

## Experiment P44: LR Circuit (Power Amplifier, Voltage Sensor)

Concept	Time	SW Interface	Macintosh® file	Windows® file
circuits	30 m	700	P44 LR Circuit	P44_LRCL.SWS

<u>EQUIPMENT NEEDED</u>	<u>FROM AC/DC ELECTRONICS LAB*</u>
• Science Workshop Interface	• resistor, 10 ohm (10 Ω)
• Power Amplifier	• (2) wire lead, 5 inch
• (2) Voltage Sensors	
• Multimeter	
• (2) Patch Cords	
• LCR Meter (optional)	

(\*The AC/DC Electronics Laboratory is PASCO EM-8656.)

### PURPOSE

This activity investigates the voltages across the inductor and resistor in an inductor-resistor circuit (LR circuit), and the current through the inductor so that the behavior of an inductor in a DC circuit can be studied.

### THEORY

When a DC voltage is applied to an inductor and a resistor in series a steady current will be established:

$$I_{\max} = \frac{V_o}{R}$$

where  $V_o$  is the applied voltage and  $R$  is the total resistance in the circuit. But it takes time to establish this steady-state current because the inductor creates a back emf in response to the rise in current. The current will rise exponentially:

$$I = I_{\max} (1 - e^{-(R/L)t}) = I_{\max} (1 - e^{-(t/\tau)})$$

where  $L$  is the inductance and the quantity  $L/R = \tau$  is the inductive time constant. The inductive time constant is a measure of how long it takes the current to be established. One inductive time constant is the time it takes for the current to rise to 63% of its maximum value (or fall to 37% of its maximum). The time for the current to rise or fall to half its maximum is related to the inductive time constant by

$$t_{1/2} = \tau(\ln 2)$$

$$\tau = \frac{t_{1/2}}{\ln 2}$$

Since the voltage across a resistor is given by  $V_R = IR$ , the voltage across the resistor is established exponentially:

$$V_R = V_o(1 - e^{-t/\tau})$$

Since the voltage across an inductor is given by  $V_L = L\left(\frac{dI}{dt}\right)$ , the voltage across the inductor starts at its maximum and then decreases exponentially:

$$V_L = V_o e^{-t/\tau}$$

After a time  $t \gg \tau$ , a steady-state current  $I_{max}$  is established and the voltage across the resistor is equal to the applied voltage,  $V_o$ . The voltage across the inductor is zero. If, after the maximum current is established, the voltage source is turned off, the current will then decrease exponentially to zero while the voltage across the resistor does the same and the inductor again produces a back emf that decreases exponentially to zero. In summary:

DC Voltage applied:

$$I = I_{max} \left(1 - e^{-t/\tau}\right)$$

$$V_R = V_o \left(1 - e^{-t/\tau}\right)$$

$$V_L = V_o e^{-t/\tau}$$

DC Voltage turned off:

$$I = I_{max} e^{-t/\tau}$$

$$V_R = V_o e^{-t/\tau}$$

$$V_L = V_{emf} \left(1 - e^{-t/\tau}\right)$$

At any time, Kirchhoff's Loop Rule applies: The algebraic sum of all the voltages around the series circuit is zero. In other words, the voltage across the resistor plus the voltage across the inductor will add up to the source voltage.

## **PROCEDURE**

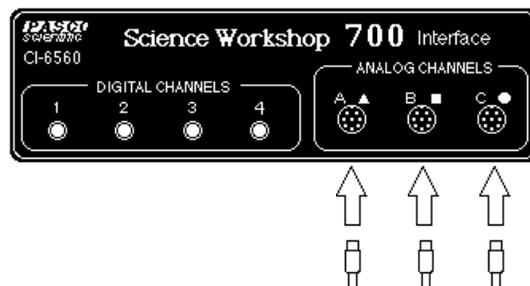
In this activity the Power Amplifier provides voltage for a circuit consisting of an inductor and a resistor. The Voltage Sensors measure the voltages across the inductor and resistor. The Signal Generator produces a low frequency square wave that imitates a DC voltage being turned on and then turned off.

The *Science Workshop* program records and displays the voltages across the inductor and resistor as the current is established exponentially in the circuit. You will use the graph display of the voltages to investigate the behavior of the inductor-resistor circuit.

## **PART I: Computer Setup**

1. Connect the *Science Workshop* interface to the computer, turn on the interface, and turn on the computer.

2. Connect one Voltage Sensor to Analog Channel A. This sensor will be "Voltage Sensor A". Connect the second Voltage Sensor to Analog Channel B. This sensor will be "Voltage Sensor B".



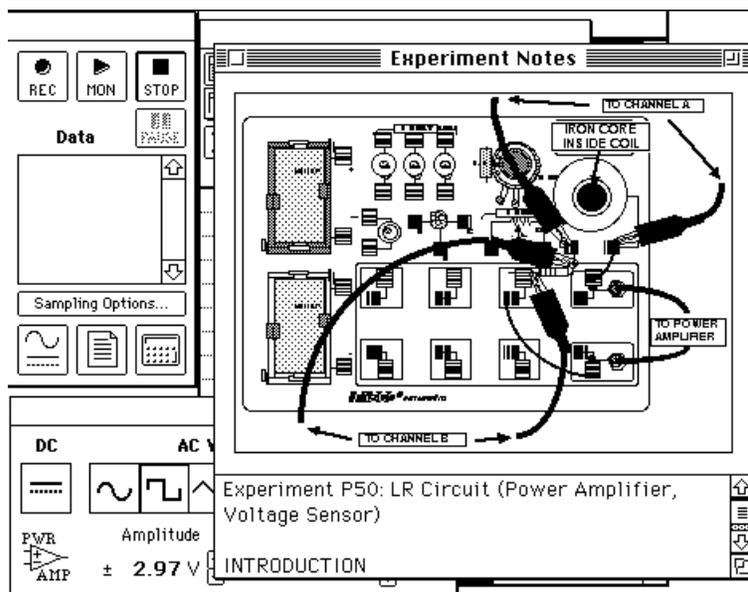
3. Connect the Power Amplifier to Analog Channel C. Plug the power cord into the back of the Power Amplifier and connect the power cord to an appropriate electrical outlet.

4. Open the *Science Workshop* document titled as shown :

Macintosh	Windows
P44 LR Circuit	P44_LRCI.SWS

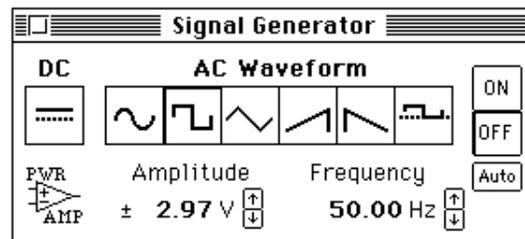
- The document opens with a Graph display of Voltage (V) versus Time (sec), and the Signal Generator window which controls the Power Amplifier.

- Note: For quick reference, see the Experiment Notes window. To bring a display to the top, click on its window or select the name of the display from the list at the end of the Display menu. Change the Experiment Setup window by clicking on the **Zoom** box or the **Restore** button in the upper right hand corner of that window.)



5. The **Sampling Options...** for this experiment are: **Periodic Samples = Fast** at 10000 Hz, **Start Condition = Ch. C** voltage at 0 volts, and **Stop Condition = Time** at 0.02 seconds.

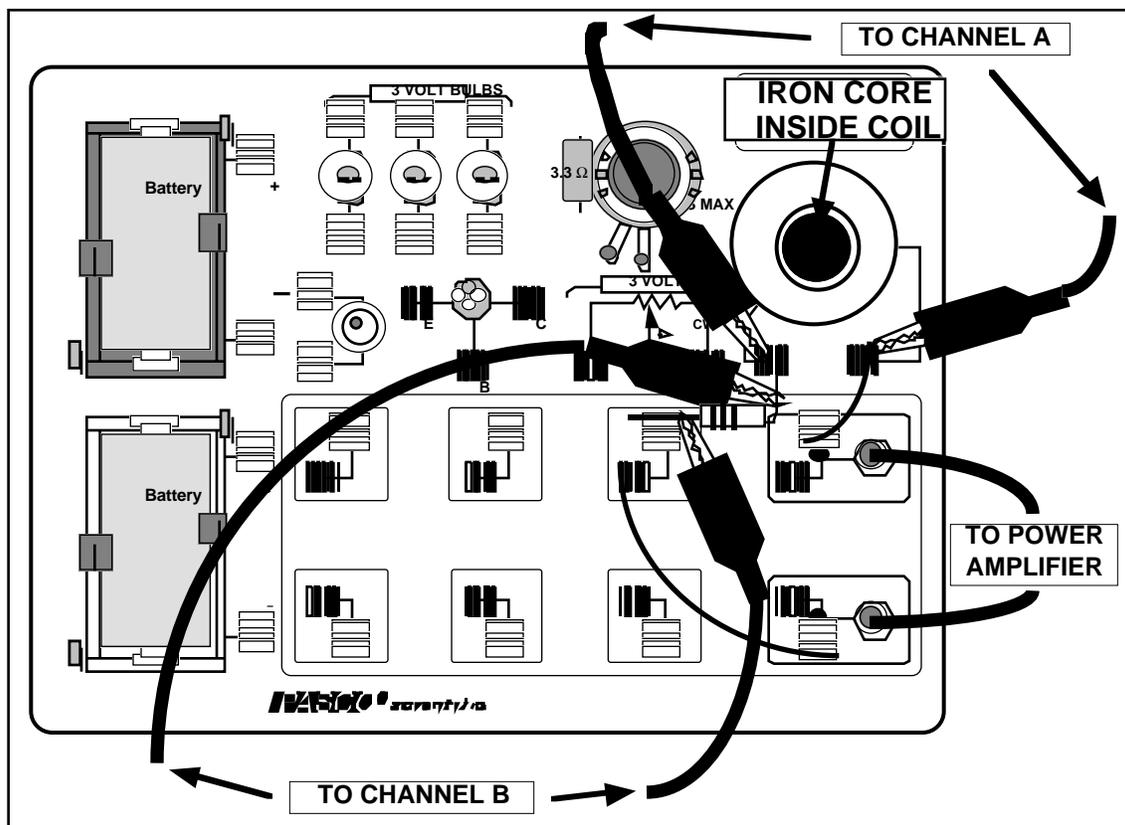
6. The Signal Generator is set to output 3.00 V, square AC Waveform, at 50.00 Hz.



- The Signal Generator is set to **Auto** so it will start automatically when you click **MON** or **REC** and stop automatically when you click **STOP** or **PAUSE**.
7. Arrange the Graph display and the Signal Generator window so you can see both of them.

## PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Power Amplifier or the Voltage Sensor.
1. Put the iron core into the inductor coil on the AC/DC Electronics Lab circuit board.
  2. 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 on the circuit board.
  3. Connect the 10  $\Omega$  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.
  4. Connect another 5 inch wire lead between the component spring nearest to the one in which one end of the 10  $\Omega$  resistor is connected and a component spring nearest to the bottom banana jack at the lower right corner of the circuit board.



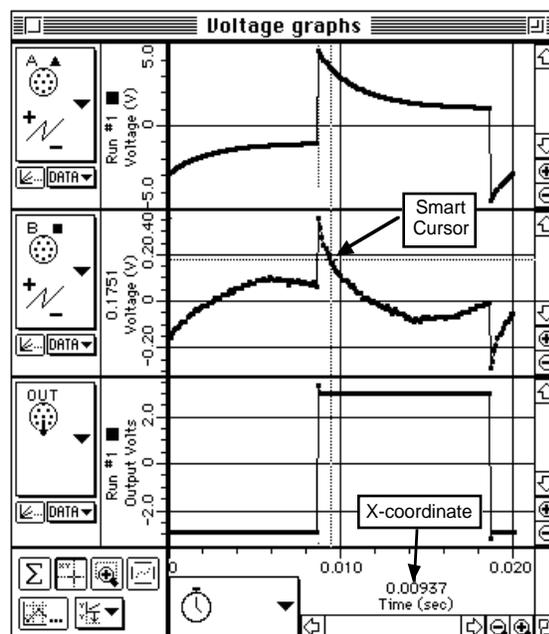
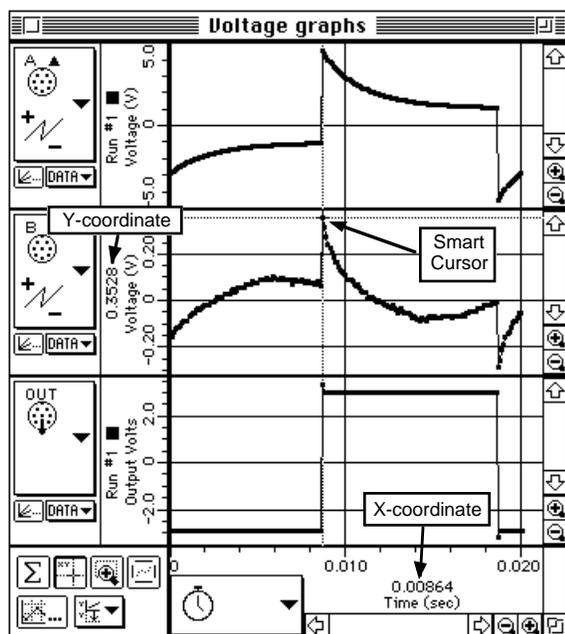
5. Put alligator clips on the banana plugs of both Voltage Sensors. Connect the alligator clips of Voltage Sensor "A" to the component springs at both sides of the inductor coil.
6. Connect the alligator clips of Voltage Sensor "B" to the wires at both ends of the 10  $\Omega$  resistor.
7. Connect banana plug patch cords from the output of the Power Amplifier to the banana jacks on the AC/DC Electronics Lab circuit board.

### PART III: Data Recording

1. Use a multimeter to measure the resistance of the inductor coil on the AC/DC Electronics Lab circuit board. Record the coil resistance in the Data section.
2. Use a multimeter to measure the resistance of the  $10\ \Omega$  resistor. Record the measured resistor value in the Data section.
  - (Optional: If you have a meter that measures inductance, use it to measure the inductance of the inductor coil with the iron core inside.)
3. Turn on the power switch on the back of the Power Amplifier.
4. Click the **REC** button () to begin collecting data. The Signal Generator will start automatically.
  - Data recording will end automatically after 0.02 seconds. **Run #1** will appear in the Data list in the Experiment Setup window.
5. Turn off the power switch on the back of the Power Amplifier.

### ANALYZING THE DATA

- The voltage across the resistor is in phase with the current. The voltage is also proportional to the current (that is,  $V = IR$ ). Therefore, the behavior of the current is studied indirectly by studying the behavior of the voltage across the resistor (measured on Analog Channel B).
1. Click the **Smart Cursor** button () in the Graph. The cursor changes to a cross-hair. Move the cursor into the display area of the Graph.
    - The Y-coordinate of the cursor/cross-hair is shown next to the Vertical Axis.
    - The X-coordinate of the cursor/cross-hair is shown next to the Horizontal Axis.
  2. Move the cursor/cross-hair to the top of the exponential part of the curve when the plot of voltage across the resistor (Analog Channel B) is at its maximum. Record the peak voltage (Y-coordinate) and the time (X-coordinate) for that point in the Data section. Determine the voltage that is half of the peak (the “half-max” voltage).



3. Move the cursor down the exponential part of the plot of resistor voltage until you reach the “half-maximum” (peak) voltage. Record the X-coordinate (time) for this point.
4. Subtract the time for the peak voltage from the time for the half-max voltage to get the time for the voltage to reach half-max. Record this time in the Data Table.
5. Calculate the inductive time constant based on the total resistance in the circuit and the value for the inductance of the inductor coil with the iron core:  $L = 18.9$  millihenry or  $0.0189$  H.

• NOTE: If you have a meter that measures inductance, use your measured value for the inductance of the coil plus core.

Inductive time constant,  $\tau = \frac{L}{R}$ .

Record the calculated value for the inductive time constant in the Data section.

### DATA TABLE

$L = 18.9$  millihenry or  $0.0189$  H for the coil plus core, unless measured otherwise.

Item	Value
Inductor resistance	$\Omega$
Resistor resistance	$\Omega$
Total resistance	$\Omega$
Peak voltage (for resistor)	V
Time at peak voltage	sec
Time at half-maximum voltage	sec
Time to reach half-maximum	sec
$\tau = \frac{t_{1/2}}{\ln 2}$	sec
$\tau = L/R$	sec

### QUESTIONS

- How does the inductive time constant found in this experiment compare to the theoretical value given by  $\tau = L/R$ ? (Remember that R is the total resistance of the circuit and therefore must include the resistance of the coil as well as the resistance of the resistor.)
- Does Kirchhoff's Loop Rule hold at all times? Use the graphs to check it for at least three different times: Does the sum of the voltages across the resistor and the inductor equal the source voltage at any given time?