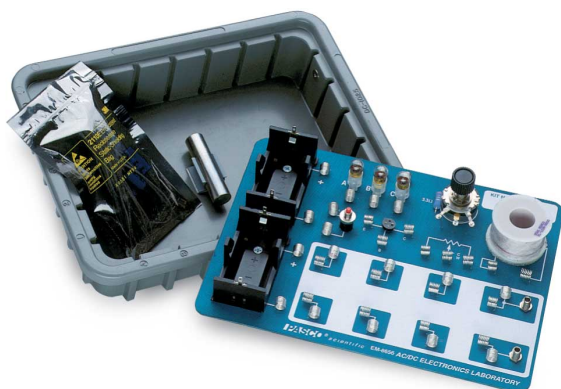


AC/DC Electronics Laboratory (EM-8656)



- ③ Light Bulb Components
 - 3x Light Sockets
 - 3x #14 Light Bulbs - 2.5 V, 0.3 A



NOTE: Due to manufacturer's tolerances, wattage may vary by 15-30% from bulb to bulb.

- ④ Transistor Socket
- ⑤ Resistor - 3.3 Ω , 2W, 5%
- ⑥ Potentiometer - 25 Ω , 2W
- ⑦ Slot for iron core
- ⑧ Coil (Renco RL-1238-8200)
- ⑨ 36x component springs
- ⑩ 2x Banana Jacks (for function generator)

The Storage Case features:

- Core clamp
- 1/2" iron core

The Component Bag includes:

- Resistors, 5%
 - 33 Ω , 5 W
 - 10 Ω , 1 W (2x)
 - 4.7 Ω , 1/2 W (2x)
 - 100 Ω , 1/2 W (2x)
 - 330 Ω , 1/2 W (4x)
 - 560 Ω , 1/2 W (2x)
 - 1 k Ω , 1/2 W (4x)
 - 10 k Ω , 1/2 W (2x)
 - 100 k Ω , 1/2 W
 - 220 k Ω , 1/2 W
 - 22 k Ω , 1/4 W (2x)
 - 3.3 k Ω , 1/4 W
- Capacitors
 - 1 μ F — 35 V
 - 10 μ F — 35 V (2x)
 - 47 μ F — 50 V
 - 470 μ F — 16 V
 - 100 μ F — 16 V
 - 330 μ F — 16 V
- 6x Diodes: 1N-4007
- 2x Transistors: 2N3904
- LEDs: red, green, yellow, bicolor (1 each)
- Wire Leads — 22 ga. (4x 5", 5x 10")

Introduction

The EM-8656 AC/DC Electronics Laboratory is designed for both DC and AC electricity experiments. The circuit board can be powered by batteries for DC experiments, or by a computer connected to a function generator for AC experiments.

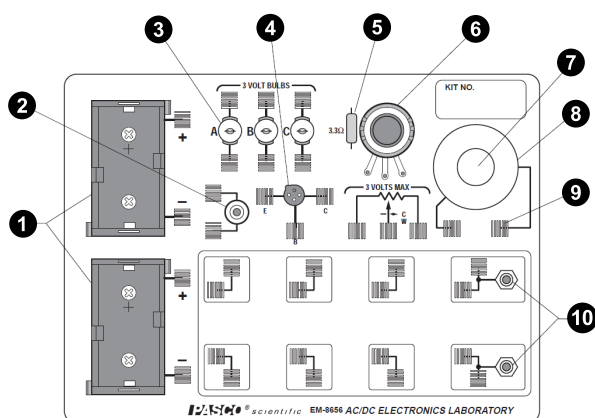
The first ten experiments in this manual are DC experiments using battery power and multimeters rather than using a computer. The rest of the experiments use a computer (Mac or PC) with a function generator. The software required is PASCO Capstone.

Equipment

The EM-8656 AC/DC Electronics Laboratory includes the following equipment:

- Electronics Lab Board
- Storage Case
- Components Bag
- Experiment Manual

The Circuit Equipment Board features:

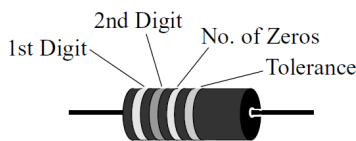


- ① 2x Battery Holders, D-cell (batteries not included)
- ② Pushbutton switch

Getting Started

1. Store the components in the Ziplock bag until needed. Keep track of the components, and return them to the bag after each experiment is completed.
2. Identify the resistor value required for the individual experiments with the help of the chart below.
3. Familiarize yourself with the board layout, as seen in the Equipment section on the previous page.
4. In some cases, the same component layout will be used from one experiment to another. Labeling of the boards and your meters will improve continuity in your work. Using removable labels or a permanent marker are two options for marking the board.

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



Fourth Band	
None	$\pm 20\%$
Silver	$\pm 10\%$
Gold	$\pm 5\%$
Red	$\pm 2\%$

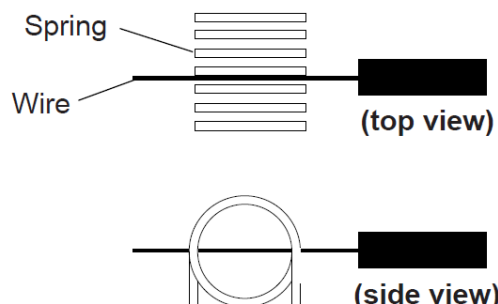


NOTE: The 4.7 ohm resistor has a gold third band to indicate that the two-digit number from the first two bands should be divided by 10.

Notes on the Electronics Lab Board

The springs are securely soldered to the board and serve as a convenient method for connecting wires, resistors, and other components. Some of the springs are connected electrically to devices like the potentiometer and the D-cells. In the large Experimental Area, the springs are connected in pairs, oriented perpendicular to each other. This setup is to facilitate the connection of various types of circuits.

Connections are made on the Electronics Lab Board by pushing a stripped wire or a lead to a component into a spring. For maximum effect, the stripped part of the wire should extend so that it passes completely across the spring, making contact with the spring at four points. This produces the most secure electrical and mechanical connection.



If a spring is too loose, press the coils together firmly to tighten it up. The coils of the spring should not be too tight, as this will lead to bending and/or breaking of the component leads when they are inserted or removed. If a spring gets pushed over, light pressure will straighten it back up.

The components, primarily resistors and small wires, can be stored in the plastic bag supplied in the storage case. Encourage students to keep careful track of the components and return them to the bag each day following the lab period.

When connecting a circuit to a D-cell battery, note the polarity (+ or -) which is printed on the board. In some cases the polarity is not important, but in some it will be imperative. Polarity is also very important for most meters.

Experiments

The experiments written up in this manual are developmental, starting from an introduction to the Electronics Lab Board and complete circuits, through series and parallel circuits, ultimately arriving at diode and transistor characteristics. These experiments can be used in combination with existing labs that the teacher employs, or may be used as a complete lab unit.

DC Experiments

- Experiment 1: Electronics Lab Board
- Experiment 2: Lights in Circuits
- Experiment 3: Ohm's Law
- Experiment 4: Resistances in Circuits
- Experiment 5: Voltages in Circuits
- Experiment 6: Currents in Circuits
- Experiment 7: Kirchhoff's Rules
- Experiment 8: Capacitors in Circuits
- Experiment 9: Diodes
- Experiment 10: Transistors

Computer-based Experiments

- Experiment 11: Ohm's Law II
- Experiment 12: RC Circuit
- Experiment 13: LR Circuit
- Experiment 14: LRC Circuit
- Experiment 15: Diode Lab - Part One
- Experiment 16: Diode Lab - Part Two
- Experiment 17: Transistor Lab 1
- Experiment 18: Transistor Lab 2
- Experiment 19: Transistor Lab 3
- Experiment 20: Induction - Magnet Through a Coil

Additional Equipment

Refer to the **Equipment Needed** section at the start of each experiment for a list of all required equipment.

Comments on Meters

Digital Multimeters

The Digital Multimeter, or DMM, is a multiple scale, multiple function meter, typically measuring voltage and resistance and often measuring current as well. These have a digital readout, often with an LCD (Liquid Crystal Display) screen. Different functions and scales are selected with either a rotating switch or a series of pushbutton switches. The PASCO SE-9786A Basic Digital Multimeter is an example of a DMM.

Advantages: DMMs are easily read, and with their typically-high input impedances ($>10^6 \Omega$) they typically give good results for circuits with high resistance. Students usually learn to read DMMs quickly and make fewer errors reading values. Reasonable quality DMMs can be purchased for \$60 or less. The use of DMMs for these experiments is strongly recommended.

Disadvantages: DMMs also require the use of a battery, although the lifetime of an alkaline battery in a DMM is quite long. The battery is used on all scales and functions. Most DMMs give the maximum reading on the selector, which may be confusing to some students; for example, under voltage, "2" means 2 volt (actually 1.99 volt) maximum.

VTVM

The Vacuum Tube Voltmeter, or VTVM, is a multiple scale, multiple function meter, typically measuring voltage and resistance but not current. The meter is an analog one with a variety of scales, selected with a rotating switch on the front of the meter.

Advantages: VTVMs have high input resistances, on the order of $10^6 \Omega$ or greater. By measuring the voltage across a known resistance, current can be measured with a VTVM.

Disadvantages: VTVMs have multiple scales; students will need practice to avoid the mistake of reading the incorrect one. An internal battery provides the current for measuring resistance and needs to be replaced from time to time. Grounding problems can occur when using more than one VTVM to make multiple measurements in the same circuit.

Panelmeters

Individual meters, frequently obtained from scientific supply houses, are available in the form of voltmeters, ammeters, and galvanometers (such as PASCO's SF-9568A Heavy-Duty Voltmeter, SF-9569A Heavy-Duty Ammeter, and SF-9500A Heavy-Duty Galvanometer). In some models, multiple scales are also available.

Advantages: Meters can be used which have the specific range required in a specific experiment. This helps to overcome student errors in reading.

Disadvantages: Using individual meters can lead to errors in choosing the correct one. With limited ranges, students may need to use another range and not have a meter of that range available. Many of the individual meters have low input impedances (voltmeters) and large internal resistances (ammeters). Ohmmeters are almost nonexistent in individual form.

Light Bulbs

The #14 bulbs are nominally rated at 2.5 V and 0.3 A. However, due to relatively large variations allowed by the manufacturer, the wattage of the bulbs may vary from 15 to 30%. Therefore, supposedly "identical" bulbs may not shine with equal brightness in simple circuits.

Get the software

You can use the sensor with PASCO Capstone software. We offer a free trial of Capstone for Windows and Mac. To get the software, go to [pasco.com/downloads](https://www.pasco.com/downloads).

If you have installed the software previously, check that you have the latest update by going to **Help** and selecting "Check for Updates".

Software help

The PASCO Capstone Help provides additional information on how to use this product with the software. You can access the help within the software or online.

Software: Help > PASCO Capstone Help

Online: help.pasco.com/capstone

Tips and Troubleshooting

Correct Circuit, Doesn't Work

- Check to make sure the circuit is indeed connected correctly and completely.
- Check to see if the battery is giving full voltage.
- Ensure each wire is making contact with the appropriate spring(s). 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 does *not* mean the measurement is trivial or unimportant; rather, it is what we hope the student will learn from their 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. Additional bulbs can be purchased from PASCO or a typical electronics store.

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.

Batteries

The AC/DC Experiment Lab 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 having to be replaced.

Resistors

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



NOTE: Using the $300\ \Omega$, $560\ \Omega$, and $1000\ \Omega$ resistors gives approximate ratios of 1:2:3, which are ideal for working towards semi-quantitative understanding of DC circuits.

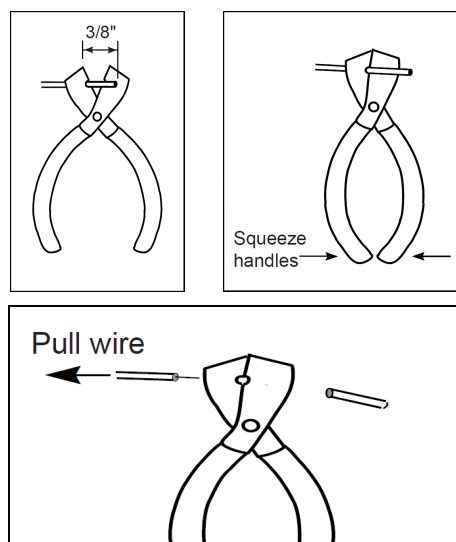
Wires

The Experiment Lab 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 board.

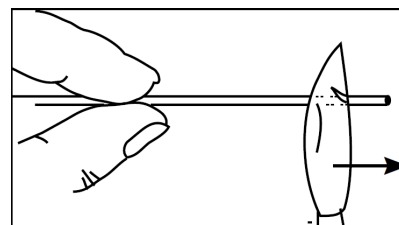
Stripping Your Own Wire

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. Pulling the wire away from the stripper causes the cut end of the insulation to slip off of the wire, leaving $3/8$ " of exposed wire.



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



Technical Support

Need more help? Our knowledgeable and friendly Technical Support staff is ready to answer your questions or walk you through any issues.

-  Chat [pasco.com](https://www.pasco.com)
-  Phone 1-800-772-8700 x1004 (USA)
+1 916 462 8384 (outside USA)
-  Email support@pasco.com

Regulatory Information

Limited Warranty

For a description of the product warranty, see the Warranty and Returns page at www.pasco.com/legal.

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Product end-of-life disposal



This electronic product is subject to disposal and recycling regulations that vary by country and region.

It is your responsibility to recycle your electronic equipment per your local environmental laws and regulations to ensure that it will be recycled in a manner that protects human health and the environment.

To find out where you can drop off your waste equipment for recycling, please contact your local waste recycle or disposal service, or the place where you purchased the product.

The European Union WEEE (Waste Electronic and Electrical Equipment) symbol on the product or its packaging indicates that this product must not be disposed of in a standard waste container.

CE statement

This device has been tested and found to comply with the essential requirements and other relevant provisions of the applicable EU Directives.

Experiment 1: Electronics Lab Board

Equipment Needed

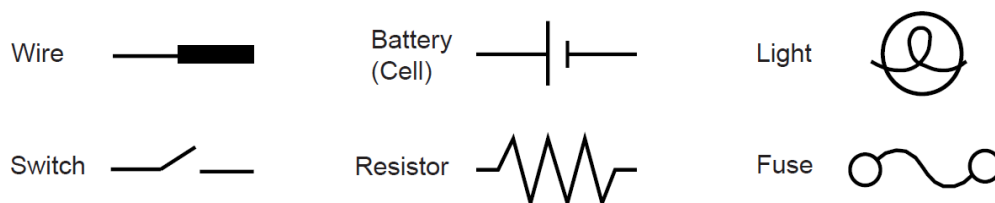
- AC/DC Electronics Lab Board
 - Wire leads
- D-cell Battery
- Graph paper

Purpose

The purpose of this lab is to become familiar with the AC/DC Electronics Lab Board, to learn how to construct a complete electrical circuit, and to learn how to represent electrical circuits with circuit diagrams.

Background

- Many of the key elements of electrical circuits have been reduced to symbol form. Each symbol represents an element of the device's operation and may have some historical significance. In this lab and the ones which follow, we will use symbols frequently, and it is necessary you learn several of those symbols.



- The AC/DC Electronics Lab Board has been designed to conduct a wide variety of experiments easily and quickly. A labeled pictorial diagram of the Lab Board appears on page 1. Refer to that page if at any point you are confused about a direction which mentions a device on the board itself.
- **Notes on the Electronics Lab Board:**
 - The springs are soldered to the board to serve as convenient places for connecting wires, resistors, and other components. Some of the springs are connected electrically to devices like the potentiometer and the D-cells.
 - If a spring is too loose, press the coils together firmly to enable it to hold a wire more tightly. If a spring gets pushed over, light pressure will straighten it back up. If you find a spring which doesn't work well for you, please notify your instructor.
 - The components, primarily resistors, are contained in a small Ziplock bag, which is stored in the plastic storage case that comes with the board. Keep careful track of the components and return them to the storage bag following each lab period; this will help you get components with consistent values from lab to lab.
 - When you connect a circuit to a D-cell (each "battery" is just a cell, with two or more cells comprising a battery), note the polarity (+ or -) which is printed on the board. Although in some cases the polarity may not matter, in others it may be crucial.
 - Due to typical differences between light bulbs, the brightness of "identical" bulbs may vary substantially.

Procedure

1. Use two pieces of wire to make connections between the springs on one of the light bulbs to the springs on the D-cell in such a way that the light will glow. Before you begin actually wiring your circuit, discuss with your lab partner which connections you intend to make and why you think it will be successful in activating the light. If you are not successful, try these steps in order: change the wiring; use another light; use another cell; ask the instructor for assistance.
 - a. Sketch the connections that the wires make when you are successful, using the symbols from the first page of this lab.
 - b. Re-sketch the total circuit you have constructed so that the wires run horizontally and vertically on the page. This is more standard in drawing electrical circuits.
2. Reverse the two wires at the *light*. Does this have any effect on the operation?
3. Reverse the two wires at the *cell*. Does this have any effect on the operation?

In the following steps, use the pushbutton switch as shown in Figure 1.1 below.

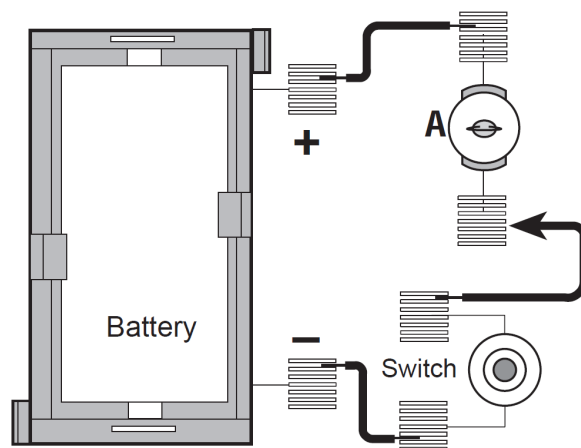


Figure 1.1

4. Use additional wires to connect a second light into the circuit in such a way that it also lights up. (Use the switch to turn the power on and off once the complete wiring has been achieved.) Discuss your plans with your lab partner before you begin.
 - a. Once you have achieved success, sketch the connections that you made in the form of a circuit diagram. Annotate your circuit diagram by making appropriate notes to the side indicating what happened with that particular circuit. If you do not immediately succeed, keep trying!



NOTE: Is your original light the same brightness, or was it brighter or dimmer than it was during Step 1? Can you explain any differences, or lack thereof, in the brightness? If not, don't worry; the topic will be revisited in later labs.

5. If you can devise another way of connecting two lights into the same circuit, try it out. Sketch the circuit diagram when finished and note the relative brightness of the lights. Compare the brightness with what you achieved with a single light by itself.
6. Disconnect the wires and return them to the plastic bag. Replace the equipment in its storage case.

Experiment 2: Lights in Circuits

Equipment Needed

- AC/DC Electronics Lab Board
 - Wire Leads
- D-cell Batteries (2)
- Graph paper

Purpose

The purpose of this lab is to determine how light bulbs behave in different circuit arrangements, as well as to investigate different ways of connecting two batteries.

Procedure

Answer the questions which appear during the experiment procedure as you complete the following steps. Pay particular attention to the "**NOTED:**" questions.

PART A



NOTE: Due to variations from bulb to bulb, the brightness of one bulb may be substantially different from the brightness of another bulb in "identical" situations.

1. Use two pieces of wire to connect a single light bulb to one of the D-cells in such a way that the light will glow. (You should have completed this step in Experiment 1. If that is the case, review what you did then; if not, continue with this step.) Include a "switch", such as the pushbutton switch, to turn the light on and off, preventing it from being on continuously.
2. Use additional wires as needed to connect a second light into the circuit in such a way that it is also lighted when the button is pressed. Discuss your plans with your lab partner before you begin.
 - a. Once you have succeeded, sketch the connections that you made in the form of a circuit diagram using standard symbols. Annotate your circuit diagram by making appropriate notes to the side, indicating what happened with that particular circuit.
3. **NOTED:** Is your original light the same brightness as in Step 1, or did it become brighter or dimmer when the second bulb was connected? Can you explain any differences, or lack of differences, in the brightness?
4. If one of the light bulbs is unscrewed, does the other bulb go out or stay on? Why do you think this is?
5. Design a circuit that will allow you to light all three lights, with each one being equally bright. Draw the circuit diagram once you have succeeded.
 - a. If you could characterize the circuit as being a series or parallel circuit, which would it be?
 - b. What happens if you unscrew one of the bulbs? Explain why this occurs.
6. Design another circuit with a different design, but which also lights all three bulbs, with the bulbs all being equally bright (though they may be brighter or dimmer than in Step 5). Draw the circuit diagram when you are successful.
 - a. What happens if you unscrew one of the bulbs in this circuit? Explain why this occurs.
7. Design and build a circuit which will light two light bulbs at the same intensity and the third at a different intensity. When you have succeeded, draw the circuit diagram.
 - a. What happens if you unscrew one of the bulbs in this circuit? Explain why this occurs.
8. **NOTED:** Are there any generalizations that you can make about different connections to a set of lights?

PART B

9. Connect a single D-cell to a single light as in step 1, using a switch such as the pushbutton switch to allow you to easily turn the current on and off. Note the brightness of the light.
10. Now connect the second D-cell into the circuit, as shown by diagram ① in Figure 2.1. What is the effect on the brightness of the light?

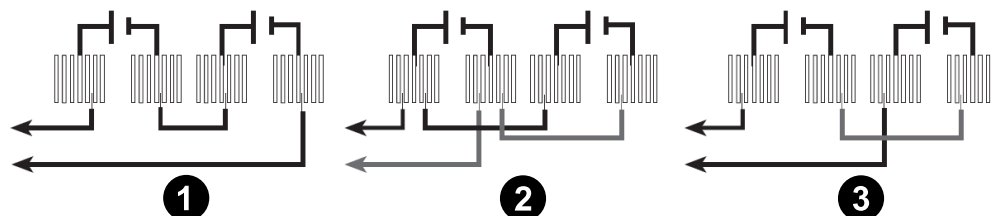


Figure 2.1

11. Reconnect the second D-cell as seen in diagram ② in Figure 2.1. What is the effect on the brightness?
12. Finally, reconnect the second D-cell as seen in diagram ③ in Figure 2.1. What is the effect on the brightness?
13. **NOTED:** Determine the nature of the connections between the D-cells you made in Steps 9 through 12.

PART C

14. Connect the circuit as shown in Figure 2.2. What is the effect of rotating the knob identified as a "Potentiometer" on the device?

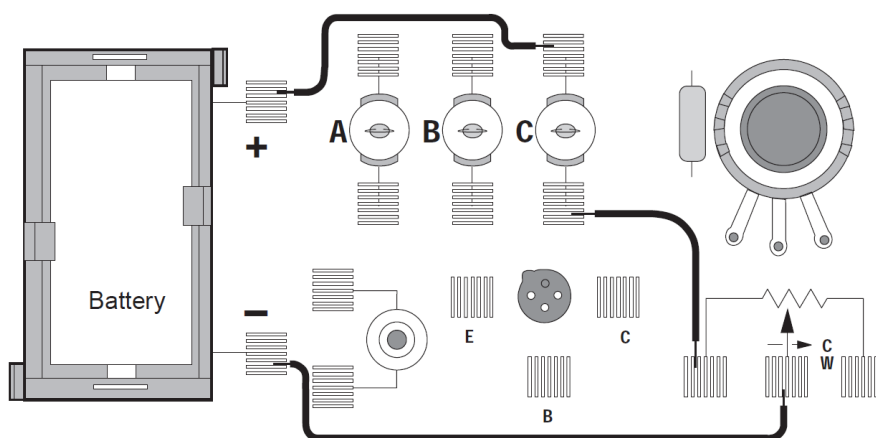


Figure 2.2

Discussion

1. What are the apparent rules for the operation of *lights*...
 - a. ...in series?
 - b. ...in parallel?
2. What are the apparent rules for the operation of *batteries*...
 - a. ...in series?
 - b. ...in parallel?
3. What is one function of a potentiometer in a circuit?

Experiment 3: Ohm's Law

Equipment Needed

- AC/DC Electronics Lab Board
 - Wire Leads
 - Resistors (assorted values)
- D-cell Battery
- Digital Multimeter (DMM)
- Graph paper

Purpose

The purpose of this lab will be to investigate the three variables involved in a mathematical relationship known as Ohm's Law.

Procedure

1. Choose one of the resistors you have been given. Using the chart on the next page, decode the resistance values and record that value in the first column of Table 3.1 on the next page.

MEASURING CURRENT

2. Construct the circuit shown in Figure 3.1a by pressing the leads of the resistor into two of the springs in the Experimental Section on the Electronics Lab Board.

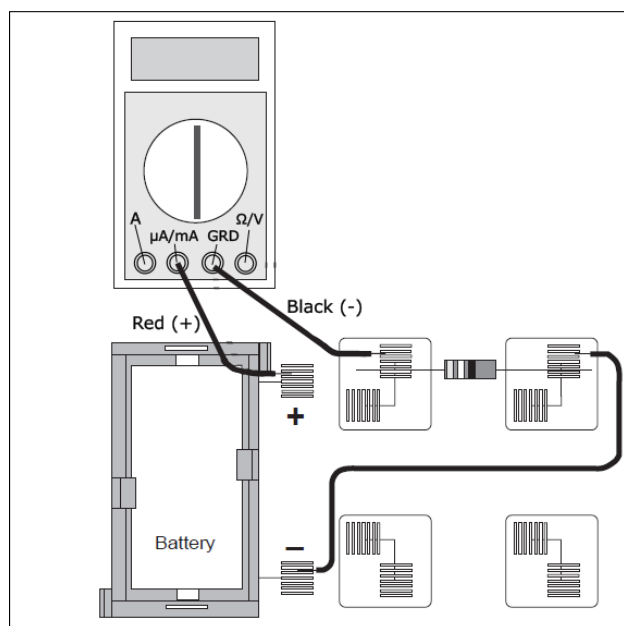


Figure 3.1a

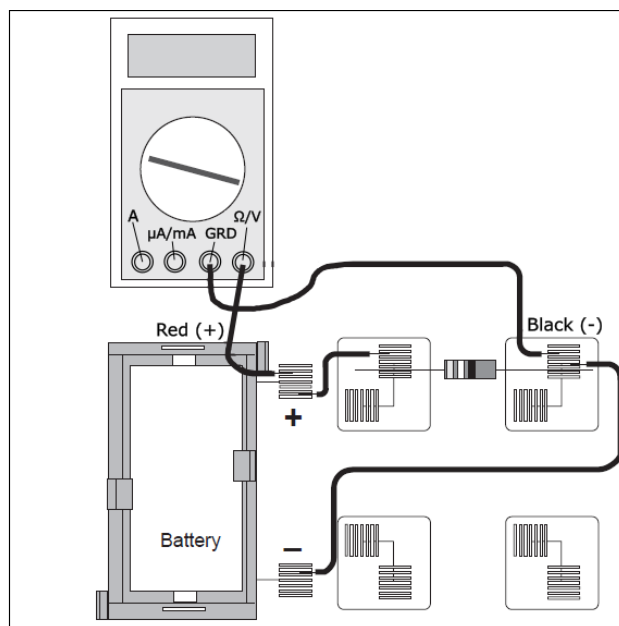


Figure 3.1b

3. Set the Multimeter to the 200 mA range, noting any special conditions needed for measuring current; make sure that the red lead is connected to the μA and mA port and the black lead is connected to the ground. Connect the circuit and read the current that is flowing through the resistor. Record this value in the second column of Table 3.1.
4. Remove the resistor and choose another. Record its resistance value in Table 3.1, then measure and record the current as in Steps 2 and 3. Continue this process until you have completed the process for all of the resistors you have been given. As you may have more than one resistor with the same value, keep them in the order you used them, since you will need to use them again in the same order in the next steps.

MEASURING VOLTAGE

- Disconnect the wires from the Multimeter and connect a wire from the positive lead (spring) of the battery directly to the first resistor you used, as shown in Figure 3.1b. Change the Multimeter to the 2 V DC scale and re-connect the leads, with the red lead now connected to the resistance and voltage port, as shown also in Figure 3.1b. Measure the voltage across the resistor and record it in Table 3.1.
- Remove the resistor and choose the next one you used. Record its voltage in Table 3.1 as in Step 5. Continue this process until you have collected data for all of the resistors.

Table 3.1

Resistance (Ω)	Current (A)	Voltage (V)	Voltage/Resistance

Data Processing

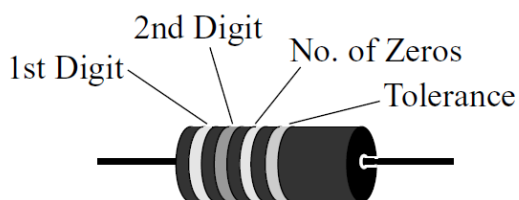
- Construct a graph of Current (y-axis) vs. Resistance (x-axis).
- For each of your sets of data, calculate the ratio of Voltage/Resistance. Compare the values you calculate with the measured values of the current.

Discussion

- From your graph, what is the mathematical relationship between Current and Resistance?
- Ohm's Law states that current is given by the ratio of voltage/resistance. Does your data agree with this?
- What were possible sources of experimental error in this lab? For each one, would you expect it to make your measured values larger or smaller?

Reference

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

Fourth Band

None	$\pm 20\%$
Silver	$\pm 10\%$
Gold	$\pm 5\%$
Red	$\pm 2\%$



NOTE: The 4.7 ohm resistor has a gold third band to indicate that the two-digit number from the first two bands should be divided by 10.

Experiment 4: Resistances in Circuits

Equipment Needed

- AC/DC Electronics Lab Board
 - Resistors (assorted values, including three with equal resistance)
- Digital Multimeter (DMM)

Purpose

The purpose of this lab is to begin experimenting with the variables that contribute to the operation of an electrical circuit. This is the first in a series of three connected labs.

Procedure

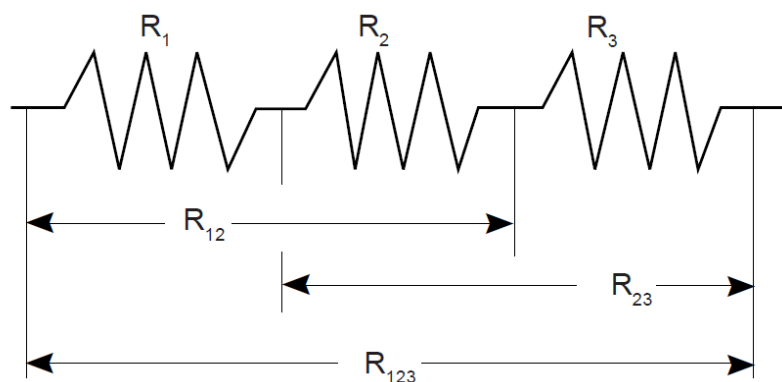
1. Choose three resistors of *the same* value. Enter those sets of colors in Table 4.1 below. We will refer to one resistor as #1, another as #2, and the third as #3.
2. Determine the coded value of your resistors using the reference image at the end of this lab. Enter the value in the column labeled "Coded Resistance" in Table 4.1. Enter the Tolerance value, as indicated by the color of the fourth band, under "Tolerance".
3. Use the Multimeter to measure the resistance of each of your three resistors. Enter these values in Table 4.1.
4. Determine the percentage experimental error of each resistance value using the equation below and enter it in the appropriate column.

$$\text{Experimental Error} = [(|\text{Measured} - \text{Coded}|) / \text{Coded}] \times 100\%$$

Table 4.1

	Color 1	Color 2	Color 3	Color 4	Coded Resistance	Measured Resistance	% Error	Tolerance
#1								
#2								
#3								

5. Now connect the three resistors into the **series circuit** seen in Figure 4.1, using the spring clips on the Electronics Lab Board to hold the leads of the resistors together without bending them. Measure the resistances of the combinations, as indicated on the diagram, by connecting the leads of the Multimeter between the points at the ends of the arrows.



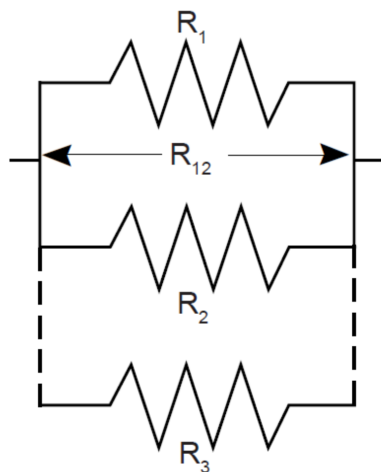
$R_{12} =$ _____

$R_{23} =$ _____

$R_{123} =$ _____

Figure 4.1: Series Circuit

6. Construct a **parallel circuit** as seen in Figure 4.2, first using combinations of two of the resistors, and then using all three. Measure and record your values for these circuits.




$R_{12} =$ _____

$R_{23} =$ _____

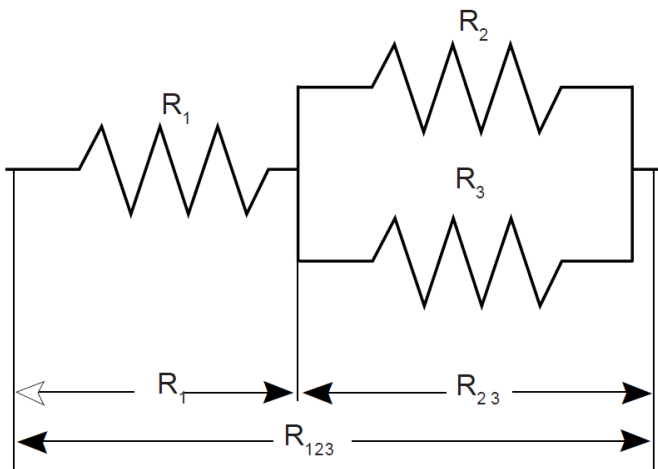
$R_{13} =$ _____

$R_{123} =$ _____

Figure 4.2: Parallel Circuit

 **NOTE:** You can measure R_{13} by replacing R_2 with R_3 in the circuit.

7. Connect the **combination circuit** in Figure 4.3 and measure the various combinations of resistances. Do these follow the rules as you discovered them before?



$R_1 =$ _____

$R_{23} =$ _____

$R_{123} =$ _____

Figure 4.3: Combination Circuit

8. Choose three resistors with *different values* from each other. Repeat steps 1 through 7 as above, recording your data in Table 4.2 and Figures 4.4 through 4.6. Note that we have called these resistors A, B, and C.

Table 4.2

	Color 1	Color 2	Color 3	Color 4	Coded Resistance	Measured Resistance	% Error	Tolerance
A								
B								
C								

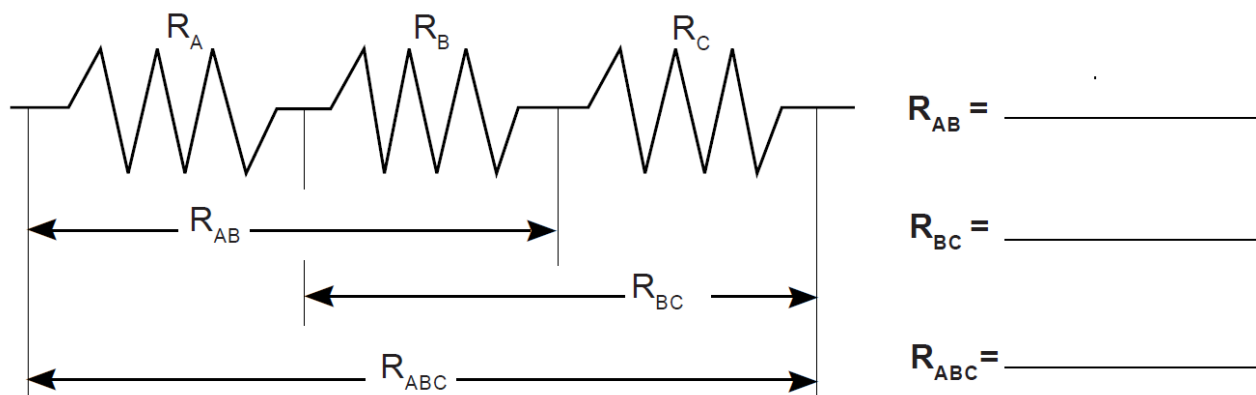


Figure 4.4: Series Circuit

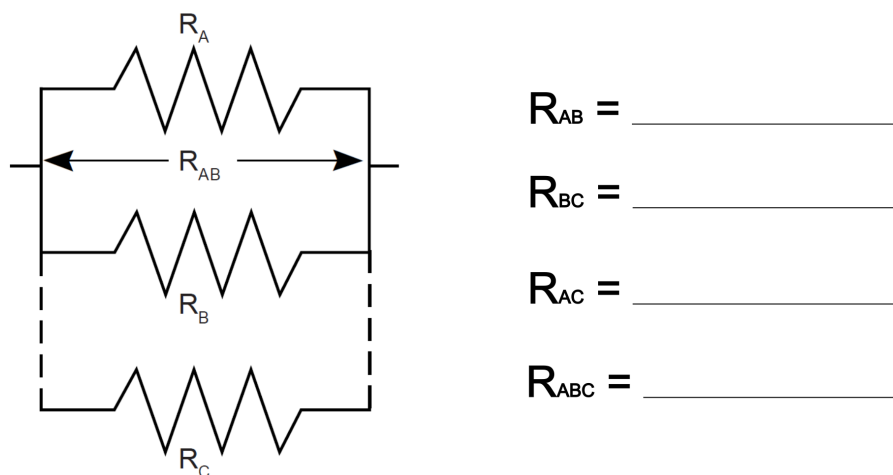


Figure 4.5: Parallel Circuit



NOTE: You can measure R_{AC} by replacing R_B with R_C .

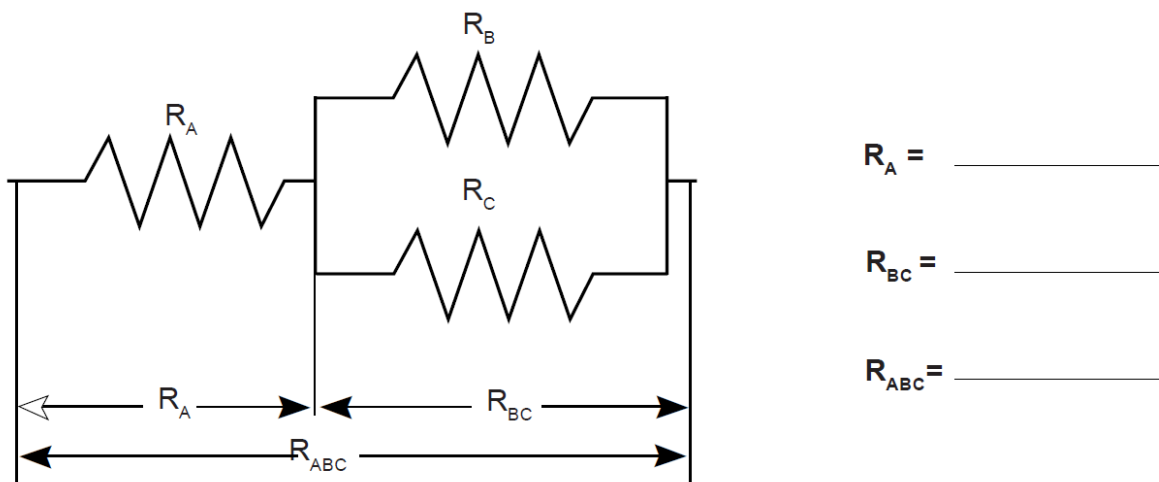


Figure 4.6: Combination Circuits

Discussion

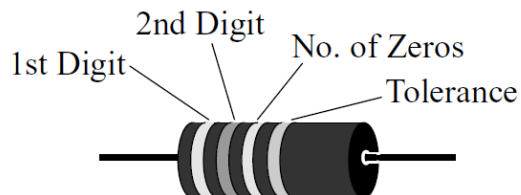
1. How does the % error compare to the coded tolerance for your resistors?
2. What is the apparent rule for combining *equal* resistances in series circuits? What about in parallel circuits? Use evidence from your data to support your answers.
3. What is the apparent rule for combining *unequal* resistances in series circuits? What about in parallel circuits? Use evidence from your data to support your answers.
4. What is the apparent rule for the *total resistance* when resistors are added in series? What about in parallel? Use evidence from your data to support your answers.

Extension

- Using the same resistance values as you used before, plus any wires needed to help build the circuit, design and test the resistance values for another combination of three resistors.
- Follow your instructor's guidelines to build circuits with four and five resistors, testing the basic concepts you discovered in this lab.

Reference

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



Fourth Band

None	$\pm 20\%$
Silver	$\pm 10\%$
Gold	$\pm 5\%$
Red	$\pm 2\%$



NOTE: The 4.7 ohm resistor has a gold third band to indicate that the two-digit number from the first two bands should be divided by 10.

Experiment 5: Voltages in Circuits

Equipment Needed

- AC/DC Electronics Lab Board
 - Wire Leads
 - Resistors (the same ones you used in Experiment 4)
- D-cell Battery
- Digital Multimeter (DMM)

Purpose

The purpose of this lab will be to continue experimenting with the variables that contribute to the operation of an electrical circuit. You should have completed Experiment 4 before working on this lab.

Procedure

1. Connect the three equal resistors you used in Experiment 4 into the **series** circuit shown in Figure 5.1, using the springs to hold the leads of the resistors together without bending them. Connect two wires to the D-cell, carefully noting which wire is connected to the negative and which is connected to the positive.
2. Now use the voltage function on the Multimeter to measure the voltages, first across the individual resistors and then across the combinations of resistors. Be careful to observe the polarity of the leads (red is +, black is -). Record your readings in the blanks below Figure 5.1, along with the resistance values you measured in Experiment 4.

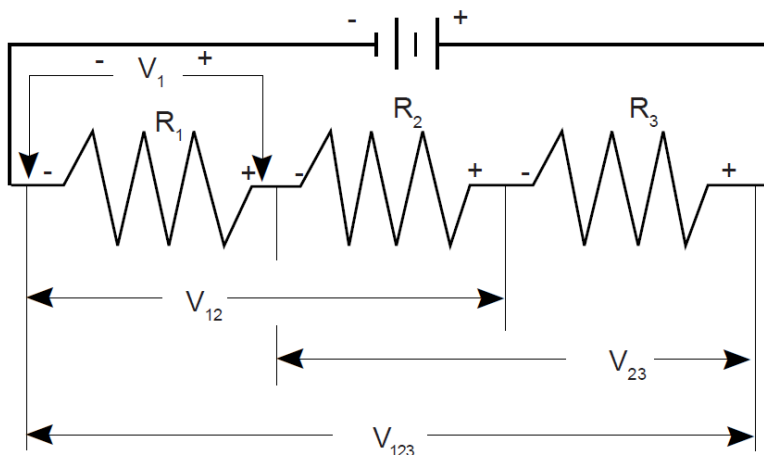


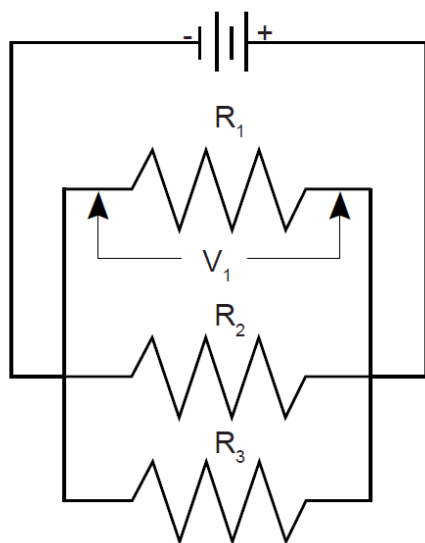
Figure 5.1: Series Circuit

$R_1 =$ _____	$V_1 =$ _____
$R_2 =$ _____	$V_2 =$ _____
$R_3 =$ _____	$V_3 =$ _____
$R_{12} =$ _____	$V_{12} =$ _____
$R_{23} =$ _____	$V_{23} =$ _____
$R_{123} =$ _____	$V_{123} =$ _____

3. Now connect the parallel circuit seen in Figure 5.2, using *all three* resistors. Measure the resistance and the voltage across each of the resistors, as well as the combination, taking care with the polarity as before. Record your values in the boxes in the diagram below.



NOTE: Keep all three resistors connected throughout the time you are making your measurements.



$$R_1 = \underline{\hspace{2cm}} \quad V_1 = \underline{\hspace{2cm}}$$

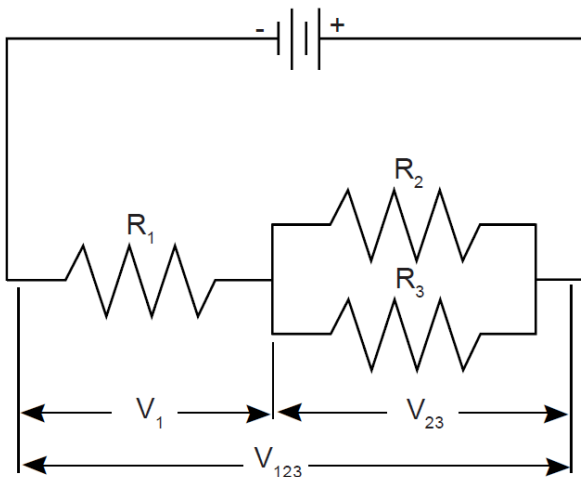
$$R_2 = \underline{\hspace{2cm}} \quad V_2 = \underline{\hspace{2cm}}$$

$$R_3 = \underline{\hspace{2cm}} \quad V_3 = \underline{\hspace{2cm}}$$

$$R_{123} = \underline{\hspace{2cm}} \quad V_{123} = \underline{\hspace{2cm}}$$

Figure 5.2: Parallel Circuit

4. Now connect the circuit in Figure 5.3 and measure the voltages. You can use the resistance readings you took in Experiment 4 for this step.



$$R_1 = \underline{\hspace{2cm}} \quad V_1 = \underline{\hspace{2cm}}$$

$$R_{23} = \underline{\hspace{2cm}} \quad V_{23} = \underline{\hspace{2cm}}$$

$$R_{123} = \underline{\hspace{2cm}} \quad V_{123} = \underline{\hspace{2cm}}$$

Figure 5.3: Combination Circuit

5. Use the three unequal resistors that you used in Experiment 4 to construct the circuits shown below. Make the same voltage measurements that you were asked to make before in Steps 1 to 4. Use the same resistors for A, B, and C that you used in Experiment 4.

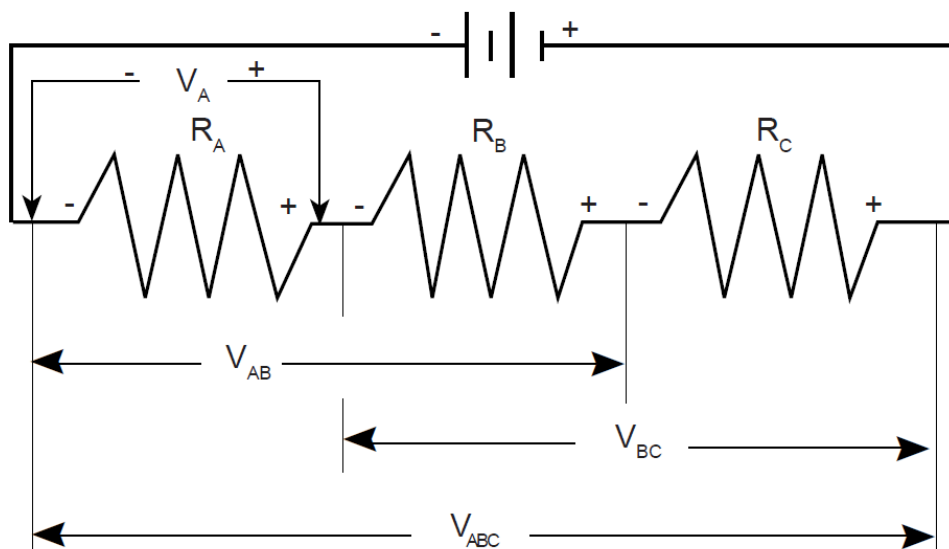
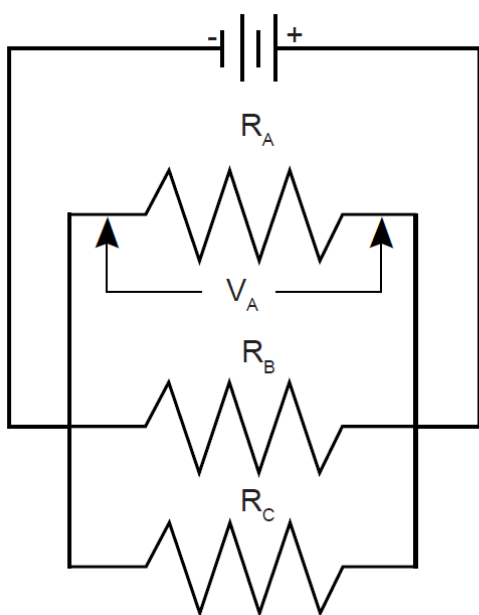


Figure 5.4: Series Circuit

$R_A =$ _____	$V_A =$ _____
$R_B =$ _____	$V_B =$ _____
$R_C =$ _____	$V_C =$ _____
$R_{AB} =$ _____	$V_{AB} =$ _____
$R_{BC} =$ _____	$V_{BC} =$ _____
$R_{ABC} =$ _____	$V_{ABC} =$ _____



$R_A =$ _____	$V_A =$ _____
$R_B =$ _____	$V_B =$ _____
$R_C =$ _____	$V_C =$ _____
$R_{ABC} =$ _____	$V_{ABC} =$ _____

Figure 5.5: Parallel Circuit

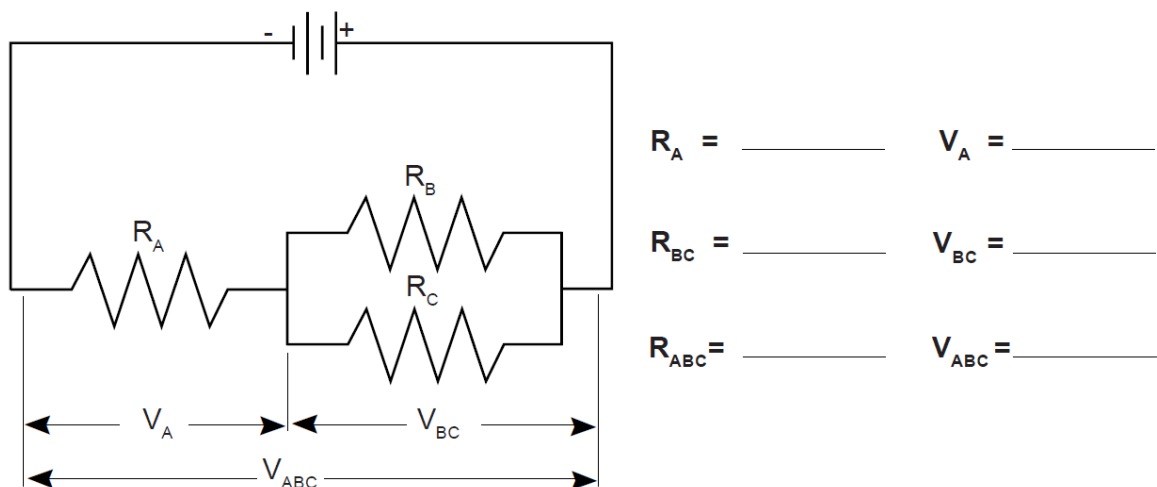


Figure 5.6: Combination Circuit

Discussion

1. Based on the data you recorded from the setup in Figure 5.1, how is voltage distributed in a **series circuit** with *equal* resistances? How is it distributed in a series circuit with *unequal* resistances, based on the setup from Figure 5.4? Is there any relationship between the size of the resistance and the size of the resulting voltage?
2. Based on the data from Figure 5.2, how is voltage distributed in a **parallel circuit** with *equal* resistances? How is it distributed in a parallel circuit with *unequal* resistances, based on the setup from Figure 5.5? Is there any relationship between the size of the resistance and the size of the resulting voltage?
3. Do the voltages in your combination circuits (see Figures 5.3 and 5.6) follow the same rules as they did in the other circuits you constructed? If not, state the rules you see operating in these circuits.

Experiment 6: Currents in Circuits

Equipment Needed

- AC/DC Electronics Lab Board
 - Resistors (the unequal resistors from Experiments 4 and 5)
 - Wire Leads
- D-cell Battery
- Digital Multimeter (DMM)

Purpose

The purpose of this lab will be to continue experimenting with the variables that contribute to the operation of electrical circuits.

Procedure

1. Connect the same three *unequal* resistors you used in Experiments 4 and 5 into the series circuit shown below, using the springs to hold the leads of the resistors together without bending them. Connect two wires to the D-cell, carefully noting which lead is positive and which is negative.



IMPORTANT: For this experiment, we will be treating the resistor previously called R_A as R_1 , the resistor previously called R_B as R_2 , and the resistor previously called R_C as R_3 .

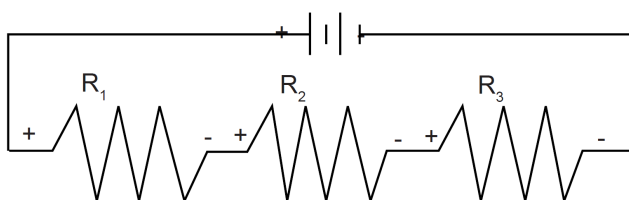


Figure 6.1

2. Now change the leads in your multimeter so that they can be used to measure current, with the red lead plugged into the $\mu A/mA$ port. You should be using the scale which goes to a maximum of 200 mA. Be careful to observe the polarity of the leads (red is +, black is -). In order to measure current, the circuit must be interrupted and the current allowed to flow through the meter. Disconnect the lead wire from the positive terminal of the battery and connect it to the red (+) lead of the meter. Connect the black (-) lead to R_1 , where the wire originally was connected. Record your reading in Table 6.1 as I_0 . See Figure 6.2 for a guide.

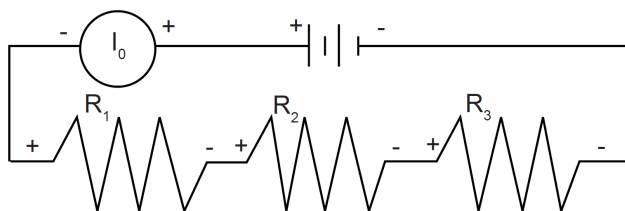


Figure 6.2

3. Now move the multimeter to the positions indicated in Figure 6.3 on the next page, each time interrupting the circuit and carefully measuring the current in each one. Complete Table 6.1 on the next page.



NOTE: You will be filling in parts of the table with values from Experiments 4 and 5.

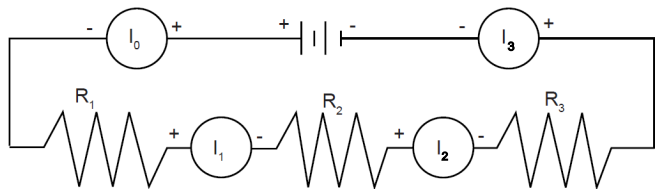


Figure 6.3

$R_1 =$ _____	$I_0 =$ _____	$V_1 =$ _____
$R_2 =$ _____	$I_1 =$ _____	$V_2 =$ _____
$R_3 =$ _____	$I_2 =$ _____	$V_3 =$ _____
$R_{12} =$ _____	$I_3 =$ _____	$V_{12} =$ _____
$R_{23} =$ _____		$V_{23} =$ _____
$R_{123} =$ _____		$V_{123} =$ _____

Table 6.1

4. Connect the **parallel circuit** in Figure 6.4, using all three resistors. Review the instructions for connecting the multimeter as an ammeter in Step 2. Connect it first between the positive terminal of the battery and the parallel circuit junction to measure I_0 . Next, interrupt the various branches of the parallel circuit and measure the individual branch currents. Record your measurements in the table inside the figure.

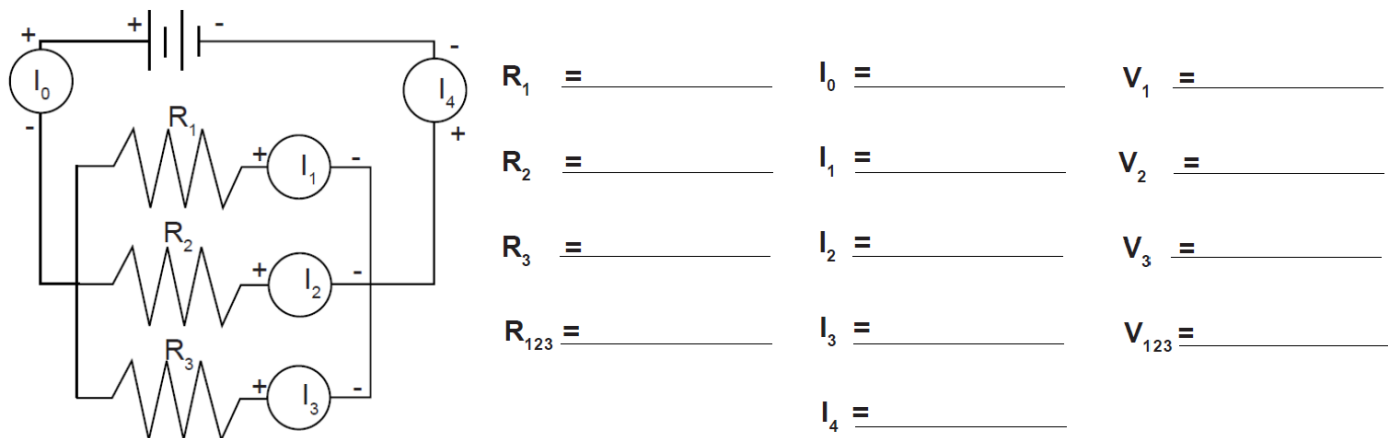


Figure 6.4

Discussion

1. Based on the first set of data, what is the pattern for how current behaves in a series circuit?
2. Based on your second set of data, what are the patterns- if any- for how current behaves in a parallel circuit?
3. Now that you have completed Experiments 4, 5, and 6, briefly describe the behavior of all three quantities- resistance, voltage, and current- in a series circuit.
4. Briefly describe the behavior of the three quantities in a parallel circuit.

Experiment 7: Kirchhoff's Rules

Equipment Needed

- AC/DC Electronics Lab Board
 - Resistors
 - Wire Leads
- D-cell Batteries (x2)
- Digital Multimeter (DMM)

Purpose

The purpose of this lab will be to experimentally demonstrate Kirchhoff's Rules for electrical circuits.

Procedure

1. Connect the circuit shown in Figure 7.1a using any of the resistors you have **except the 4.7 Ω or 10 Ω ones**. Use Figure 7.1b as a reference along with 7.1a as you record your data. Before adding each resistor to the circuit, record their resistance values in Table 7.1 below.

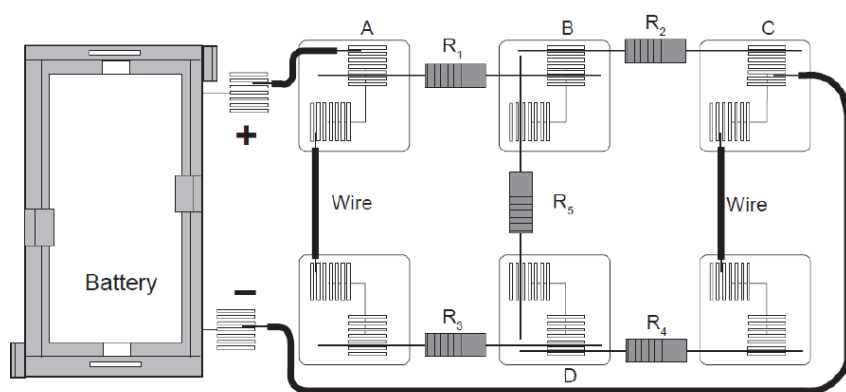


Figure 7.1a

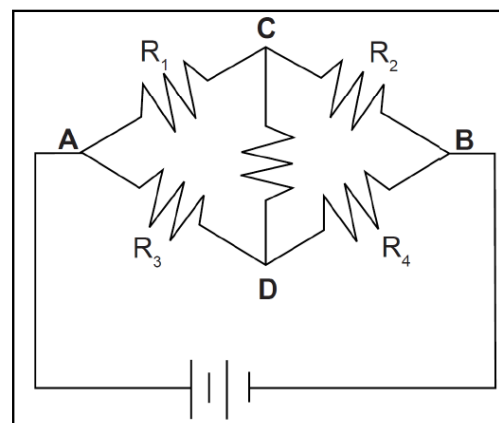


Figure 7.1b

2. With the circuit connected to the battery and the current flowing, measure the voltage across each of the resistors; record the values in Table 7.1. On the circuit diagram in Figure 7.1b, indicate which side of each of the resistors is positive relative to the other end by placing a "+" at that end.
3. Now measure the current through each of the resistors. Interrupt the circuit and place the multimeter **in series** with the resistor being studied to obtain your current reading. Make sure you record each of the individual currents, as well as the current flowing into or out of the main part of the circuit, I_T .

Table 7.1

Resistance (Ω)	Voltage (V)	Current (mA)
R_1	V_1	I_1
R_2	V_2	I_2
R_3	V_3	I_3
R_4	V_4	I_4
R_5	V_5	I_5
R_T	V_T	I_T

Analysis

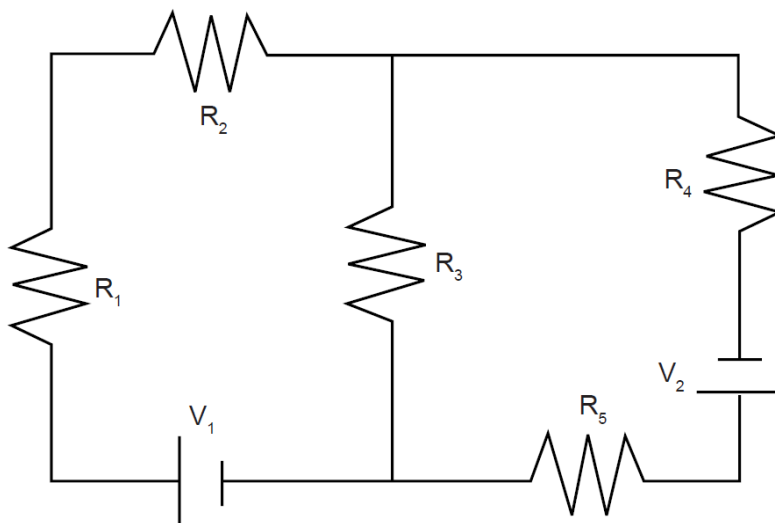
1. Determine the net current flow into or out of each of the four "nodes" in the circuit.
2. Determine the net voltage change around at least three (3) of the seven closed loops. Remember: if the potential goes up, treat the voltage change as positive (+); if the potential goes down, treat it as negative (-).

Discussion

1. Use your experimental results to analyze the circuit you built in terms of Kirchhoff's Rules. Be specific and *state the evidence* for your conclusions.

Extension

Build the circuit below and apply the same procedure you used previously. Analyze it in terms of Kirchhoff's Rules. If possible, try to analyze the circuit ahead of time and compare your measured values with the theoretically computed values.



Experiment 8: Capacitors in Circuits

Equipment Needed

- AC/DC Electronics Lab Board
 - Capacitors: 100 μF and 330 μF
 - Resistors: 100 $\text{k}\Omega$ and 220 $\text{k}\Omega$
 - Wire Leads
- D-cell Battery
- Stopwatch or timer with 0.1 sec resolution
- Electrometer (such as the ES-9078A Basic Electrometer), **OR** Digital Multimeter (DMM) that has an input impedance of 10 $\text{M}\Omega$ or greater (such as the SE-9786A Basic Digital Multimeter)

Purpose

The purpose of this lab will be to determine how capacitors behave in RC circuits. The manner in which capacitors combine will also be studied.

Procedure

1. Connect the circuit shown in Figure 8.1, using a 100 $\text{k}\Omega$ resistor and a 100 μF capacitor. Connect the electrometer or multimeter so the black "ground" lead is on the side of the capacitor that connects to the negative terminal of the battery and set it so that it reads a maximum of about 1.5-3 V DC.

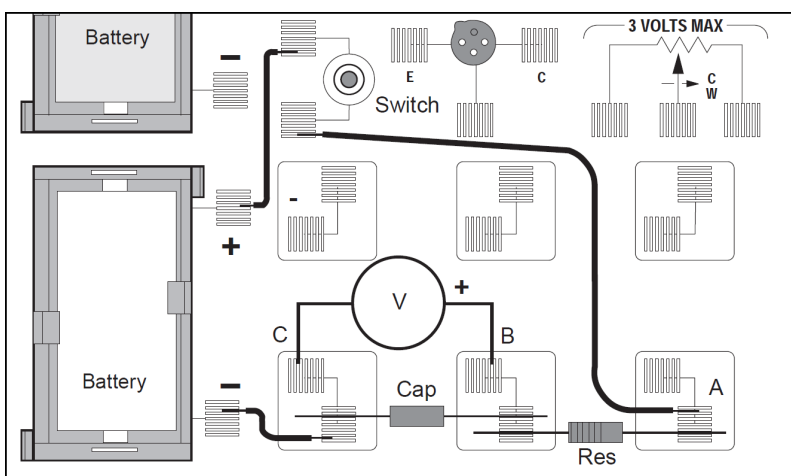


Figure 8.1

2. Start with no voltage on the capacitor and the switch off. If there is any remaining voltage on the capacitor, use a piece of wire to "short" the two leads together, draining any remaining charge. (Touch the ends of the wire to points **B** and **C** as shown in Figure 8.1 to discharge the capacitor.)
3. Now close the switch by pushing and holding the button down. Measure the voltage across the capacitor using the electrometer or multimeter. How would you describe the manner in which the voltage changes?
4. Open the switch by releasing the button; the capacitor should remain at its present voltage with a very slow drop over time. This indicates that the charge you placed on the capacitor has no way to move back to neutralize the excess charges on the two plates.
5. Connect a wire between points **A** and **C** in the circuit, allowing the charge to drain back through the resistor. Observe the voltage readings on the electrometer or multimeter as the charge flows back. How would you describe the manner in which the voltage falls?
6. Repeat Steps 3-5 until you have a good feeling for the process of charging and discharging of a capacitor through a resistor.

7. Now repeat Steps 3-5 again, this time recording the time taken to move from 0.0 volts to 0.95 volts while charging (t_c) and the time taken to move from 1.5 volts to 0.55 volts while discharging (t_D). Record your times, along with the resistance and capacitance values, in Table 8.1 below.
8. Replace the 100 μF capacitor with a 330 μF capacitor. Repeat Step 7, recording the charging and discharging times in Table 8.1. If a third capacitor is available, use it in the circuit as well, recording its data in the table.
9. Return to the original 100 μF capacitor, but replace the 100 $\text{k}\Omega$ resistor with a 220 $\text{k}\Omega$ resistor. Repeat Step 7, recording your data in Table 8.1. If a third resistor is provided, use it in the circuit as well, recording its data in the table.

Table 8.1

Trial	Resistance ($\text{k}\Omega$)	Capacitance (μF)	t_c (s)	t_D (s)
1				
2				
3				
4				
5				
6				
7				
8				

10. Return to the original 100 $\text{k}\Omega$ resistor, but use the 100 μF capacitor in series with the 330 μF capacitor. Repeat Step 7, recording t_c and t_D in Table 8.2.
11. Rearrange the circuit so that the 100 μF and 330 μF capacitors are in parallel. Repeat Step 10.

$R =$ _____; $C_1 =$ _____; $C_2 =$ _____

Table 8.2

Type of Circuit	t_c	t_D
Series		
Parallel		

Discussion

1. Based on the data in Table 8.1, what is the effect on charging and discharging times if the capacitance is increased? What mathematical relationship exists between your times and the capacitance?
2. Based on the data in Table 8.1, what is the effect on charging and discharging times if the *resistance* is increased? What mathematical relationship exists between your times and the resistance?
3. Based on the data in Table 8.2, what is the effect on the total capacitance if capacitors are combined in series? What if they are combined in parallel?

Experiment 9: Diodes

Equipment Needed

- AC/DC Electronics Lab Board
 - Resistors: 1 k Ω and 330 Ω
 - 1N-4007 Diode
 - Wire Leads
- Digital Multimeter (DMM)
- D-cell Batteries (x2)
- Scratch paper

Purpose

The purpose of this lab will be to experimentally determine some of the operating characteristics of semiconductor diodes.

Procedure

1. Connect the circuit shown in Figure 9.1a using the 1N-4007 diode you've been supplied with and the 1 k Ω resistor. Use Figure 9.1b as a reference, along with Figure 9.1a, as you record your data. Note the direction that the diode is oriented, with the differently-colored band closer to point **B**.

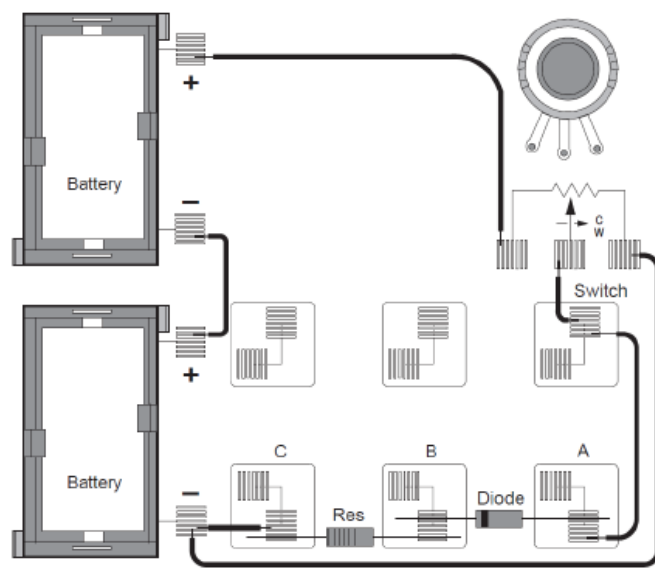


Figure 9.1a

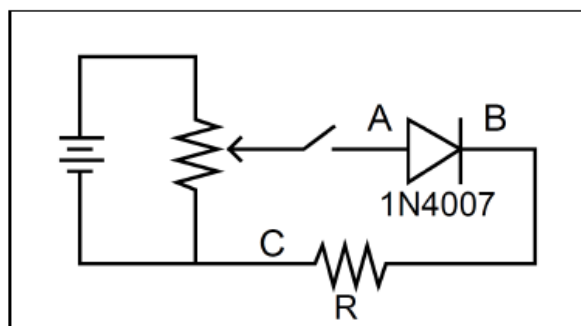


Figure 9.1b

2. Construct a table on scratch paper like the one in Table 9.1; make sure to leave room for a large number of rows to fit all the data that will be collected.
3. With the "switch" closed and the current flowing, adjust the potentiometer until there is a voltage of 0.05 volts between **B** and **C** (V_{BC}). Measure the voltage across the diode (V_{AB}). Record both voltages in the left-hand side of your table, under "Forward Bias".
4. Adjust the potentiometer to attain the following values for V_{BC} : 0.1 V, 0.2 V, 0.3 V, and so on through 2.0 V. Record the two voltages for each case in your table.
5. Remove the 1 k Ω and replace it with a 330 Ω resistor. Repeat Steps 3 and 4, setting V_{BC} to 0.3 V, 0.4 V, and so on through 2.0 V.
6. Reverse the orientation of the diode. Set the diode voltage (V_{AB}) to the values of 0.5 V, 1.0 V, and so on through 3.0 V. Measure the resistor voltage (V_{BC}) in each case. Record these values in your table in the "Reverse Bias" columns.

Analysis

1. Determine the current flow (I) for each setting by dividing the voltage across the resistor (V_{BC}) by the resistance. Remember to change the divisor for any setting after you switched the resistors!
2. Construct a graph of current (y-axis) vs the diode voltage V_{AB} (x-axis), with the graph extending into the second quadrant and treating the values of V_{AB} from Step 6 as negative.

Discussion

1. Discuss the shape of your graph and what it means for the operation of a semiconductor diode.
2. Did the diode operate the same way in Steps 3 through 5 as it did in Step 6?
3. In Steps 3 through 5 the diode was "Forward Biased", while in Step 6 it was "Reverse Biased". Based on your data, what do you think these terms mean?
4. What use might we have for diodes in the real world?

Sample Data Table

Diode Type: _____

Forward Bias

Reverse Bias

Table 9.1

R (Ω)	V_{AB} (V)	V_{BC} (V)	I (mA)	R (Ω)	V_{AB} (V)	V_{BC} (V)	I (mA)

Extensions

1. If your instructor has a zener diode, carry out the same investigations that you did above with it replacing the 1N-4007 diode. What differences are there between basic diodes and zener diodes?
2. Use an LED (light emitting diode) to carry out the same investigations. What differences are there between basic diodes and LEDs?

Experiment 10: Transistors

Equipment Needed

- AC/DC Electronics Lab Board
 - Resistors: 1 k Ω and 100 Ω
 - 2N3904 Transistor (NPN)
 - Wire Leads
- D-cell Batteries (x2)
- Digital Multimeter (DMM)
- *Optional:* Additional Digital Multimeter

Purpose

The purpose of this lab will be to experimentally determine some of the operating characteristics of a transistor.

Procedure

1. Connect the circuit shown in Figure 10.1a using the 2N3904 Transistor you've been given. Resistor $R_1 = 1 \text{ k}\Omega$ and resistor $R_2 = 100 \Omega$. Use Figure 10.1b as a reference along with Figure 10.1a as you record your data. Note the leads on the transistor, as marked next to the socket in the drawing.

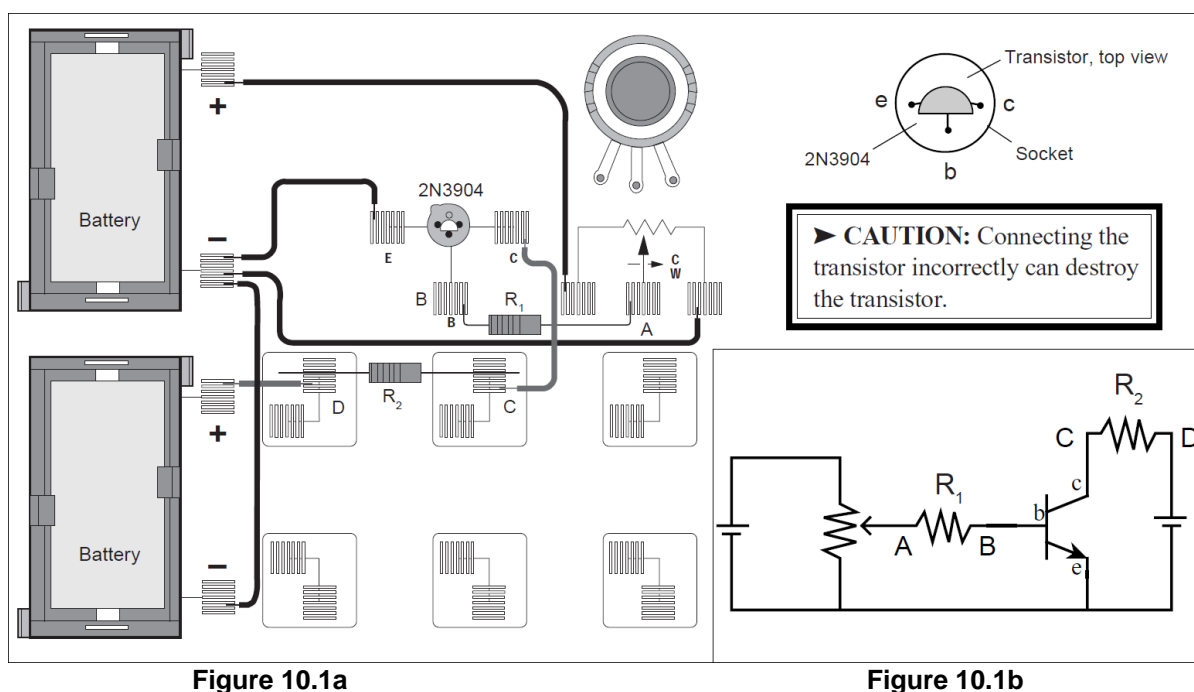


Figure 10.1a

Figure 10.1b

2. Adjust the potentiometer carefully until the reading between points **A** and **B** is approximately 0.002 volts (2.0 mV). Now read the voltage between points **C** and **D**. Record these readings in a table like Table 10.1. Note that V_{AB} divided by R_1 gives the current flowing to the base of the transistor, while V_{CD} divided by R_2 gives the current flowing to the collector part of the circuit.



NOTE: Make sure to measure V_{CD} from **D** to **C** to prevent the multimeter from reading the current as negative.

3. Adjust the potentiometer to give V_{AB} the following readings, each time reading and recording the corresponding V_{CD} in your table: 0.000, 0.005, 0.010, 0.015, 0.020, 0.025, 0.030, 0.035, 0.040, 0.045, 0.050, 0.055, 0.060, 0.080, 0.100, 0.150, 0.200, and 0.250 volts.

Analysis

- For each of your sets of readings, calculate:

$$I_B = V_{AB} / R_1 \text{ and } I_C = V_{CD} / R_2$$

Record all of your current readings in mA.

- Plot a graph of I_C (y-axis) vs. I_B (x-axis). If you find an area or areas where you need more points to fill out any curves or sudden changes, return to Step 2 and make the appropriate measurements.

Discussion

- What is the general shape of the graph? Is there a straight-line region? If so, does it go through the origin? Why or why not? Relate the behavior of the transistor at the beginning of the graph to the behavior of the diode used in Experiment 9.
- What does the leveling off of the graph indicate? Electronics experts refer to the transistor as being "saturated". How would you describe saturation based on your experiment?
- Find the slope of the straight-line region of the graph. This ratio (I_C / I_B) is referred to as the **current amplification** of the transistor. It describes how many times greater the changes in the collector current are than the changes in the base current. What is the current amplification of your transistor?

Sample Data Table

Transistor Type: _____

R_1 (Ω)	V_{AB} (V)	I_B (mA)	R_2 (Ω)	V_{CD} (V)	I_C (mA)

Extensions

- What effect would changing the resistance in the collector circuit (R_2) make? Try changing the value to 300 Ω or 560 Ω . Does the graph have the same shape? Is the current amplification the same as before? How does the amplification depend on R_2 ?
- Obtain a different transistor and repeat the measurements you made in Steps 2 and 3. If it is a PNP transistor, you will need to reverse the wires coming from the D-cells, as the emitter needs to be positive instead of negative, and the collector will be negative. What effect does this have on your results?

Experiment 11: Ohm's Law II

Equipment Needed

- AC/DC Electronics Lab Board
 - 10 Ω Resistor
 - 3 V light bulb
 - Wire leads
- Computer with PASCO Capstone
- 850 Universal Interface (UI-5000) **OR** 550 Universal Interface (UI-5001)
- 2 banana plug patch cords (such as SE-9750)

Purpose

The purpose of this experiment is to investigate the relationship between current and voltage in Ohmic and non-Ohmic materials.

Theory

Ohm discovered that when the voltage across a resistor changes, the current through the resistor also changes. He expressed this relationship as $I = V/R$, meaning current is directly proportional to voltage and inversely proportional to resistance. In other words, as the voltage increases, so does the current; the proportionality constant is the value of the resistance. The current is **inversely** proportional to the resistance: as the resistance increases, the current decreases.

If the voltage across an "Ohmic" resistor (that is, a resistor with a constant resistance) is increased, the graph of voltage versus current shows a straight line. The slope of the line is the value of the resistance. However, if the resistance **changes** (that is, if the resistor is "non-Ohmic"), the graph of voltage versus current will not be a straight line, but rather a curve with a changing slope.

The resistance of an object is partially dependent on its temperature. For a light bulb, the resistance of the filament will change as it heats up and cools down. At high AC frequencies, the filament does not have time to cool down, so it remains at a nearly constant temperature and the resistance stays relatively constant. However, at low AC frequencies (such as those less than one Hertz), the filament has time to change temperature. Because of this, the resistance of the filament changes dramatically, resulting in a measurable change in current through the filament.

In the first part of this activity, you will investigate a 10 Ω resistor. In the second part, you will investigate the filament of a small light bulb.

Procedure

Part A: Ten Ohm Resistor

Computer Setup

1. Connect your 850 or 550 Universal Interface to your computer via the attached USB cable. Turn on the interface.
2. Open PASCO Capstone and check **Hardware Setup** to ensure that the interface has connected automatically.
3. In **Hardware Setup**, enable monitoring of the output voltage from the interface by clicking the yellow circle on the "Output" port you will be using and selecting "Output Voltage-Current Sensor" (for 850 Interface) **OR** "Output Voltage Sensor" (for 550 Interface) from the menu.
4. Set up the Signal Generator to output a triangle wave with a frequency of **60 Hz** and an amplitude of **3 V**. Be sure to check the "Auto" box to make the program automatically start outputting the signal when you begin recording data. When finished, your settings should match those shown in Figure 11.1.



NOTE: For instructions on adjusting the settings on the Signal Generator, or questions about any other aspect of Capstone in this or subsequent labs, **consult the PASCO Capstone online help.**

5. Set up a **Graph** display, with Output Voltage on the y-axis, Output Current on the x-axis, and a sample rate of 1 kHz.

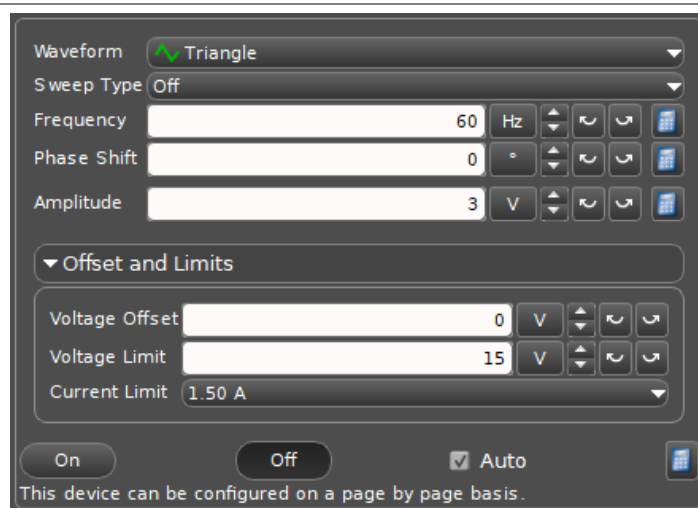


Figure 11.1

Equipment Setup

1. Place a $10\ \Omega$ resistor in the pair of component springs nearest to the banana jacks at the lower right corner of the AC/DC Electronics Lab Board.
2. Connect banana plug patch cords from the Output ports of the 850 or 550 Universal Interface to the banana jacks on the AC/DC Electronics Lab Board.

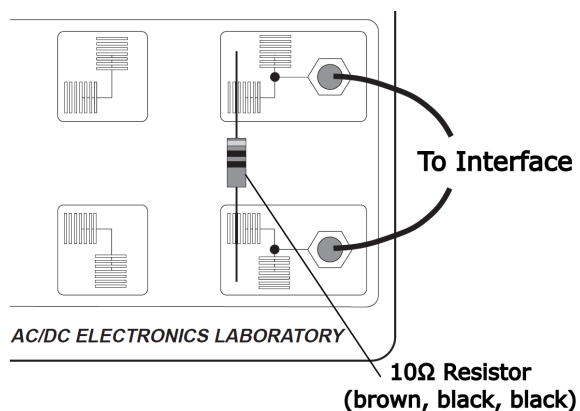



Figure 11.2

Data Recording - Resistor ($10\ \Omega$)

1. When you are ready, begin data recording. Observe the data as it is captured.
2. After a few seconds, stop data recording.
3. Use the **Scale to Fit**  tool to adjust the x-axis and y-axis to best fit your data.

Analysis

1. Using the Capstone tools, create a best fit line for the captured data. Measure the slope of this line to obtain the slope of the data; record this value below.

Slope ($10\ \Omega$) = _____ Volts/Amps

2. *OPTIONAL:* Replace the $10\ \Omega$ resistor with a $100\ \Omega$ resistor and repeat the Data Recording steps. Record the slope of this graph as well.

Part B: Light Bulb Filament

Computer Setup

For this portion of the experiment, you will start from the setup you worked with in Part A, making any necessary adjustments from there.

1. Return to the Signal Generator and change the frequency of the output to **0.3 Hz** and the amplitude to **2.5 V**.
2. In the graph, change the sample rate to 50 Hz.
3. Create a Start condition such that the program automatically begins recording data after 0.1 seconds.

Equipment Setup

1. Remove the resistor from the component springs on the AC/DC Electronics Lab Board.
2. Use two of the 10" wire leads to connect the component springs near the banana jacks to the component springs above and below the 3 volt light bulb labeled "C", as shown in Figure 11.3 below.

Data Recording - Light Bulb Filament

1. Start data recording when you are ready. Observe the graph as data is collected.
2. Wait several seconds, then stop data recording.

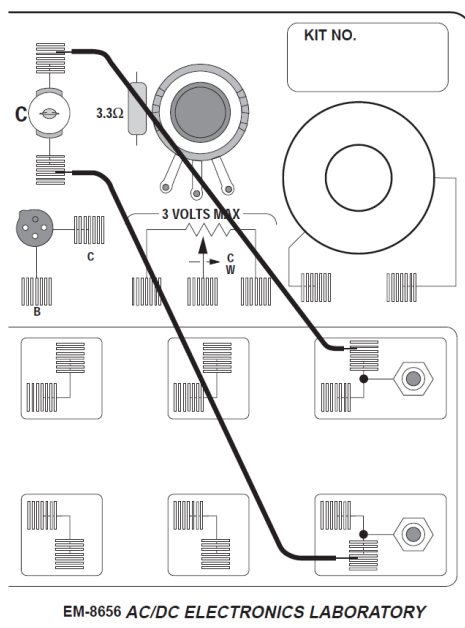


Figure 11.3

Discussion

1. Compare the slope you measured for the $10\ \Omega$ resistor (and, if applicable, the $100\ \Omega$ resistor) to the printed value of resistance. How close is the slope to this value?
2. Why does the light bulb's data change its slope over time?
3. Does the resistor have a constant resistance? Does the light bulb? Why or why not in each case?
4. The slope of the graph for the light bulb is not symmetrical, following a different path when increasing than when decreasing. Why do you think the slope of the data is different when the filament is heating up compared to the slope when the filament is cooling down?

Experiment 12: RC Circuit

Equipment Needed

- Computer with PASCO Capstone
- 850 Universal Interface (UI-5000) **OR** 550 Universal Interface (UI-5001)
- Voltage Sensor, shrouded (UI-5110) or unshrouded (UI-5100)
- AC/DC Electronics Lab Board
 - 100 Ω resistor
 - 330 μF capacitor
- 2 banana plug patch cords (such as SE-9750)
- *Optional*: LRC (inductance-resistance-capacitance) meter

Purpose

The purpose of this experiment is to investigate how the voltage across a capacitor varies as it charges, and to find the capacitive time constant.

Theory

When an uncharged capacitor is connected across a DC voltage source, the rate at which it charges up decreases as time passes. At first, the capacitor is easy to charge because there is very little charge on the plates. However, as charge accumulates on the plates, the voltage source must "do more work" to move additional charges onto the plates because the plates already have charge of the same sign on them. As a result, the capacitor charges exponentially, quickly at the beginning and more slowly as the capacitor becomes fully charged.

The charge on the plates at any time is given by:

$$q = q_0(1 - e^{-t/\tau})$$

where q_0 is the maximum charge on the plates and τ is the capacitive time constant; more specifically, $\tau = RC$, where R is resistance and C is capacitance.



NOTE: The stated value of a capacitor may vary by as much as $\pm 20\%$ from the actual value.

Taking the extreme limits, notice that when $t = 0$, $q = 0$ as well, meaning there is no initial charge on the plates. Also notice that as t goes to infinity, q goes to q_0 , meaning it takes an infinite amount of time to *completely* charge the capacitor.

The time it takes to charge the capacitor to half full is called the **half-life** and is related to the time constant as seen below:

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

In this experiment, the charge on the capacitor will be measured indirectly by measuring the voltage across the capacitor, since these two values are proportional to each other ($q = CV$).

Procedure

Computer Setup

1. Connect the 850 or 550 Universal Interface to the computer via the attached USB cable. Turn on the interface.
2. Open PASCO Capstone and check **Hardware Setup** to ensure that the interface has connected automatically.
3. Connect the Voltage Sensor to Analog Channel A of the Universal Interface. Check **Hardware Setup** to ensure it has automatically connected. The system should automatically recognize it as a Voltage Sensor; if it does not, select "Voltage Sensor" from the list of sensor options for the channel.
4. Set up the Signal Generator to output a square wave with a frequency of **0.40 Hz** and an amplitude of **4 V**. Be sure to check the "Auto" box to make the program automatically start outputting the signal when you begin recording data.
5. Set up a **Graph** display, with Voltage on the y-axis, time on the x-axis, and a sample rate of 1 kHz.

- Set up a stop condition so that the program automatically stops data recording after 4 seconds.

Equipment Setup

- Place a 100 Ω resistor (brown, black, brown) in the pair of upper component springs nearest to the *top* banana jack at the lower right corner of the AC/DC Electronics Lab Board.
- Connect a 330 microfarad (μF) capacitor between the component spring on the left end of the 100 Ω resistor and the component spring closest to the *bottom* banana jack.
- Attach alligator clips to the Voltage Sensor banana plugs. Connect these alligator clips to the wires at both ends of the 330 μF capacitor.
- Connect banana plug patch cords from the Output ports of the Universal Interface to the banana jacks on the AC/DC Electronics Lab Board.

Your completed circuit should match the diagram in Figure 12.1.

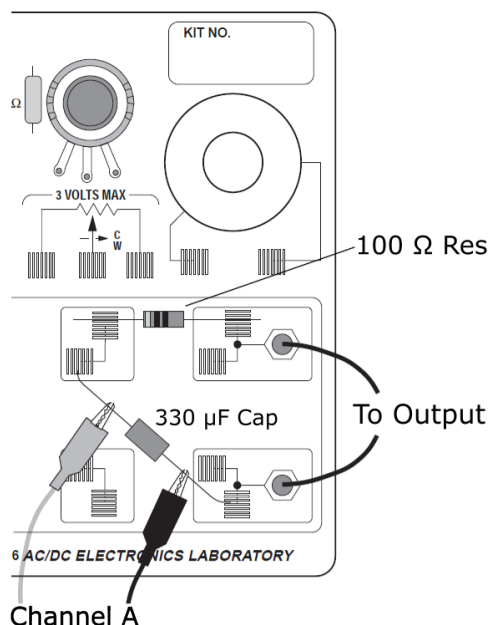


Figure 12.1

Data Recording

- When you are ready, begin recording. Observe the data as it is collected.
- After 4 seconds, the program will automatically stop collecting data.

Analysis

- Choose a section of the graph where the voltage is increasing from 0 to 4 V. Identify the time at which the voltage crosses the x-axis, which we will call the "beginning time", and the time at which it reaches 2 V; record both of these times in the blanks below.
- Find the difference between the two times; record it as $t_{1/2}$, the time to the "half-max".

Beginning time = _____; Time to 2.0 V = _____; $t_{1/2}$ = _____



TIP: PASCO Capstone's **Delta** tool can be useful in determining these values.

- Use the equation $t_{1/2} = \tau \ln 2$, or $t_{1/2} = (0.693)RC$, to calculate the capacitance (C) of the capacitor.

Capacitance = _____ F

- If a capacitance meter is available, use it to measure the capacitance of the capacitor. Using the Percent Difference method, compare the measured value to the experimental value. If you do not have a capacitance meter, use the Percent Difference Method to compare the stated value (330 μF) to the experimental value.

Discussion

1. The time to half-maximum voltage is how long it takes the capacitor to charge halfway. Based on your data, how long does it take for the capacitor to charge to 75% of its maximum?
2. After four "half-lives" ($t_{1/2}$), to what percentage of the maximum charge is the capacitor charged?
3. What is the maximum charge for the capacitor in this experiment?
4. What are some factors that could account for the percent difference between the stated and experimental values?

Experiment 13: LR Circuit

Equipment Required

- Computer with PASCO Capstone
- 850 Universal Interface (UI-5000) **OR** 550 Universal Interface (UI-5001)
- 2 Voltage Sensors, shrouded (UI-5110) or unshrouded (UI-5100)
- AC/DC Electronics Lab Board
 - Inductor coil and core
 - 10 Ω resistor
 - Wire leads
- Multimeter
- 2 banana plug patch cords (such as SE-9750)
- *Optional:* LRC meter

Purpose

This experiment displays the voltages across the inductor and resistor of 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 eventually be established:

$$I_{\max} = \frac{V_0}{R}$$

where V_0 is the applied voltage and R is the **total** resistance in the circuit. However, 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:

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

where L is the inductance and $\tau = L/R$ is the **inductive time constant**, a quantity related to the rate at which the current is 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 as follows:

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

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

$$V_R = V_0(1 - e^{-\frac{t}{\tau}})$$

The voltage across an inductor is given by the inductance times dI/dt , the derivative of current with respect to time. Therefore, the voltage across the inductor starts at its maximum and then decreases exponentially:

$$V_L = L \left(\frac{dI}{dt} \right) = V_0 e^{-\frac{t}{\tau}}$$

After a time $t \gg \tau$, a steady-state current I_{\max} is established; at this point, the voltage across the resistor is equal to the applied voltage, V_0 , and the voltage across the inductor is zero. If, after this maximum current is established, the voltage source is abruptly turned off, the current will then decrease exponentially to zero while the voltage across the resistor does the same. The inductor will again produce a back-emf, which will also decrease exponentially to zero over time.

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:

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


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

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

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

Computer Setup

1. Connect the 850 or 550 Universal Interface to the computer via the attached USB cable. Turn on the interface.
2. Open PASCO Capstone and check **Hardware Setup** to ensure that the interface has connected automatically.
3. Connect the Voltage Sensors to Analog Channels A and B of the Universal Interface. Check **Hardware Setup** to ensure they have automatically connected. The system should automatically recognize them as Voltage Sensors; if it does not, select "Voltage Sensor" from the list of sensor options for each channel.
4. Enable monitoring of the output voltage from the interface by clicking the yellow circle on the "Output" port you will be using. From the menu, select "Output Voltage-Current Sensor" (for 850 Interface) OR "Output Voltage Sensor" (for 550 Interface).
5. Set up the Signal Generator to output a *positive-only* square wave with a frequency of **50 Hz** and an amplitude of **3 V**. Be sure to check the "Auto" box to make the program automatically start outputting the signal when you begin recording data.
6. Set up a **Graph** display, with Voltage from the Channel A sensor on the y-axis, time on the x-axis, and a sample rate of 20 kHz.
7. Use the **New Plot Area**  tool to create two additional **Graph** displays using the same x-axis; set the y-axis on the second graph to display Voltage from the Channel B sensor, and set the y-axis on the third graph to display the Output Voltage.
8. Set up start and stop conditions so that the program automatically starts recording data when the Output Voltage rises above 0.01 and stops after 0.02 seconds.

Equipment Setup

See Figure 13.1 for guidelines on connecting the circuit.

1. Connect a 5 inch wire lead between a component spring next to the top banana jack and the component spring at the right 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 the 10 Ω resistor is connected and the component spring nearest to the bottom banana jack at the lower right corner of the board.
4. Put alligator clips on the banana plugs of both Voltage Sensors. Connect the alligator clips of the Channel A Voltage Sensor to the component springs at both sides of the inductor coil, with the red positive (+) lead on the right and the black negative (-) lead on the left.
5. Connect the alligator clips of the Channel B Voltage Sensor to the wires at both ends of the 10 Ω resistor.
6. Connect banana plug patch cords from the output of the Universal Interface to the banana jacks on the AC/DC Electronics Lab Board.

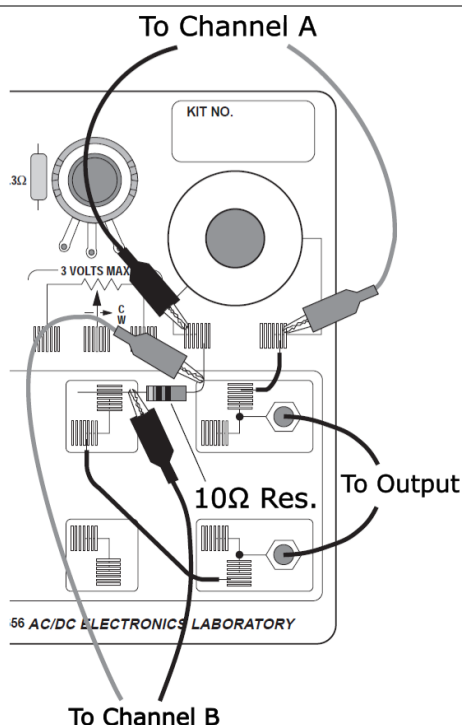



Figure 13.1

Data Recording

1. When you are ready, start recording. The program should automatically stop after 0.02 seconds.
2. Scale the x-axis and y-axis to clearly display your data.

Analysis

The voltage across the resistor is in phase with the current. The voltage is also proportional to the current (that is, $V = IR$). Therefore, we can indirectly study the behavior of the current by studying the behavior of the voltage across the resistor, as measured on Channel B.

1. Using a multimeter, measure the resistances across the resistor and across the inductor. Record these values in the Data Table below.
2. Using the Coordinates Tool , identify the point where the voltage across the resistor (as recorded by Channel B) is at its maximum. Record the peak voltage (y-coordinate for this point) and the time at which it occurs (x-coordinate for this point) in the Data Table.
3. Determine the voltage that is half of the peak for V_R , which we refer to as the *half-max voltage*, as well as the time at which the resistor experiences this voltage. Record these values in the Data Table.
4. Subtract the initial time from the time at which the half-max voltage occurs to get the time for the voltage to reach half-max; record this time in the Data Table.
5. Using the half-max voltage you measured in Step 4 and the fact that $t_{1/2} = \tau \ln 2$, find the inductive time constant τ for this circuit.
6. 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 H), calculate the *theoretical* value of $\tau = L/R$. (If you have an LCR meter, you can use this to experimentally measure the inductance of the coil instead.)

Data Table

Inductor Resistance	Ω
Resistor Resistance	Ω
Inductance	H
Peak V_R	V
Time at Peak V_R	sec
Time at Half-Max Voltage	sec
Time to reach Half-Max	sec
Experimental \mathcal{T}	
Theoretical \mathcal{T} (L/R)	

Discussion

1. How does the inductive time constant you found experimentally compare to the theoretical value given by $\mathcal{T} = L/R$? (Remember: R is the **total** resistance of the circuit and therefore must include the resistance of the coil as well as that of the resistor.)
2. Does Kirchhoff's Loop Rule hold at all times? Use the graphs to check it for at least three different points in time. Does the sum of the voltages across the resistor and the inductor ($V_R + V_L$) equal the source voltage at any given time?
3. You may notice that, in your data, the values that V_L and V_R go to are different than what we would expect from our equations (0 and V_0 respectively). What factor do you think might cause this?

Extension

Place the iron core in the coil and repeat the Data Recording section. From the relationship $\mathcal{T} = L/R$ and $t_{1/2} = \mathcal{T} \ln(2)$, find the new value of the inductor.

Experiment 14: LRC Circuit

Equipment Needed

- Computer with PASCO Capstone
- 850 Universal Interface (UI-5000) **OR** 550 Universal Interface (UI-5001)
- Voltage Sensor, shrouded (UI-5110) or unshrouded (UI-5100)
- AC/DC Electronics Lab Board
 - Inductor coil and core
 - 10 Ω resistor
 - 100 μF capacitor
 - Wire lead(s)
- LCR (inductance-capacitance-resistance) meter (SE-8792A)
- 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_0) in a series LRC circuit is dependent on the amplitude of the applied voltage (V_0) and the impedance (Z).

$$I_0 = \frac{V_0}{Z}$$

Since the impedance depends on frequency, the current also varies with frequency. The impedance is given by:

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

where $X_L = \omega L$ is inductive reactance, $X_C = 1/(\omega C)$ is the capacitive reactance, R is resistance, and $\omega = 2\pi\nu$ is the angular frequency (with ν being the linear frequency). The current will be at its maximum when the circuit is driven at the **resonant frequency**, which is defined as:

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

We can show that, at the resonant frequency, $X_L = X_C$, and thus the impedance Z is equal to R . Therefore, at resonance, the impedance is the lowest value possible and the current will be the largest possible.

In this experiment, the ratio of V_R (the voltage across the resistor) to the output voltage will be plotted against the frequency. Since this ratio is maximum at the resonant frequency and less for higher and lower frequencies, the graph should peak at the resonant frequency.

Procedure

Computer Setup

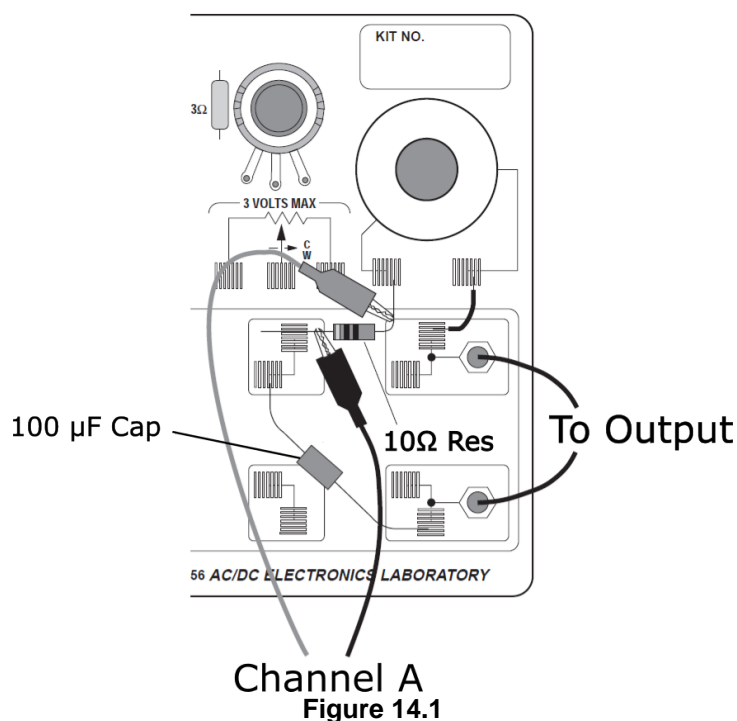
1. Connect the 850 or 550 Universal Interface to the computer via the attached USB cable. Turn on the interface.
2. Open PASCO Capstone and check **Hardware Setup** to ensure that the interface has connected automatically.
3. Connect the Voltage Sensor to Analog Channel A of the Universal Interface. Check **Hardware Setup** to ensure it has automatically connected. The system should automatically recognize it as a Voltage Sensor; if it does not, select "Voltage Sensor" from the list of sensor options for the channel.

4. Enable monitoring of the output voltage from the interface by clicking the yellow circle on the "Output" port you will be using. From the menu, select "Output Voltage-Current Sensor" (for 850 Interface) OR "Output Voltage Sensor" (for 550 Interface).
5. Set up the Signal Generator to output a sine wave with a frequency of **10 Hz** and an amplitude of **3 V**. Be sure to check the "Auto" box to make the program automatically start outputting the signal when you begin recording data.
6. Set up a **Scope** display in **Fast Monitor Mode**, with Voltage and Output Voltage on the y-axis, time on the x-axis, and a sample rate of 10 kHz.

Equipment Setup

See Figure 14.1 for a guide to assembling the components of this lab.

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 the 10 Ω resistor is connected and the component spring nearest to the bottom banana jack at the lower right corner of the 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 as shown in Figure 14.1.
5. Place the iron core into the inductor coil.
6. Connect banana plug patch cords from the output of the Universal Interface to the banana jacks on the AC/DC Electronics Lab Board.



Data Recording

1. When you are ready, press **Monitor** to begin monitoring data.
2. After a few seconds, press **Stop** to pause data observation.
3. Using the **Coordinates** tool, determine the maximum values of the Output Voltage and the voltage across the resistor. Record these values in a table (on a separate page) like the one in Table 14.1.
4. In the Signal Generator tool, increase the frequency by 10 Hz.

- Repeat Steps 1 through 4, recording V_0 and V_R at each stage, until you reach 250 Hz. Increase the sample rate as you go if needed.
- Use the data you have collected to estimate the resonant frequency, where voltage across the resistor reaches a maximum; enter this value into the Frequency box in the Signal Generator tool.
- Change the Scope display to measure Output Voltage on the x-axis and the voltage across the resistor on the y-axis.
- Click **Monitor** and observe the pattern produced to see whether or not the two voltages are in phase with each other. If the voltages are in phase, the Scope display will show a diagonal line; if they are not, the Scope display will show an oval.
- While the Scope is still running, adjust the frequency of the Signal Generator until you reach the resonant frequency, at which point the voltages will be in phase. Once you have verified this value, record this frequency in Table 14.2.
- Using the LCR meter, experimentally measure the capacitance of the 100 μF capacitor and the inductance of the inductor. Record these values in Table 14.2.

Analysis

- Create a graph of the ratio of resistor voltage to output voltage (V_R/V_0) versus the linear frequency.



NOTE: The frequency in the Signal Generator tool is the linear frequency.

- Using the resonant frequency found from the Scope display, calculate the resonant *angular* frequency using the equation below and record the value in Table 14.2.

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

- Calculate the *theoretical* resonant angular frequency using the following equation:

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

Data Tables

Table 14.1

Frequency (Hz)	V_0 (V)	V_R (V)
10		
20		
30		
40		
50		
60		

Table 14.2

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

Discussion

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

$$\text{Percent difference} = \frac{|\text{theoretical} - \text{actual}|}{\text{theoretical}} * 100\%$$

2. Is the plot of V_R/V_0 versus frequency symmetrical about the resonant frequency? Explain.
3. At resonance, the reactances of the inductor and capacitor cancel each other so that the impedance (Z) is equal to just the resistance (R). On a new Scope display, measure the amplitude of the current (I_{\max}) at the resonant frequency. Using this value, calculate the total resistance of the circuit using the equation $R = V_0/I_{\max}$. Is this resistance equal to $10\ \Omega$? If not, why not?

Extension

1. Determine whether the resonant frequency depends on the resistance. To do this, set the Signal Generator to the resonant frequency and then replace the $10\ \Omega$ resistor with a $100\ \Omega$ resistor. Does the resonant frequency increase, decrease, or stay the same?
2. Use the Voltage Sensor to measure the peak voltage across each of the components in the circuit individually. The sum of these peak voltages do not equal the applied peak voltage. Why not? Draw a phasor diagram to explain your answer.

Experiment 15: Diode Lab - Part One

Equipment Needed

- Computer with PASCO Capstone
- 850 Universal Interface (UI-5000) **OR** 550 Universal Interface (UI-5001)
- 2 Voltage Sensors, shrouded (UI-5110) or unshrouded (UI-5100)
- AC/DC Electronics Lab Board
 - 1N-4007 diode
 - Light-emitting diodes (LEDs): red, yellow, green, bi-color
 - 1 kΩ resistor
 - Wire leads
- 2 banana plug patch cords (such as SE-9750)

Purpose

In this experiment, you will investigate the properties of various types of diodes.

Theory

A diode (or p - n junction rectifier) is an electronic device which only allows current to flow in one direction through it once a certain forward voltage is established across it. If the voltage is too low, no current will flow through the diode. If the voltage is reversed, no current (except for a very small reverse current) will flow through the diode either.

A light-emitting diode emits light as current passes through the diode in the forward direction. A red-green diode, also known as a bi-color LED, is actually two diodes connected together antiparallel so that the red diode allows current to flow in one direction and the green diode allows current to flow in the opposite direction. Thus, if DC is applied to the red-green diode, it will glow only red or only green depending on the polarity of the DC voltage. However, if AC is applied to the red-green diode, the diode will repeatedly switch between glowing red and green as the current repeatedly changes direction.

A bi-color LED is an example of a **Zener diode**. A Zener diode allows current to flow in one direction when the forward voltage is large enough, and it allows current to flow in the opposite direction when the *reverse* voltage- also called the "breakdown" voltage- is large enough (usually a few volts).

Overview

There are four sections to the Diode Lab. You will complete the first two sections in Part One (this experiment) and complete Sections 3 and 4 in Part Two (the next experiment).

Section	Focus
1	Investigate the general properties of a diode
2	Investigate LEDs and Zener diodes
3	Rectify a sine wave
4	Set up the circuitry for a basic power supply

Section 1 - Diode Properties

Computer Setup

1. Connect the 850 or 550 Universal Interface to the computer via the attached USB cable. Turn on the interface.
2. Open PASCO Capstone and check **Hardware Setup** to ensure that the interface has connected automatically.
3. Connect the Voltage Sensors to Analog Channels A and B of the Universal Interface. Check **Hardware Setup** to ensure they have automatically connected. The system should automatically recognize them as Voltage Sensors; if it does not, select "Voltage Sensor" from the list of sensor options for each channel.
4. Enable monitoring of the output voltage from the interface by clicking the yellow circle on the "Output" port you will be using. From the menu, select "Output Voltage-Current Sensor" (for 850 Interface) OR "Output Voltage Sensor" (for 550 Interface).
5. In the Calculator tool, create a new variable labeled "Current" which is equal to the voltage from Channel B and is measured in milliamps (mA).




NOTE: The measurement is defined this way because the Channel B Voltage Sensor will measure the voltage across the 1 k Ω resistor. The current through the resistor is defined by Ohm's Law as $I = V/R$, with this current being measured in amps (A). Converting from A to mA requires multiplying the numerical value of the current by 1000; therefore, since the voltage across the resistor is being divided by 1000 Ω and then multiplied by 1000, the numerical values of the voltage across the resistor in ohms and the current through the resistor in milliamps will be approximately equal.

6. Set up the Signal Generator to output a positive ramp wave with a frequency of **2 Hz** and an amplitude of **6 V**. Be sure to check the "Auto" box to make the program automatically start outputting the signal when you begin recording data.
7. Set up a **Graph** display with the defined Current variable on the y-axis, the voltage from Channel A (in other words, voltage across the diode) on the x-axis, and a sample rate of 500 Hz.
8. Set up start and stop conditions so that the program automatically starts recording data when the Output Voltage is above -5.9 V and stops after 0.49 seconds.


Equipment Setup

1. Connect the 1N-4007 diode between the component spring next to the top banana jack and the component spring to the left of the banana jack. Arrange the diode so the differently-colored band is at the *left side*.
2. Connect the 1 k Ω resistor (brown, black, red) between the component spring next to the bottom banana jack and the component spring to the left of the bottom banana jack.
3. Connect a 5 inch wire lead between the component spring at the left end of the diode and the component spring at the left end of the 1 k Ω resistor.
4. Put alligator clips on the banana plugs of each Voltage Sensor. Connect the alligator clips on the Channel A Voltage Sensor to the wires at both ends of the diode, as shown in Figure 15.1.
5. Connect the alligator clips on the Channel B Voltage Sensor to the wires at both ends of the 1 k Ω resistor, as shown in Figure 15.1.
6. Connect banana plug patch cords from the Universal Interface to the banana jacks on the AC/DC Electronics Lab Board.

Data Recording: 1N-4007 Diode and 1 k Ω Resistor

1. When you are ready, start data recording. Capstone will automatically stop data collection after about half a second has passed.
2. Use the **Scale to Fit**  tool to view your collected data.

Analysis: 1N-4007 Diode and 1 k Ω Resistor

1. Using the Coordinates Tool , identify the point where the current reaches 2 milliamps.
2. Record the value of voltage across the diode at which the current reaches 2 milliamps in Table 15.1.

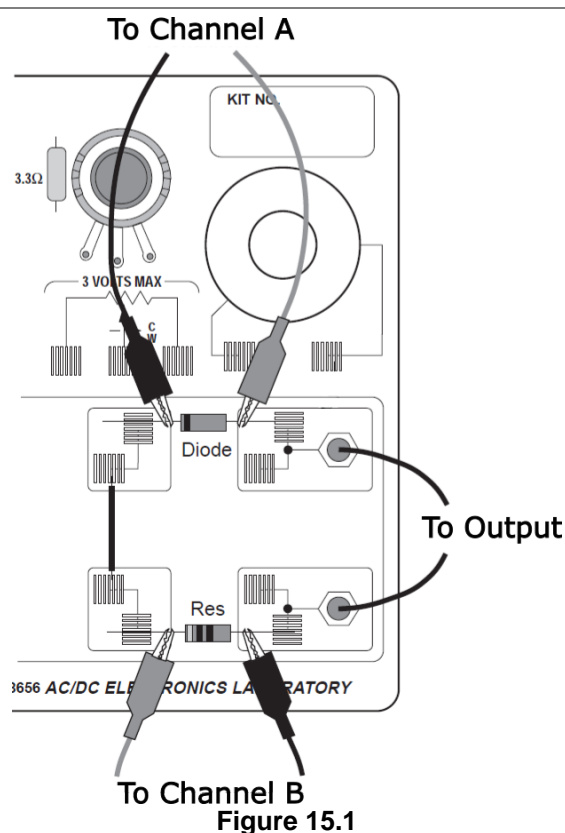


Figure 15.1

Section 2 - Light-Emitting Diodes

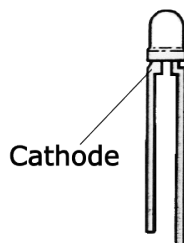
Computer Setup

The setup for this section is identical to that of Section 1.

Equipment Setup

Begin from the equipment setup you used in Section 1.

1. Prepare the red, yellow, and green LEDs by very carefully bending the wire leads so they can fit into the component springs in place of the diode used in Section 1.
2. Replace the diode from Section 1 with the red LED. Arrange this first LED so the short lead (cathode) is to the left.
 - The wire lead that is connected to the cathode of the LED is slightly shorter and has a beveled shoulder near where the wire enters the LED, as seen below.



Data Recording: Light-Emitting Diodes

1. When you are ready, begin recording data. The program should automatically stop collecting data after half a second.
2. Replace the red LED with the yellow LED. Repeat Step 1.
3. Replace the yellow LED with the green LED. Repeat Step 1.

By using the **Data Selector**  tool, you can display the data sets for all three LEDs simultaneously.

Analysis: Light-Emitting Diodes


1. In the red LED's data set, use the Coordinate Tool  to identify the point at which the current reaches 2 mA.
2. Record the voltage at which the current through the red LED reaches 2 mA in Table 15.1.
3. Repeat Steps 1 and 2 for the data sets for the yellow and green LEDs, recording the data in Table 15.1.

Table 15.1

Description	Voltage (V) when 2 mA reached
① N1-4007 Diode	
② Red LED	
③ Yellow LED	
④ Green LED	

Data Recording: Bi-Color LED

1. Replace the green LED with the *clear* (bi-color) LED.
2. Remove the starting condition from the graph, so that your data will now start collecting as soon as you press the **Record** button.
3. When you are ready, start data collection. The system will automatically stop data collection after 0.5 seconds.

Analysis: Bi-Color LED


1. Using the Coordinate Tool , identify the voltage across the diode at which the current is 2 mA. Record this voltage in Table 15.2 below.
2. Identify the voltage at which the current is -2mA. Record this voltage in Table 15.2 as well.

Table 15.2

Description	Voltage (V) when 2 mA reached	Voltage (V) when -2 mA reached
⑤ Bi-Color LED		

Discussion

1. In Section 1, what does the plot of Current versus Diode Voltage imply?
2. In Section 2, which LED has the lowest turn-on voltage? Which LED has the highest turn-on voltage?
3. In Section 2, how does the forward turn-on voltage for the bi-color LED compare to that of any of the colored LEDs? How does the reverse, "breakdown" voltage for the bi-color LED compare to the forward voltage of the colored LEDs?
4. Compare and contrast the bi-color LED with a typical "Zener" diode.

Experiment 16: Diode Lab - Part Two

Equipment Needed

- Computer with PASCO Capstone
- 850 Universal Interface (UI-5000) **OR** 550 Universal Interface (UI-5001)
- 2 Voltage Sensors, shrouded (UI-5110) or unshrouded (UI-5100)
- AC/DC Electronics Lab Board
 - 4 1N-4007 diodes
 - 1 Light-emitting diode (LED) of any single color
 - Resistors: 10 Ω , Ω , and 1 k Ω
 - 470 μ F capacitor
 - Wire leads
- 2 banana plug patch cords (such as SE-9750)

Purpose

In this experiment, you will use diodes to rectify an AC signal and to build part of the basic circuitry of a power supply.

Theory

A diode (or *p-n* junction rectifier) is an electronic device which only allows current to flow in one direction through it once a certain forward voltage is established across it. If the voltage is too low, no current will flow through the diode. If the voltage is reversed, no current (except for a very small reverse current) will flow through the diode either.

A diode can be used to provide DC current from an AC source. In other words, the diode **rectifies** the AC current.

When the rectified current is smoothed using electronic filters, the diodes make up part of a power supply.


Overview

There are several sections to the Diode Lab. You completed the first two sections in Part One (the previous experiment) and will complete Section 3 and Section 4 in Part Two (this experiment).

Section	Focus
3	Rectify a sine wave
4	Setup the circuitry for a basic power supply

Section 3 - Rectifying a Sine Wave

Computer Setup

1. Connect the 850 or 550 Universal Interface to the computer via the attached USB cable. Turn on the interface.
2. Open PASCO Capstone and check **Hardware Setup** to ensure that the interface has connected automatically.
3. Connect the Voltage Sensors to Analog Channels A and B of the Universal Interface. Check **Hardware Setup** to ensure they have automatically connected. The system should automatically recognize them as Voltage Sensors; if it does not, select "Voltage Sensor" from the list of sensor options for each channel.
4. Set up the Signal Generator to output a sine wave with a frequency of **2 Hz** and an amplitude of **6 V**. Be sure to check the "Auto" box to make the program automatically start outputting the signal when you begin recording data.
5. Set up a **Graph** display, with Voltage from the Channel A Voltage Sensor on the y-axis, time on the x-axis, and a sample rate of 200 Hz.
6. Use the **New Plot Area**  tool to create an additional **Graph** display using the same x-axis; set the y-axis on this graph to display Voltage from the Channel B Voltage Sensor.
7. Set up a stop condition so that the program automatically stops recording data after 1.5 seconds.

Equipment Setup

1. Connect the 1N-4007 diode between the component spring next to the top banana jack and the component spring to the left of the banana jack. Arrange the diode so the differently-colored band is at the *left side*.
2. Connect the 1 k Ω resistor (brown, black, red) between the component spring next to the bottom banana jack and the component spring to the left of the bottom banana jack.
3. Connect a 5 inch wire lead between the component spring at the left end of the diode and the component spring at the left end of the 1 k Ω resistor.
4. Put alligator clips on the banana plugs of each Voltage Sensor. Connect the alligator clips on the Channel A Voltage Sensor to the wires at both ends of the diode, as shown in Figure 15.1.
5. Connect the alligator clips on the Channel B Voltage Sensor to the wires at both ends of the 1 k Ω resistor, as shown in Figure 15.1.
6. Connect banana plug patch cords from the Universal Interface to the banana jacks on the Electronics Lab Board.

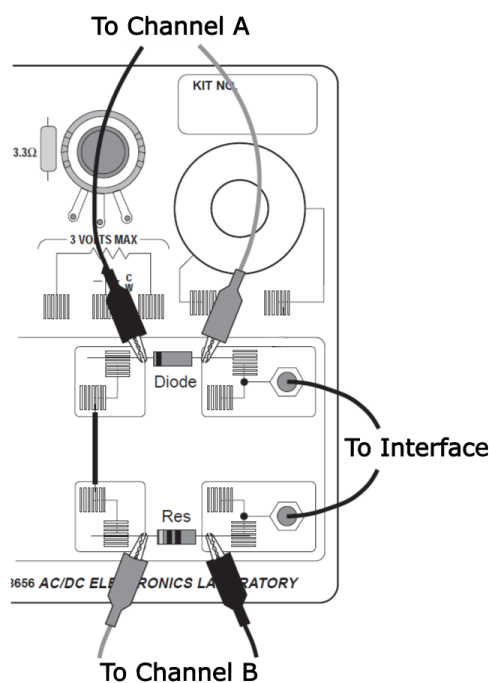



Figure 16.1

Data Recording: Rectifying a Sine Wave with a Diode

1. When you are ready, begin recording data. Capstone will automatically stop data collection after 1.5 seconds.
2. Use the **Scale to Fit**  tool to view the collected data.

Analysis: Rectifying a Sine Wave with a Diode

1. Make note of the shape and structure of the graphs by taking a screenshot or drawing a sketch of the data on a separate sheet of graph paper.

Data Recording: Rectifying a Sine Wave with an LED

1. Remove the 1N-4007 diode from the component springs. Carefully place a colored LED in the same component springs, with the short lead on the left.
2. Begin recording data. Capstone will automatically stop data collection after 1.5 seconds.

Analysis: Rectifying a Sine Wave with an LED

1. Compare and contrast the data you collected from the 1N-4007 diode with the data collected from the LED. How are they similar? What is different between them?
2. Make note of the shape and structure of the graphs by taking a screenshot or drawing a sketch of the data on a separate sheet of graph paper.

Section 4A - Power Supply, Single Diode

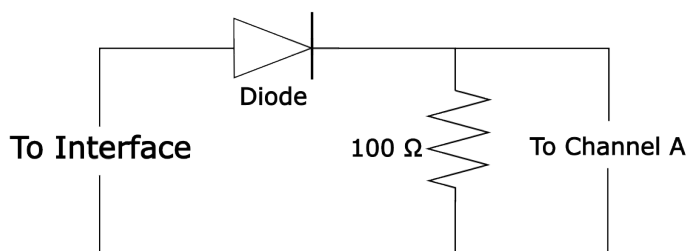
Computer Setup

1. Remove the Voltage Sensor from Analog Channel A of the Universal Interface. Capstone should automatically remove the sensor from its list of available sensors; if not, go to **Hardware Setup**, then right-click the sensor under Channel A and select "Remove Sensor".
2. Delete the data from Section 3. *Make sure you already have a record of the data before doing this step!*
3. Adjust the signal generator to output a sine wave with a frequency of 60 Hz and an amplitude of 3 V.
4. Enable monitoring of the output voltage from the interface by clicking the yellow circle on the "Output" port you will be using. From the menu, select "Output Voltage-Current Sensor" (for 850 Interface) OR "Output Voltage Sensor" (for 550 Interface).
5. Set up a new **Graph** display so that the y-axis measures both the voltage from the Voltage Sensor and the Output Voltage, the x-axis measures time, and the sample rate is 2.5 kHz (2500 Hz).
6. Set up a stop condition so that the program automatically stops recording data after 0.05 seconds.



Equipment Setup

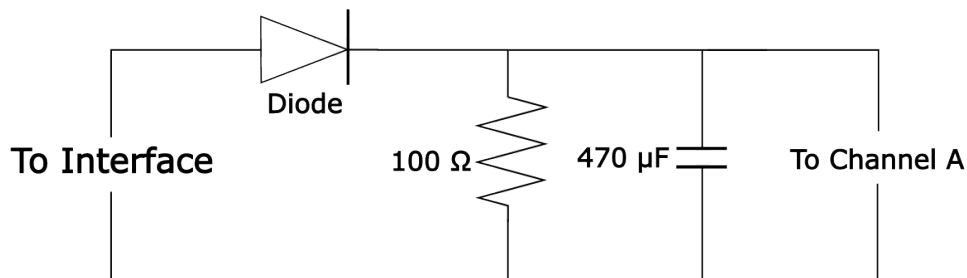
For this experiment, continue from the setup used in Section 3.


1. Replace the colored LED with the original 1N-4007 diode used in Section 3.
2. Replace the 1 k Ω resistor in the component springs near the bottom banana jack with a 100 Ω resistor. This resistor will be the "load" resistor for the circuit. The circuit you construct should resemble the diagram below.

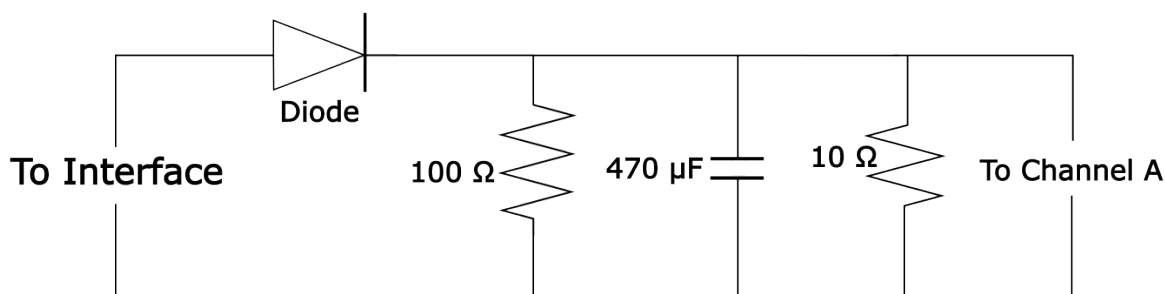



Data Recording: Power Supply, Single Diode

1. When you are ready, begin data recording. The system will automatically stop recording data after 0.05 seconds.
2. Use the **Auto Scale from Zero** option under the **Scale to Fit**  tool to view your data.
3. In the **Data Summary**  window, rename this run of data "**Rectified Voltage**".
4. Add a 470 μF capacitor in parallel to the 100 Ω resistor. Carefully bend the leads of the capacitor so they can fit in the same component springs as the resistor; place the shorter wire lead of the capacitor in the right hand component spring. The capacitor will act as a "filter".




5. Repeat Steps 1 and 2 with the capacitor in place.
6. In the **Data Summary**  window, rename this run of data "**Filtered Voltage**".
7. Add a 10 Ω resistor in parallel with the 100 Ω and the 470 μF capacitor. The 10 Ω resistor simulates a motor or small light bulb.



8. Repeat Steps 1 and 2 with the 10 Ω resistor in place.
9. In the **Data Summary**  window, rename this run of data "**Load Resistor Voltage**".

Analysis: Power Supply, Single Diode

1. Remove the Output Voltage from the y-axis so that the graph now only plots the voltage from the Voltage Sensor versus time.
2. Using the **Show All Runs**  tool, set up the graph so that all three of the runs collected are displayed on the graph at the same time. Use the **Auto Scale from Zero** function again if needed.
3. Make note of the shape and structure of each of the graphs by taking a screenshot or drawing a sketch of the data on a separate sheet of graph paper.

Section 4B - Power Supply, Four Diode Bridge**Computer Setup**

The computer setup for this section is the same as the initial computer setup for Section 4A.

Equipment Setup

1. Remove all components except the banana plug patch cords from the AC/DC Electronics Lab Board.
2. Place a 1N-4007 diode between the second and third component springs to the left of the top banana jacks. Align the diode so the differently-colored (cathode) end is to the right, toward the banana jack.

3. Place a second 1N-4007 diode parallel to the first, between the second and third component springs to the left of the bottom banana jack. Align the diode so that the cathode end is to the right, toward the banana jack.
4. Place a third diode between the component spring at the right end of the top diode and the component spring at the right end of the bottom diode. Place the diode so the cathode end is toward the bottom.
5. Place a fourth diode between the component springs at the left end of the top diode and the component spring at the left end of the bottom diode. Place the diode so the cathode end is toward the bottom. The diodes now form a square; this arrangement of diodes is known as a "diode bridge".
6. Place the $100\ \Omega$ resistor diagonally between the upper left corner and lower right corner of the square of diodes.
7. Use a five inch wire lead to connect a component spring next to the top banana jack and the component spring at the *right* end of the first (top) diode.
8. Use a ten inch wire lead to connect a component spring next to the bottom banana jack and the component spring at the *left* end of the second (bottom) diode.
9. Connect the alligator clip of the red Voltage Sensor lead to the component spring at the *lower right* corner of the diode bridge. Connect the clip of the black Voltage Sensor lead to the component spring at the *upper left* corner of the diode bridge on the opposite side of the resistor from the red lead.

The circuit you construct should match that seen in Figure 16.3. A circuit diagram for the four diode bridge can be seen in Figure 16.4.

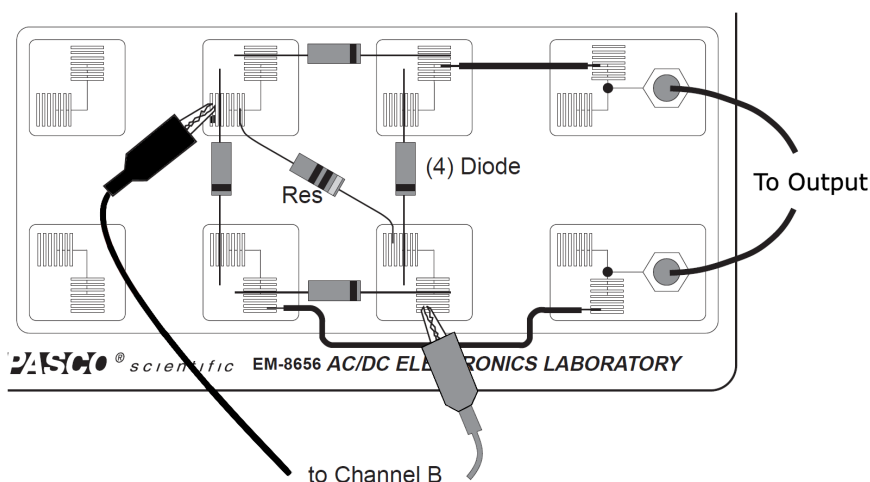


Figure 16.3

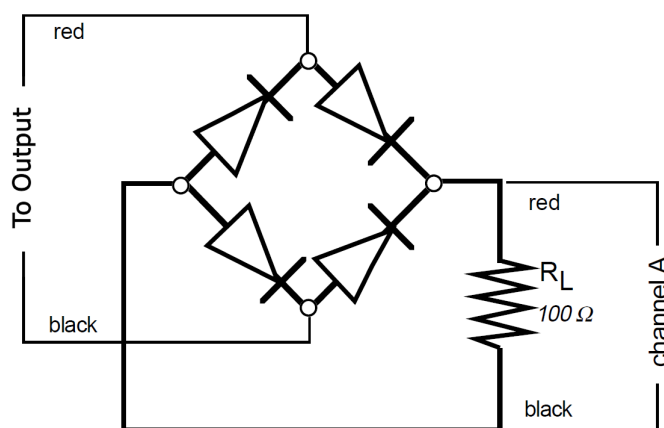







Figure 16.4

Data Recording: Power Supply, Four Diode Bridge

1. When you are ready, begin recording data. Capstone will automatically stop data collection after 0.05 seconds.
2. Use the **Auto Scale from Zero** option under the **Scale to Fit**  tool to view your data.
3. In the **Data Summary**  window, rename this run of data "**Full Rectified Voltage**".
4. Add a 470 μF capacitor in parallel to the 100 Ω resistor.
5. Repeat Steps 1 and 2 with the capacitor in place.
6. In the **Data Summary**  window, rename this run of data "**Filtered Full Rectified Voltage**".
7. Add a 10 Ω resistor in parallel with the 100 Ω and the 470 μF capacitor. The 10 Ω resistor simulates a motor or small light bulb.
8. Repeat Steps 1 and 2 with the 10 Ω resistor in place.
9. In the **Data Summary**  window, rename this run of data "**Load Resistor Voltage**".

Analysis: Power Supply, Four Diode Bridge

1. Remove the Output Voltage from the y-axis so that the graph now only plots the voltage from the Voltage Sensor versus time.
2. Using the **Show All Runs**  tool, set up the graph so that all three of the runs collected are displayed on the graph at the same time. Use the **Auto Scale from Zero** function again if needed.
3. Make note of the shape and structure of each of the graphs by taking a screenshot or drawing a sketch of the data on a separate sheet of graph paper.

Discussion

1. In Section 3, how do the plots of voltage across the diode and voltage across the resistor compare to a complete sine wave?
2. Based on your previous investigation of diodes, why do the plots of voltage across the diode and voltage across the resistor from Section 3 have the shape and size that they do?
3. In Section 3, how did the plots of voltage across the diode and voltage across the resistor change when the diode was replaced with the LED? Explain your answer.
4. In Section 4A, what happens to the plot of voltage across the 100 Ω resistor when the 470 μF capacitor is added in parallel with the resistor? Why is the capacitor considered a "filter"?
5. In Section 4A, what happens to the plot of voltage across the 100 Ω resistor when the 10 Ω resistor is added in parallel with the capacitor and the 100 Ω resistor?
6. In Section 4B, how does the plot of voltage across the 100 Ω resistor in the four diode bridge compare to the plot of voltage across the diode in Section 3?
7. In Section 4B, what happens to the plot of voltage across the 100 Ω resistor in the four diode bridge when the 470 μF capacitor is added in parallel with it? How does the shape of this plot compare to the similar "filtered" plot in Section 4A?
8. In Section 4B, what happens to the plot of voltage across the 100 Ω resistor in the four diode bridge when the 10 Ω resistor is added in parallel with the 470 μF capacitor and the 100 Ω resistor? How does the shape of this plot compare to the similar "load resistor voltage" plot in Section 4A?
9. Compare the performance of the single diode circuit to the four diode bridge. Which is better at providing a steady, constant direct current when a low resistance load is connected?

Experiment 17: Transistor Lab 1 - The NPN Transistor as a Digital Switch

Equipment Needed

- Computer with PASCO Capstone
- 850 Universal Interface (UI-5000)



NOTE: See the Tip on page 60 for advice on using a 550 Universal Interface (UI-5001) with this lab.

- Voltage Sensor, shrouded (UI-5110) or unshrouded (UI-5100)
- AC/DC Electronics Lab Board
 - 2N3904 transistor
 - Resistors: 22 k Ω and 330 Ω
 - Red light-emitting diode (LED)
 - Wire leads
- 2 banana plug patch cords (such as SE-9750)
- BNC Function Generator Output Cable, shrouded (UI-5129) or unshrouded (UI-5119)

Purpose

The purpose of this experiment is to investigate how the *npn* transistor operates as a digital switch.

Theory

The transistor is an essential ingredient of every electronic circuit, from the simplest amplifier or oscillator to the most elaborate digital computer. Integrated circuits (ICs), which have largely replaced circuits constructed from individual transistors, are actually arrays of transistors and other components built from a single wafer-thin piece or "chip" of semiconductor material.

The transistor is a semiconductor device that includes two p-n junctions in a sandwich configuration, which may be either p-n-p or, as in this activity, n-p-n. The three regions are usually called the emitter, base, and collector; Figure 17.1 shows how they are arranged in the transistor used in this experiment.

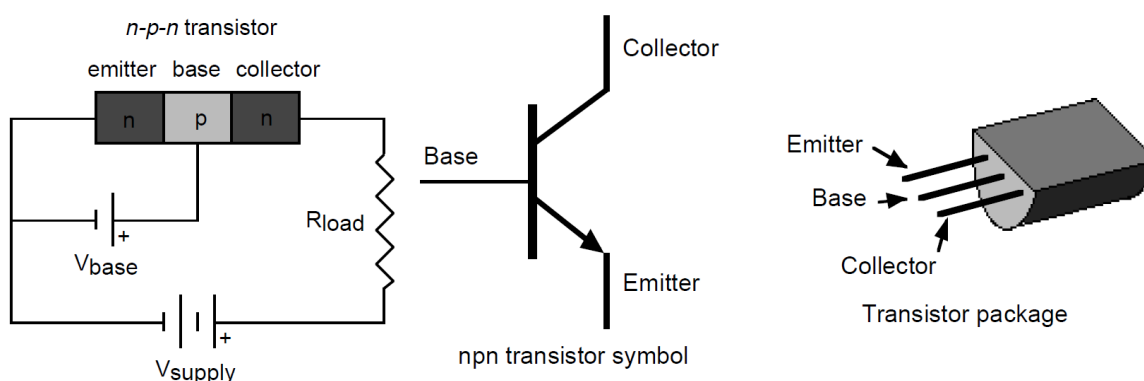


Figure 17.1

In a transistor circuit, the current through the collector "loop" is controlled by the current to the base.

The collector voltage can be considerably larger than the base voltage. Therefore, the power dissipated by the resistor may be much larger than the power supplied to the base by its voltage source. The device therefore functions as a **power amplifier** (as compared to, for example, a step-up transformer, which is a voltage amplifier but *not* a power amplifier). The output signal can have more power in it than the input signal. The extra power comes from an external source (the power

supply). A transistor circuit can amplify current or voltage. The circuit can be a constant current source or a constant voltage source.

A transistor circuit can serve as a 'digital' electric switch. In a mechanical electric switch, a small amount of power is required to 'switch on' an electrical device (such as a motor) that can deliver a large amount of power. In a 'digital' transistor circuit, a small amount of power supplied to the base is used to 'switch on' a much larger amount of power from the collector.

In broad terms, a transistor is a three-terminal device. Voltage at a transistor terminal relative to ground is indicated by a single subscript; for example, V_C is the voltage of the collector. Voltage between two terminals is indicated by a double subscript; for example, V_{BE} is the voltage difference between the base and the emitter. Finally, if the same letter is repeated, it means a power-supply voltage; V_{CC} is the positive power-supply voltage associated with the collector.

A typical *npn* transistor follows these "rules":

1. The collector must be more positive than the emitter.
2. The base-to-emitter and base-to-collector circuits behave like diodes. The base-emitter diode is normally conducting if the base is more positive than the emitter by 0.6 to 0.8 volts (the typical forward "turn on" voltage for a diode). The base-collector diode is reverse-biased.




NOTE: See Experiments 15 and 16 for information about diodes.

3. The transistor has maximum values of I_C , I_B , and V_{CE} , as well as other limits such as power dissipation ($I_C V_{CE}$) and temperature.
4. If rules 1 through 3 are obeyed, the current gain (or amplification) is the ratio of the collector current, I_C , to the base current, I_B . A small current flowing into the base controls a much larger current flowing into the collector. The ratio, called "beta", is typically around 100.

Procedure

Computer Setup

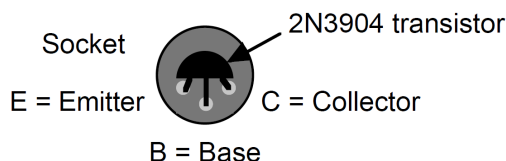
1. Connect your 850 Universal Interface to your computer via the attached USB cable. Turn on the interface.
2. Open PASCO Capstone and check **Hardware Setup** to ensure that the interface has connected automatically.
3. Connect the Voltage Sensor to Analog Channel A of the Universal Interface. Check **Hardware Setup** to ensure it has automatically connected. The system should automatically recognize it as a Voltage Sensor; if it does not, select "Voltage Sensor" from the list of sensor options for the channel.
4. Enable monitoring of the Output Voltage from Output 1 by clicking the yellow circle on the Output 1 port and selecting "Output Voltage-Current Sensor" from the dropdown menu.
5. Set up the Signal Generator so that:
 - Output 1 outputs a sine wave with a frequency of 1 Hz and an amplitude of 1.6 V.
 - Output 2 outputs a DC voltage of 5 V.
 - Both Outputs are set to automatically start outputting the signals when you begin recording data.
6. Set up a **Graph** display, with Output Voltage on the y-axis, time on the x-axis, and a sample rate of 200 Hz.
7. Use the **New Plot Area**  tool to create an additional **Graph** display using the same x-axis; set the y-axis on this graph to display the voltage measured by the Voltage Sensor.
8. Set a start and stop condition such that the program begins recording data when the voltage measured by the Voltage Sensor is above 0.01 V and stops data collection after 1 second.



TIP: This experiment can also be performed using the 550 Universal Interface (UI-5001). However, because the 550 Interface only has one Output port, a separate +5 V voltage source will be required for use in place of Output 2.

Equipment Setup

1. Insert the 2N3904 transistor into the socket on the AC/DC Electronics Lab Board. The transistor has a half-cylinder shape with one flat side. The socket has three holes labeled "E" (emitter), "B" (base), and "C" (collector). When held so that the flat side faces you and the wire leads point down, the left lead is the emitter, the middle lead is the base, and the right lead is the collector.



IMPORTANT: Connecting the transistor incorrectly can destroy the transistor.

2. Connect the 22 k Ω resistor (red, red, orange) between the component springs at the left edge of the component area.
3. Connect the 330 Ω resistor (orange, orange, brown) horizontally between the first and second springs to the left of the top banana jack.
4. Carefully bend the wire leads of the red light-emitting diode (LED) so it can be mounted between the component springs. Connect the LED from the component spring containing the left side of the 330 Ω resistor to the next component spring over, as shown in Figure 17.2. Arrange the LED so its cathode (short lead) is to the left, away from the resistor.
5. Connect a wire lead from the component spring at the base terminal of the transistor to the component spring at the top of the 22 k Ω resistor.
6. Connect another wire lead from the component spring at the collector terminal of the transistor to the component spring at the left end of the LED.
7. Place alligator clips on the banana plugs of the Voltage Sensor. Connect the red lead of the sensor to the component spring at the right end of the 330 Ω resistor and the black lead to the left end of the resistor.
8. Connect banana plug patch cords to Output 1 of the 850 Universal Interface. Place alligator clips on the other ends of both cords.
9. Using the alligator clip on the banana plug patch cable, connect the positive (+) terminal of Output 1 to the component spring on the bottom of the 22 k Ω resistor.

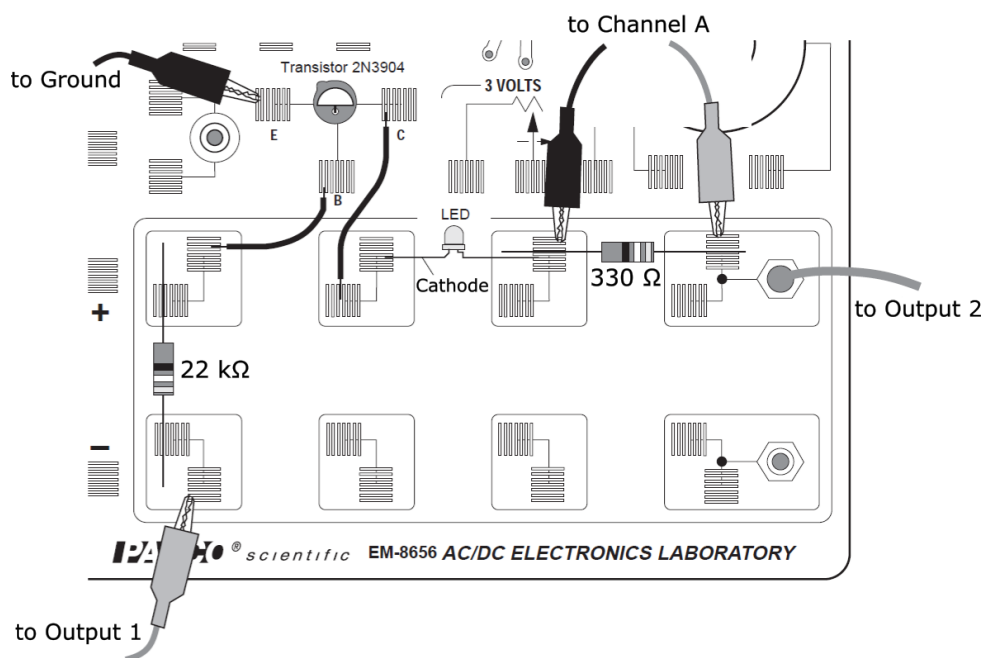
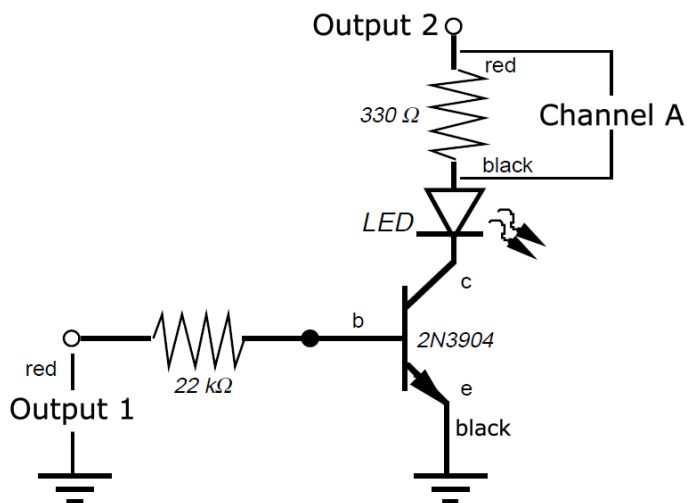


Figure 17.2

- Using the alligator clip on the banana plug patch cable, connect the negative (-) terminal of Output 1 to the component spring of the transistor's emitter terminal.
- Connect the red lead (+) of the BNC Function Generator Output Cable from Output 2 of the 850 Universal Interface to the top banana jack on the AC/DC Electronics Lab Board. (You do not need to connect the black lead (-), as the current from Output 2 will already go to ground through Output 1's negative terminal.)


A circuit diagram for the completed circuit can be seen in Figure 17.3.



npn Transistor as Digital Switch

Figure 17.3

Data Collection

- When you are ready, begin recording data. As data is collected, carefully observe the behavior of the LED. Capstone will automatically stop recording data after 1 second.
- Use the **Scale to Fit**  tool to view the collected data.

Analysis

For the purposes of this analysis, we will presume that the output voltage from Output 1 is equal to V_B , the voltage at the base, since there is only a small voltage drop across the 22 k Ω resistor.

- Identify the time on the plot at which the voltage across the resistor starts to increase above zero.
- Using the **Multi-Coordinates Tool**, find the value of V_B at the point where the voltage across the resistor V_R begins to increase above zero. Record this value in the space below.

$V_B = \underline{\hspace{2cm}} \text{ V}$

- In the **Calculator** window, create a new variable called "Current" which is measured in amps (A) and is equal to the voltage from the Voltage Sensor divided by the resistance of the resistor. (If you have a multimeter, experimentally measure the resistance; otherwise, use 330 Ω .)
- Create a new graph with the new Current variable on the y-axis and time on the x-axis.
- Plot your data from this run on the new graph. Briefly describe how the current through the resistor behaves as V_B changes.

Discussion

- How does the LED behave when the circuit is active?
- How does the general shape of the plot for V_B (Output Voltage) compare to the plot of V_R ?
- What is the voltage on the V_B plot at which the LED turns on?
- In general, how did the current from the collector to the emitter behave in this experiment?

Experiment 18: Transistor Lab 2 - Current Gain: The NPN Emitter-Follower Amplifier

Equipment Needed

- Computer with PASCO Capstone
- 850 Universal Interface (UI-5100)



NOTE: As with the previous lab, the 550 Universal Interface (UI-5101) may only be used if an external +5 V power supply is available.

- 2 Voltage Sensors, shrouded (UI-5110) or unshrouded (UI-5100)
- AC/DC Electronics Lab Board
 - 2N3904 transistor
 - Resistors: 1 k Ω and 22 k Ω
 - Wire leads
- 2 banana plug patch cords (such as SE-9750)
- BNC Function Generator Output Cable, shrouded (UI-5129) or unshrouded (UI-5119)

Purpose

The purpose of this experiment is to investigate the DC transfer characteristics of the *npn* transistor, and to determine the current gain of the transistor.

Theory

Transistors are the basic elements in modern electronic amplifiers of all types. In a transistor circuit, the current through the collector "loop" is controlled by the current to the base, as seen in Figure 18.1 below.

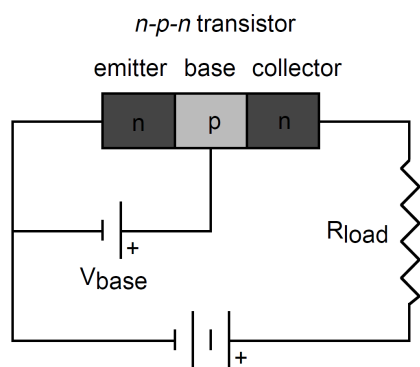


Figure 18.1

The voltage applied to the base is called the *base bias voltage*. If it is positive, electrons in the emitter are attracted onto the base. Since the base is very thin (approximately 1 micron), most of the electrons in the emitter flow across into the collector, which is maintained at a positive voltage. A relatively large current, I_C , flows between the collector and the emitter, while a much smaller current, I_B , flows through the base.

A small change in the base voltage due to an input signal causes a large change in the collector current and therefore a large voltage drop across the output resistor, R_{load} . The power dissipated by the resistor may be much larger than the power supplied to the base by its voltage source; thus, the device functions as a **power amplifier**. What is important for amplification (or *gain*) is the change in collector current for a given change in base current. *Gain* can be defined as the ratio of output current to input current.

A transistor circuit can amplify current or voltage.

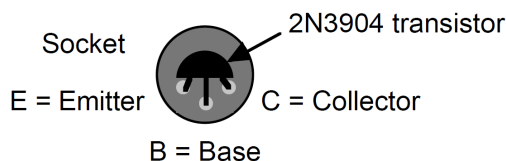
Procedure

Computer Setup

1. Connect your 850 Universal Interface to your computer via the attached USB cable. Turn on the interface.
2. Open PASCO Capstone and check **Hardware Setup** to ensure that the interface has connected automatically.
3. Connect the first Voltage Sensor to Analog Channel A of the Universal Interface, then connect the other Voltage Sensor to Analog Channel B. Check **Hardware Setup** to ensure both sensors have automatically connected. The system should automatically recognize them as Voltage Sensors; if it does not, select "Voltage Sensor" from the list of sensor options for each channel.
4. Enable monitoring of the Output Voltage from Output 1 by clicking the yellow circle on the Output 1 port and selecting "Output Voltage-Current Sensor" from the dropdown menu.
5. Set up the Signal Generator so that:
 - Output 1 outputs a sine wave with a frequency of 1 Hz and an amplitude of 4 V.
 - Output 2 outputs a DC voltage of 5 V.
 - Both Outputs are set to automatically start outputting the signals when you begin recording data.
6. Create a **Graph** display, with the voltage from Channel B on the y-axis, the voltage from Channel A on the x-axis, and a sample rate of 200 Hz.
7. Set up start and stop conditions such that Capstone automatically starts capturing data when the Output Voltage is greater than 0.01 V and ends data recording after 1 second.

Equipment Setup

1. Insert the 2N3904 transistor into the socket on the AC/DC Electronics Lab Board. The transistor has a half-cylinder shape with one flat side. The socket has three holes labeled "E" (emitter), "B" (base), and "C" (collector). When held so that the flat side faces you and the wire leads point down, the left lead is the emitter, the middle lead is the base, and the right lead is the collector.



IMPORTANT: Connecting the transistor incorrectly can destroy the transistor.

2. Connect the 1 k Ω resistor (brown, black, red) vertically between the upper and lower component springs at the left edge of the component area.
3. Connect the 22 k Ω resistor (red, red, orange) vertically between the upper and lower component springs to the right of the 1 k Ω resistor.
4. Connect a wire lead between the component spring for the *emitter* terminal of the transistor and the component spring at the top end of the 1 k Ω resistor.
5. Connect another wire lead between the component spring for the *base* terminal of the transistor and the component spring at the top end of the 22 k Ω resistor.
6. Connect a third wire lead between the component spring for the *collector* terminal of the transistor and the component spring next to the top banana jack.
7. Connect banana plug patch cords to Output 1 of the 850 Universal Interface. Place alligator clips on the other ends of both cords.
8. Using the alligator clip on the banana plug patch cable, connect the positive (+) terminal of Output 1 to the component spring on the bottom of the 22 k Ω resistor.
9. Using the alligator clip on the banana plug patch cable, connect the negative (-) terminal of Output 1 to the component spring on the bottom of the 1 k Ω resistor.

10. Connect the red lead (+) of the BNC Function Generator Output Cable from Output 2 of the 850 Universal Interface to the top banana jack on the AC/DC Electronics Lab Board. (You do not need to connect the black lead (-), as the current from Output 2 will already go to ground through Output 1's negative terminal.)

The full circuit you construct should match that shown in Figure 18.2. A circuit diagram for the completed circuit is provided in Figure 18.3.

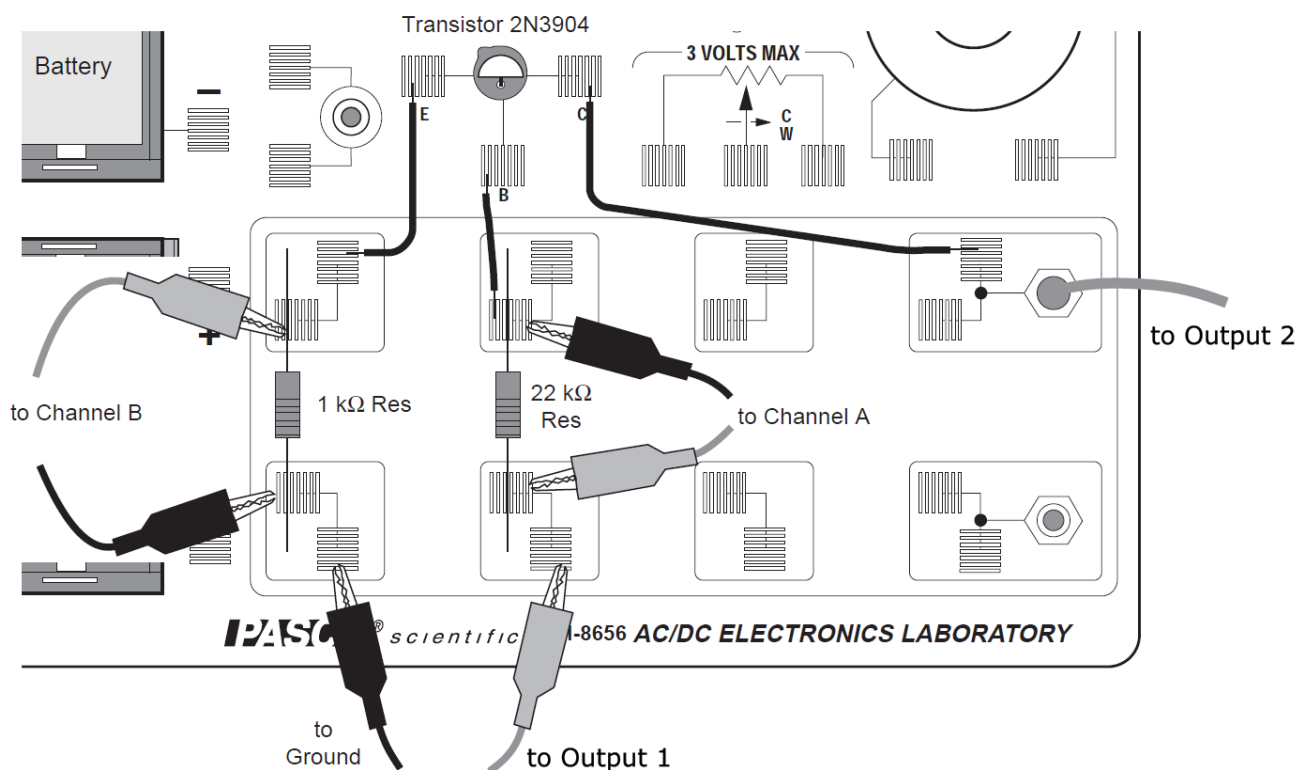
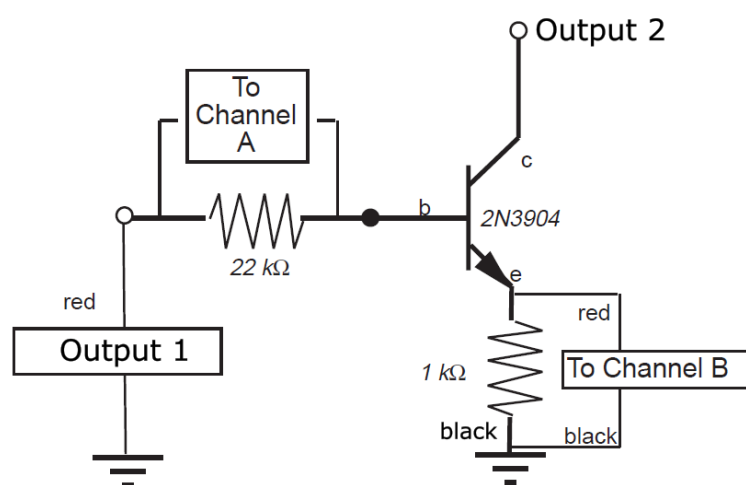



Figure 18.2



Current gain: *n*p*n* Transistor Emitter-Follower Amplifier

Figure 18.3

Data Recording

1. When you are ready, begin data collection. Capstone will automatically stop recording data after 1 second.
2. Use the **Scale to Fit**  tool to view the collected data.

Analysis

1. In the **Calculator**, create a new variable called "I_c" which is equal to the voltage from Channel B divided by the resistance of the 1 k Ω resistor (either using the printed value or measuring the resistance with a multimeter); this variable should be measured in (A). This measures the current which passes through the collector, also known as the **output current**.
2. Create another new variable called "I_b" which is also measured in amps and is equal to the voltage from Channel A divided by the resistance of the 22 k Ω resistor (either using the printed value or measuring the resistance with a multimeter). This measures the current which passes through the base, also known as the **input current**.



TIP: If desired, multiply the values from I_c and I_b by 1000 to convert from amps to milliamps (mA).

3. Create a new plot area or Graph display; plot I_c versus I_b in this area. Draw a sketch or take a screenshot of the results.
4. Using the **Highlight** and **Curve Fit** tools, create a linear fit of the diagonal portion of the I_c versus I_b data.
5. The "m" value of the Linear Fit line is the slope of that linear region. Record the value of the slope.
6. The slope of this region can be interpreted as:

$$\text{slope} = \frac{\Delta I_c}{\Delta I_b} = \beta$$

where β is called the *current gain* of the transistor. Record the current gain of the 2N3904 transistor you used in the space below.

Current gain = _____

Discussion

1. Create a new graph showing I_c versus the voltage measured by Channel A. How does the general shape of this plot compare to the plot of current versus voltage for a diode?
2. What is the current gain of the 2N3904 transistor? Does it make sense with what you learned about current gain in the previous experiment?

Experiment 19: Transistor Lab 3 - Common-Emitter Amplifier

Equipment Needed

- Computer with PASCO Capstone
- 850 Universal Interface (UI-5000)



NOTE: As with the previous two labs, the 550 Universal Interface (UI-5001) can only be used if an external +5 V voltage source is available.

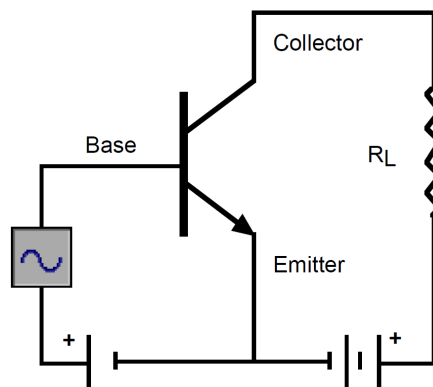
- Voltage Sensor, shrouded (UI-5110) or unshrouded (UI-5100)
- AC/DC Electronics Lab Board
 - 2N3904 transistor
 - Resistors: 1 k Ω (4), 10 k Ω , and 22 k Ω (2)
 - Capacitors: 1 μ F and 10 μ F
 - Wire leads
- Banana plug patch cords (such as SE-9750)
- BNC Function Generator Output Cable, shrouded (UI-5129) or unshrouded (UI-5119)

Purpose

The purpose of this experiment is to investigate the voltage and current amplification characteristics of the *npn* transistor in a *common-emitter* amplifier circuit.

Theory

In the *npn* transistor, the current flow to the base is much smaller than the current flow to the collector. This allows the transistor to be used as an amplifier. The transistor can amplify current and voltage.



npn Common-emitter amplifier

If the input voltage is small enough so that it is much smaller than the forward bias on the emitter connection, the input current will encounter small impedance. The input voltage will not need to be large in order to produce sizeable currents.

Additionally, since the output voltage across the load resistor R_L is the product of the output current (collector current) and the value of R_L , the output voltage can also be made large. As a result, the output voltage can be much larger than the input voltage.

The *common-emitter* amplifier derives its name from the fact that the base wire of the transistor and the collector wire of the transistor meet at the emitter wire; they have the emitter wire in common.

Each section of the common-emitter amplifier circuit performs a specific function, as you can see in Figure 19.1. In Section 1, the Input Coupling Circuit keeps DC voltages from changing the bias circuit. The function of Section 2, the Bias Circuit, is to provide a voltage that keeps the transistor in its active region. Section 3 is the Amplifier circuit. Section 4, the Output Coupling Circuit, allows only the AC signal from the transistor to reach the load resistor so that the load resistance doesn't affect the operating voltage.

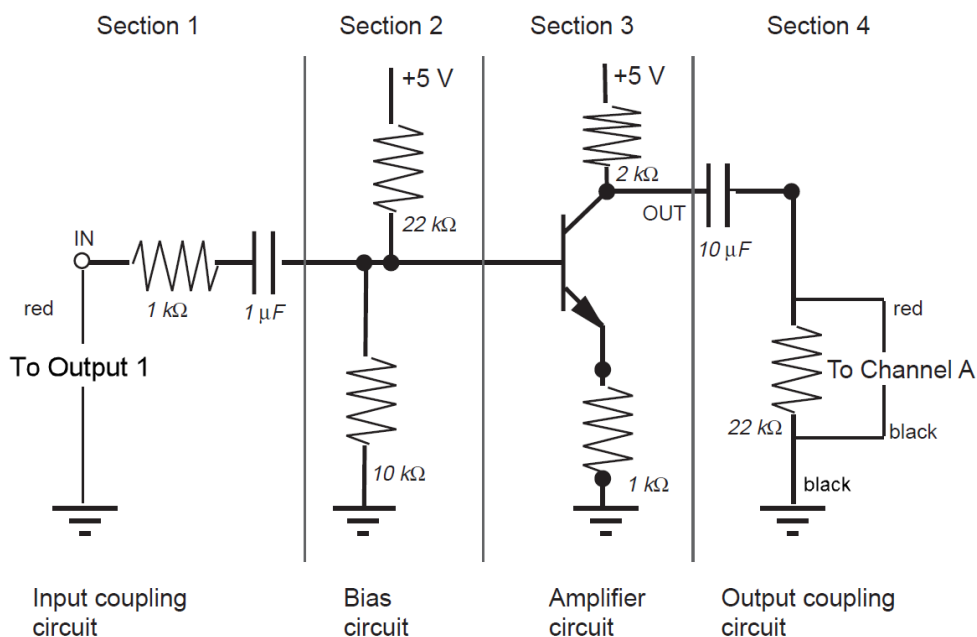


Figure 19.1

Procedure

Computer Setup

1. Connect your 850 Universal Interface to your computer via the attached USB cable. Turn on the interface.
2. Open PASCO Capstone and check **Hardware Setup** to ensure that the interface has connected automatically.
3. Connect the Voltage Sensor to Analog Channel A of the Universal Interface. Check **Hardware Setup** to ensure it has automatically connected. The system should automatically recognize it as a Voltage Sensor; if it does not, select "Voltage Sensor" from the list of sensor options for the channel.
4. Enable monitoring of the Output Voltage from Output 1 by clicking the yellow circle on the Output 1 port and selecting "Output Voltage-Current Sensor" from the dropdown menu.
5. Set up the function generator so that:
 - Output 1 outputs a sine wave with a frequency of 300 Hz and an amplitude of 0.2 V.
 - Output 2 outputs a DC voltage of 5 V.
 - Both Outputs are set to automatically start outputting the signals when you begin recording data.
6. Set up a **Scope** display with both Output Voltage and the voltage from the Voltage Sensor on the y-axis and time (in milliseconds) on the x-axis. Set the Recording Mode to **Fast Monitor Mode**.

Equipment Setup

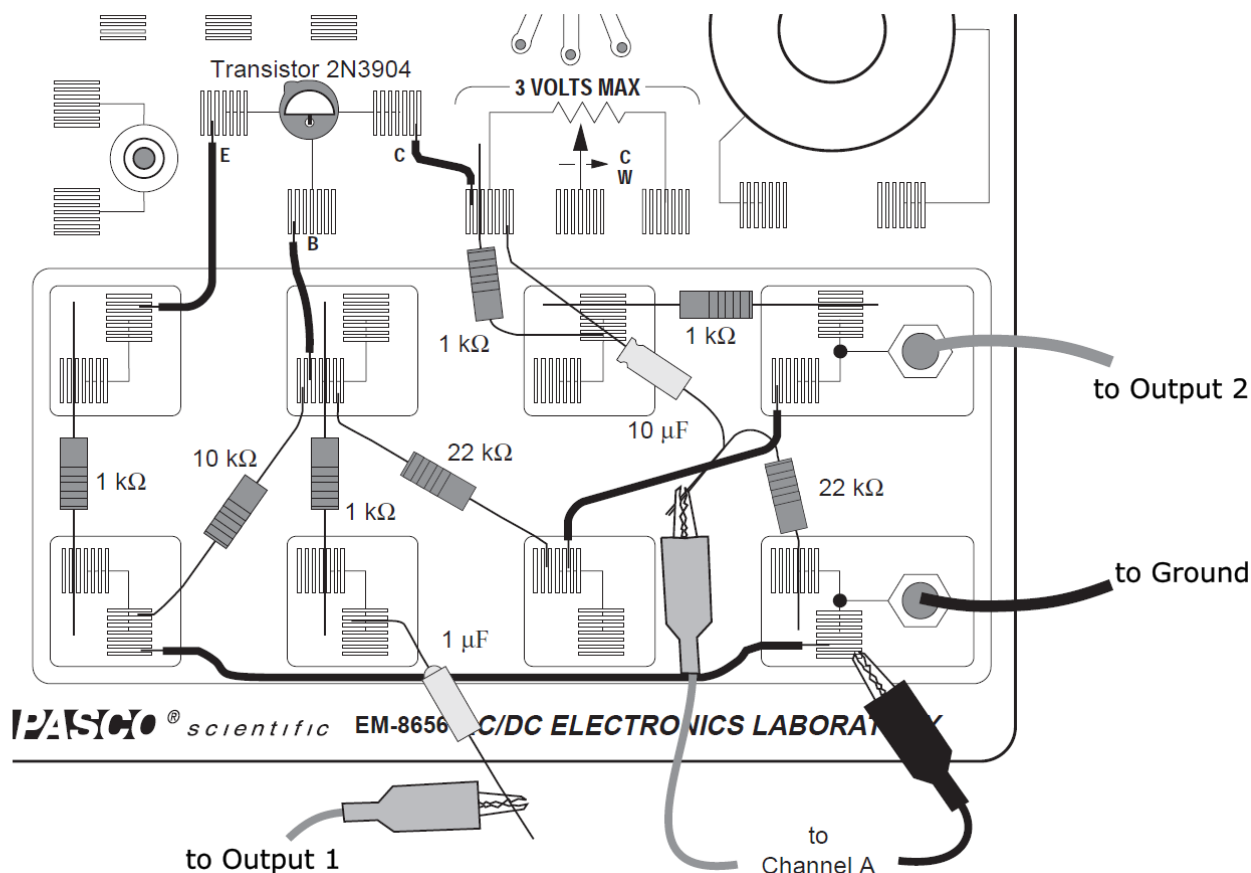
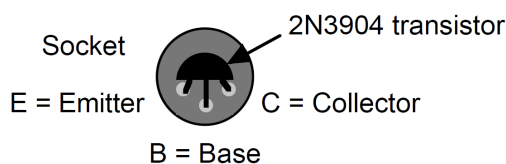


Figure 19.2

1. Insert the 2N3904 transistor into the socket on the AC/DC Electronics Lab Board. The transistor has a half-cylinder shape with one flat side. The socket has three holes labeled "E" (emitter), "B" (base), and "C" (collector). When held so that the flat side faces you and the wire leads point down, the left lead is the emitter, the middle lead is the base, and the right lead is the collector.

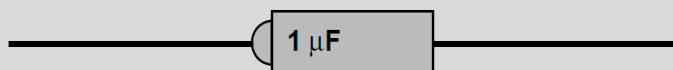


IMPORTANT: Connecting the transistor incorrectly can destroy the transistor.

2. Connect one five inch wire lead from the component spring at the transistor's *base* terminal to the component spring immediately below the base terminal spring.
3. Connect a 1 kΩ resistor from the component spring at the bottom of the wire lead in Step 2 to the component spring directly below it (at the bottom of the lab board).
4. Connect the wire at the negative end of a 1 μF capacitor to the same component spring at the bottom edge of the lab board. Do not connect the capacitor's other wire lead to anything yet.

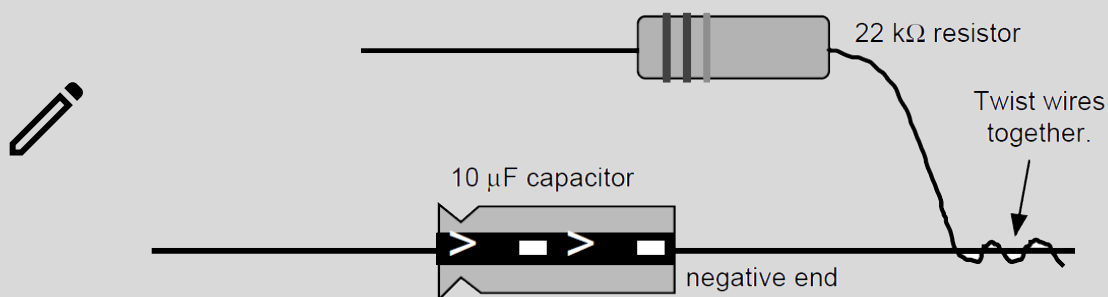


NOTE: The negative end of the 1 μF capacitor can be identified by a small round bump.



5. Connect a five inch wire lead from the component spring at the transistor's *emitter* terminal to the component spring at the top left corner of the component area.
6. Connect a 1 k Ω resistor from the component spring at the top left corner of the component area to the component spring directly below.
7. Connect a five inch wire lead from the component spring at the transistor's *collector* terminal to the component spring to the right and slightly below.
8. Connect a 1 k Ω resistor from the component spring at the end of the wire lead from Step 7 to the component spring below and slightly to the right of the spring at the end of the wire lead from Step 7.
9. Connect a 1 k Ω resistor from the component spring to the right of the top banana jack to the component spring directly to the left of that spring.
10. Connect the red lead (+) of the BNC Function Generator Output Cable from Output 2 of the 850 Universal Interface to the top banana jack on the lab board. (You do not need to connect the black lead (-), as the current from Output 2 will go to ground through Output 1's negative terminal.)
11. Connect a black banana plug patch cord from the negative (-) terminal of Output 1 to the bottom banana jack on the lab board.
12. Connect a ten inch wire lead from the component spring next to the bottom banana jack to the component spring at the bottom end of the 1 k Ω resistor connected to the transistor's emitter terminal.
13. Connect the 10 k Ω resistor from the component spring at the non-base terminal end of the wire lead from Step 2 to a component spring at the bottom left corner of the board (such as the one which holds the left side of the ten inch wire lead from Step 12).
14. Return to the component spring at the non-base terminal end of the wire lead from Step 2; connect a 22 k Ω resistor from this component spring to the component spring that is to the right and below (at the edge of the lab board).
15. Connect a five inch wire lead from the component spring at the end of the 22 k Ω resistor from Step 14 to a component spring next to the top banana jack.
16. Place an alligator clip on one end of a red banana plug patch cord. Connect the alligator clip to the wire at the end of the 1 μ F capacitor and the other end of the cable to the positive (+) terminal of Output 1.
17. Place alligator clips on the banana plugs of the Voltage Sensor. Connect the alligator clip of the black wire of the Voltage Sensor to the component spring next to the bottom banana jack at the lower right corner of the lab board. Do not connect the red cable to anything yet.
18. Twist the wire from the negative end of a 10 μ F capacitor with the wire at one end of a second 22 k Ω resistor.

NOTE: The negative end of the 10 μ F capacitor has a slight bump; the positive end has an indentation around it. There is a band on the side of the capacitor with arrows that point to the negative end.





19. Connect the wire from the positive end of the 10 μ F capacitor to the component spring at one end of the wire lead connected to the collector terminal. Connect the free wire from the 22 k Ω resistor twisted with the capacitor to a component spring next to the bottom jack at the lower right corner of the lab board.
20. Carefully connect the alligator clip of the Voltage Sensor's red wire to the twisted wires of the 10 μ F capacitor and the 22 k Ω resistor.

Data Recording



NOTE: For the rest of the lab, we will refer to the voltage supplied by Output 1 as V_0 and the voltage measured by the Voltage Sensor as V_A .

1. When you are ready, begin data monitoring.
2. Wait at least three seconds to allow the voltage traces to overlap, then stop data monitoring.
3. Use the **Scale to Fit**  tool to view your data in more detail.
4. Using the **Coordinates**  tool, identify the peak values of V_0 and V_A ; record these values in the space below.
 Voltage (peak) of V_0 : _____ V
 Voltage (peak) of V_A : _____ V

Analysis

1. Use the voltage you recorded to calculate the ratio of the transistor's input voltage V_{in} (the peak voltage of V_0) to the transistor's output voltage V_{out} (the peak voltage of V_A).

$$\frac{V_{in}}{V_{out}} = \frac{\text{peak } V_0}{\text{peak } V_A} = \underline{\hspace{2cm}}$$

2. The theoretical output voltage of the transistor is given by:

$$V_{out} = -V_{in} \frac{R_C}{R_E} = \underline{\hspace{2cm}}$$

where R_C is the value of the resistor(s) in series with the collector terminal (in this case, 2 k Ω) and R_E is the value of the resistor(s) in series with the emitter terminal (in this case, 1 k Ω). Calculate the theoretical output voltage for the common-emitter amplifier.

Discussion

1. What is the phase relationship between the input signal and the output signal?
2. How does the actual output voltage compare to its theoretical value? What are some possible sources of error causing the discrepancy?

Extension

1. Increase the amplitude of the signal from Output 1 by 0.02 volt increments. Observe the shape of the output signal.
2. Increase the frequency of the signal from Output 1. Observe the shape of the output signal.

Extension Discussion

1. How does the shape of the output signal change as the input amplitude increases?
2. Is the voltage gain of the amplifier dependent on or independent of the frequency? Explain your answer.

Experiment 20: Induction - Magnet Through a Coil

Equipment Needed

- Computer with PASCO Capstone
- 850 Universal Interface (UI-5000) **OR** 550 Universal Interface (UI-5001)
- Voltage Sensor, shrouded (UI-5110) or unshrouded (UI-5100)
- AC/DC Electronics Lab Board
- Alnico bar magnet (EM-8620)

Purpose

This experiment shows the Electromotive Force (EMF) induced in a coil when a magnet is dropped through the center of the 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 \mathcal{E} is the induced EMF, N is the number of turns of wire in the coil, and $\Delta\phi/\Delta t$ 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

Computer Setup

1. Connect the 850 or 550 Universal Interface to the computer via the attached USB cable. Turn on the interface.
2. Open PASCO Capstone and check **Hardware Setup** to ensure that the interface has connected automatically.
3. Connect the Voltage Sensor to Analog Channel A of the Universal Interface. Check **Hardware Setup** to ensure it has automatically connected. The system should automatically recognize it as a Voltage Sensor; if it does not, select "Voltage Sensor" from the list of sensor options for the channel.
4. Create a **Graph** display with the voltage measured by the Voltage Sensor on the y-axis, time (in seconds) on the x-axis, and a sample rate of 1000 Hz.
5. Set up start and stop conditions so that the program automatically starts recording data when the measured voltage is greater than 0.01 V and stops data collection after 0.25 seconds.

Equipment Setup

1. Place alligator clips on the ends of the Voltage Sensor leads.
2. Attach the clip on the red positive (+) wire to the left component spring next to the coil on the AC/DC Electronics Lab Board. Attach the clip on the black negative (-) wire to the right component spring next to the coil.
3. Arrange the lab board so the corner with the coil is beyond the edge of the table, allowing a magnet dropped through the coil to fall freely.

Your final setup should resemble that seen in Figure 20.1.

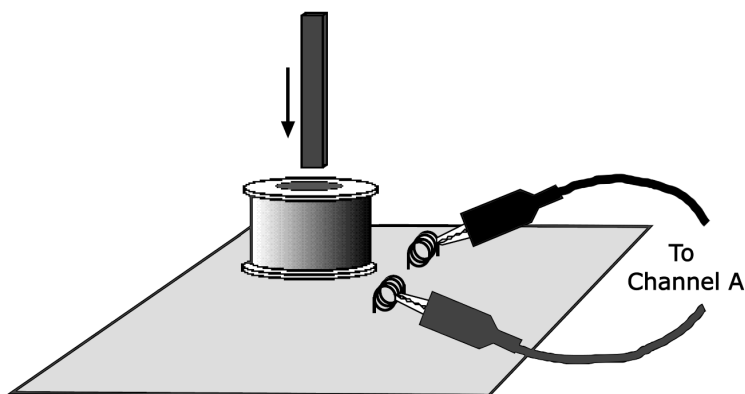



Figure 20.1

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 **S** symbol.
2. When you are ready, begin recording data and then quickly let the magnet drop through the coil.



TIP: To improve the accuracy of dropping the magnet, roll a piece of paper into a tube and place it over the opening of the inductor coil, then drop the magnet inside the tube.

3. Data recording will automatically begin when the magnet starts to fall through the coil and induces a voltage, and will end automatically after 0.25 seconds.
4. Use the **Scale to Fit**  tool to view your data in more detail.

Analysis

1. In the Graph display, highlight the first peak of the Voltage vs. Time plot.
2. Using the appropriate tools, measure the area under this peak. Record this value in the space below.
Area (first peak) = _____ V*s
3. Repeat this process to measure the area under the second peak. Record this value in the space below.
Area (second peak) = _____ V*s

Discussion

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?

Extension

Repeat the data recording and analysis procedures for each of the following scenarios:

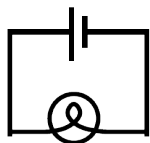
1. Tape two bar magnets together so both south ends are pressed together.
2. Rearrange the two bar magnets so that the south end of one is connected to the north end of the other.
3. Try dropping the original magnet from different heights.

Teacher's Guide

Exp. 1: Electronics Lab Board

Procedure

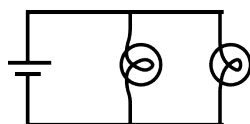
1) The circuit diagram for this step should match this design:



2-3) Reversing the wires should not have any effect on the circuit.

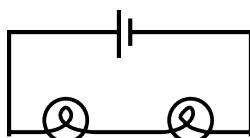
4-5) There are two ways of putting lamps into the circuit: parallel and series.

Parallel:



In this circuit, each light will be approximately the same brightness as the bulb in Step 1.

Series:

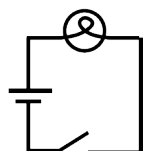


In this circuit, the lights will be dimmer than in Step 1.

Exp. 2: Lights in Circuits

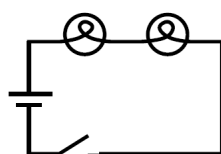
Procedure

1) The circuit diagram for this step should match this design:



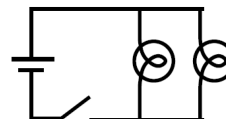
2-4) As with the last lab, there are two ways to construct this circuit.

Series:



In the series circuit, the lights will be dimmer than the one in Step 1. The current has to pass through both bulbs for the circuit to be complete, so disconnecting a bulb will cause both to go out. (This is how those infuriating older Christmas lights are wired.)

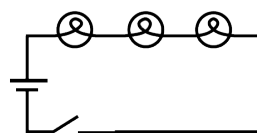
Parallel:



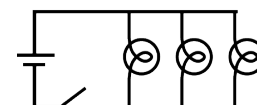
In the parallel circuit, the lights will be about as bright as the one in Step 1. The circuit is still complete if one bulb is removed, so disconnecting one does not affect the other. (This is how newer Christmas lights are wired.)

5-6) Again, this circuit may be either series or parallel. These circuits have the same characteristics as the ones in Steps 2 and 3.

Series

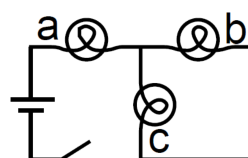


Parallel

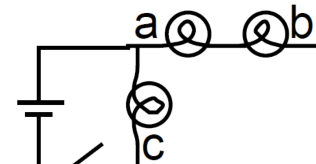


7) There are two ways to construct this circuit:

Parallel-in-Series



Series-in-Parallel



What happens if you unscrew one of the bulbs depends on which bulb you unscrew. In the first circuit, unscrewing bulb A will turn everything off, whereas unscrewing B or C will make A dimmer but make the other bulb brighter. In the second circuit, unscrewing bulb C will make bulbs A and B brighter; unscrewing A or B will make C brighter and turn the other bulb off.

10-12) Placing the batteries as shown in diagram 1 will make the bulbs the brightest, since this orientation provides the highest voltage. Placing the batteries as in diagram 2 will have the same effect as a single battery. Finally, placing the batteries as in diagram 3 will have no effect at all unless one of the batteries is nearly dead.

13) In diagram 1, the batteries are in series; in diagram 2, the batteries are in parallel; and in diagram 3, the batteries are opposed.

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

Discussion

- 1) Adding additional lights in *series* causes the original light to become dimmer. Adding additional lights in *parallel* causes no change to the original light.
- 2) Adding additional batteries in *series* causes the lights in the circuit to become brighter. Adding additional batteries in *parallel* causes no change in the brightness of the lights.
- 3) One function of a potentiometer is to adjust the amount of current in a circuit without having to alter the structure of the circuit.

Exp. 3: Ohm's Law

Procedure

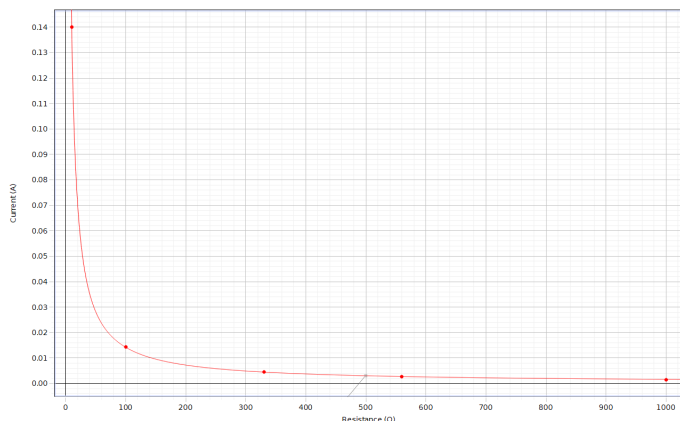
Warn the students to be particularly careful when setting up the multimeter to measure current. Attaching an ammeter the wrong way can cause severe damage to the meter.

Data Processing

Below is a sample data set for Table 3.1.

Resistance (Ω)	Current (A)	Voltage (V)	V/R
100	0.0144	1.515	0.0152
560	0.0027	1.523	0.0027
330	0.0045	1.522	0.0046
1000	0.0015	1.524	0.0015
10	0.140	1.446	0.145

A plot of Resistance vs. Current from the above data, along with a curve fit of this data, can be seen below.



Discussion

- 1) Current is inversely proportional to resistance.
- 2) Yes, the data agrees; the values we calculated for V/R are very close to the current measurements, and the points on the graph form an inverse curve.
- 3) The greatest source of error is the ammeter itself; because the meter has some internal resistance, the measured current will be less than the current in the circuit when the meter is not present.

Exp. 4: Resistances in Circuits

Procedure

1-4) Below is a sample data set for Table 4.1, using three 100 Ω resistors.

	Colors	Coded Resistance
#1	Orange-orange-brown-gold	330 Ω
#2	Orange-orange-brown-gold	330 Ω
#3	Orange-orange-brown-gold	330 Ω

	Measured Resistance	% error	Tolerance
#1	327 Ω	0.9%	5%
#2	326 Ω	1.2%	5%
#3	326 Ω	1.2%	5%

5) For the series circuit:

- $R_{12} = 654 \Omega$
- $R_{23} = 652 \Omega$
- $R_{123} = 979 \Omega$

6) For the parallel circuit:

- $R_{12} = 163 \Omega$
- $R_{23} = 163 \Omega$
- $R_{13} = 163 \Omega$
- $R_{123} = 108.1 \Omega$

7) For the combination circuit:

- $R_1 = 327 \Omega$
- $R_{23} = 163 \Omega$
- $R_{123} = 490 \Omega$

8) Below is some sample data collected for a set of resistors consisting of a 100 Ω resistor, a 330 Ω resistor, and a 560 Ω resistor.

	Colors	Coded Resistance
A	Brown-black-brown-gold	100 Ω
B	Orange-orange-brown-gold	330 Ω
C	Green-blue-brown-gold	560 Ω

	Measured Resistance	% error	Tolerance
A	99 Ω	1%	5%
B	327 Ω	0.9%	5%
C	553 Ω	1.2%	5%

For the series circuit:

- $R_{AB} = 426 \Omega$
- $R_{BC} = 880 \Omega$
- $R_{ABC} = 979 \Omega$

For the parallel circuit:

- $R_{AB} = 76 \Omega$
- $R_{BC} = 205 \Omega$
- $R_{AC} = 84 \Omega$
- $R_{ABC} = 66 \Omega$

For the combination circuit:

- $R_A = 99 \Omega$
- $R_{BC} = 205 \Omega$
- $R_{ABC} = 305 \Omega$

Discussion

1) The percent error should be significantly smaller than the value of the tolerance for each resistor.

2-4) For both equal and unequal resistors, total resistance is found in the same ways. In a series circuit, total resistance is equal to the sum of the individual resistances ($R_{\text{total}} = R_1 + R_2 + R_3 + \dots$). In a parallel circuit, the *reciprocal* of the total resistance is equal to the sum of the *reciprocals* of the individual resistances ($1/R_{\text{total}} = 1/R_1 + 1/R_2 + 1/R_3 + \dots$).

Exp. 5: Voltages in Circuits

Procedure

1-4) The following sample data sets utilize the three 330 Ω resistors from Experiment 4.

Series Circuit:

Measurement	Resistance	Voltage
R_1	327 Ω	0.513 V
R_2	326 Ω	0.511 V
R_3	326 Ω	0.509 V
R_{12}	654 Ω	1.022 V
R_{23}	652 Ω	1.019 V
R_{123}	979 Ω	1.531 V

Parallel Circuit:

Measurement	Resistance	Voltage
R_1	327 Ω	1.517 V
R_2	326 Ω	1.517 V
R_3	326 Ω	1.517 V
R_{123}	108.1 Ω	1.517 V

Combination Circuit:

Measurement	Resistance	Voltage
R_1	327 Ω	1.016 V
R_{23}	163 Ω	0.507 V
R_{123}	490 Ω	1.524 V

5) The following sample data sets utilize the three unequal resistors from Experiment 4.

Series Circuit:

Measurement	Resistance	Voltage
R_A	99 Ω	0.154 V
R_B	327 Ω	0.509 V
R_C	553 Ω	0.861 V
R_{AB}	426 Ω	0.663 V
R_{BC}	880 Ω	1.370 V
R_{ABC}	979 Ω	1.524 V

Parallel Circuit:

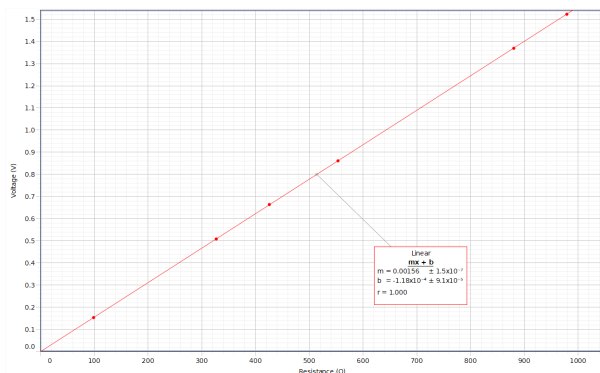
Measurement	Resistance	Voltage
R_A	99 Ω	1.512 V
R_B	327 Ω	1.512 V
R_C	553 Ω	1.512 V
R_{ABC}	66 Ω	1.513 V

Combination Circuit:

Measurement	Resistance	Voltage
R_A	99 Ω	0.495 V
R_{BC}	205 Ω	1.027 V
R_{ABC}	305 Ω	1.522 V

Discussion

1) In both Figures 5.1 and 5.4, voltage is distributed based on the size of resistors; the larger a resistor's resistance is, the greater the drop in voltage across that resistor will be. This forms a linear relationship, as seen in the graph of voltage vs. resistance for Figure 5.4 below.



2) In any parallel circuit, the voltage will be the same across all of the resistors.

3) In a combination circuit, the voltage acts as if any resistors in parallel were a single resistor in series with the other resistors. Beyond this, the rules from the two previous questions apply.

Exp. 6: Currents in Circuits**Procedure**

This sample data was created using the three unequal resistors used in the key for Experiments 4 and 5.

Series Circuit

No matter where the ammeter is inserted into the series circuit, a current of 1.5 mA will be recorded.

Parallel Circuit

The resistance and voltage values carry over from the sample data for Figure 5.5. The current values measured for this circuit are:

- $I_0 = 0.0207$ A
- $I_1 = 0.0143$ A
- $I_2 = 0.0044$ A
- $I_3 = 0.0026$ A
- $I_4 = 0.0207$ A

Discussion

1) In a series circuit, there is only a single current which runs through the entire circuit, and thus the value of current at any point will be the same as at any other point.

2) In a parallel circuit, the total current from the voltage source splits across each of the resistors before coming back together at the end. The amount of current through each resistor is inversely related to the resistance of that resistor: the greater the resistance, the less current that will pass through that resistor.

3-4) In any circuit- series, parallel, or combination- the voltage, current, and resistance are all related by Ohm's Law: $V = IR$. This pattern and conclusion should be readily apparent from student data.



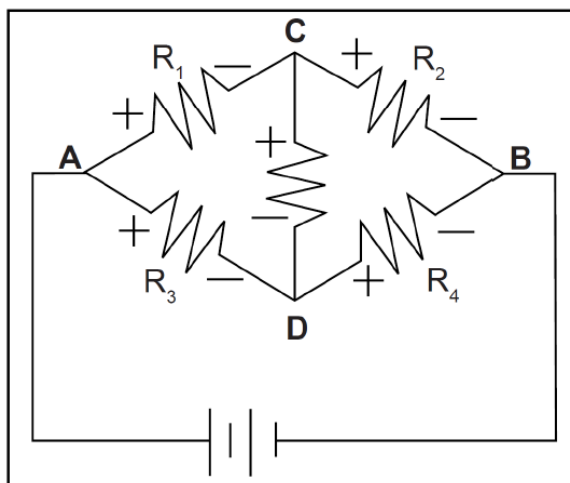
NOTE: The value you obtain by multiplying current measurements by resistance will generally be lower than the measured value of voltage. This is due to the ammeter having internal resistance, which reduces the amount of current which flows through the circuit when the meter is included. This margin of error should be less than 5% for most meters.

Exp. 7: Kirchhoff's Rules**Procedure**

Below is a sample data set for Table 7.1.

	Resistance (Ω)	Voltage (V)	Current (mA)
R_1	100	0.393	3.8
R_2	560	1.128	1.9
R_3	330	1.019	3.0
R_4	100	0.501	4.8
R_5	330	0.627	1.8
R_{total}	214	1.521	6.8

Below is a circuit diagram showing the direction of voltage drops in this particular case. Note that, depending on your resistance values, the current on the central resistor might be reversed in your circuit.



Analysis

1) The net current flow into or out of each node is as follows:

- Node (1,3): 0 mA
- Node (1,2,5): 0.1 mA out
- Node (3,4,5): 0 mA
- Node (2,4): 0.1 mA out

2) The net voltage around each loop is as follows:

- Loop (battery,1,2): 0 V
- Loop (battery,3,4): 0.001 V
- Loop (battery,1,5,4): 0 V
- Loop (battery,3,5,2): 0.001 V
- Loop (1,2,4,3): 0.001 V
- Loop (1,5,3): -0.001 V
- Loop (2,4,5): 0 V

Discussion

1) This circuit verifies Kirchhoff's Rules within the margins of error of the multimeter used. The net current flowing into or out of any junction is approximately zero, and the sum of voltage around any loop is approximately zero.

Extension

Below is a sample data set for the Extension circuit. The last two rows contain data for the battery on the bottom left (B1) and the battery on the far right (B2).

	Resistance (Ω)	Voltage (V)	Current (mA)
R ₁	100	0.259	2.5
R ₂	560	1.443	2.5
R ₃	330	0.177	0.5
R ₄	100	0.313	3.0
R ₅	330	1.031	3.0
B1	N/A	1.524	2.5
B2	N/A	1.521	3.0

The net current flow into or out of each node is:

- Node (2,3,4): 0 V
- Node (B1,3,5): 0 V

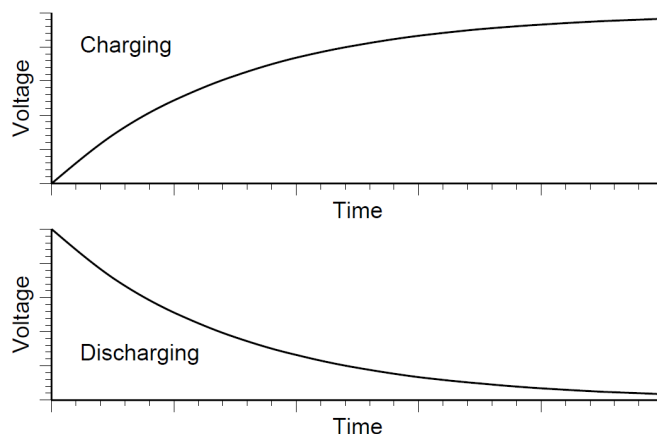
The net volt around each loop is:

- Loop (B1,1,2,4,B2,5): -0.001 V
- Loop (B1,1,2,3): -0.001 V
- Loop (B2,5,3,4): 0 V

Exp. 8: Capacitors in Circuits

Procedure

3-5) The charging and discharging of the capacitor over time can be described by the graphs below.



7-11) Some sample data for Table 8.1:

Resistance (k Ω)	Capacitance (μ F)	t_c (s)	t_d (s)
100	100	11.62	11.32
100	330	37.77	37.54
220	100	25.68	25.28

Sample data for Table 8.2:

Type of Circuit	t_c	t_d
Series	9.05	9.08
Parallel	48.62	48.92

Discussion

1-2) Increasing capacitance and increasing resistance both result in a larger time to charge or discharge the circuit. In other words, charging and discharging time are directly proportional to both resistance and capacitance.

3) For a parallel circuit, the total capacitance is given by $C_{\text{total}} = C_1 + C_2$. For a series circuit, the total capacitance is given by $1/C_{\text{total}} = 1/C_1 + 1/C_2$.

Exp. 9: Diodes

Procedure

Your students' data table(s) should demonstrate that, while the diode is forward biased, the diode voltage increases as the resistor voltage increases; however, this amount by which V_{AB} increases for a given change in V_{BC} becomes smaller as V_{BC} increases. When the diode is reverse biased, no current at all should flow through the diode, and thus V_{BC} will always be zero.

Below is a partial set of sample data for Table 9.1.

Forward Bias

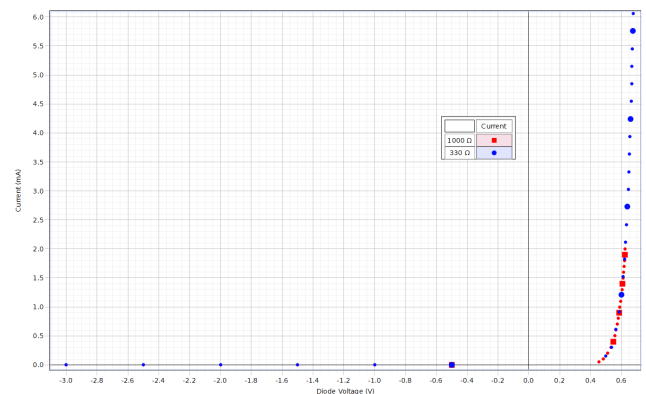
R (Ω)	V_{AB} (V)	V_{BC} (V)	I (mA)
1000	0.05	0.454	0.05
1000	0.1	0.482	0.1
1000	0.2	0.512	0.2
1000	0.3	0.533	0.3
330	0.05	0.499	0.15
330	0.1	0.535	0.3
330	0.2	0.565	0.61
330	0.3	0.585	0.91

Reverse Bias

R (Ω)	V_{AB} (V)	V_{BC} (V)	I (mA)
1000	0	0.5	0
1000	0	1	0
1000	0	1.5	0

Analysis

2) Below is an example of a sample plot of current (in milliamps) versus V_{AB} . The red (square) points represent the data from the 1 Ω resistor, while the blue (circle) points represent data from the 330 Ω resistor.



Discussion

1) The shape indicates that current can only flow through the diode when it is forward biased, and that a certain amount of voltage is required for the diode to fully "open up" and allow current through freely.

2) No, the diode did not operate the same way; in Steps 3 through 5 current was able to pass freely through the diode once sufficient voltage was reached, whereas in Step 6 no current was able to flow at all.

3) These terms refer to the orientation of the diode, with "Forward Biased" meaning that the diode is aligned so that current can flow through it and "Reverse Biased" meaning it is aligned so that current is blocked.

4) In the real world, diodes are used as one-way "valves" for electricity, ensuring that current is only able to flow through a circuit in one direction.

Extension

1) A zener diode would be similar to the 1N-4007 diode; however, there would be a breakdown point on the reverse biasing of the zener diode, beyond which the current would flow through it. This makes zener diodes useful for power regulation.

2) The difference between an LED and a regular diode is that an LED produces light when current is flowing through it and typically requires a higher voltage than the 1N-4007 diode to open up.

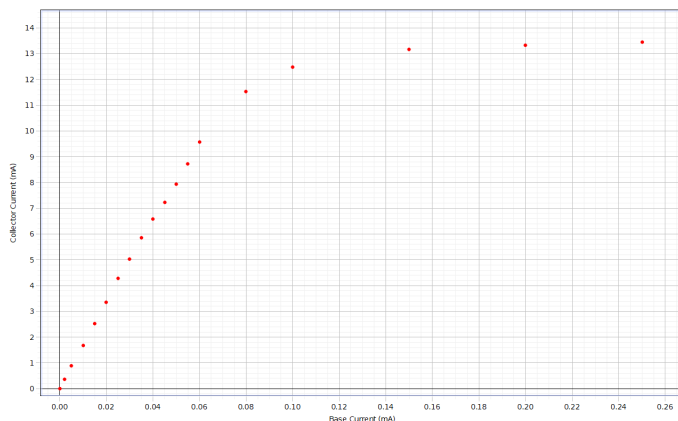
Exp. 10: Transistors

Analysis

1) A sample data set for the table has been provided below. In this case, $R_1 = 1 \text{ k}\Omega$ and $R_2 = 100 \text{ }\Omega$ for all rows.

$V_{AB} \text{ (V)}$	$I_B \text{ (mA)}$	$V_{CD} \text{ (V)}$	$I_C \text{ (mA)}$
0	0	0	0
0.002	0.002	0.0375	0.375
0.005	0.005	0.0883	0.883
0.010	0.010	0.1679	1.679
0.015	0.015	0.252	2.52
0.020	0.020	0.335	3.35
0.025	0.025	0.428	4.28
0.030	0.030	0.502	5.02
0.035	0.035	0.586	5.86
0.040	0.040	0.659	6.59
0.045	0.045	0.723	7.23
0.050	0.050	0.794	7.94
0.055	0.055	0.873	8.73
0.060	0.060	0.957	9.57
0.080	0.080	1.153	11.53
0.100	0.100	1.248	12.48
0.150	0.150	1.316	13.16
0.200	0.200	1.333	13.33
0.250	0.250	1.345	13.45

2) A plot of the sample data set:



Discussion

1) There is a straight line region extending from $V_{AB} = 0.002 \text{ V}$ to approximately 0.06 V . This region does not include the origin, since the junctions within the transistor require a nonzero voltage to turn on, similar to the diodes seen in Lab 9.

2) The leveling off of the graph represents the "saturation point". Beyond this point the transistor is acting like a short circuit, offering no resistance to the current; therefore, past this point there is no amplification and the current is limited only by the battery and resistor.

3) The slope of the straight line region in our sample data set is approximately 158; this value is equal to the amplification of the transistor. In other words, for this particular transistor, a change in I_B results in a change 158 times larger in I_C . Note that this value will vary from transistor to transistor; for the 2N3904 transistors used in this lab, the amplification is usually between 150 and 250.

Extension

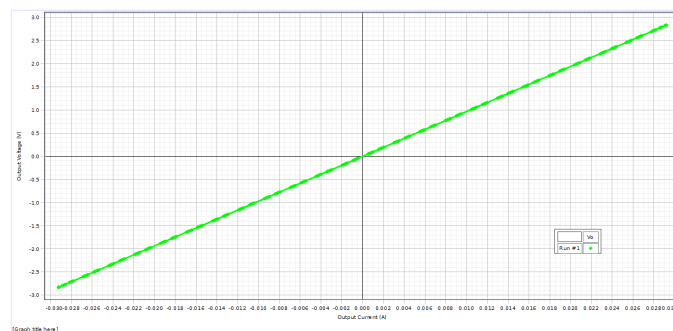
1) Changing the resistance R_2 would result in different values for saturation, as well as the amount of time it takes to reach saturation. In general, a greater resistance for R_2 will mean that the straight line region of the graph is shorter and that the saturation voltage is lower. However, the slope of the straight-line region would generally remain the same, indicating that the amplification of the transistor is unchanged.

2) Changing the transistor will likely result in a different amplification and/or saturation value; however, the overall shape of the graph will remain the same.

Exp. 11: Ohm's Law II

Part A - Data Recording

Your data should resemble the example shown below:



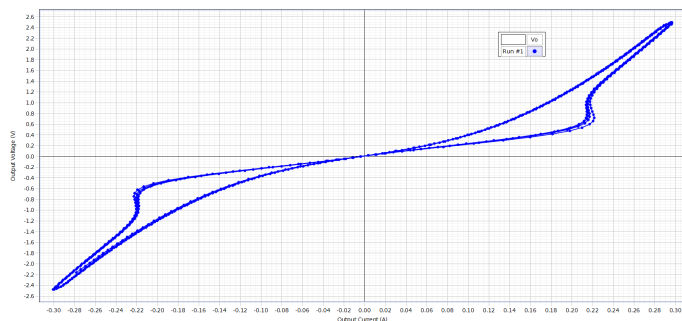
Part A - Analysis

1) Using a $10 \text{ }\Omega$ resistor, our sample data set has a slope of 10.1 volts/amp.

2) When replacing the $10 \text{ }\Omega$ resistor with a $100 \text{ }\Omega$ one, our new data set has a slope of 98.9 volts/amp.

Part B - Data Recording

2) Your data set for this section should resemble the sample shown here:



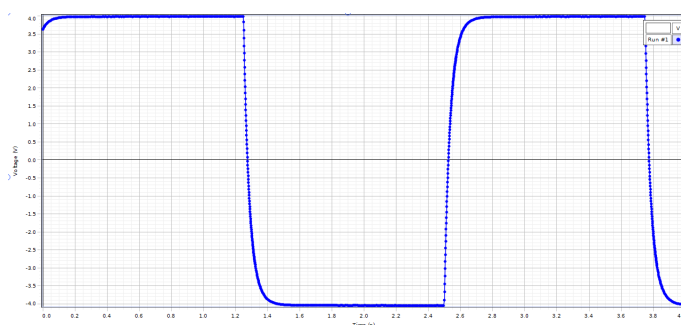
Discussion

- 1) For both the $10\ \Omega$ and $100\ \Omega$ resistors, the measured value of the slope is very close to the value of resistance, falling within the printed tolerance.
- 2) The light bulb's data changes its slope over time because of the change in resistance due to temperature. As the filament heats up while voltage is applied and current flows through it, the resistance of the wire increases, causing the slope of the data to increase as well; as the filament cools while voltage decreases to 0, the resistance of the wire decreases, causing the slope to decrease as well.
- 3) The resistor does have a constant resistance, due to being constructed of material which requires a large amount of energy to significantly change its temperature. The light bulb does not have a constant resistance, since the filament needs to be able to easily change temperature- and thus resistance- in order to be quickly turned on and off. In general, the more energy is required to change a conducting material's temperature, the more consistent the resistance of that material will be.
- 4) The reason for the asymmetry is because the filament does not disperse heat at the same rate at which its temperature increases. If the frequency were significantly reduced to much less than 1 Hz, so that the filament has more time to respond to changes in temperature, the gap between the two paths would close and the plot would follow the same curve in both directions.

Exp. 12: RC Circuit

Data Recording

Your collected data should resemble what is shown below.



Analysis

1-2) For a sample data set, our values are:

- Beginning time = 1.275 s
- Time to 2.0 V = 1.300 s
- $t_{1/2} = 0.026\text{ s}$

3) Given the equation $t_{1/2} = (0.693)RC$, we find that capacitance is given by $C = t_{1/2}/(0.693 \cdot R) = 375\ \mu\text{F}$.

4) Using the Percent Difference Method, we find that the measured value of the capacitance is approximately 13.6% different from the printed value. This falls within the $\pm 20\%$ margin of error for capacitors.

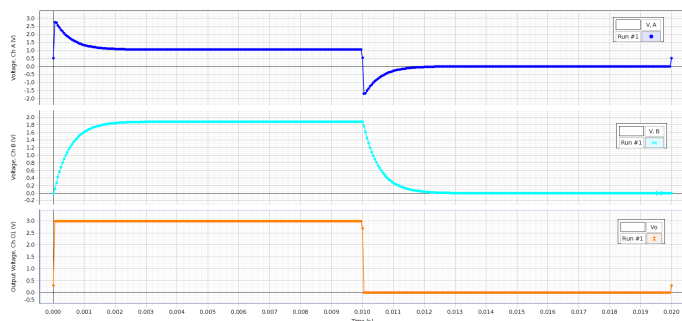
Discussion

- 1) Based on sample data, the time required for the capacitor to reach 75% of the maximum charge is 0.052 seconds, or twice the value of $t_{1/2}$.
- 2) After four half-lives, the capacitor should be charged to approximately 93.75% of its maximum charge, since each interval of $t_{1/2}$ has the capacitor gain half as much charge as it did in the previous interval of $t_{1/2}$.
- 3) The charge on the capacitor is equal to $q = CV$; therefore, the maximum charge can be found with $q_0 = CV_{\text{max}} = (375\ \mu\text{F})(4.0\text{ V}) = 0.0015\text{ C}$, or 1.5 mC (millicoulombs).
- 4) Some possible causes of the error in the capacitance include the internal resistance of the wires and Universal Interface, impurities in the composition of the capacitor, and differences between the printed and actual resistance of the resistor used.

Exp. 13: LR Circuit

Data Recording

Your graphs should generally resemble what is shown below.



Analysis

Below is a completed version of the data table created using a sample data set.

Inductor Resistance	5.7 Ω
Resistor Resistance	10.0 Ω
Inductance	0.008017 H
Peak V_R	1.881 V
Time at Peak V_R	0.00355 sec
Time at Half-Max Voltage	0.00037 sec
Time to reach Half-Max	0.00032 sec
Experimental τ	0.00046
Theoretical τ	0.00051

Discussion

- 1) Using our sample data set, we obtain an error of approximately 9.8% between our experimental value and theoretical value of τ . This is considered an acceptable margin of error for such circuits.
- 2) Yes, Kirchhoff's Loop Rule holds at all times. At any point on the graph, the value of $V_L + V_R$ should equal the value of the output voltage at that same point.
- 3) The reason V_L and V_R do not go to the expected values is the internal resistance of the inductor. Our initial estimates assumed that the inductor had no resistance and was a perfect conductor. In reality, because the inductor has some amount of internal resistance (5.7 Ω in the case of our sample data), there will be a non-zero voltage drop across the inductor even after the voltage stabilizes; therefore, due to Kirchhoff's loop rules, the peak voltage across the resistor will also not be equal to V_0 as expected.

Extension

The values of the inductor and resistor resistances are the same as in the Analysis.

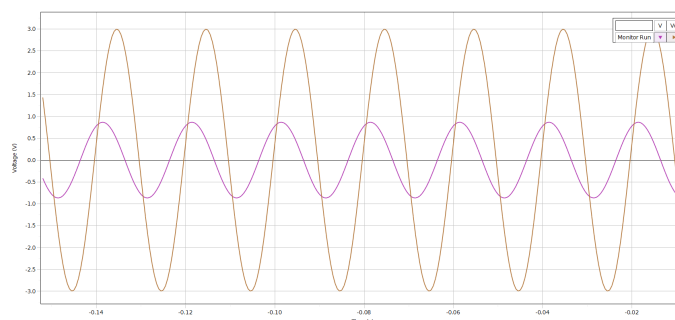
Peak V_R	1.840 V
Time at Peak V_R	0.00920 sec
Time at Half-Max Voltage	0.00124 sec
Time to reach Half-Max	0.00119 sec
Calculated τ	0.00172

Given that $\tau = L/R$, we can use our calculated τ value to identify that $L = 0.027$ H, or 27 millihenries.

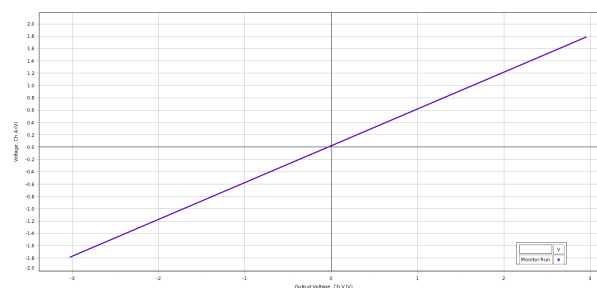
Exp. 14: LRC Circuit

Data Recording

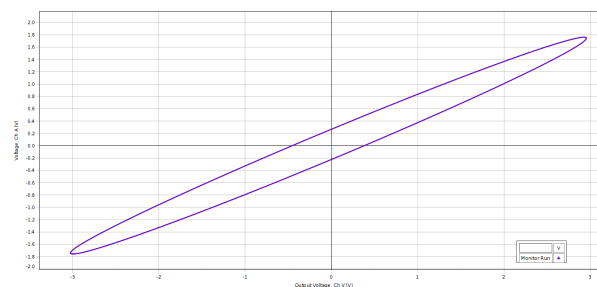
During Steps 1 through 5, your data should broadly resemble what is shown below.



When the voltages in Step 8 are in phase, the Scope display will show a diagonal line:

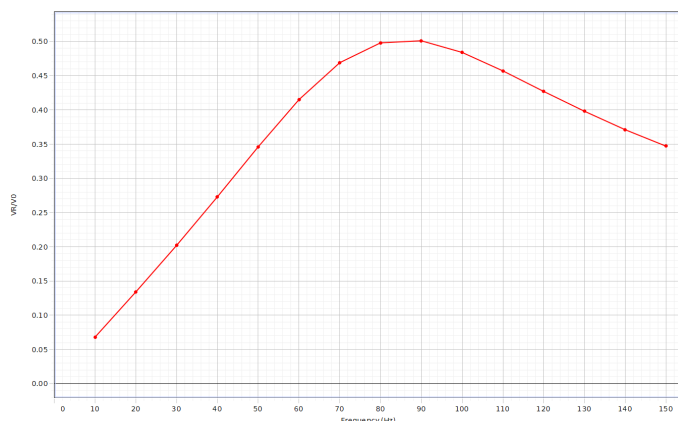


When the voltages are out of phase, the Scope display will instead show an oval:



Analysis

1) Your plot of V_R/V_0 should resemble what is shown below.



2-3) See Table 14.2 sample data.

Data Tables

Table 14.1

Frequency (Hz)	V_0 (V)	V_R (V)
10	3.006	0.205
20	3.006	0.403
30	3.006	0.607
40	3.006	0.820
50	3.006	1.039
60	3.006	1.247
...		

Table 14.2

Item	Value
Resonant frequency	88.5 Hz
Resonant angular frequency	556.1 Hz
Inductance	27.3 mH
Capacitance	97 μ F
Theoretical resonant angular frequency	614.5 Hz

Discussion

1) Our sample data indicates a percent difference of 9.5% between the actual and theoretical resonant angular frequencies. This is considered an acceptable margin of error, due to the iron core causing uncertainties in the inductance value.

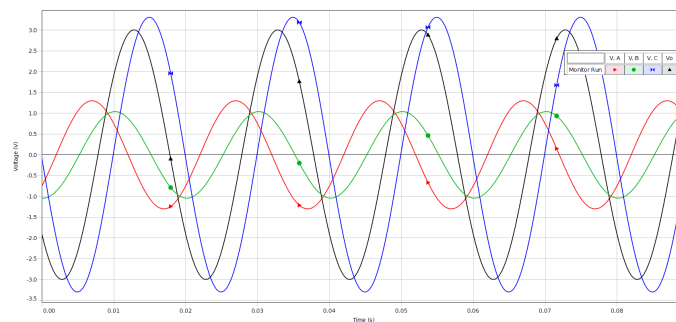
2) No, the plot of V_R/V_0 vs. linear frequency will not be symmetrical about the resonant frequency; instead, the ratio of resistor voltage to output voltage will decrease more gradually as frequency increases above the resonant frequency than it does as frequency decreases below the resonant frequency. This is because the resistor voltage- and thus the ratio V_R/V_0 - goes to zero at frequencies of 0 Hz and infinity; therefore, the portion of the graph which goes to zero at 0 Hz will do so much more quickly than the portion which goes to zero at infinity.

3) In the case of our experiment, the amplitude of current at the resonant frequency (88.5 Hz) is 0.152 A. Therefore, $R = V/I$ gives us a total resistance of 19.77 Ω , which is not equal to the 10 Ω resistance of the resistor. The reason for the discrepancy is because the other components, such as the inductor and the wires, have their own internal resistances which add to the resistance of the circuit.

Extension

1) No, the resistance does not seem to have a significant effect on the resonant frequency; changing out the resistors should still produce a straight line on the V_0 versus V_R graph. This is reflected in the equation for resonant frequency, which only depends on capacitance and inductance.

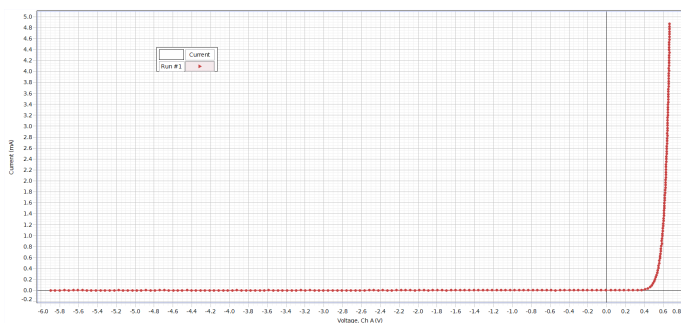
2) The reason the peak voltages add up to more than the peak output voltage is because the components are out of phase with each other; the peak voltages across the inductor, resistor, and capacitor each occur at different points within a single "cycle". Specifically, the resistor is always in phase with the current; the inductor is always 90 degrees ahead of the current; and the capacitor is always 90 degrees behind the current. At any given point in time, the sum of the voltages across each component will equal the total voltage across the circuit. See the example image below, in which the red curve represents the inductor, the green curve the resistor, the blue curve the capacitor, and the black curve the output voltage from the interface.



Exp. 15: Diode Lab - Part One

Analysis - Section 1

Your collected data should approximately match the data shown below.



Analysis - Section 2

Below are sample data sets for Tables 15.1 and 15.2, covering all Analysis sections for this experiment.

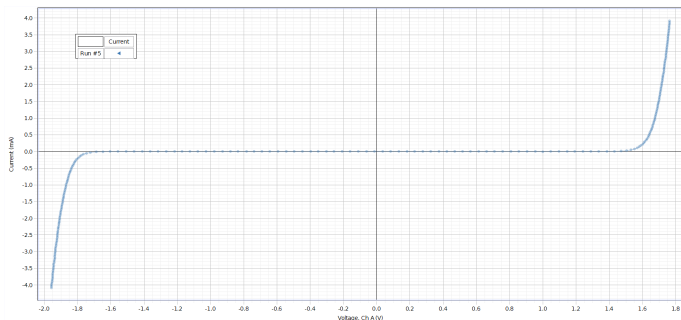
Table 15.1

Description	Voltage (V) when 2 mA reached
N1-4007 Diode	0.623
Red LED	1.782
Yellow LED	1.8025
Green LED	1.881

Table 15.2

Description	2 mA Voltage (V)	-2 mA Voltage (V)
Bi-Color LED	1.711	-1.906

Your data collected from the bi-color LED should resemble what is shown below.



Discussion

1) The plot produced in Section 1 implies that, as the theory suggests, current is only able to flow through the diode in one direction, when the voltage across it is

positive, and that a small amount of positive voltage (in this case, a little over 0.6 V) is required to allow current to flow freely through the diode.

2) The red LED has the lowest turn-on voltage, while the green LED has the highest.

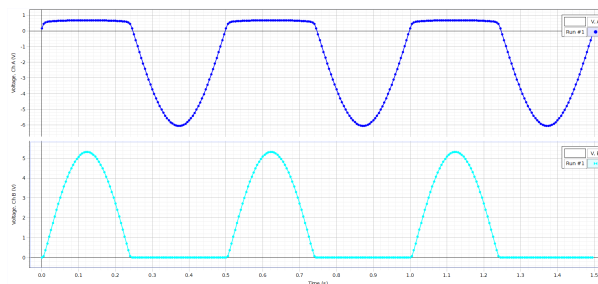
3) The bi-color LED's forward turn-on voltage is lower than that of any of the single color LEDs. By contrast, its breakdown voltage is higher than the forward voltage of any of the single color LEDs.

4) A typical zener diode operates similarly to a bi-color LED, allowing current to pass mostly freely through it in one direction but requiring a certain reverse voltage to allow current through the other way; however, the forward voltage is usually significantly lower than the "breakdown" voltage for a zener diode, whereas for a bi-color LED the two values are very close to each other. A typical zener diode also does not produce light, unlike an LED.

Exp. 16: Diode Lab - Part Two

Data Recording: Rectifying a Sine Wave with a Diode

Your data from this section should resemble what is shown below.

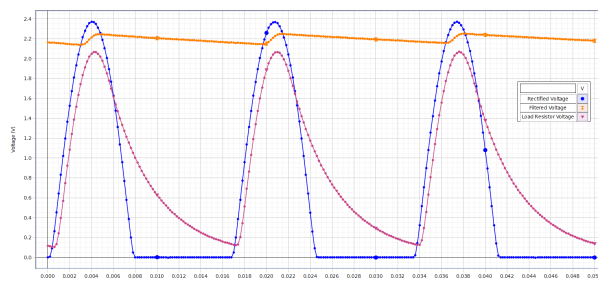


Analysis: Rectifying a Sine Wave with an LED

1) Students should observe that the color LED's graph includes higher plateaus in the diode voltage and shorter peaks in the resistor voltage, as the color LEDs were found in the last lab to have a greater turn-on voltage than the N1-4007 diode.

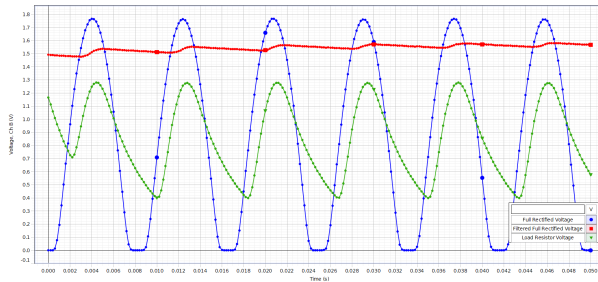
Analysis: Power Supply, Single Diode

Plotted together, your results from this section should resemble the graph shown below.



Analysis: Power Supply, Four Diode Bridge

Plotted together, your results from this section should resemble the graph shown below.



Discussion

1-2) When the plots of voltage across the diode and voltage across the resistor are added together, they form a complete sine wave equivalent to the output voltage. The structure of these graphs can be explained by the diode preventing current from flowing backwards through it: the plateaus in the diode voltage and peaks in the resistor voltage represent times when current is able to flow through the diode, whereas the negative peaks in the diode voltage and the plateaus at 0 in the resistor voltage represent times when the current is blocked by the diode.

3) See "Analysis: Rectifying a Sine Wave with an LED".

4) When the $470\ \mu\text{F}$ capacitor is added, the peaks of the plot are significantly spread out, greatly reducing the time at the minimum voltage; the range of voltages is also reduced, so that the difference between the maximum and minimum voltage is much smaller. The reason why the capacitor is considered a filter is because it essentially "filters out" the lower voltages supplied by the voltage source, providing a steadier current.

5) When the $10\ \Omega$ resistor is added, the plot of voltage assumes a shape in-between those of the previous two runs. The range of voltages across the resistor is almost as large as it was at the start, but there are no longer long stretches where the voltage across the resistor is 0; the capacitor ensures that there is always at least a small amount of current flowing through the resistor.

6) The initial plot of voltage in the four diode bridge has a similar structure to the diode voltage from Section 1, consisting of positive peaks separated by sections in which the voltage across the resistor is 0. However, the maximum voltage across the resistor here is smaller than the maximum voltage across the resistor in the single diode circuit; in addition, the frequency of these peaks is greater, with less time spent at 0 V between them.

7) When the $470\ \mu\text{F}$ capacitor is added, the peaks of the plot are spread out significantly; the range of the voltages is also greatly reduced from the previous run. This plot has a similar structure to the filtered plot from Section 4A

but includes an even narrower range of values.

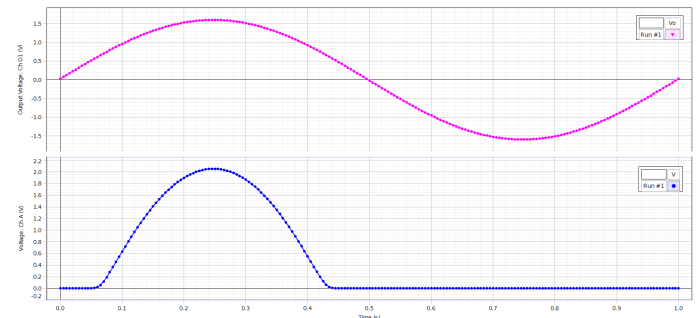
8) When the $10\ \Omega$ resistor is added, the plot of voltage changes to one between the rectified and filtered plots; the voltage no longer approaches zero at any point, remaining in a nonzero range at all times. Much like in the previous question, this plot shares a structure with the corresponding plot in Section 4A but fluctuates over a smaller range of voltages, varying by less than 1 V.

9) The diode bridge is better at providing a steady, constant current than the single diode circuit, since the voltage across the bridge fluctuates only about half as much as the voltage across the diode in the single diode circuit; the diode bridge also has a higher minimum voltage than the minimum in the single diode circuit.

Exp. 17: Transistor Lab 1

Data Collection

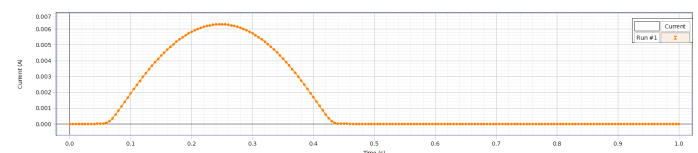
Your collected data should resemble what is shown below.



Analysis

1-2) For our sample data set, the voltage across the resistor starts to increase at 0.055 seconds. At this time, the output voltage is **0.566 V**.

3-5) Your graph of Current vs. time should resemble what is shown below. Using a multimeter, we determined that the resistance of the resistor was $327\ \Omega$. As V_B increases above the value necessary to allow current to flow through the collector, the current begins to follow a similar path to V_R , forming a single peak before returning to 0, as seen below.



Discussion

1) While the circuit is active, the LED is lit when V_B is large enough to allow current to flow from the collector to the emitter; when V_B is not large enough, the LED is unlit.

2) The plot for V_B forms a consistent sine wave, whereas the voltage V_R across the resistor forms a single peak

within the range for which V_B is greater than or equal to 0.566 V, but is 0 outside this range. The peak value of V_R is greater than the peak value of V_B .

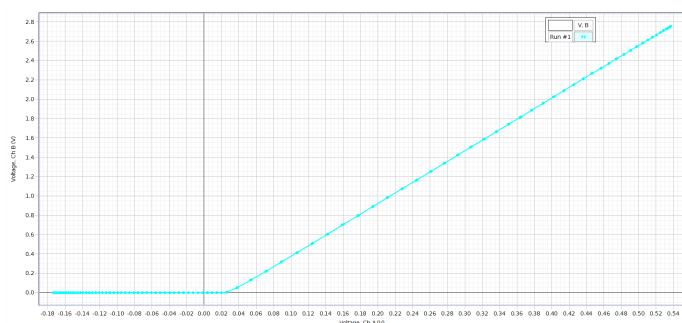
3) The LED turns on at around $V_B = 0.566$ V, the same voltage at which current begins to flow through the collector to the emitter.

4) In general, the current from the collector to the emitter behaves similarly to the voltage across the resistor. The value of current is 0 for any value of V_B less than 0.566 V, and it rises to a peak of 6.3 mA as V_B increases past 0.566 V to its peak voltage before declining again.

Exp. 18: Transistor Lab 2

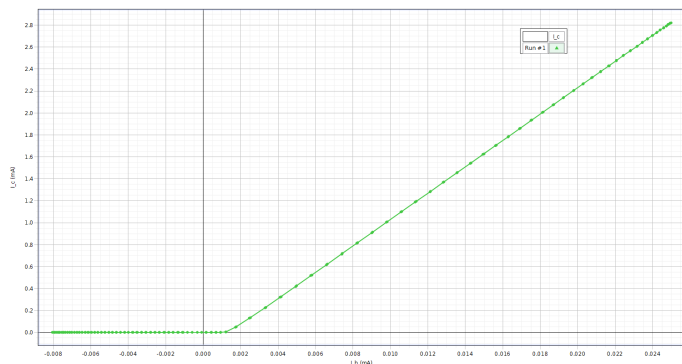
Data Recording

The collected data should resemble what is shown below.



Analysis

3-6) The plot of I_c versus I_b for a sample data set is shown below. The resistances measured for this run were 327Ω and $21.5 \text{ k}\Omega$. In this case, the slope of the diagonal region is given as $m = 120$; therefore, the current gain β is also equal to 120.



Discussion

1) The shape of the plot of I_c versus the voltage from Channel A should maintain the same general shape as the graph of I_c versus I_b . This graph broadly resembles the plot of current versus voltage for a diode; in both cases, the current remains at zero until a certain voltage threshold is reached, at which point current begins to increase. However, unlike in the diode, where reaching the turn-on voltage caused the diode to begin acting as a

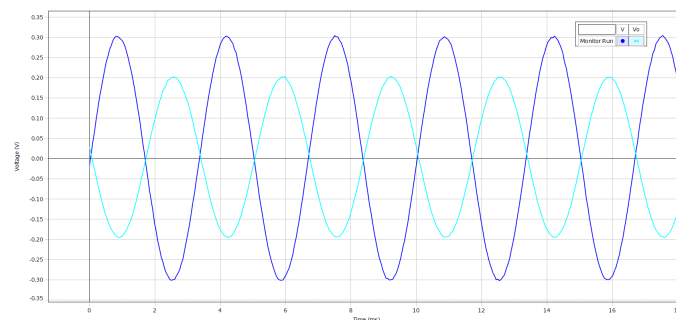
short circuit, the increase in I_c is linear, gradually increasing in response to an increase in the voltage supplied to the base.

2) As seen in the Analysis portion, the current gain of this transistor is 120. This does indeed make sense, since the gain of a typical *npn* transistor is usually around 100, as stated in the Theory section of Experiment 17.

Exp. 19: Transistor Lab 3

Data Recording

3) The captured traces should resemble what is shown below.



4) For a sample data set, the peak values of V_0 and V_A are:

Voltage (peak) of V_0 : 0.202 V

Voltage (peak) of V_A : 0.317 V

Analysis

1) The ratio of input voltage to output voltage is given by $V_{in}/V_{out} = 0.63$.

2) Using the provided equation, we find that the theoretical output voltage is given by $V_{out} = -0.2 \text{ V} * (2000 \Omega / 1000 \Omega) = -0.4 \text{ V}$.

Discussion

1) The input signal and output signal are approximately 180 degrees out of phase with each other; this can be explained by the theoretical output voltage equation, which shows that the output voltage will always be the opposite sign of the input voltage.

2) There is a fairly substantial difference between the measured and theoretical output voltages, with a percent error of approximately 20.8%. Some possible causes of this error include the internal resistances of components such as the wires, the introduction of the voltage sensor into the circuit, and effects of the charged capacitors on the flow of current.

Extension Questions

1) As the input amplitude is increased, the output amplitude also increases by an amount which preserves the voltage gain; therefore, however much the peak voltage of V_0 is increased by, the peak voltage of V_A

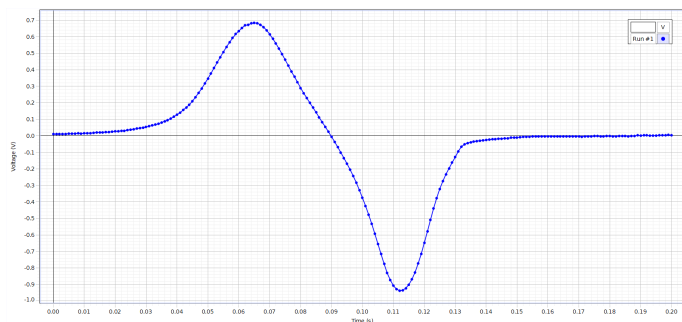
increases by that amount times approximately 1.5 (the inverse of 0.66).

2) The voltage gain of the amplifier is independent of the frequency; no matter how much frequency is increased, the amplitude of both the input and output voltages will remain the same, meaning the gain is not changed.

Exp. 20: Induction

Data Recording

Your data should generally resemble what is shown below.



Analysis

2-3) The area under the peaks for our sample data is:

$$\text{Area (first peak)} = 0.021 \text{ V}\cdot\text{s}$$

$$\text{Area (second peak)} = -0.021 \text{ V}\cdot\text{s}$$

Discussion

1) Within acceptable margins of error, the incoming flux and outgoing flux are indeed equal.

2) The height of each peak is determined by the velocity of the magnet at the moment the peak's maximum is reached. Because the magnet is in free fall, its velocity will be greater when the second peak is induced than it was when the first peak was induced, and thus a greater voltage will be induced and the peak will be taller.

3) The reason the peaks are in opposite directions is because, according to the equation for magnetic flux seen in the Theory section, the voltage produced by the magnet is proportional to the change in magnetic flux over time. The first peak is produced by the magnet falling into the coil, during which the magnetic flux is increasing; this causes the coil to generate an EMF to counteract the flux, leading to a positive voltage being measured. The second peak is produced by the magnet exiting the coil, during which the flux is decreasing; this causes the coil to generate an EMF in the opposite direction to resist the change in flux, leading to negative voltages being measured.

Extension

1) When two identical bar magnets are pressed together with the corresponding sides connected, they produce a magnetic flux twice as strong as the original flux.

Therefore, when the two magnets are dropped through the coil from the same height as in the initial experiment, they produce peaks which are approximately twice as tall as those you observed during Data Collection.

2) When two identical bar magnets are pressed together with the *opposite* sides connected, the two magnetic fields will mostly cancel each other out, as the north pole of one magnet is now directly adjacent to the equally powerful south pole of the other. Therefore, when the magnets are dropped through the coil, they will induce only a negligible voltage in the circuit.

3) In general, you will notice that a change in height will affect the shape of the curves. The higher the magnet is above the coil when it is released, the faster it will be traveling when it passes through the coil; therefore, magnets falling from a greater height will produce taller and narrower curves than those dropped from just above the coil.