Includes Teacher's Notes and Typical Experiment Results
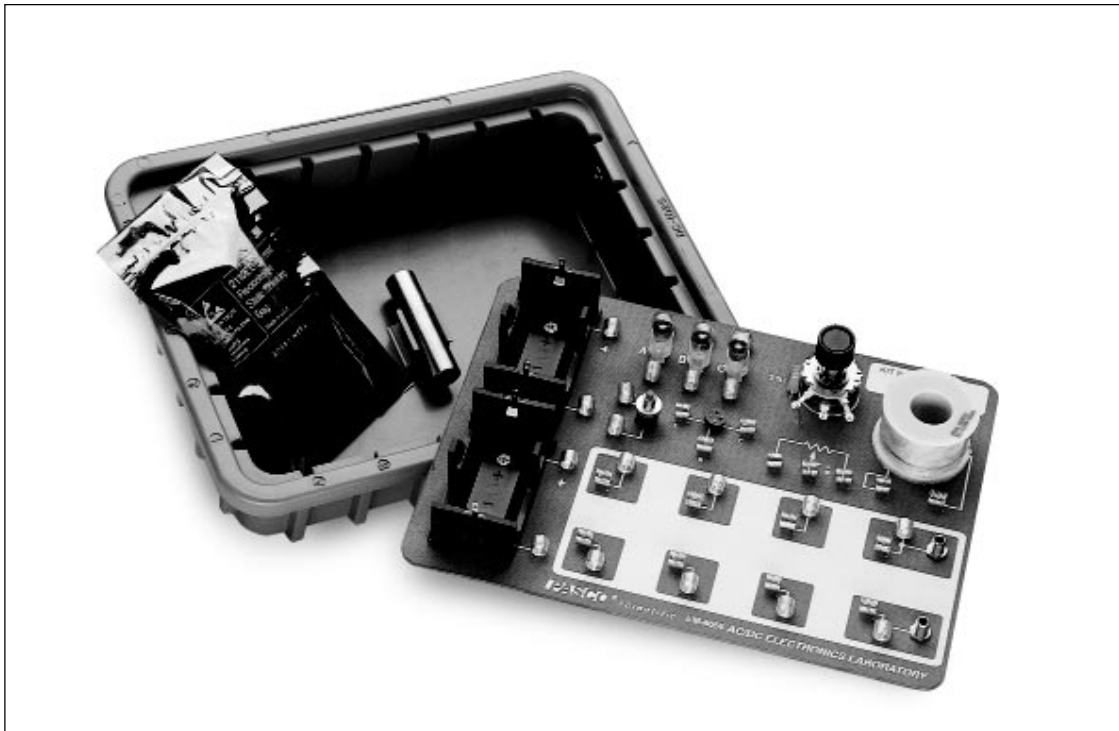
Instruction Manual and Experiment Guide for the PASCO scientific Model EM-8656

AC/DC ELECTRONICS LABORATORY

$15.00

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Table of Contents

Experiment 13: LR Circuit

EQUIPMENT NEEDED:

– Computer and *Science Workshop*™ Interface
– Power Amplifier (CI-6552A)
– (2) Voltage Sensor (CI-6503)
– AC/DC Electronics Lab Board (EM-8656): inductor coil & core, 10 Ω resistor, wire leads
– Multimeter
– (2) banana plug patch cords (such as SE-9750)
– LCR (inductance-capacitance-resistance) meter (optional)

Purpose

This experiment displays 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 <u>total</u> 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:

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

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

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

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 $V_L = L\left(\dfrac{dI}{dt}\right)$, the voltage across the inductor starts at its maximum and then decreases exponentially:

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

After a time $t >> t$, 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 which 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:

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

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

$$V_L = V_0\left(1 - e^{-(t/\tau)}\right)$$

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

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 receptacle
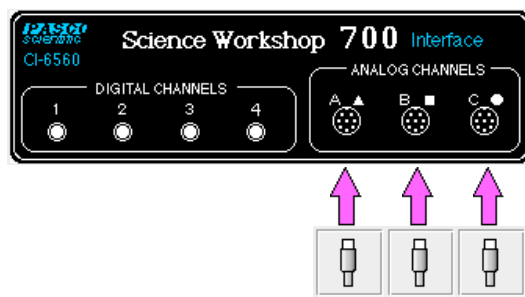
④ In the Physics Folder of the *Science Workshop* Experiment Library, open the document:

Macintosh: "P50 LR Circuit" / Windows: "P50_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.
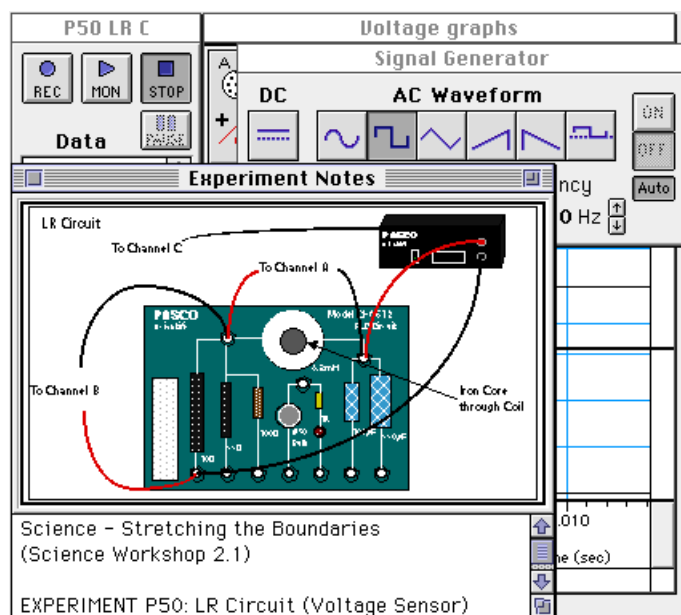

> ➤ **NOTE:** For quick reference, see the Experiment Notes window. To bring a display to the top, click on its window or select the name of the display from the list at the end of the Display menu. Change the Experiment Setup window by clicking on the "Zoom" box or the Restore button in the upper right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

⑤ The "Sampling Options…" for this experiment are: Periodic Samples = Fast at 10000 Hz, Start Condition when Analog C voltage goes to 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.
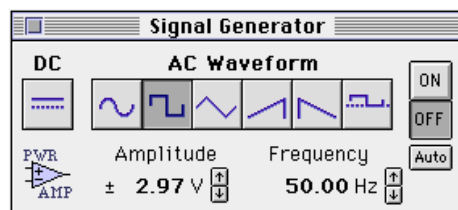

⑥ Arrange the Graph display and the Signal Generator window so you can see both of them.

PART II: Sensor Calibration and Equipment Setup

• You do not need to calibrate the Power Amplifier, or the Voltage sensors.

① 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.

② 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.

③ Connect another 5 inch wire lead 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 Board.

④ 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.

⑤ Connect the alligator clips of Voltage Sensor "B" to the wires at both ends of the 10 resistor.

⑥ Connect banana plug patch cords from the output of the Power Amplifier to the banana jacks on the AC/DC Electronics Lab Board.
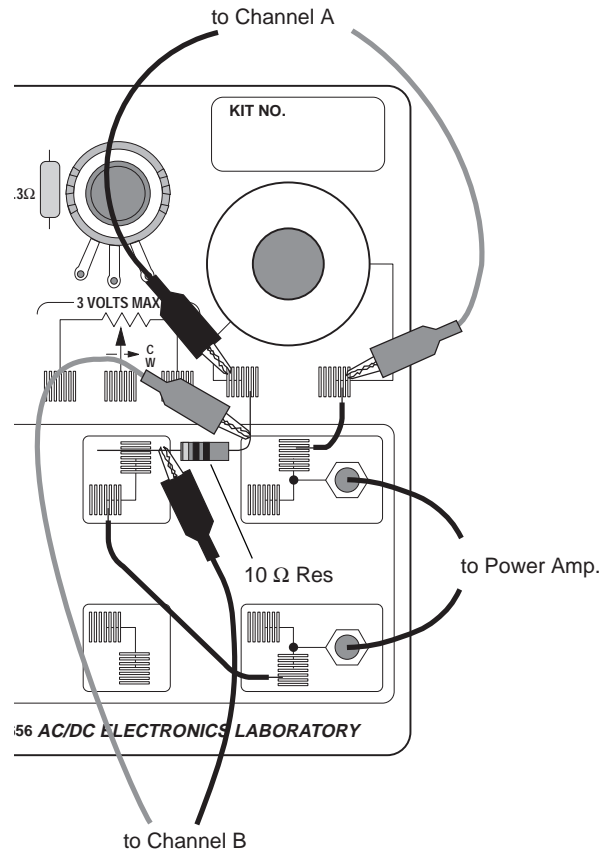
Part III: Data Recording

① Use the multimeter to measure the resistance of the inductor coil. Record the resistance in the Data Table.

② Use the multimeter to check the resistance of the 10 Ω resistor. Record the resistance in the Data Table.

③ Turn on the power switch on the back of the Power Amplifier.

④ Click the "ON" button (ON) in the Signal Generator window. The power amplifier output will begin.

⑤ Click the "REC" button (REC) to begin data recording.

• Data recording will end automatically after 0.02 seconds. Run #1 will appear in the Data list in the Experiment Setup window.

⑥ Click the "OFF" button (OFF) in the Signal Generator window. 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).

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① Click the "Smart Cursor" button ([xy+]) in the Scope. The cursor changes to a cross-hair. Move the cursor into the display area of the Scope.

- 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 Table. Determine the voltage that is half of the peak (the half-max voltage).
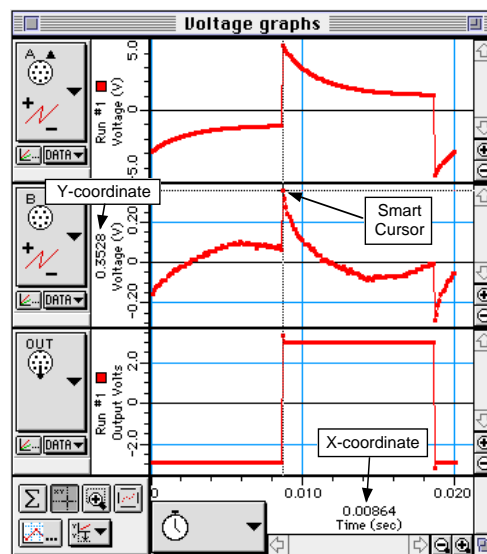
③ Move the cursor down the exponential part of the plot of resistor voltage until half the maximum (peak) voltage is reached. Record the X-coordinate (time) for this point.
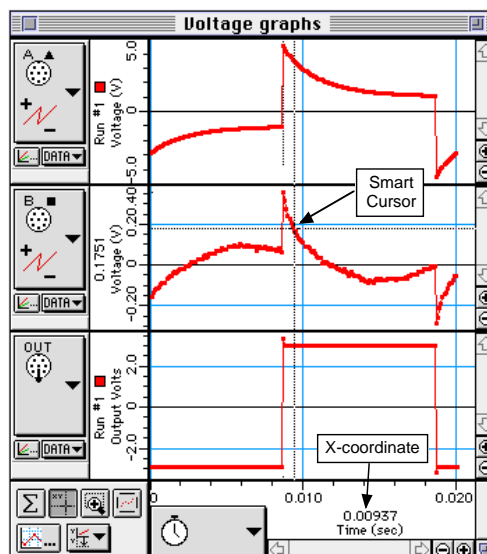
④ Subtract the time for the peak voltage from the time for the half-max voltage to get the time for the voltage to reach half-max. Record this time in the Data Table.

⑤ Based on the total resistance in the circuit and the stated value for the inductance of the inductor coil (8.2 millihenry or 0.0082 mH), calculate $\tau = \dfrac{L}{R}$.

Data Table

Inductor Resistance		Ω
Resistor Resistance		Ω
Peak Voltage (for Resistor)		V
Time at Peak Voltage		sec
Time at Half-Maximum Voltage		sec
Time to reach Half-Maximum		sec
$\tau = L/R$		

Questions

① How does the inductive time constant found in this experiment compare to the theoretical value given by $t = L/R$? (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.)

① 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?

Extension

Place the iron core in the coil and repeat "Part III: Data Recording". From the relationship $\tau = \dfrac{L}{R}$ and $t_{1/2} = \tau \ln(2)$ find the new value of the inductor.

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Experiment 14: LRC Circuit

EQUIPMENT NEEDED:

– Computer and *Science Workshop*™ Interface
– Power Amplifier (CI-6552A)
– Voltage Sensor (CI-6503)
– AC/DC Electronics Lab Board (EM-8656): inductor coil & core, 10 Ω resistor,
    100 µF capacitor, wire lead
– LCR (inductance-capacitance-resistance) meter (SB-9754)
– (2) banana plug patch cords (such as SE-9750)
– graph paper

Purpose

The purpose of this experiment 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.

Theory

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:

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

where X_L = inductive reactance = ωL, X_C = capacitive reactance = $\dfrac{1}{\omega C}$, R = resistance, and ω = angular frequency = $2\pi\nu$ (ν = 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, $X_L = X_C$ at resonance and thus the impedance (Z) is equal to R. So at resonance the impedance is the lowest value possible and the current will be the largest possible.

In this experiment the amplitude of the current vs. frequency is plotted. Since the current is a maximum at the resonant frequency and is less for higher or lower frequencies, the graph is expected to peak at the resonant frequency.

Procedure

PART I: Computer Setup

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

② Connect the Power Amplifier to Analog Channel A. Plug the power cord into the back of the Power Amplifier and connect the power cord to an appropriate electrical receptacle.

③ Connect the Voltage Sensor to Analog Channel B. The voltage measured at Analog Channel B will be used to calculate the current, I, which is related to the voltage across the resistor by

$$I = \frac{V_R}{R}.$$
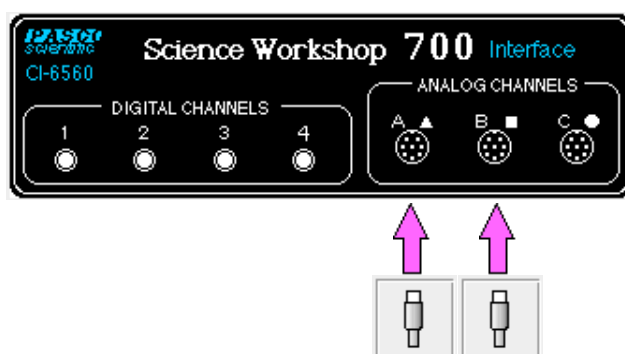

④ In the Physics Folder of the *Science Workshop* Experiment Library, open the document:
Macintosh: "P51 LRC Circuit" / Windows: "P51_LRCC.SWS"

The document opens with a Scope (oscilloscope) display of Voltage (V) versus Time (msec), and the Signal Generator window which controls the Power Amplifier.
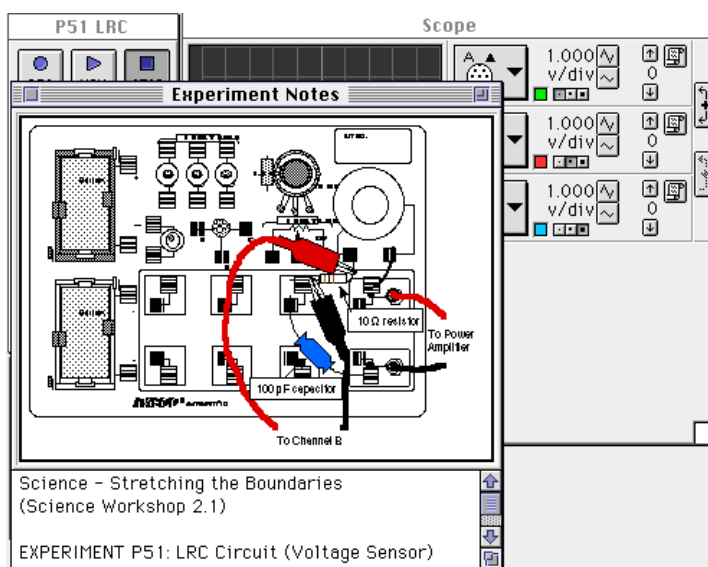
> ➤ **NOTE:** For quick reference, see the Experiment Notes window. To bring a display to the top, click on its window or select the name of the display from the list at the end of the Display menu. Change the Experiment Setup window by clicking on the "Zoom" box or the Restore button in the upper right hand corner of that window.

④ The Signal Generator is set to output 3.00 V, sine AC waveform, at 10.00 Hz. The "ON/OFF" button is set to "Auto" so the Signal Generator will start automatically when you click MON (Monitor) or REC (Record) and stop automatically when you click STOP or PAUSE.
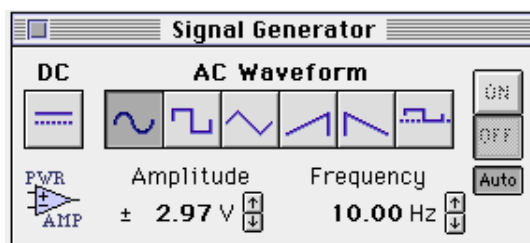

⑤ Arrange the Scope display and the Signal Generator window so you can see both of them.

PART II: Sensor Calibration and Equipment Setup

• You do not need to calibrate the Power Amplifier.

① 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.

② 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.

③ 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 Board.

④ Put alligator clips on the banana plugs of the Voltage Sensor. Connect the alligator clips of the Voltage Sensor to the wires at both ends of the 10 Ω resistor.

⑤ Connect banana plug patch cords from the output of the Power Amplifier to the banana jacks on the AC/DC Electronics Lab Board.
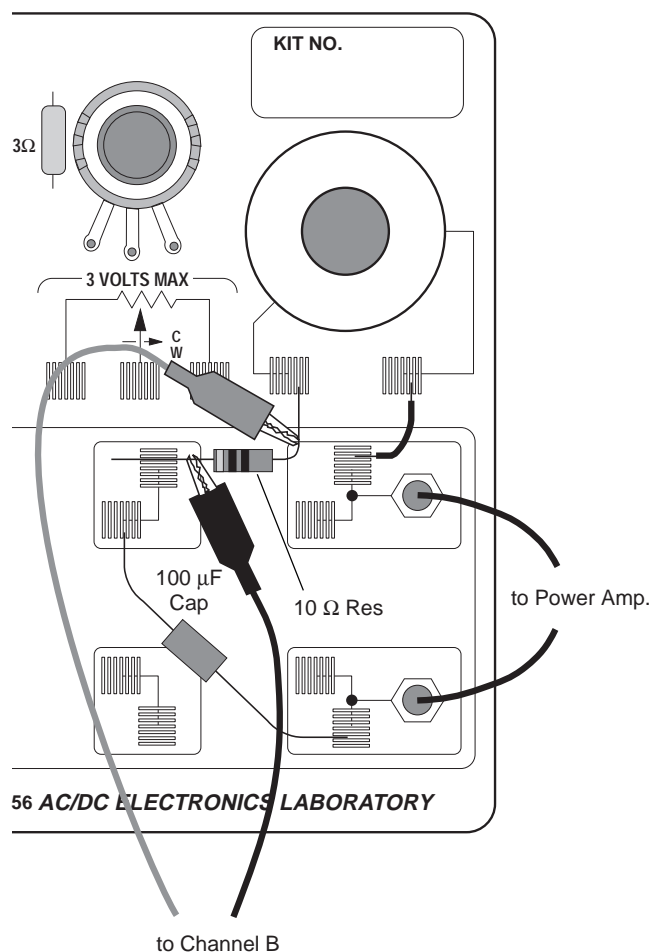
Part III: Data Recording

① Turn on the power switch on the back of the power amplifier.

② Click the "MON" button (▷ MON) to begin data monitoring. Record the value of the frequency in the Data Table.

• Use the Smart Cursor in the Scope to measure the source voltage and the resistor voltage. To find the resonant frequency of the LRC circuit, adjust the frequency in the Signal Generator window until the voltage across the resistor increases to a maximum value.

③ To measure the output voltage, click the "Smart Cursor" button (xy ⊞) in the Scope display. The cursor changes to a cross-hair. Move the cursor/cross-hair to a peak of the output voltage, V_o (trace for Channel A). Record the voltage that is displayed next the Input menu button.
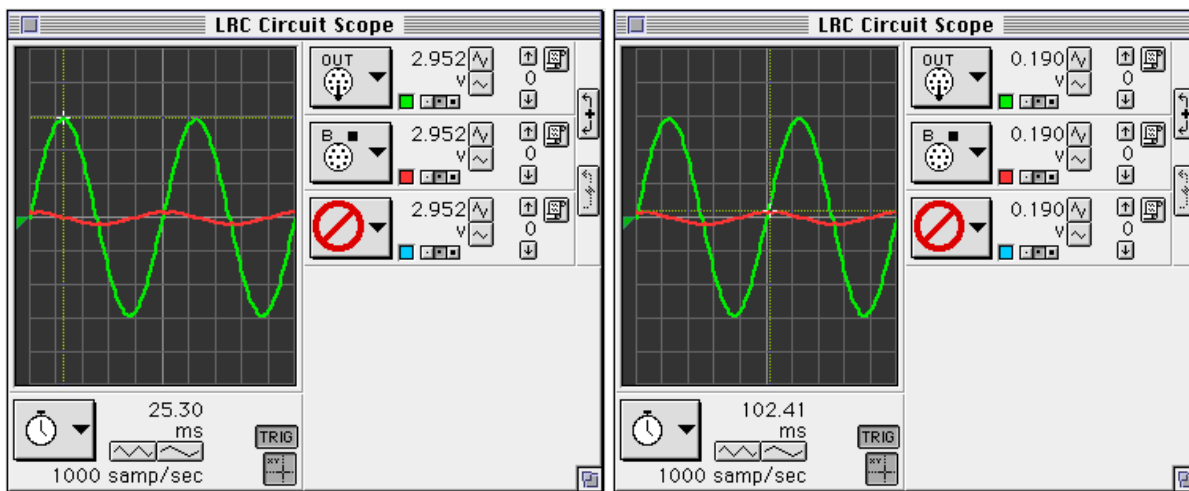
④ To measure the voltage across the resistor, move the cursor/cross-hair to a peak of the voltage across the resistor, V_R (trace for Channel B). Record the voltage.

⑤ In the Signal Generator window, click on the Up arrow (↑) to increase the frequency by 10 Hz. Record the new frequency in the Data Table. Repeat the process of using the Smart Cursor to find the new voltages for the output, V_o, and the resistor, V_R.

⑥ Repeat the process until 150 Hz is reached. As the frequency is increased, adjust the sweep speed in the Scope display using the "Increase Speed" button (∿) as needed.

⑦ Look at the Data Table and determine approximately the resonant frequency (where voltage across the resistor reaches a maximum).

⑧ Click on the frequency in the Signal Generator window to highlight it. Type in the approximate resonant frequency, then press "enter".
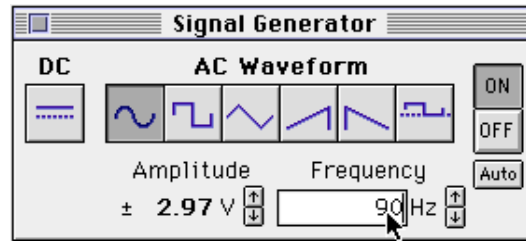
⑨ Make fine adjustments to the frequency until the trace of voltage from Channel B is in phase with the trace of Output Voltage. You can adjust the frequency by clicking the "Up" or "Down" Frequency arrows while pressing the following modifier keys:

To adjust the frequency	Press this key while clicking
1 Hz	Control
0.1 Hz	Option
0.01 Hz	Command or ALT

⑩ To check whether the trace of voltage from Channel B is in phase with the trace of Output Voltage, switch the Scope display to "X-Y" mode:

a. Click the "STOP" button ( ). Click the Horizontal Axis Input menu button ( ).

Select "Analog B" from the Horizontal Axis Input menu.
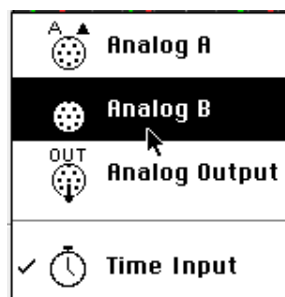
b. Click the Channel B Input menu button ( ) along the right edge of the Scope. Select

"No Input" from the Channel B Input menu.
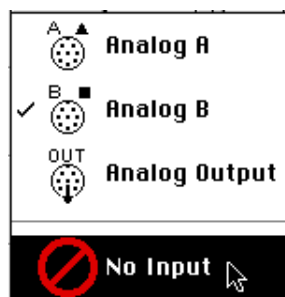
c. Click the "MON" button to begin monitoring data again. Adjust the frequency in the Signal Generator window as needed to reach the resonant frequency. Record the resonant frequency.

• When the two inputs are in phase, the Scope display in "X-Y" mode will show a diagonal line. Any phase difference will cause an oval trace.

• XY mode at 40 Hz

• XY mode at resonant frequency
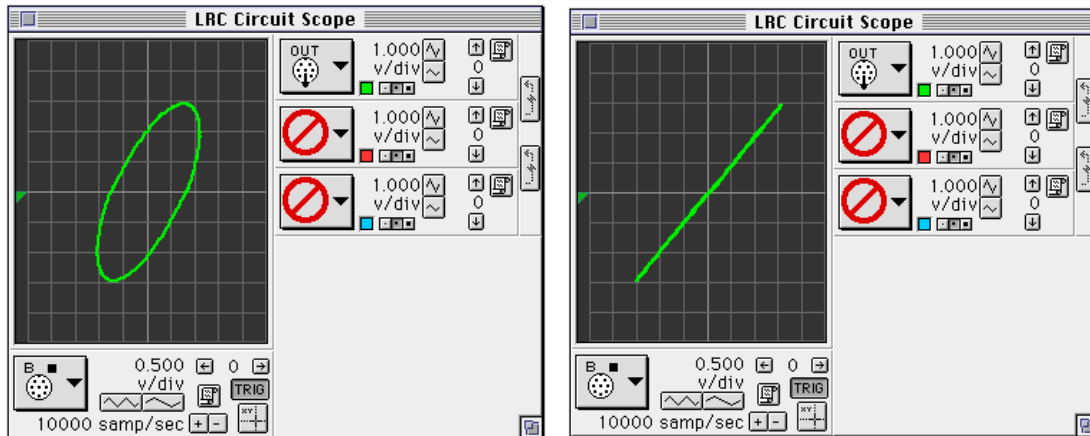
⑪ Click the "STOP" button. Turn off the switch on the back of the power amplifier.

⑫ Use the LCR meter to measure the inductance of the inductor coil with core, and the capacitance of the 100 µF capacitor. Record these values in the Data Table.

Analyzing the Data

① Graph the current (or voltage across the resistor divided by output voltage: V_R/V_o) versus the linear frequency on separate graph paper. (**NOTE**: The frequency in the Signal Generator window is the linear frequency.)

② Using the resonant frequency found from the Scope display, calculate the resonant angular freqeuncy and record the value in the Data Table:

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

③ Calculate the theoretical resonant angular frequency using the following:

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

Data Table

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

Item	Value
Resonant frequency	Hz
Resonant angular frequency	Hz
Inductance	mH
Capacitance	µF
Theoretical resonant angular frequency	Hz

Questions

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

Remember, $\text{Percent difference} = \dfrac{|theoretical - actual|}{theoretical} x100\%$

② Is the plot of current (V_R/V_o) 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 $R = \dfrac{V}{I}$ (where V is the amplitude of the applied voltage). Is this resistance equal to 10 Ω? 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 Ω resistor by a 100 Ω resistor. Does the resonant frequency increase, decrease, or stay the same?

Experiment 20: Induction – Magnet Through a Coil

EQUIPMENT NEEDED:

– Computer and *Science Workshop*™ Interface
– Voltage Sensor (CI-6503)
– AC/DC Electronics Lab Board (EM-8656)
– Alnico bar magnet (EM-8620)
– OPTIONAL: Photogate (ME-9204A or ME-9498)

Purpose

This experiment shows the Electromotive Force (EMF) induced in a coil by a magnet dropping through the center of a coil.

Theory

When a magnet is passed through a coil there is a changing magnetic flux through the coil which induces an Electromotive Force (EMF) in the coil. According to Faraday's Law of Induction:

$$\mathcal{E} = -N\frac{\Delta\phi}{\Delta t}$$

where ε is the induced EMF, N is the number of turns of wire in the coil, and $\frac{\Delta\phi}{\Delta t}$ is the rate of change of the flux through the coil.

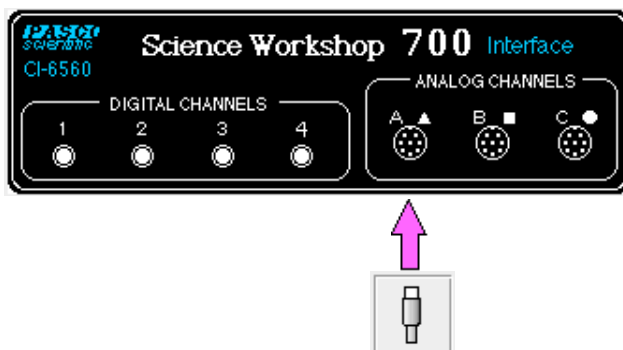In this experiment, a plot of the EMF vs. time is made and the area under the curve is found by integration. This area represents the flux since

$$\mathcal{E}\Delta t = -N\Delta\phi$$

PROCEDURE

PART I: Computer Setup

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

② Plug the DIN plug of the Voltage Sensor into Analog Channel A.

③ In the Physics Folder of the *Science Workshop* Experiment Library, open the document:

Macintosh: "P47 Induction-Magnet" / Windows: "P47_INDU.SWS"

The document opens with a Graph display of Voltage (V) versus Time (sec).
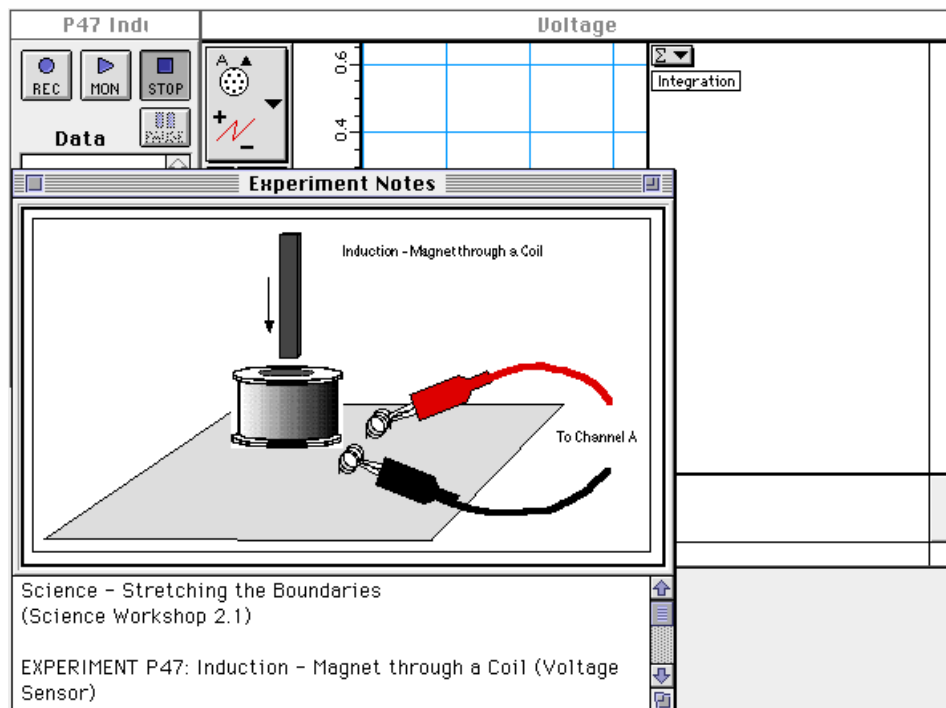
> ➤ **NOTE:** For quick reference, see the Experiment Notes window. To bring a display to the top, click on its window or select the name of the display from the list at the end of the Display menu. Change the Experiment Setup window by clicking on the "Zoom" box or the Restore button in the upper right hand corner of that window.

④ The "Sampling Options…" for this experiment are: Periodic Samples = Fast at 1000 Hz, Start condition is voltage from Channel A = 0.08 V, Stop condition is Time = 0.5 seconds.

PART II: Sensor Calibration and Equipment Setup

• You do not need to calibrate the Voltage Sensor.

① Put alligator clips on the ends of the voltage sensor leads.

② Attach a clip to one component spring next to the coil on the AC/DC Electronics Lab Board. Attach the other clip to the other component spring next to the coil.

③ Arrange the lab board so the corner with the coil is beyond the edge of the table, and a magnet dropped through the coil can fall freely.

Induction - Magnet through a Coil

To Channel A
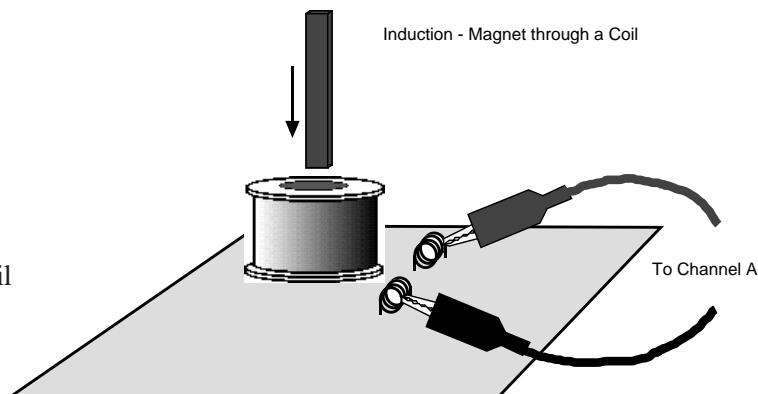
> ➤ **NOTE:** The bar magnet will be dropped through the coil. Make sure that the magnet does not strike the floor, or it may break.

Part III: Data Recording

① Hold the magnet so that the south end is about 5 cm above the coil. If you are using the Alnico Bar Magnet (EM-8620) the South end is indicated by the narrow horizontal groove.

② Click the "REC" button ([REC]) and then quickly let the magnet drop through the coil.

• Data recording will begin when the magnet begins to fall through the coil and induces a voltage. Data recording will end automatically after 0.5 seconds.

• Run #1 should appear in the Data list in the Experiment Setup window.

ANALYZING THE DATA

① Click the Graph to make it active. Select "Save As…" from the File menu to save your data.

② In the Graph display, use the cursor to click-and-draw a rectangle around the first peak of the voltage plot.
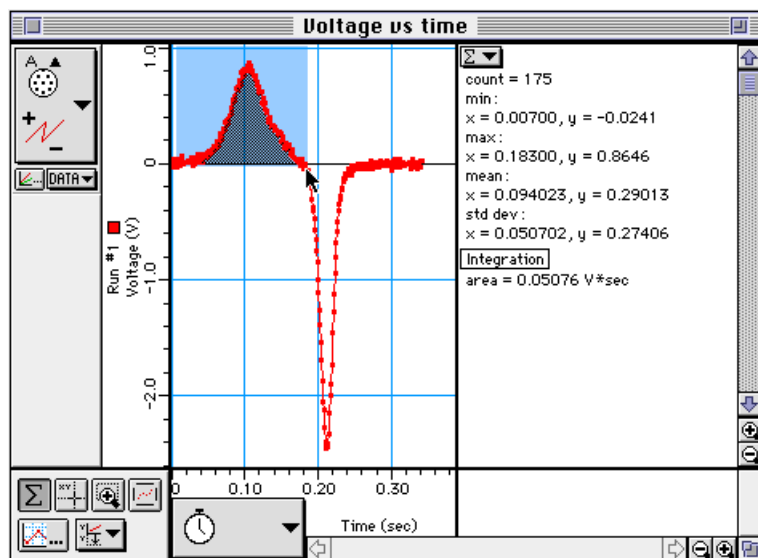
• The area under the curve for the first peak will appear in the Statistics area.

③ Record the value of Integration for the first peak.

    Integration (first peak) = _____ V*sec

④ Repeat the process to find the area under the second peak. Record the value.

    Integration (second peak) = _____ V*sec

Questions

① Is the incoming flux equal to the outgoing flux?

② Why is the outgoing peak higher than the incoming peak?

③ Why are the peaks opposite in direction?

Optional

Repeat the data recording and data analysis procedures for the following:

① Tape two bar magnets together so both south ends are together.

② Rearrange the two bar magnets so that the south end of one is with the north end of the other.

③ Try dropping the magnet from different heights.

Appendix: Tips and Troubleshooting

Correct Circuit, Doesn't Work

- Check to see if the circuit is indeed connected correctly and completely.

- Check to see if the battery is giving full voltage.

- Check to see if each wire is making contact with the spring. If magnet wire is used, the enamel coating on the outside will prevent electrical connection and needs to be removed. In some cases, students may try to make a complete circuit through the insulation.

Surprising Results

In some cases, there will be no difference in the measurements from one point in the circuit to another. This doesn't mean the measurement is trivial or unimportant, rather it is what we hope the student will learn from his/her lab work. Not all measurements have to be different.

Lights and Relative Brightness

The lights for this experiment board, #14 bulbs, are designed for 2.5 volts and 0.3 amperes. A single D-cell will not light a bulb to maximum brightness, but two cells in series will give a very bright light.

The labs asking for relative brightness ask students to judge relative brightness only, not an absolute brightness. This part of the experiment would be aided by having the room mostly darkened. Additional bulbs can be purchased from PASCO, at Radio Shack, an electronics store, at auto supplies stores, or possibly a local discount store.

Batteries

The Circuits Experiment Board is designed to use one or two D-cells. The voltage delivered by a D-cell is 1.5 volts ±. In practice, alkaline cells give the longest life, but the less expensive zinc-carbon cells will give adequate results. A single set of batteries was used successfully by ten different classes to complete labs 1,3,4,5, 6 and 7 before being replaced.

Resistors

The resistors supplied are listed in the *Equipment* section of this manual. The values have been chosen for clear results and for helping to extend the life of the D-cells. If resistors are lost or broken, replacements can be purchased from PASCO, or at any electronics store, including Radio Shack. Other values can be substituted, but for Experiments 3 through 7, the values should be between $100 \, \Omega$ and $1500 \, \Omega$ for best results.

> ➤**NOTE:** Using the $330 \, \Omega$, $560 \, \Omega$ and $1000 \, \Omega$ resistors gives approximate ratios of 1:2:3 for working towards semi-quantitative understanding of d.c. circuits.

The diagram below shows the resistor color code. For example, a resistor having the colors Orange-Orange-Brown-Silver has the value $330 \, \Omega \pm 10\%$.

Color	Digit
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9

1st Digit · 2nd Digit · No. of Zeros · Tolerance

Fourth Band
|	
None	±20%
Silver	±10%
Gold	±5%
Red	±2%

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Wires

The Circuits Experiment Board can be used with a large variety of wire types and sizes. We recommend 20 or 22 gauge solid wire with colorful insulation. This will help students to follow their work more easily and minimize difficulties in making the transition from paper circuit to actual circuit on the Circuits Experiment Board.

Stripping Your Own Wire

The wire included with the Basic Electricity Lab is 22 gauge insulated, solid wire in 5" and 10" lengths. The lengths are stripped at each end.

If you choose to strip your own additional wires, a commercially available wire stripper can be used to remove the insulation from each end. The jaws of the wire stripper are placed on the wire 3/8" from the end. By squeezing the handles together, the jaws will close on the wire and cut only as deep as the insulation.

Figure 2a

Squeeze handles
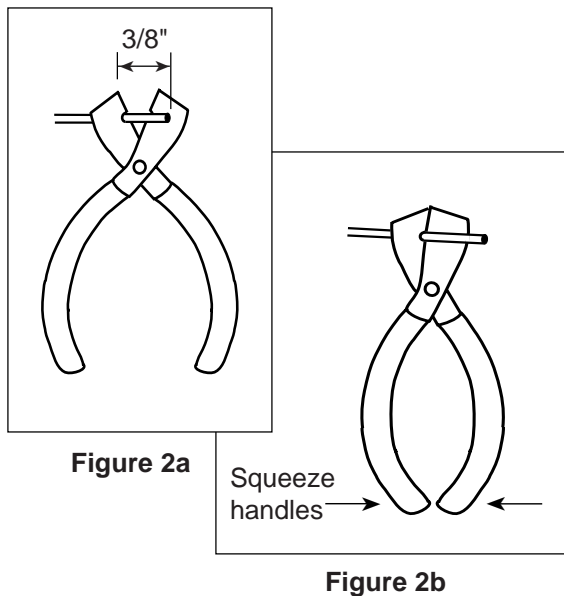
Figure 2b

Pulling the wire away from the stripper (Figure 2c) causes the cut end of the insulation to slip off of the wire, leaving 3/8" of exposed wire.
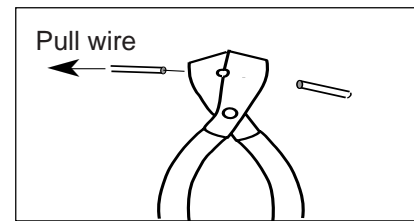

Pull wire

Figure 2c

If you do not have access to a wire stripper, the wire may also be stripped by carefully using a knife. Place the wire on a solid surface. Set the knife blade on the insulation about 3/8" from the end. With the blade at an angle so it cannot cut downward into the wire, use the knife to shave off the insulation.
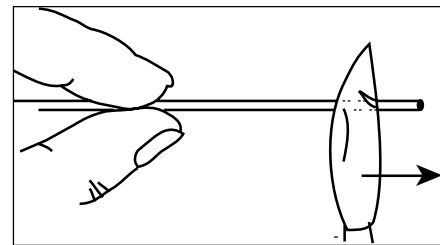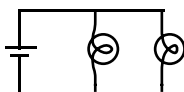

Figure 3

After one part of the insulation is removed, turn the wire and continue shaving off the rest of the insulation.

Teacher's Guide (Experiments 1-10)

Exp 1 - Circuits Experiment Board
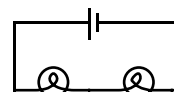
①

② Reversing things at either end had no effect.

④⑤   There are two different ways of putting two lamps into the circuit: parallel and serial.

Parallel:

With this method, the lights will each be approximately the same brightness as in part 1.

Serial:

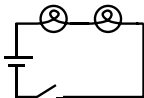Using this circuit, the lights will be dimmer than in part 1.

Exp 2 - Lights in Circuits

➤**NOTE:** It is best to do these experiments with both batteries, rather than just one. Connect them in series, as shown in figure 2.1a. This will make the lights brighter and easier to see when some of the dimmer circuits are built.
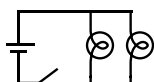
Procedure

①

②③   There are two ways of making the circuit so that both lights are on with the same intensity.

Series

The lights will be dimmer than in part 1. The electric current must go through one bulb to reach the other, so disconnecting a bulb will cause both to go out. (This is how those maddening "if-one-goes-out-they-all-die-so-Merry-Christmas" lights are wired.)

Parallel

The lights will show the same intensity as in part 1. The electric current is going through both bulbs at the same time, so disconnecting one does not affect the other. (This is how the Christmas lights you wish you had bought are wired.)

④⑤   Again, the circuit may be series or parallel.

Series   **Parallel**
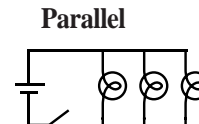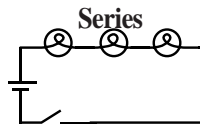
These circuits have the same characteristics as the ones in part 2-3

⑥ There are two ways of doing this as well.

Parallel-in-Series   **Series-in-Parallel**
a   b   a   b

c   c
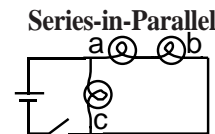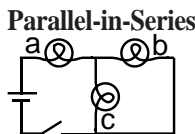
(The parallel portion of the first circuit will be very dim.)

What happens if you unscrew one of the bulbs depends on which bulb you unscrew. In the first circuit, unscrewing (a) will turn everything off. Unscrewing (b) or (c) will make (a) dimmer and leave the other one unaffected. In the second circuit, unscrewing (c) will make (a) and (b) brighter; while unscrewing (a) or (b) will make (c) brighter and turn the other one off.

⑦-⑩   Putting the batteries in series (2.1a) will make things the brightest, because then the voltage to the lights is the highest. Batteries in parallel (2.1b) will have the same effect as one battery. Batteries opposed (2.1c) will have no effect at all unless one of the batteries is nearly dead.

⑪ The potentiometer, when used this way, adjusts the brightness of the lamp. (For best results, use the batteries in series for this part of the lab.)

Exp 3- Ohm's Law

Procedure

②-⑥) Warn the students to be particularly careful when setting up the multimeter to measure current. Attaching an ammeter the wrong way can damage the meter.

Data Processing

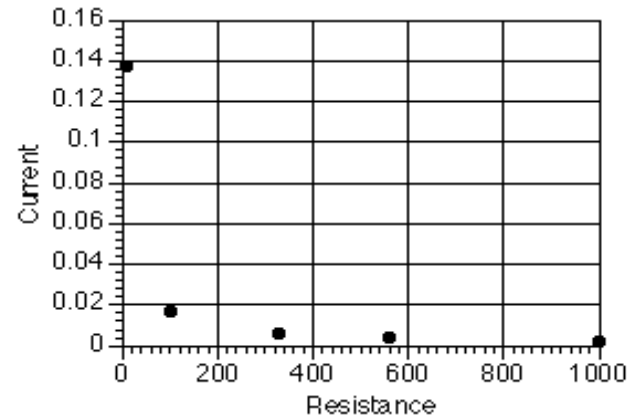| Resistance	Current	Voltage	V/R	% difference
100	0.02	1.579	0.02	-1.87%
560	0.00	1.582	0.00	-2.73%
330	0.00	1.582	0.00	-3.32%
1000	0.00	1.583	0.00	-9.17%
10	0.14	1.549	0.15	-13.31%

Discussion

① Current is inversely proportional to R

② Yes. A curve fit of the graph above gives Current = $1.36 \times \text{Resistance}^{-0.98}$, which is quite close to the theoretical equation.

③) The greatest source of error is caused by the meter itself. Because the ammeter has some internal resistance, the measured current is less than the current when the meter is not there.

Exp 4- Resistances in Circuits

Procedure

①-④

	Colors	coded	measured	% error	tolerance
#1	brown-black-brown-gold	100	98.9	-1.10%	±0.05%
#2	brown-black-brown-gold	100	99.6	-0.40%	±0.05%
#3	brown-black-brown-gold	100	99.7	-0.30%	±0.05%

⑤ **Series**

$R_{12} =$ 198.3Ω
$R_{23} =$ 199.1Ω
$R_{123} =$ 298Ω

⑥ **Parallel**

$R_{12} =$ 49.7Ω
$R_{23} =$ 49.9Ω
$R_{123} =$ 33.3Ω
$R_{13} =$ 49.8Ω

⑦ **Combination**

$R_{1} =$ 98.9Ω
$R_{23} =$ 49.9Ω
$R_{123} =$ 148.7Ω

⑧ **Series**

$R_{AB} =$ 428Ω
$R_{BC} =$ 891Ω
$R_{ABC} =$ 989Ω

Parallel

$R_{AB} =$ 76.1Ω
$R_{BC} =$ 207Ω
$R_{ABC} =$ 67.0Ω
$R_{AC} =$ 84.1Ω

Combination

$R_{A} =$ 98.9Ω
$R_{BC} =$ 207Ω
$R_{ABC} =$ 306Ω

	Colors	coded	measured	% error	tolerance
A	brown-black-brown-gold	100	98.9	-1.10%	±0.05%
B	orange-orange-brown-gold	330	330	0.00%	±0.05%
C	green-blue-brown-gold	560	561	0.18%	±0.05%

Discussion

① The actual value matches the coded value much more closely than required by the tolerances.

②-④   In series, the resistances are added. $R = R_1 + R_2 + R_3 + ...$In parallel, the reciprocals of the resistances are added. $1/R = 1/R_1 + 1/R_2 + 1/R_3 +...$ This is evidenced in all the data sets above.

Exp 5- Voltages in Circuits

Procedure

Equal Resistors:

Series

measurement	Resistance	Voltage
1	100	0.523
2	100	0.528
3	100	0.527
12	200	1.051
23	200	1.055
123	300	1.578

Parallel

measurement	Resistance	Voltage
1	33.33	1.565
2	33.33	1.565
3	33.33	1.565
123	33.33	1.565

Combination

measurement	Resistance	Voltage
1	100	1.049
23	50	0.529
123	150	1.578

Different Resistors:

Series

measurement	Resistance	Voltage
A	100	0.157
B	330	0.526
C	560	0.897
AB	430	0.685
BC	890	1.423
ABC	990	1.581

Parallel

measurement	Resistance	Voltage
A	67.49	1.574
B	67.49	1.574
C	67.49	1.574
ABC	67.49	1.574

Combination

measurement	Resistance	Voltage
A	100.00	0.509
BC	207.64	1.07
ABC	307.64	1.579

Discussion
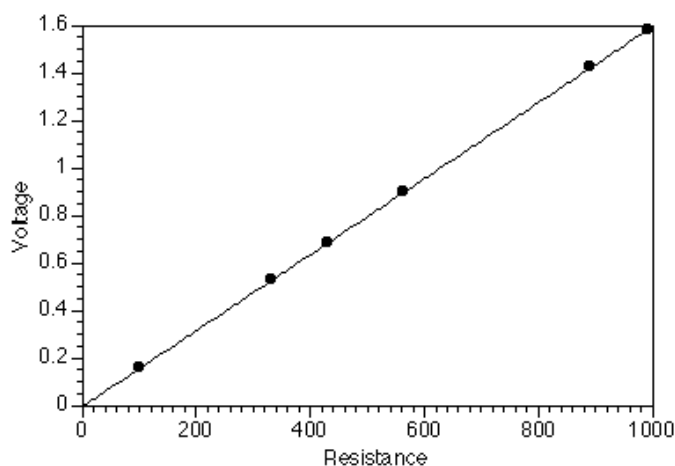
In any series circuit, the voltage is distributed according to the size of the resistors. (Notice that the graph above, of the data from the second series circuit, shows this direct relationship.)

In any parallel circuit, the voltage is the same across all elements.

In the combination circuit, the voltage acts as if the parallel resistors were actually one resistor, which is then in series with the first. The rules are the same.

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Exp 6- Currents in Circuits

➤**NOTE:**   The resistors used were:

$R_1 =$ 100Ω
$R_2 =$ 330Ω
$R_3 =$ 560Ω

These are the same resistors as were used in the previous lab, and some of the data here originates in lab 5.

Procedure

Series:

The current was the same—1.5 mA—no matter where it was measured in the circuit.

Parallel:

Measurement	Resistance	Current	Voltage
1	100	0.0156	1.574
2	330	0.0047	1.574
3	560	0.0028	1.574
123	67.5	0.0229	1.574

Discussion

In any resistance circuit—series, parallel, or both—the voltage, current, and resistance are related by Ohm's Law:

V = IR

This pattern, and conclusion, should be apparent in student data.

➤**NOTE**:   The product of the resistances and currents obtained experimentally will generally be lower than the measured voltage. This is due to the nonzero resistance of the ammeter. When the meter is in the circuit, its own resistance lessens the current through that circuit. With most meters, this error should be less than 5% or so.

Exp 7- Kirchoff's Rules

The current leaving the node is equal to the current entering the node. The sum of the voltage drops around a closed loop equals zero.
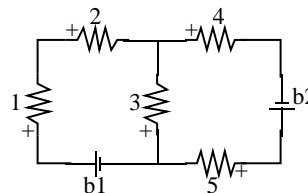
Procedure
First circuit:
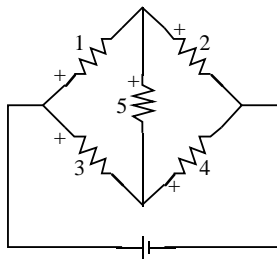
	R (Ω)	V (V)	I (mA)
1	100	0.40	3.9
2	560	1.17	2.0
3	330	1.05	3.1
4	100	0.52	5.1
5	330	0.65	1.9
T	216	1.57	7.1

Second circuit:

	R (Ω)	V (V)	I (mA)
1	100	0.27	2.6
2	560	1.50	2.6
3	330	0.19	0.5
4	330	1.07	3.2
5	100	0.32	3.2
b1		1.573	2.6
b2		1.588	3.2

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Analysis

First circuit:

① node (1,3):   0.1 mA

   node (1,2,5):   0.0 mA

   node (3,4,5):   -0.1 mA

   node (2,4):   0.0 mA

② loop (1,5,3):   0.001 V

   loop (1,2,4,3):   0.001 V

   loop (5,2,4):   0.000 V

   loop (batt,1,2):   0.001 V

   loop (batt,3,4):   0.000 V

   loop (batt,1,5,4):   0.001 V

   loop (batt,3,5,2):   0.000 V

Second circuit:

① node (2,3,4):   -0.1 mA

   node (b1,3,5):   0.1 mA

② loop (b1,1,2,3)   0.001 V

   loop (b2,5,3,4)   0.001 V

   loop (b1,1,2,4,b2,5)   0.002 V

Discussion

Within the experimental uncertainty of the measuring device used (a DMM) Kirchoff's Rules are verified. The net current flowing into or out of any junction is approximately zero, and the sum of the voltages around any loop is approximately zero.
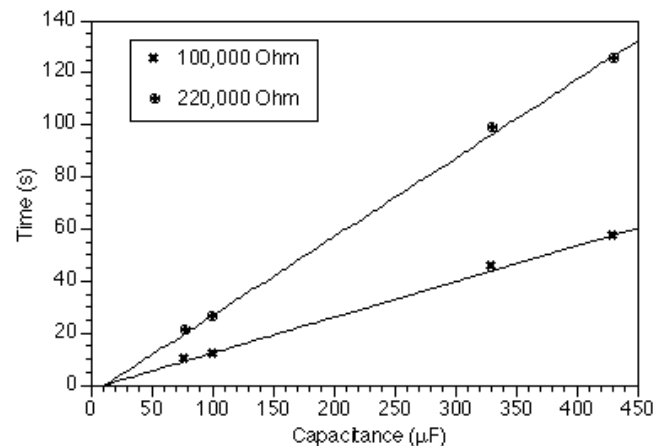

Exp 8- Capacitors in Circuits

Procedure

④ The rate at which the capacitor loses its charge depends on the impedance of the meter used to measure the voltage, as well as on the size of the capacitor. For this reason, most analog meters are not sufficient for this lab.

⑤
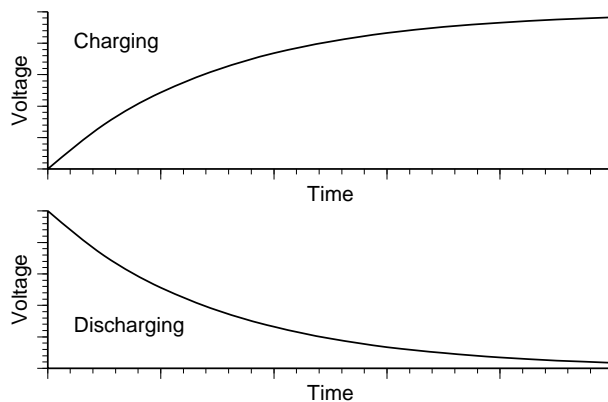
⑦-⑪

➤**NOTES**:

①② Charging: $t = - R\,C \ln(1 - V/V_o)$
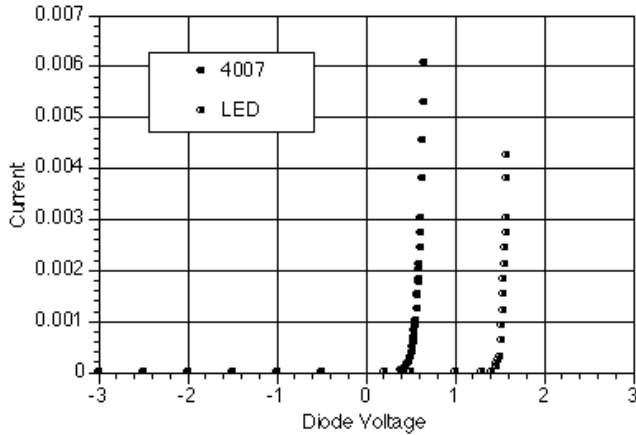
  Discharging: $t = - R\,C \ln(V/V_o)$

  In either case, the time is linearly dependent on both resistance and capacitance.

③ Parallel: $C_p = C_1 + C_2$

  Series: $1/C_s = 1/C_1 + 1/C_2$

Exp 9- Diodes

Analysis

The diode acts as a one-way valve for electricity. Current can flow in one direction, but not in the other.

Extensions

① A zener diode would be similar to the 4007, except that there would be a breakdown point on the reverse biasing, beyond which the current would flow. This makes them useful for power regulation.

②) The LED opens up at a higher voltage than the 4007 (and it lights up).

Exp 10- Transistors

Analysis

②
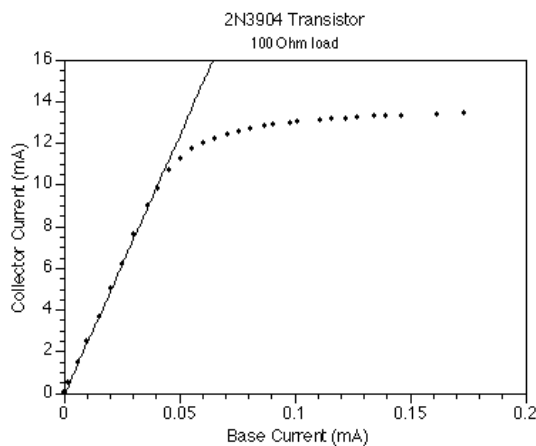
③ The linear region does not include the origin, due to the nonzero voltage that the junctions within the transistor require to turn on. (Similar to the effect in lab 9)

④ Beyond the "saturation point", the transistor is acting like a short circuit. It offers no resistance to the current; so beyond that point, there is no amplification. The current is limited only by the battery and resistor.

⑤ The current amplification of the transistor tested was 249. This value will vary from transistor to transistor; it's usually between 150 and 250 for the 2N3904 transistors supplied with the lab.

Discussion

① This graph shows the results of applying different values for R2. The amplification remains the same in each linear region, but the size of that linear region changes.
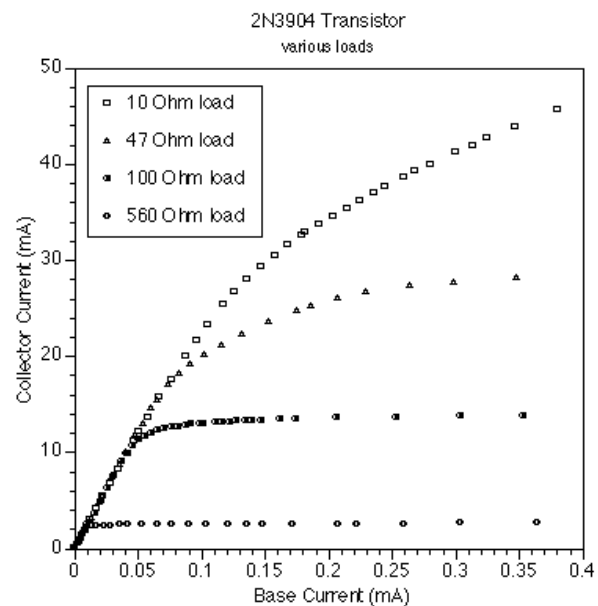
② The gain and/or saturation characteristics of the transistor will vary, although the basic shape of the graph will remain the same.

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To Reach PASCO

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email: techsupp@PASCO.com

Tech support fax: (916) 786-3292

Contacting Technical Support

Before you call the PASCO Technical Support staff it would be helpful to prepare the following information:

• If your problem is computer/software related, note:

  Title and Revision Date of software.

  Type of Computer (Make, Model, Speed).

  Type of external Cables/Peripherals.

• If your problem is with the PASCO apparatus, note:

  Title and Model number (usually listed on the label).

  Approximate age of apparatus.

  A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.)

  If possible, have the apparatus within reach when calling. This makes descriptions of individual parts much easier.

• If your problem relates to the instruction manual, note:

  Part number and Revision (listed by month and year on the front cover).

  Have the manual at hand to discuss your questions.