Complex Circuits

Introduction

In this laboratory you will connect electric lamps together in a variety of circuits. The purpose of these exercises is to extend your understanding of the “physics” of simple electrical circuits. That is, the purpose is for you to learn qualitative properties of circuits. There is an additional purpose, to help you learn the skills of being able to predict what you expect to happen, observe what happens, and correct the original misunderstanding, if necessary. What you learn in assembling, observing, and measuring the properties of these circuits will be applicable to the real-world electrical circuits you will meet on the job and in everyday life.

Note that, as in the last lab, you will be asked to make predictions, then measurements, and then to discuss how the predictions and measurements agreed. You will not be graded on the predictions, but rather on your measurements, observations, and discussion.

1. Series connections

a. A second type of bulb

Introduction

This week you will use two different types of bulbs. One has the number 425 on the base, the other 502. The first task is to find out how these two bulbs differ.

Procedure

• Construct a single-bulb circuit with the power supply set at 5 volts.
• Screw first one bulb into the socket and then the second type. Compare their brightnesses.

Prediction

Based on these observations which bulb do you think has more current flowing through it when 5V is applied across it? State a reason for your choice.
**Prediction**

Based on these observations and your answer to the previous question, which bulb do you think has a greater resistance under these conditions; that it, when both are powered by the same supply voltage, 5V? (This prediction should be consistent with the prior one. Is it?) Explain.

**Procedure cont.**

- Now you will measure each bulb’s resistance to see if you are correct. Make sure your DMM is configured to measure voltage. Use it to measure the voltage of the power supply and record the result in the *Table 1* below. (If you do not make any further adjustments to the supply voltage you can record this value as the measured supply voltage for each bulb.)

- Reconfigure the DMM to measure current using the 10Amp range rather than the 300mA range. Measure the current with each bulb placed in the socket in turn. Record your results in *Table 1* below. Make note of the units with all your measurements.

- Finally, calculate the resistance of each bulb under these operating conditions and record the results in the table.

<table>
<thead>
<tr>
<th>Bulb Type</th>
<th>Measured Supply Voltage</th>
<th>Measured Current</th>
<th>Calculated Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>#502</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#425</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 1*

- Recall from last week’s lab that a light bulb is non-ohmic. Its resistance depends on how hot it is, which depends on how much current is flowing through it. In light of this fact it very important that you state clearly the specific operating conditions under which the bulbs’ resistances are being compared.

In this comparison, in which both bulbs are powered by the same 5V supply voltage, which type of bulb has the most current flowing through it? Which bulb has the greatest resistance? Was your prediction correct?
b. Two different bulbs in series

Introduction You now know, when each type of bulb in powered individually by a 5V supply, which type is brighter, which draws more current and which has a higher resistance. You will now explore if this is enough information to predict how the two bulbs will behave when they are both wired into the same circuit in an arrangement that is called a series combination. A circuit with two bulbs in series is shown in Figure 1.

![Series Circuit Diagram](image)

Figure 1: Series Circuit

Prediction Predict which bulb will be brighter when the two lamps, one a 425 the other a 502, are connected in series and powered by a 5V supply voltage. Give a reason for your prediction based on your results in the previous section.

Procedure
- Now try the experiment. Construct the circuit shown in Figure 1. Again, set the power supply at 5 volts. Remember to put a 425 bulb in one socket and a 502 in the other.
- Describe what you observe and discuss any discrepancies with your predictions.
• There is a mystery here; one bulb is not emitting any light.

One possibility is that there is no current flowing through it. To test this hypothesis unscrew the bulb that doesn’t light. Describe what you observe and why this is evidence that current really was flowing through the unlit bulb.

The comparison made in the previous section was one in which the voltage dropped across each bulb was the same. Is that necessarily the case in this comparison? What quantity is the same for each bulb in this comparison? Explain.

Develop your own reasonable hypothesis to explain as fully as you can why the one bulb does not light when it is in series with the other bulb, but does light when it is the lone bulb in a circuit.

c. The equivalent resistance of a series combination

Introduction

Each bulb acts as an obstacle to the flow of charge and develops a potential drop across it. You can also consider the two bulbs in series as a single obstacle. There is a current through “it” and a potential difference across “it,” so “it” has a resistance. In this section you will explore how the resistance of this series combination compares with the resistances of each bulb.

Procedure

• With the two bulbs in series, determine the resistance of each bulb. Remember, since the resistance of a bulb depends on the current through it, you cannot use the ohmmeter setting of the DMM, or the measurements you made in the previous section, to find the resistances. Rather, you must make a new measurement of the current through the bulbs, and then measure the potential difference across each bulb.
• In the box below draw three separate circuits for the three different measurements you must make. Use only the following symbols as needed.

- dc Voltage Supply
- Incandescent Lamp
- Wire
- Current Meter (or ammeter)
- Voltage Meter (or voltmeter)

• Conduct the measurements, making sure to properly configure the DMM for each type of measurement. Use the 10Amp range for the current measurement. Record the results in Table 2 below, and then calculate the resistance of each bulb under these operating conditions.

<table>
<thead>
<tr>
<th>Bulb</th>
<th>Measured Bulb Current</th>
<th>Measured Bulb Voltage</th>
<th>Calculated Bulb Resistance (show work)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#502</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#425</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 2*

• What current and what voltage do you need to measure to experimentally determine the combined resistance of the two bulbs in series? In the box below describe the two measurements that need to be made and draw a circuit diagram for each.
• Carry out the measurements, record the results in Table 3 below, and calculate from your data the combined equivalent resistance of the two bulbs in series.

<table>
<thead>
<tr>
<th>Measured Current</th>
<th>Measured Voltage</th>
<th>Calculated Combined Resistance (show work)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 3*

• Compare the resistance of the series combination to the resistance of any one of the two bulbs; namely, is it smaller, equal to, or larger than either single bulb resistance?

• Do your results suggest a mathematical relationship between the individual resistances and the combined resistance? If so, what?
2. Parallel connections

a. Two bulbs in parallel

Introduction
In part 2 of this lab you will explore how bulbs behave when combined in a different type of circuit configuration called a parallel combination.

Prediction
Imagine the two circuits shown in Figure 2. All three bulbs are the same type. Bulb C in the circuit on the right is said to be “in parallel” with the bulb B.

![Figure 2: Single Bulb and Parallel Bulb Circuits](image)

Now, make a prediction. What will be the order of brightness of the three bulbs, A, B, and C? In other words, which will be brightest, second brightest, and least bright. You may also say that you think two or more bulbs will have the same brightness. Write down your prediction and a supporting reason.

Procedure
- Build the circuits, using #502 bulbs, and see. A good way to compare brightnesses, almost simultaneously, is to build only the circuit on the right and watch the brightness of B as you quickly connect and disconnect C. When C is disconnected bulb B behaves as bulb A would. Record the order of brightness. Any surprises?

- What can you conclude about the current in each of the parallel bulbs in comparison with the current through the single bulb? (Be careful with this question. Let your observations tell you the answer, not your preconceptions.)
• Let’s check this conclusion by making some current measurements. To help you make these measurements, change the wiring slightly to that shown in Figure 3 below. Use one clip lead or wire between points B and C and another between B and G. Then use a third one to connect to the power supply at A. Do the same for DE, EH, and EF. Make sure both bulbs light.

![Figure 3: Parallel Bulbs - Prediction](image)

**Prediction**

Before making a measurement, make a quantitative prediction. Suppose the current through the filament of the bulb labeled #1 is $i_1$. In the boxes shown in Figure 3, one for each wire, write your prediction for the current in every wire in terms of the current $i_1$. Discuss the predictions carefully with your partner.

**Procedure cont.**

• Measure the actual currents in the various branches of the circuit, and write down the results, with units, in the boxes shown in Figure 4 below. (Note that you will have to think carefully about making this measurement. To measure the current in wire AB you have to replace the wire with the ammeter. The same is true for the wire BC. Use the 10Amp range on the DMM for each of the six measurements.)

![Figure 4: Parallel Bulbs - Measured](image)

• Discuss any discrepancies between your predictions and your measurements.
b. Current in the branches

Introduction
In the parallel circuit you just studied each branch of the circuit contained an identical #502 bulb. Both bulbs were equally bright, had the same current, and the sum of their currents equaled the total supply current. In this section you will explore what happens when one of the branches is changed in some way so that it is different than the other branch. How does the change in one branch affect the other branch?

Prediction
Consider the previous circuit shown in Figure 3; both bulbs are type 502. Predict what would happen to the current through bulb #1 if you were to remove bulb #2 from its socket. Explain.

Prediction
Predict what would happen to the current through bulb #1 (a type 502) if you were to replace bulb #2 (also a type 502) with a type 425. Explain.

Procedure
- Try it. Unscrew bulb #2. What do you see? Does what you see agree with your prediction?
- With bulb #2 still unscrewed measure the current through bulb #1. Record your result here.
- While measuring the current through bulb #1 screw a 425 bulb into the #2 socket. What happens to the current through bulb #1?
- Measure the current through bulb #2, now a 425, and record the result.
• Also measure the current coming out of the positive terminal of the power supply. Record your result.

• Are the currents in the two branches, one containing a 502 bulb the other a 425 bulb, equal? Is their sum equal to the current from the supply? In other words, is Kirchhoff’s node law satisfied?

**Summarize**

Summarize what you have learned so far about parallel circuits with two branches by answering these three questions.

i) Describe how the currents in the branches of a parallel circuit compare to the total current.

ii) Describe how the current in one branch depends on the current in the other branch.

iii) Describe how the voltages across the two branches compare with each other and with the voltage produced by the power supply.

**Prediction**

What would happen if a third bulb was put in parallel with the other two? Pat, Leslie, and Robin disagree.

**Pat** says that the first two bulbs would get dimmer, because the current through them would decrease in order to satisfy Kirchhoff’s node law.

**Leslie** says that one-third of the current would go through the new bulb, so the currents through the other bulbs would adjust.

**Robin** says that the brightness of the first two bulbs wouldn’t change, because the power supply would supply whatever current was needed.
With whom do you agree? Use the knowledge you gained in the experiment above to write brief comments to the three students.

Comment to Pat:

Comment to Leslie:

Comment to Robin:

c. The equivalent resistance of a parallel combination

Introduction
Each bulb acts as an obstacle to the flow of charge and develops a potential drop across it. You can also consider the two bulbs in parallel as a single obstacle. There is a current through “it” and a potential drop across “it,” so “it” has a resistance. In this section you will explore how the resistance of this parallel combination compares with the resistances of each bulb.

Procedure
- Determine the resistance of the 502 and 425 bulbs while operating in parallel. You have made all the necessary current and voltage measurements previously. Compile your results in Table 4 below. Then calculate the resistance of each bulb. If you are unsure about any measurement, repeat it.

<table>
<thead>
<tr>
<th>Bulb</th>
<th>Measured Bulb Current</th>
<th>Measured Bulb Voltage</th>
<th>Calculated Bulb Resistance (show work)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#502</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#425</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4

- What current and what voltage do you need to measure to experimentally determine the combined resistance of the two bulbs in parallel? Describe the two measurements that need to be made. Draw a circuit diagram if you think that would help your explanation. If you have made them previously record your results immediately in Table 5 below; if not, make the measurements first and then calculate the combined resistance.
### Table 5

<table>
<thead>
<tr>
<th>Measured Current</th>
<th>Measured Voltage</th>
<th>Calculated Combined Resistance (show work)</th>
</tr>
</thead>
</table>

- Compare the resistance of the parallel combination to the resistance of any one of the two bulbs; namely, is it smaller, equal to, or larger than either single bulb resistance?

- Do your results suggest a mathematical relationship between the individual resistances and the combined resistance? If so, what?

### 3. Series-parallel circuits

**Introduction**

In the last part of this lab you will examine circuits that contain a combination of series and parallel components.

#### a. First look at a series-parallel circuit

**Prediction**

Consider the circuit shown in Figure 5. Assuming it is built with three identical bulbs, predict the order of brightness of the bulbs. Explain your reasoning.

![Figure 5: A series-parallel combination](image)

**Procedure**

- Construct the circuit in Figure 5, using three identical bulbs. Since this is the first time you have constructed a circuit from a schematic diagram, you might want to have the instructor check it.
- Is it really working? Try unscrewing either bulb B or C. Explain how this demonstrates that current actually flows through these bulbs.
• Why are these bulbs acting the way they are? How do the currents in bulbs B and C compare with that in A?

**Prediction**

In the previous section, when you worked with bulbs in parallel, unscrewing one bulb produced no change in the brightness of the second. Why is this no longer the case? To understand this you must consider the voltage across bulb A and the voltage across bulbs B and C. First predict the relative voltages. That is, is the voltage across A less than, equal to, or greater than, the voltage across B and C? Fully explain your prediction.

**Procedure**

• Measure the voltages across the bulbs.

\[ V_A = \underline{\text{__________}} \quad V_B = \underline{\text{__________}} \quad V_C = \underline{\text{__________}} \]

• Predict what will happen to the voltage across bulb B if you unscrew bulb C.

• Try it. Did you predict correctly? Explain why the observed result occurred.

**b. Short circuits**

**Prediction**

A “short circuit” is a frequent problem in electrical circuits. A short circuit is simply a wire, or other good conductor, connected across a circuit element, like a bulb. Thus, you can think of a short circuit as a resistor with \( R = 0 \). Still working with the circuit you just constructed predict what will happen to the brightness of all three bulbs if you short out bulb C by clipping a wire across its leads.
Complex Circuits

Procedure

• Try it! To make sure it really is a short circuit, measure the potential drop across the wire or clip lead. Describe what you observe and any discrepancies with the predictions you made.

• Predict what will happen to the brightnesses of all three bulbs if a short circuit were connected across bulb A instead of C. Try it and comment on the result.

c. Open circuits

Introduction

An “open circuit” is a break in a circuit through which no current can pass. In the series-parallel circuit you created an open circuit when you unscrewed the bulb. Another common open circuit is a switch in the “off” position. You might think of an open circuit as a resistor with $R = \infty$.

Procedure

• Create an open circuit by unscrewing bulb A from its socket. Predict the voltage across the socket that held bulb A.

• Measure the voltage and compare with your prediction.

d. Multi-bulb circuits

Prediction

Consider the series-parallel circuit in Figure 6 containing three identical bulbs. Predict the relative brightness of the bulbs.

![Figure 6: 3-bulb circuit](image)

Here is how you might reason your way to a sound prediction. Bulbs B and C are in series, and together the unit, (B+C) is in parallel with A. Because they are in parallel the potential drop across bulb A is the same as that across (B+C). Current is potential drop divided by resistance. Since (B+C) is a series combination, its resistance is larger than A. So the current through the unit (B+C) is less than that through A. Because bulbs B and C are in series, each has the same current, and thus will be equally bright. So, bulb A
must have the largest current and be the brightest. B and C have equal but smaller currents, so they are equal in brightness and dimmer than A. Thus

\[ A > B = C \]

Make predictions, using the same reasoning, for the four-bulb circuits shown in Figure 7 below. You don’t have to write down your explanations, but do discuss them with your lab partner.

**Figure 7: Four-bulb circuits**

**Procedure**

- Build each circuit to test your predictions. Note your correct and incorrect predictions. Be sure to spend time understanding what went wrong with those that were incorrect. Talk to your lab partner or to your instructor.