Introduction

Preparation: Before coming to lab, read the lab handout and Giancoli Chapter 19, sections 19-1 through 19-3 plus section 19-8. Then prepare your pre-lab. Preparing a thorough pre-lab is especially important for your success with this experiment so your TF will check your pre-lab at the beginning of the lab section. The pre-lab must include a sketch of each circuit and preliminary answer to the bold questions. Be sure to leave plenty of extra space between answers. In the lab you will use this space for your observations as you build and test each circuit, and for revisions or final corrections to the bold questions if needed. Note questions 21, 26, 32, 34, and 35 cannot be answered until you take data in the lab. When you finish the lab, hand in one document that contains your pre-lab, your observations and your answers to all the bold questions. All tasks to be performed in the lab appear in italics throughout this handout. Be sure to bring writing paper, graph paper, a ruler, a calculator and your copy of the Lab Companion to the lab.

Objective: In part I, series and parallel circuits will be studied using light bulbs. In Part II, Kirchhoff’s Rules will be verified using carbon resistors. Finally, ohmic and nonohmic devices will be investigated with a variable voltage divider.

Theory

If two circuit elements are in series, the same current must flow through them.

If two circuit elements are in parallel, the voltage across each element is the same.

At any junction, the current that flows in will equal the current that flows out.

For any loop in a circuit, the sum of the voltage changes around the loop is zero.

The voltage change across a resistor is negative if the change is in the direction of the current flow (a voltage drop).

The voltage change across a resistor is positive if the change is in a direction opposite to the current flow (a voltage rise).

An Ohmic device is one which obeys Ohm’s Law, \( V = IR \), where \( R \) is constant. A non-Ohmic device is one that does not have a constant resistance. A light bulb is a simple example; the filament undergoes huge changes in temperature when current passes through it. Therefore, the resistance of the filament is not constant, rather, it increases with increased current.
Part I: Qualitative Measurements with Light Bulbs

Circuit 1. The Single Bulb Circuit

In the following qualitative experiments, we will assume that if more current flows through a light bulb, it glows brighter. In Part II, circuit 8 we will test this assumption.

Examine any standard light bulb made with clear glass. Suitable light bulbs are available in the help room for prelab inspection if needed.

1→How many conductors are on the outside of the bulb? How many insulators are in the bulb?

2→How many wires connect to the filament? Do they go to the same place?

3→ Draw a sketch of your bulb clearly showing which parts of the bulb are conductors and which parts are insulators.

4→Examine the light bulb socket: How does it work? Draw a sketch of the socket.

Now build circuit 1. The bulb should light when the switch is closed. The brightness of this bulb will be used as a standard of comparison in subsequent circuits.

→Caution: Be careful not to short-circuit the battery! Never, directly connect the battery terminals to each other through a wire. Also in order to avoid draining your battery; please open the switch as soon as measurements and observations have been made!

5→Will the same result be achieved if the direction of the current is reversed? Explain.

Remember that “conventional” current flows from high to low potential (except in the battery!).

Switch the wires at the battery. Can you observe any difference?

Leave Circuit 1 hooked up. You will need it for comparison below.
Circuit 2. The Two-Bulb Series Circuit

Now let’s consider a more complicated circuit — the series circuit. Refer to the diagrams of circuits 1 and 2 for the following discussion. First, consider circuit 2. Bulbs A and B are in series. The bulbs and the battery form a single loop. In such a circuit, the current is the same through each circuit element.

6→Given that the bulbs and batteries in both circuits 1 and 2 are identical, rank what you would expect the order of brightness of the bulbs to be when the switch is closed. That is, relate the brightness of A, B, and C with >, <, or = signs. Explain.

7→What happens if you unscrew one of the bulbs in circuit 2? What would happen if you short out one of the bulbs? How does the brightness of the unshorted bulb compare to that of the single bulb C in circuit 1?

8→What would you predict for the brightness of the bulbs if a third bulb were added in series with A and B? Explain your reasoning.

9→For a given battery, does the same amount of current always flow or does it depend on the particular circuit connected to it? Explain your reasoning.

Build circuit 2 and check your answers. If any answer differs from your pre-lab please discuss it.

Circuit 3. The Two Bulb Parallel Circuit

A second way two bulbs can be connected in a circuit is as shown in circuit 3. Bulbs D and E are connected in parallel. Again, let’s compare this new circuit to circuit 1.

10→Rank the brightness of bulbs C, D and E using >, <, or = signs when the switch is closed. Explain your reasoning.

11→Would removing one bulb change the brightness of the other bulb? Explain.
12→Will the total current through the battery increase, decrease, or stay the same when you unscrew one bulb? Explain.

Build circuit 3 and check your answers. If any answer differs from your pre-lab please discuss it.

13→Suppose we were to increase the number of bulbs to three. What would happen to the brightness of each bulb? Explain.

Add a third bulb to Circuit 3 to check your answer. If your answer differs from your pre-lab please discuss it.

14→Would you say your battery is a constant voltage source or a constant current source? Explain.

Circuit 4. The Three Bulb Series Parallel Circuit

Now you can combine the knowledge gained in the one and two bulbs circuits. Consider circuit 4. With the switch 2 open and switch 1 closed, this circuit is identical to Circuit 2. However, a third bulb F can be added in parallel with bulb B by closing switch 2.

15→Rank the brightness of bulbs A, B and F using >, <, or = signs when switch number 1 is closed. Explain your reasoning.

16→The brightness of bulb A indicates the total current in the circuit. Will the total current in the circuit increase, decrease, or stay the same when switch number 2 is closed and bulb F is added to the circuit? Explain.

17→Did the total resistance of the circuit increase, decrease, or remain the same when F was added? Explain.

18→What happens to the current at the junction marked “a”? Explain.

Build circuit 4 and check your answers. If any answer differs from your pre-lab please discuss it.
Part II: Quantitative Measurements With Multimeters

Introduction to the Multimeter

For this part of the lab, you use two multimeters. You will use a digital meter to measure voltage and an analog meter to measure current. You can also use either meter as an ohmmeter to measure the values of resistors or to check for continuity between components.

The accuracy of each meter is assumed to be one percent of the full-scale reading. The internal resistance or (input resistance) of the digital meter in the voltage measuring mode is about $10^6$ ohms. The internal resistance of the analog meter in the current mode is one ohm on the 500mA scale; greater on the other scales See Giancoli, section 19-8, pages 541-545, to learn more about multimeters and how they work.

→ Note: To reduce the risk of damaging the voltmeters and ammeters, there are some basic rules to be aware of before continuing with this part of the lab:

1. **ALWAYS SET YOUR METER TO THE HIGHEST SCALE (LEAST SENSITIVE) WHEN MEASURING AN UNKNOWN CURRENT OR VOLTAGE AND THEN WORK YOUR WAY DOWN TO LOWER (MORE SENSITIVE) SCALES!**

2. When measuring current, you measure the flow of current THROUGH a circuit component; the meter is therefore put in series with the circuit. The internal resistance of the analog meter in the current mode is about an ohm, essentially a short circuit. **IT IS THEREFORE VERY IMPORTANT TO HAVE ENOUGH RESISTANCE IN SERIES WITH THE METER TO LIMIT THE CURRENT THROUGH THE METER! IF YOU'RE NOT SURE, ASK YOUR TF TO CHECK YOUR CIRCUIT.**

3. When measuring voltage you always measure **across** a circuit element. For example, you might measure the voltage drop from one side of a resistor to the other.

4. When using a meter to measure resistance, you isolate the component of interest from the rest of the circuit. If the component is not isolated, you might be measuring the resistance of the rest of the circuit.

5. **WHEN MEASURING OHMS, ALWAYS MAKE SURE THAT THERE IS NO VOLTAGE APPLIED TO THE COMPONENT YOU ARE TESTING!**

6. When you have finished making measurements on all of your circuits, please turn the meters off.
Circuit 5. The Series Circuit: One Resistor

19→ Using the component values shown in the figure, predict how much current will flow through the ammeter when the switch is closed.

20→ What will the voltmeter read? Explain.

Build circuit 5 and check your answers. If any answer differs from your pre-lab please discuss it.

21→ Calculate the power dissipated in $R_1$ from your measured values.

Circuit 6. The Series Circuit: Two Resistors

22→ Using the component values shown in the figure, predict how much current will flow through the ammeter when the switch is closed. Compare this with the current predicted for Circuit 5. Explain.

23→ Predict the voltage drop across $R_2$ ($V_{ab}$).

24→ Predict the voltage drop across $R_3$ ($V_{bc}$).

25→ Using Kirchhoff’s Loop Rule, predict the relationship between $V_{ab}$, $V_{bc}$, and $V_{bat}$, the voltage across the battery.

Build circuit 6. And check your answers. If any answer differs from your pre-lab please discuss it.

26→ Using your measurements, calculate the actual values of $R_2$ and $R_3$. Do your results fall within the values specified by the manufacturer? (Consult the appendix for information about how to determine resistor values and tolerances from color code markings).

Circuits such as number 6 are often called voltage dividers. If we had a series of ten resistors, we would have ten different voltages available. In circuit 8, you will use a variable resistor (potentiometer) as a continuously variable voltage source.
**Circuit 7. The Parallel Circuit**

27→ Predict the current through R₄ (I₄) when the switch is closed.

28→ Predict the current through R₅ (I₅) when the switch is closed.

29→ Predict the current flow through the battery (I_total) when the switch is closed.

30→ Using Kirchhoff's Junction Rule, predict the relationship between I₄, I₅ and I_total.

31→ Using resistor-addition rules, calculate the equivalent resistance for R₄ in parallel with R₅.

*Build circuit 7 and check your answers by measuring I₄, I₅, I_total, and V. If any answer differs from your pre-lab please discuss it.*

32→ Using measured values for I_total and V, determine the circuits equivalent resistance and compare with the result from question 31.

→ CAUTION: NEVER CONNECT THE AMMETER’S LEADS DIRECTLY ACROSS THE BATTERY! HAVE YOUR TF CHECK THIS CIRCUIT BEFORE YOU CLOSE THE SWITCH.

**Circuit 8. Potentiometers and Variable Voltage Circuits**

In Circuit 8 the potentiometer Rᵥ behaves as a variable voltage divider. The resistance between points d and f is adjusted by changing the location of the center contact. The resistance between points d and e is fixed at 25 ohms, while the resistance between d and f varies from 0 to 25 ohms. If a voltage is applied across the potentiometer, any percentage of that voltage will be applied to the center terminal f. That is, if V_de = 6.5 volts, then V_fe can be set to any voltage between 0 and 6.5 volts. The volume control on your radio is an example of a potentiometer.
33→ Predict the maximum current flow through R₆ when the switch is closed. Explain.

Build Circuit 8. Use the potentiometer to vary the voltage V applied across R₆, so that you can measure I₆ as a function of applied voltage. Take about ten readings and then construct a graph of current versus voltage. Plot the current, I₆ on the vertical axis, and the voltage Vₑ on the horizontal axis. The axes should be divided into convenient intervals and span the full range of Vₑ from 0 to 6.5V, and I₆ from 0 to I₆ max. To save time you may ignore error analysis and error bars for this graph. You should get a straight line, showing that the resistor follows Ohm’s law.

34→ From the slope of the graph, determine the actual value of R₆. Compare with the nominal range specified by the manufacturer.

Note → The equation V = IR means that V must be expressed in volts, I in amperes, and R in ohms. Mixing units leads to trouble. In addition, since you plotted I on the vertical axis and V on the horizontal axis, the rise has units of Amperes and the run units of Volts. The slope, therefore, has units of Amperes/Volt which equal 1/ohms, so the next step is to take the reciprocal of that slope to obtain the resistance.

Next, replace R₆ with one of your light bulbs. Again take several readings and plot I versus V on the same sheet of graph paper used above

35→ Compare your two curves. Is the light bulb an ohmic or non-ohmic component? Explain.
Appendix: Circuit Symbols

This is a carbon resistor. It has four colored stripes, A, B, C, and D, clustered toward one end. For the first three stripes, each color corresponds to a digit from 0 to 9. This correspondence is as follows:

<table>
<thead>
<tr>
<th>Color</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>0</td>
</tr>
<tr>
<td>Brown</td>
<td>1</td>
</tr>
<tr>
<td>Red</td>
<td>2</td>
</tr>
<tr>
<td>Orange</td>
<td>3</td>
</tr>
<tr>
<td>Yellow</td>
<td>4</td>
</tr>
<tr>
<td>Green</td>
<td>5</td>
</tr>
<tr>
<td>Blue</td>
<td>6</td>
</tr>
<tr>
<td>Violet</td>
<td>7</td>
</tr>
<tr>
<td>Gray</td>
<td>8</td>
</tr>
<tr>
<td>White</td>
<td>9</td>
</tr>
</tbody>
</table>

The first two stripes A and B (those closest to the end of the resistor), give the first two digits of the resistance; the third stripe, C, tells how many zeros to add on after A and B. For example, brown-green-black is 15 ohms, yellow-violet-orange is 47,000 ohms. The fourth band, D, shows the precision of the resistor. A gold stripe indicates that the resistor is within 5% of its advertised value, a silver stripe 10%.