac{1}{\omega C}$, R = resistance, and ω = angular frequency = $2\pi f$ (f = linear frequency). The current will be maximum when the circuit is driven at its resonant frequency:

$$\omega_{res} = \frac{1}{\sqrt{LC}}$$

One can show that, at resonance, $X_L = X_C$ and thus the impedance (Z) is reduced to R . At resonance, the impedance is the lowest value possible and the current will be the largest value possible.

SAFETY REMINDER

- Follow all safety instructions.

**THINK SAFETY
ACT SAFELY
BE SAFE!**

For You To Do

Use the ‘Output’ feature of the *ScienceWorkshop* interface to produce an alternating current through the LRC circuit. Use the Voltage Sensor to measure the voltage drop (potential difference) across the resistor in the circuit.

The amplitude of the current depends on the impedance in the circuit, which varies with frequency. Calculate the theoretical resonant frequency for your circuit. Use the *ScienceWorkshop* or *DataStudio* program to control the frequency. If the current is a maximum at the resonant frequency and is less than maximum for greater or lesser frequencies, the current should peak at the resonant frequency. Determine the amplitude of the current through the resistor and then plot current versus frequency. The current can be determined from the ratio of the resistor voltage to the resistance. Compare the theoretical resonant frequency to your measured resonant frequency.

Also, investigate the phase relationship between the applied voltage and the resistor voltage as you vary the frequency.

Use *DataStudio* or *ScienceWorkshop* to record and display both the applied voltage and the resistor voltage.



PART I: Computer Setup

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Voltage Sensor to Analog Channel B.
3. Connect banana plug patch cords into the ‘OUTPUT’ ports on the interface.
4. Open the document titled as shown:

<i>DataStudio</i>	<i>ScienceWorkshop</i> (Mac)	<i>ScienceWorkshop</i> (Win)
P52 LRC Circuit.DS	(See end of activity)	(See end of activity)

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook. The document also has a Scope display of ‘Output Voltage’ and ‘Voltage, Ch B’.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.

Name _____

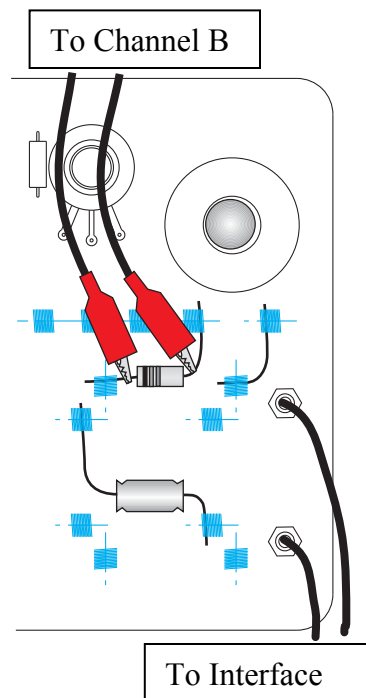
Class _____

Date _____

- The Signal Generator is set to output a sine wave at 2.97 volts with the initial frequency at 10 Hz. The Signal Generator is set to 'Auto' so it will start and stop automatically when you start and stop measuring data.

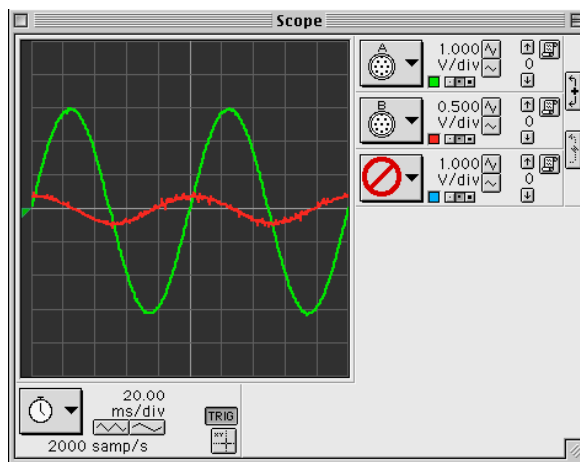
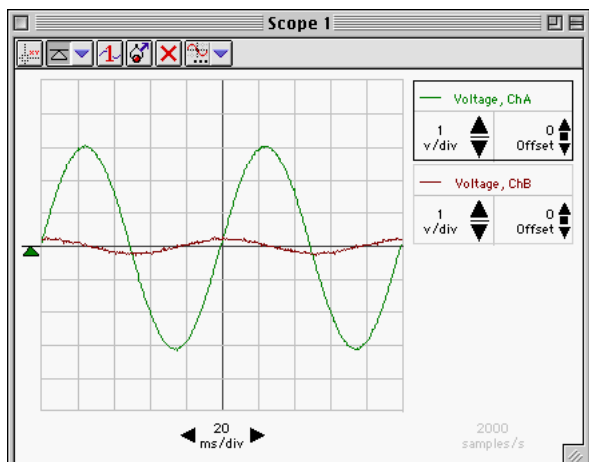
PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Voltage Sensors. The following setup shows the AC/DC Electronics Board (EM-9656).
- Connect a 5-inch wire lead between a component spring next to the top banana jack, and the component spring at the right hand edge of the inductor coil. Put the iron core inside the inductor coil.
 - Connect the 10-Ω resistor (brown, black, black) between the component spring at the left-hand edge of the inductor coil, and the second component spring to the left of the top banana jack.
 - Connect the 100-μF capacitor between the component spring nearest to the one in which one end of the 10-Ω resistor is connected, and a component spring nearest to the bottom banana jack at the lower right corner of the AC/DC Electronics Lab circuit board.
 - Put alligator clips on the banana plugs of the Voltage Sensor connected to Analog Channel B. Connect the alligator clips of the Voltage Sensor to the wires at both ends of the 10-Ω resistor. The voltage measured at Analog Channel B is related to the current through the resistor by $I = \frac{V_R}{R}$.
 - Connect banana plug patch cords from the banana jacks on the edge of the AC/DC Electronics Lab Board to the ‘OUTPUT’ ports on the *ScienceWorkshop* interface.





Part III: Data Recording

- Check the Signal Generator window. Set the waveform to “sine”. Set the output voltage to 3 volts. Set the output frequency to 10 Hz.
 - Start measuring data. (Click ‘Start’ in *DataStudio* or ‘MON’ in *ScienceWorkshop*.)
- The Scope display shows the ‘Output’ voltage, V , from the interface, and the voltage, V_R , across the resistor (Channel B).

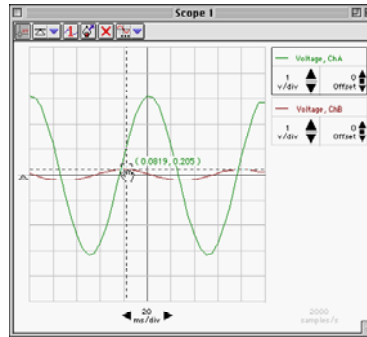


3. In the Scope display, determine the voltage, V_R , across the resistor (i.e., voltage from Channel B).

- Hint: In *DataStudio*, click the 'Smart Tool' button () in the Scope display toolbar. In *ScienceWorkshop*, click the 'Smart Cursor' button () along the bottom edge of the display. Move the cursor/cross-hair to a peak of the signal that shows the voltage across the resistor, V_R (Channel B).

4. Record the voltage, V_R , in the Data Table in the Lab Report section next to 10 Hz.

- Hint: In *DataStudio*, the voltage is the first number in the Smart Tool's ordered pair. In *ScienceWorkshop*, the voltage is displayed next to the Input Menu button for Channel B.



5. Adjust the function generator to 20 Hz. Repeat the process to find the new value of voltage and record it in the Data Table next to 20 Hz.
6. Increase the frequency in 10 Hz increments until 150 Hz. Repeat the process of using the Smart Cursor to find each new value for the resistor voltage, V_R . Record each voltage value in the Data Table.


- NOTE: Adjust the Sweep Speed in the Scope display using the **Sweep Speed** button as needed.

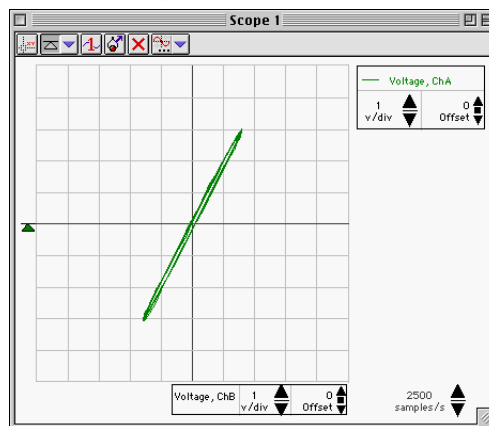
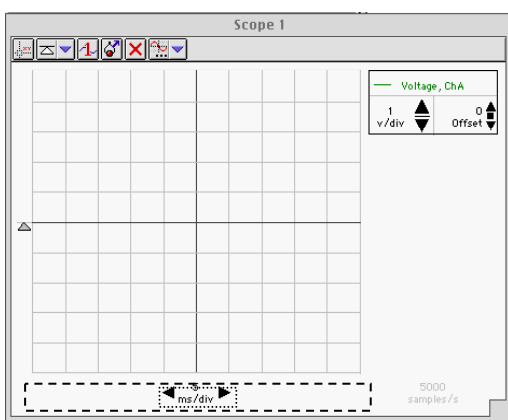
7. Look at the Data Table and estimate the approximate resonant frequency (where voltage across the resistor reaches a maximum).
8. Adjust the function generator to the value of your estimate of the resonant frequency. Make fine adjustments to the frequency until the trace of voltage from Channel B is *in phase* with the trace of voltage from Channel A.

- Hint: Switch the Scope display to X-Y mode to check whether the trace of voltage from Channel B (resistor voltage) is *in phase* with the trace of voltage from Channel A (the function generator). See the descriptions below.

9. Record the new resonant frequency in the Data Table.
10. Stop measuring data.



Frequency Adjustment in XY Mode: *DataStudio*

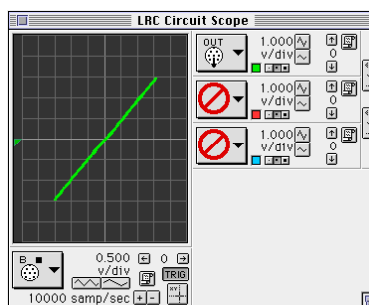
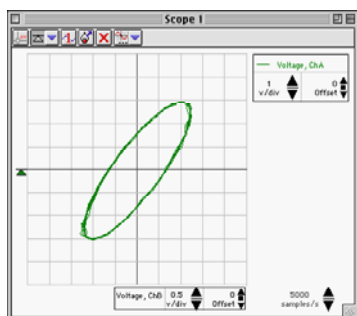
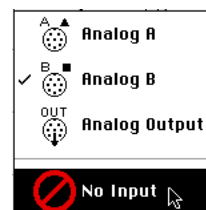
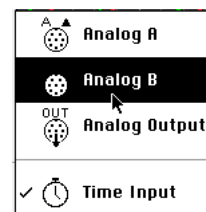
1. Click Stop.
2. In the display, temporarily remove 'Voltage ChB'. (Hint: Click 'Voltage ChB' to select the input and then click the 'Remove' button () in the Scope toolbar.)
3. Click and drag 'Voltage ChB (v)' from the Summary list to the bottom edge of the Scope display. Drop 'Voltage ChB (v)' onto the Sweep Speed control panel.



- Note: The Sweep Speed control panel will be surrounded by a dashed rectangle when the new input ('Voltage ChB (v)') is on top of the control panel. (See the illustration.)
4. Click 'Start' to begin monitoring the data again.
 5. Adjust the function generator frequency until the Scope display shows a diagonal line. An oval trace means the signals are out-of-phase.

Frequency Adjustment in XY Mode: ScienceWorkshop

- Click STOP.
- In the Scope display, click the 'Horizontal Axis Input' menu button () (). Select 'Analog B' from the Horizontal Axis Input menu.
- In the Scope, click the 'Channel B Input' menu button () (). Select 'No Input' from the Channel B Input menu.
- Click the 'MON' button to begin monitoring data again.
- Adjust the function generator frequency as needed to reach the resonant frequency. When the two inputs are in phase, the Scope display in X-Y mode will show a diagonal line. An oval trace means the signals are out-of-phase.



- If you have a meter that can measure inductance, resistance, and capacitance, use it to measure the inductance of the coil with the core inside, the resistance of the 10 Ohm resistor, and the capacitance of the 100 microfarad capacitor. Record your values in the Data Table.

Analyzing the Data

1. Calculate the current through the resistor for each increment of frequency and record the values in the Data Table.
2. Graph the current versus the linear frequency. You can use the software or graph paper. (NOTE: The function generator frequency is the linear frequency.)
3. Using the resonant frequency found from the Scope display, calculate the resonant angular frequency and record the value in the Data Table:

$$\omega_{res} = 2\pi\nu_{res}$$

4. Calculate the theoretical resonant angular frequency using the values of the inductance and capacitance:

$$\omega_{res} = \frac{1}{\sqrt{LC}}$$

Record your results in the Lab Report section.

Lab Report - Activity P52: LRC Circuit

What Do You Think?

The purpose of this activity is to study resonance in an inductor-resistor-capacitor circuit (LRC circuit) by examining the current through the circuit as a function of the frequency of the applied voltage. What will happen to the amplitude of the current in the LRC circuit when the frequency of the applied voltage is at or near the resonant frequency of the circuit?

Data Table

Freq (Hz)	V_R	Current (V_R/R)	Freq (Hz)	V_R	Current (V_R/R)
10			90		
20			100		
30			110		
40			120		
50			130		
60			140		
70			150		
80					

Item	Value
Inductance	
Resistance	
Capacitance	

Resonant frequency (linear)	
Resonant angular frequency	
Theoretical resonant angular frequency	

Questions

1. How does your measured value for resonant angular frequency compare to the theoretical value for resonant angular frequency?

Remember, **Percent difference** = $\left| \frac{\textit{theoretical} - \textit{actual}}{\textit{theoretical}} \right| \times 100\%$

2. Is the plot of current versus frequency symmetrical about the resonant frequency? Explain.
3. At resonance, the reactances of the inductor and the capacitor cancel each other so that the impedance (Z) is equal to just the resistance (R). Calculate the resistance of the circuit by using the amplitude of the current at resonance in the equation $R = \frac{V}{I}$ (where V is the amplitude of the applied voltage). Is this resistance equal to 10 ohms? Why not?

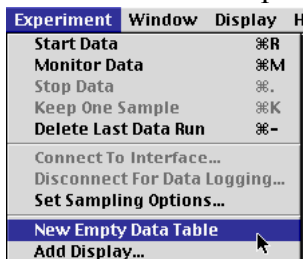
Optional

1. Use the Voltage Sensor in Analog Channel B to measure the peak voltage across each of the components of the circuit individually. The sum of these peak voltages do not equal the applied peak voltage. Why not? Draw a phasor diagram to explain this.
2. Determine whether the resonant frequency depends on the resistance.
(To see if the resistance makes a difference, set the Scope to the resonant frequency and then replace the 10-ohm resistor by a 100-ohm resistor. Does the resonant frequency increase, decrease, or stay the same?)

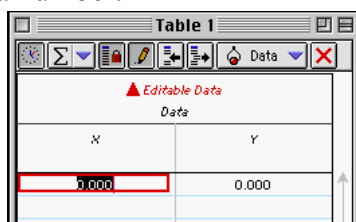
Graphing Current vs. Linear Frequency using DataStudio

You can enter data into a Table display and then show the data in a Graph window.

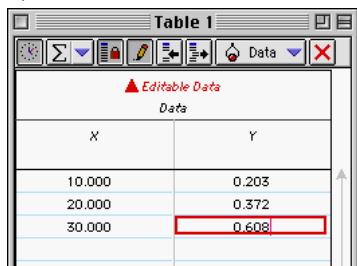
1. Select 'New Empty Data Table' from the Experiment menu.



2. The Table has two columns labeled 'X' and 'Y'. The first cell under the 'X' column is ready for you to enter a number.



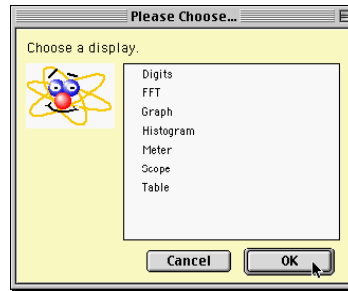
3. Enter the first value of frequency (Freq (Hz)), click <TAB>, and enter the first value of current (Current = V_R/R). Click <TAB> to move to the second row.



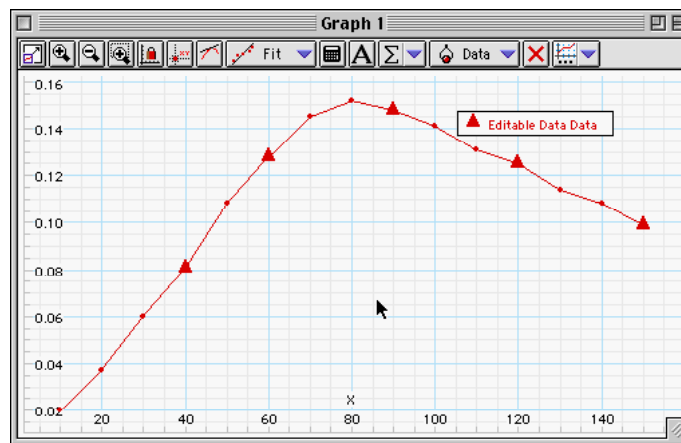
4. Continue to enter values of frequency and current. (Note: *DataStudio* anticipates the next value of frequency for you.)
5. Select 'Add Display...' from the Experiment menu.



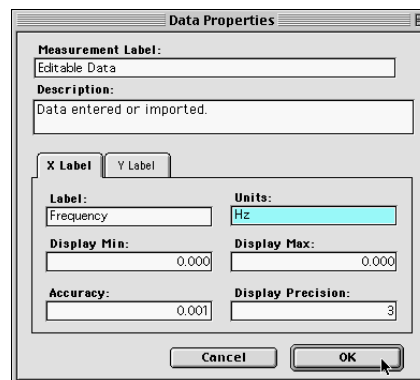
6. Click 'Graph' and then click 'OK' in the 'Please Choose...' window.



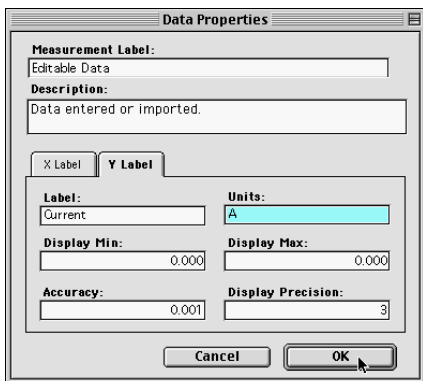
7. From the Summary list, click and drag 'Data' (under 'Editable Data') to the new Graph.
- The Graph shows that current peaks at about 80.



- To add labels to the Y-axis and X-axis, double-click on 'Editable Data' in the Summary



list to open the Data Properties window.



- Enter 'Current' for the Y Label and 'A' for the Units, and enter 'Frequency' for the X Label and 'Hz' for the units. Click 'OK' to return to the Graph.

Graphing Current vs. Linear Frequency using ScienceWorkshop



You can type data into the Notes window and then display the data in a Graph window.







1. Clear the text and graphics (if any) from the Notes window.
2. Type data into the Notes window using the following procedure:
 <independent variable value #1><TAB><dependent variable value #1><return>
 <independent variable value #2><TAB><dependent variable value #2><return>, etc.

- In this case, the independent variable is frequency, and the dependent variable value is the current.
 - For example, the figure shows two columns of numbers typed into a Notes window. The first column represents the linear **frequencies**. The second column represents hypothetical values of **current**.
3. Use the cursor to select (highlight) the two columns of numbers, or click the 'Edit' menu and pick 'Select All'.

Experiment Notes	
10	7
20	15
30	21
40	30
50	38
60	47
70	51
80	55
90	52
100	50
120	41
130	35
140	32

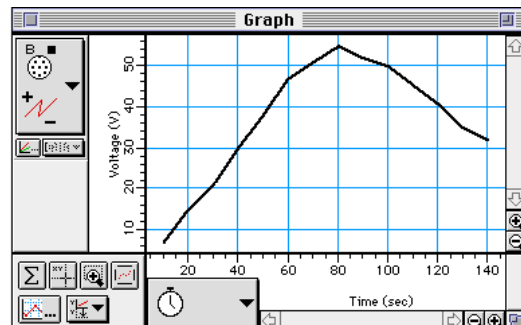
Edit Experiment	
Cut	⌘H
Copy	⌘C
Paste	⌘V
Clear	
Select All	⌘A

4. Copy the selection (use 'Copy' from the Edit menu).
5. Click the Display Menu and select 'New Graph'.
6. Click the **Plot Data Options** button () in the new graph display. The Plot Data Options window will open.
7. Click **Paste** to paste your numbers for frequency and current into the graph. Click **OK** to return to the graph. Click the **Autoscale** button () to rescale the graph to fit your data.

Display	
12.3 New Digits	
 New Meter	
 New Scope	
 New FFT	
 New Table	
 New Graph	
Set Up Active Display...	⌘E
Hide Active Display	⌘H
 Scope	

- Notice that the horizontal axis shows "Time (sec)" rather than frequency, but that the range for the horizontal scale is correct.

Plot Data Options	
<input type="checkbox"/> Show Prior Runs While Recording	
Match Data:	Load...
0 Points	Paste
	Delete
Cancel	OK



Modify an existing *ScienceWorkshop* file.**Open the *ScienceWorkshop* File**

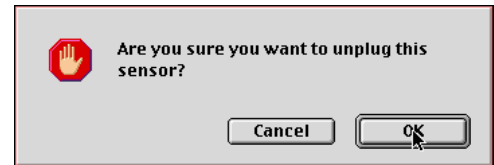
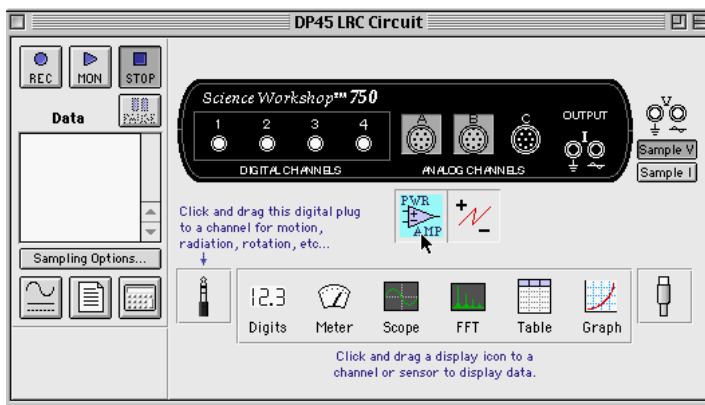
Open the file titled as shown:

<i>ScienceWorkshop</i> (Mac)	<i>ScienceWorkshop</i> (Win)
P45 LRC Circuit	P45_LRCC.SWS

This activity uses the ‘Output’ feature of the *ScienceWorkshop* 750 interface to provide the output voltage. Remove the Power Amplifier in the Experiment Setup window.

Remove the Power Amplifier Icon

In the Experiment Setup window, click the Power Amplifier icon and press <delete> on the



keyboard.

Result: A warning window opens. Click ‘OK’ to return to the setup window.