18-100: Intro to Electrical and Computer Engineering
LAB01: Circuits Lab
Due: Wednesday, January 29th at 10 PM

Name: ____

Andrew ID: ____

How to submit labs:

Download from this file from *Canvas* and edit it with whatever PDF editor you're most comfortable with. Some recommendations from other students and courses that use Gradescope include:

DocHub	An online PDF annotator that works on desktop and mobile platforms.
pdfescape.com	A web-based PDF editor that works on most, if not all, devices.
iAnnotate	A cross-platform editor for mobile devices (iOS/Android).

If you have difficulties inserting your image into the PDF, simply append them as an extra page to the END of your lab packet and mark the given box. ***Do NOT insert between pages.***

If you'd prefer not to edit a PDF, you can print the document, write your answers in neatly and scan it as a PDF. *(Note: We do not recommend this as unreadable lab reports will not be graded!).* Once you've completed the lab, upload and submit it to *Gradescope*.

Note that while you may work with other students on completing the lab, this writeup is to be completed alone. Do not exchange or copy measurements, plots, code, calculations, or answer in the lab writeup.

Your lab grade will consist of two components:

1. Answers to all lab questions in your lab handout. The questions consist of measurements taken during the lab activities, calculations on those measurements and questions on the lab material.
2. A demonstration of your working lab circuits and conceptual understanding of the material. This demo will occur during office hours.

Question:	1	2	3	4	Total
Points:	12	7	10	16	45
Score:					

Lab Outline

The purpose of this lab is to help students become familiar with the lab equipment and measurements (specifically, the breadboard, multimeter and power supply) as well as give a practical understanding of Ohm's Law and LEDs in circuits (both skills that will be heavily used/tested in future labs).

1. Introduction
2. Ohm's Law and Resistor Fundamentals
3. Resistor Networks and Sensors
4. LED Circuits

Equipment Required

- Breadboard
- Breadboard Power Supply
- 9 Volt battery
- Digital Multimeter w/ Probes
- Wire Strippers
- Diagonal Cutters
- Needle-nose Pliers

Bill of Materials

1x  47Ω Resistor
2x  100Ω Resistors
3x  470Ω Resistors
4x  1kΩ Resistor
2x  4.7kΩ Resistor

5x Red LEDs
1x Light-dependent resistor (Box 2)
Jumper Wire

Introduction

Welcome to 18-100 labs! These assignments are meant to be the hands-on component to material covered in lecture. The labs are also a great opportunity to get familiar with some of the equipment you will use in future lab course and through your entire career as an electrical and/or computer engineer!

Each lab will come with a handout (a.k.a. what you're reading right now!) that contains the exercises that you are to complete each week. You will be asked to generate data from each experiment and draw conclusions from it. **Make sure to thoroughly read the handout before attempting the lab!**

Following the completion of the lab, you will submit a writeup to `Gradescope` (instructions are on the cover of every lab) and then complete a demonstration to a TA. These demonstrations consist of explaining your completed circuit and then answering a few high-level conceptual questions on the lab material. These questions are *not* meant to trick you and, if you completed the lab, you should not have to "study" for them. The circuits you will be asked to demo will be clearly marked in the lab packet with a message that looks similar to this:

> ⚠ **Do NOT take your circuit apart yet! You will need it for lab checkoff!**

These labs, writeups, and demonstrations are meant to be completed on your own. We want you to collaborate and discuss the labs with other students however, come time to submit/demo, **all work must be your own! Students found building other students' circuits, copying data, or plagiarizing answers to writeup questions will be found in violation of the course's policy on academic integrity (see the Syllabus for more information).**

With that said, we wish you the best on your future laboratory endeavors in 18-100! If you get stuck on any of the parts of the lab or don't feel you can finish the lab before the due date, reach out to your group TA; they're here to help!

1. Tools and Setup

Take a moment to ensure you have all the necessary equipment in your lab kit. A list of each component and where to find it in the lab kit can be found on *Canvas*.

Continuity Tester

Troubleshooting is one of the most important skills that you will develop over the course of 18-100 labs. You will want to develop a systematic approach to use your tools to find errors in your circuits and fix them. In most cases, the TAs will guide you and not touch your circuit board. If your circuit doesn't work, the first question TAs will ask you is "what have you tried to do to fix the problem?" They are not being cold; on the contrary, your TAs want to empower you to solve your own problems and build self-confidence.

Your first step on this journey is understanding the most important tool in your toolbox: **the digital multimeter (DMM)**. The purpose of this exercise is for you to understand some of the common troubleshooting tasks you can do with your DMM. The first tool is one you will use to diagnose open circuits: the **continuity tester**, which is marked by a sound wave symbol on your meter (Figure 1).

Figure 1: Selecting the continuity tester on the digital multimeter

Plug the test leads into your multimeter. The black lead goes into COM and the red lead goes into the port on the right (V · Ω · mA). When there is **electrical continuity** between the leads (i.e. a conductive path between them), the meter will beep.

Hold the two leads together. You'll hear a beep if your tester is working. We encourage you to test the continuity of several things in your room or lab kit. Good conductors will beep, everything else won't.

Your kit comes with 6x 25' spools of 22AWG wire to build your circuits. The wire is designed to easily make electrical connections on a breadboard, but you can't just use it right off the spool. You'll have to strip the insulation off of each end of the wire to reveal the copper conductor inside. You can use your kit's yellow-handled **wire-strippers** (Figure 2) to do this.

Figure 2: Using the wire strippers

Use them to cut off a short piece of wire, then strip some insulation from each end of the wire. Then use your continuity tester to verify that the wire is indeed a conductor. If you can't hear the beep, make sure you strip off enough insulation and are making good contact between the DMM probes and the copper. **In general you should strip around 1cm (check with a ruler) of insulation to prevent issues in your circuits.** Stripping too much can result in wires touching when you don't want them to, and stripping too little results in poor electrical contact with the breadboard.

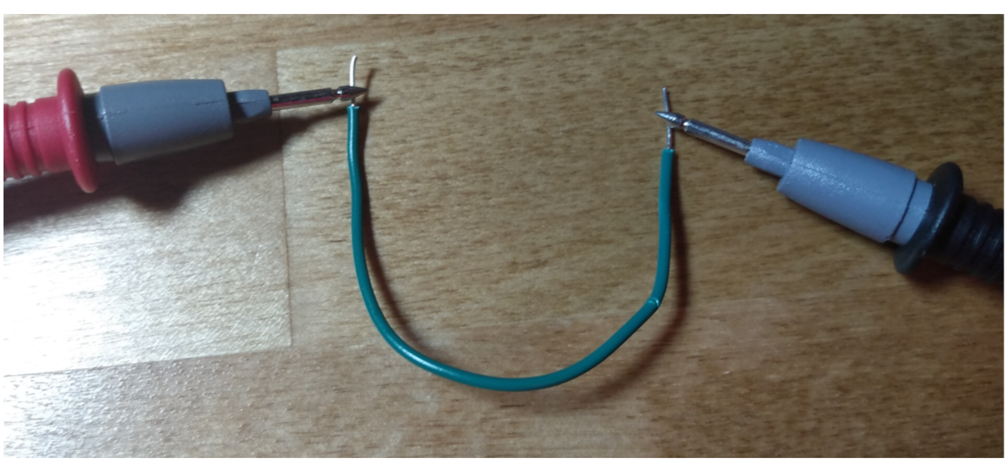


Figure 3: Testing the continuity of the wire with a digital multimeter.

The **breadboards** that come with your kit will be the base for all the circuits you build in 18-100. Breadboards allow you to quickly make electrical connections between components. The holes in the breadboard are electrically connected in groups of five (by column when in the orientation shown in Figure 4). No connections cross the center groove. There are also **power buses**, marked by a strip of red or blue, where all holes are connected. These are convenient for voltage supply connections, which usually need multiple connections throughout the circuit.

Don't take our word for it - use your continuity tester and your own breadboard to determine which of these points on the breadboard pictured in Figure 4 are electrically connected, and fill in the table next to it. Please note that there are two blue wires connecting some of the rows together.

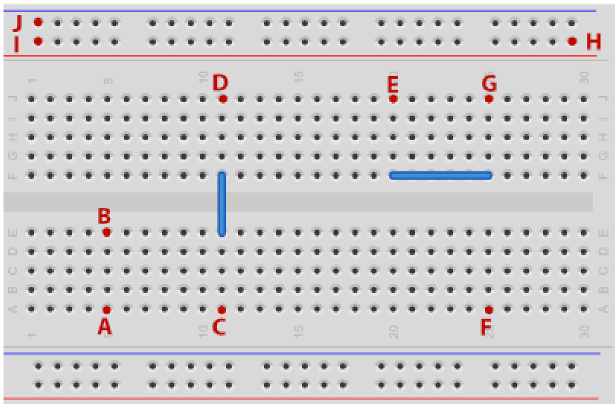


Figure 4: Determine the continuity between certain points.

4 pts

1.1 Which of the following pairs of points are connected? Which are not connected? Mark accordingly using the check boxes.

Pair	**Connected**	**Not Connected**
A,B	☐	☐
A,C	☐	☐
C,D	☐	☐
E,F	☐	☐
F,G	☐	☐
E,G	☐	☐
H,I	☐	☐
I,J	☐	☐

Breadboard Setup

Now that you understand how the connections within the breadboard work, it's time to set up our breadboard. In order to set up the breadboard, remove it from its packaging and install the terminal plugs. Then connect the +/- power rails to each other. Also connect wires to the terminal plugs and connect these to an empty row on the breadboard. A video of installing the terminal plugs is on Canvas. In the end your breadboard should look like this:

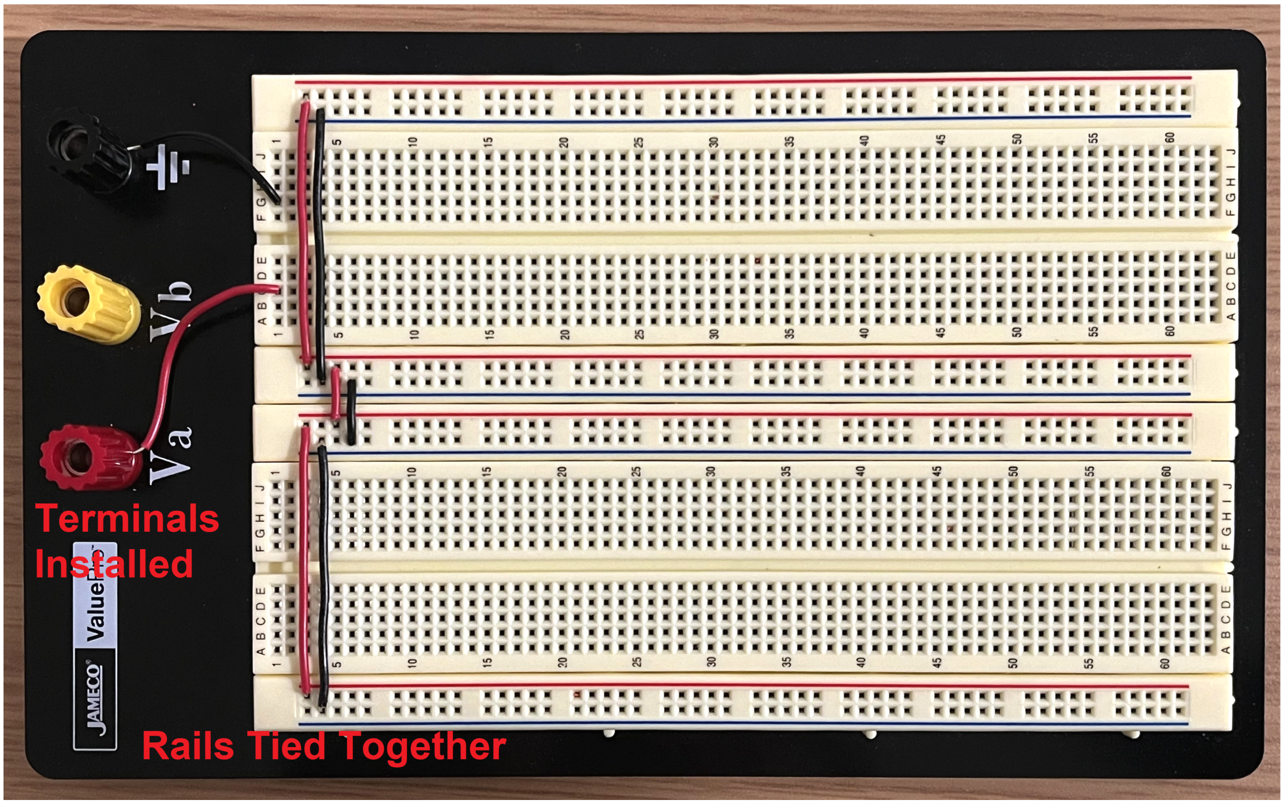


Figure 5: Breadboard setup complete

5 pts

1.2 Set up your breadboard as described above. Make sure to install the breadboard terminals, connect them to the breadboard rails using jumper wire, and tie all the breadboard rails together. Repeat this process with your second breadboard as well. [1]

> ⚠ **Do NOT take your circuit apart yet! You will need it for lab checkoff!**

If you need assistance setting up your breadboard, feel free to reach out to your group TA!

[1] That's right! A whole five points just for setting it up correctly!

Voltmeter

Another handy measuring tool we have on our DMM is the **voltmeter**. It measures the **potential** or **voltage** present between the two probes.

Because voltage is a relative measurement across two points, one of the probes (COM, black lead) is interpreted as the reference, so the reading is the difference between the red probe (V) and the black probe (COM). As with the ohmmeter, there are several range settings marking the maximum voltage. In 18-100, your voltage measurements will usually be direct current (V⎓) as opposed to alternating current (V∼).

You have several 9-volt batteries in your lab kit. A fresh battery's voltage should be above 9V. As it is used up, the battery voltage will drop as low as 6V before it is no longer usable. Test the voltage of a battery by selecting the voltmeter and connecting one probe to each of the battery's terminals. Connect the red probe to the positive terminal of the battery and the black probe to the negative terminal as demonstrated in Figure 6.

Figure 6: Measuring battery voltage

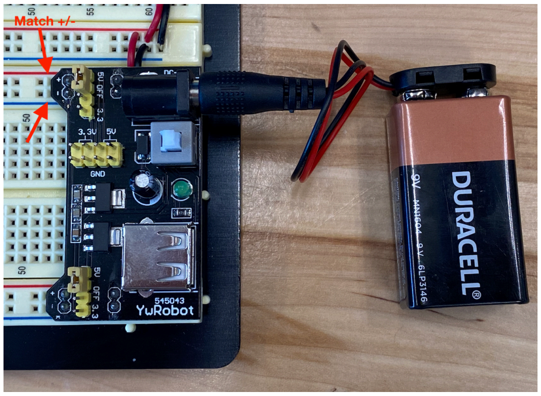
1 pts **1.3** What voltage did you measure?

V = V

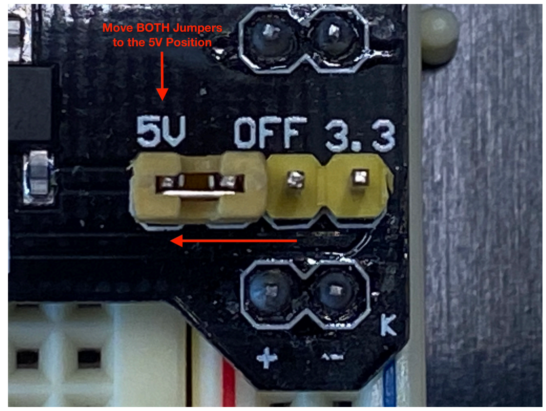
2 pts **1.4** Switch the red and black probes. What happens to the voltage you measure and why?

Power Sources

There are two main branches of ways to supply power to your circuit: fixed and adjustable. In this course we provide with a fixed 5V supply that is inserted directly into the breadboard power rails. The fixed power supply is depicted below:



(a) Power Supply Installed



(b) Switch Jumpers to 5V!

Insert the prongs into the rails (the 2 columns on both sides of the breadboard marked with red and blue lines) as shown in (a). It's a tight fit so don't be afraid to use a little force. **Make sure the + on the power supply aligns with the red rail and the - sign with the blue rail.**

The breadboard power supply is useful when you simply need 5V, like you will in this lab as well as Labs 2 and 3.

2. Resistance

Let's move on to another useful tool on the DMM: the **ohmmeter**. This measures the electrical resistance present between the two probes. Simply use the dial on your multimeter to one of the 5 settings with an Ω symbol.

How do you know which setting to select? The different resistances give ranges for the *maximum* resistance that the meter can measure. If the resistance that you're measuring goes over the maximum setting, you simply need to adjust your range to a higher setting. Smaller ranges give your measurements more precision. It's best practice to round up to a resistance a bit higher than what you expect. You can then lower the range to get a more precise measurement if possible.

In this section we'll gain practice with the DMM by looking at resistors and their behavior in circuits.

Standard resistors use a color-coding system to denote their resistance. The first three bands mark the value, and the last golden band means a manufacturing tolerance of 5%. Sometimes, it can be hard to tell some colors apart, so it can be useful to verify the resistance with your Ohmmeter.

2 pts

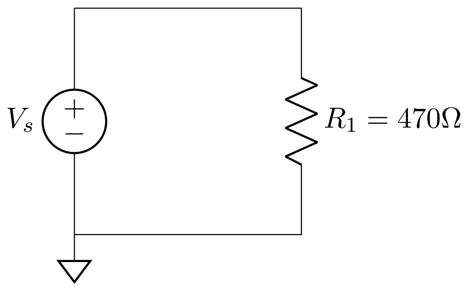
2.1 Based on the gold tolerance band on the resistor, calculate the minimum and maximum values each resistor can have to be within tolerance. Also measure the actual resistance using the ohmmeter settings of the DMM.

Resistor	**Minimum Value (Ω)**	**Measured Value (Ω)**	**Maximum Value (Ω)**
47Ω			
100Ω			
470Ω			
1kΩ			
4.7kΩ			

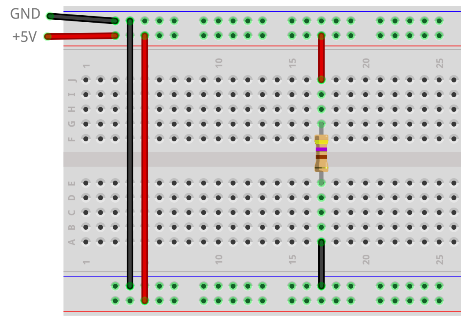
1 pts

2.2 Do any of the measurements you took in 2.1 change if you flip the probes?

Connect a 470Ω resistor to the breadboard by placing one of the leads in a row of five holes and the other lead in a separate row. Use the breadboard power supply to set the rails to 5V. Connect each end of the resistor to a power rail, as shown in the diagram.



Simple Resistor Circuit (Schematic)



Simple Resistor Circuit (Breadboard)

Figure 8: Measuring Voltage across Resistor

1 pts **2.3** What voltage do you measure across the resistor?

Measured Value = ____________ V

1 pts **2.4** Using Ohm's law, what should the current be flowing through the circuit? Show all work.

$I =$ ____________ mA

Now let's see if the current flowing through the resistor matches the value we calculated. To measure the actual current, we will need to use the **ammeter** function of the DMM. For all currents measured in this class, we will use the setting shown in 9. Unlike when we measure voltage, measuring current requires that we place the ammeter in series with the components we are measuring. This involves physically breaking the circuit and connecting the meter in series as discussed in class.

Figure 9: Measuring DC current

Measure and record the current through the resistor using the multimeter. Before measuring current, verify that you've connected the multimeter correctly in series.

⚠ **Measuring current incorrectly can damage your multimeter!**
Always check your probes before powering on a circuit!

1 pts

2.5 What is the actual current flowing through the circuit?

Measured Value = ______ mA

1 pts

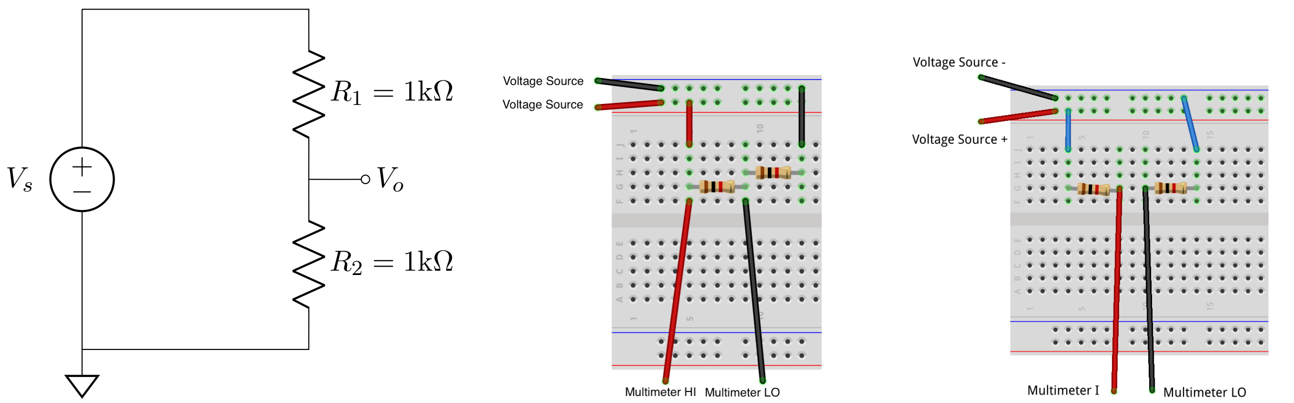
2.6 Using the measurements collected in 2.3 and 2.5, calculate the power consumed by the resistor. Show all work.

$P =$ ______ mW

3. Resistor Networks

Series Resistors / Voltage Divider

Build the circuit shown below in Figure 10 which features a pair of 1kΩ resistors wired in series.



(a) Series Circuit (Schematic) (b) Series Voltage Measurement (c) Series Current Measurement

Figure 10: Measuring Series Resistors

1 pts

3.1 *Calculate* the equivalent resistance, R_{eq}, of the circuit as seen from the voltage source, V_s.

$R_{eq} =$ ____________ kΩ

1 pts

3.2 *Measure* the voltage across, and current through, each resistor in Figure 10. Use Figures (b) and (c) to aid in your measurement process. The voltage source $V_s = 5V$. R_1 and $R_2 = 1\text{k}\Omega$

$V_1 =$ ________ V $I_1 =$ ________ mA $V_2 =$ ________ V $I_2 =$ ________ mA

2 pts

3.3 Using Ohm's Law and KVL/KCL, *calculate* the voltage across, and current through, each resistor in Figure 10. The voltage source $V_s = 5V$. R_1 and $R_2 = 1\text{k}\Omega$. Show work.

$V_1 =$ ________ V $I_1 =$ ________ mA $V_2 =$ ________ V $I_2 =$ ________ mA

1 pts

3.4 Replace the resistor R_2 in Figure 10 with a 4.7kΩ resistor. *Measure* the voltage across, and current through, each resistor in Figure 10.

$V_1 =$ __________ V $I_1 =$ __________ mA $V_2 =$ __________ V $I_2 =$ __________ mA

2 pts

3.5 Using Ohm's Law and KVL/KCL, *calculate* the voltage across, and current through, each resistor in Figure 10. The voltage source $V_s = 5V$. $R_1 = 1\text{k}\Omega$ and $R_2 = 4.7\text{k}\Omega$. Show work.

$V_1 =$ __________ V $I_1 =$ __________ mA $V_2 =$ __________ V $I_2 =$ __________ mA

Light Dependent Resistor

Now let's make something a little more interesting. First, find your kit's light dependent resistor (LDR, Figure 11). The resistivity of the red material changes with the intensity of light striking it.

Figure 11: A light dependent resistor

Measure the LDR's resistance with your Ohmmeter. Cover the face of the LDR with your hand. This is its dark resistance R_{dark}. Now shine a light into the LDR. This its light resistance R_{light}.

1 pts

3.6 What are the dark and light resistances that you measured?

$R_{dark} =$ __________ Ω $R_{light} =$ __________ Ω

Now replace the resistor R_2 in Figure 10 with your LDR as shown in the schematic in Figure 12. Use your voltmeter to measure V_o in the dark (V_{dark}) and in the light (V_{light}).

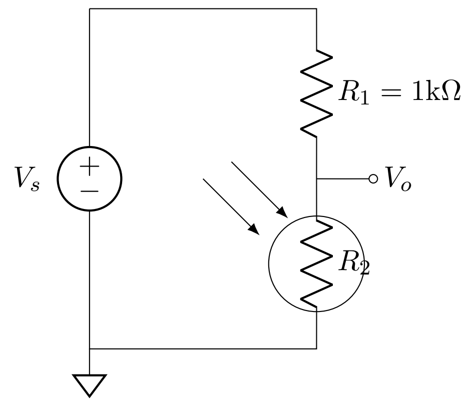


Figure 12: Light-dependent voltage divider circuit

1 pts

3.7 What are the dark and light voltages that you measured?

V_{dark} = [ ] V V_{light} = [ ] V

1 pts

3.8 Is the output voltage V_o higher in the dark or in the light? Why?

4. LED Circuits

Create the following circuit (Figure 13) on your breadboard using a red LED. Note: the **longer** wire is the **anode** (**positive** end) and the **shorter** wire is the **cathode** (**negative** end).

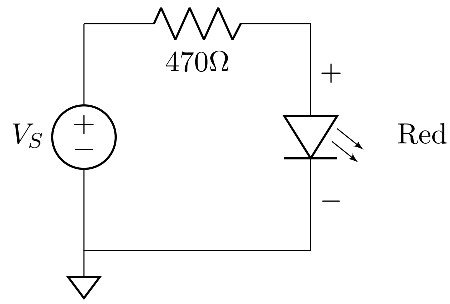


Figure 13: Single-LED Circuit
Hint: It should light up

1 pts

4.1 Once the LED lights up, flip the LED's direction. Does the LED continue to emit light?

Assemble the following circuit (Figure 14) on your breadboard.

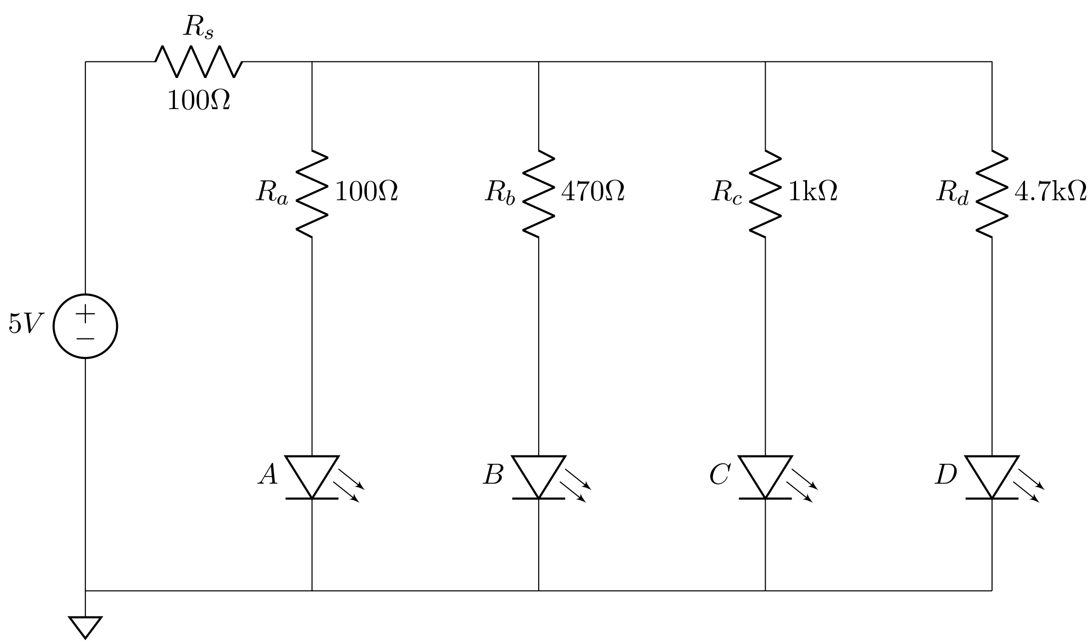


Figure 14: 4-LED Circuit

The figure below (Figure 15) shows the circuit connections on the breadboard. Refer to the diagram if you have difficulties wiring up the circuit. Note that the bent leg in Figure 15 correspond to the longer legs of your LEDs.

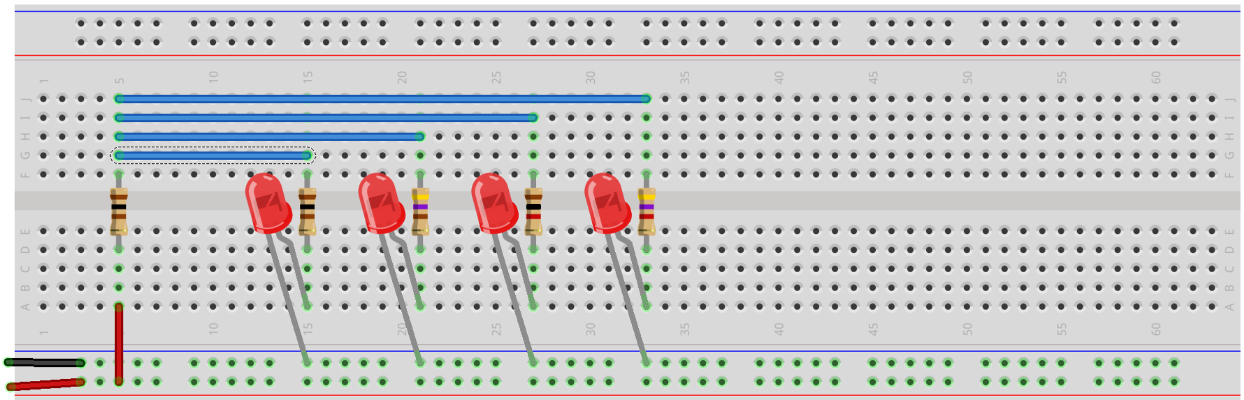


Figure 15: LED circuit breadboard diagram.

1 pts

4.2 Observe the light intensity of each LED and provide a ranking from the least bright to the brightest (e.g. $B < A < D < C$).

2 pts

4.3 Measure the voltages across the 100Ω, 470Ω, 1kΩ, and 4.7kΩ resistors ($R_a - R_d$) as well as the voltage across each of the LEDs. Sum them together.

Branch	**Resistor Voltage** (V_{Rx})	**LED Voltage** (V_{Dx})	**Total Voltage** (V_x)
A			
B			
C			
D			

2 pts

4.4 Measure the current through R_s (I_S) and the currents through LED A, B, C, and D (I_A, I_B, I_C, I_D). Remember that current is measured in series!

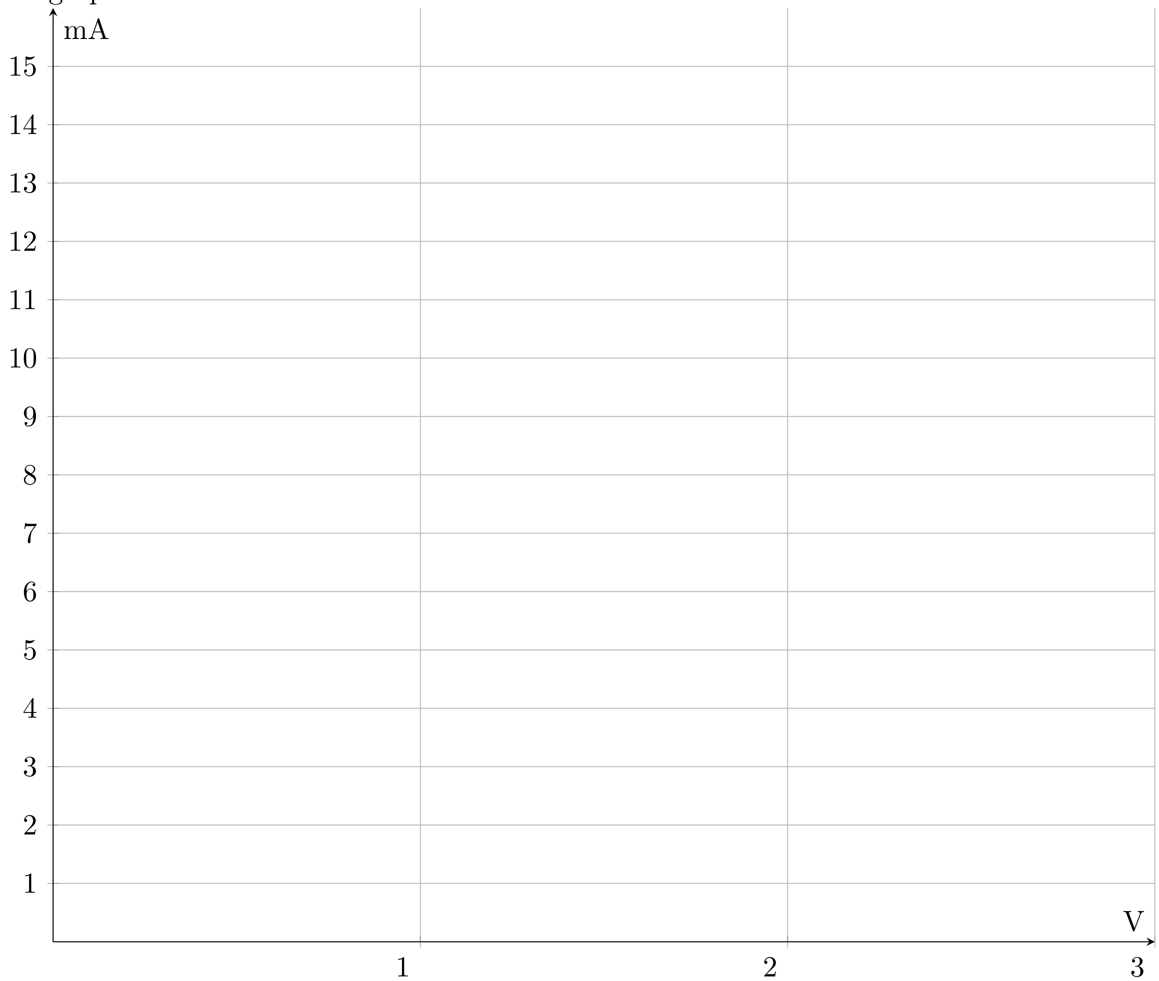
Quantity	**Measured Current (mA)**
I_S	
I_A	
I_B	
I_C	
I_D	

1 pts

4.5 What relationship do you hypothesize about the current through R_s (I_S), and the LED currents (I_a, I_b, I_c, I_d)? Write down the hypothesis and prove that it holds (roughly) with empirical data.

2 pts

4.6 Plot the measured current through each LED over the measured voltages across each LED on the graph below.



2 pts

4.7 Do the LED Voltage and LED current of each LED obey a linear relationship? How does it compare to a resistor (i.e. Ohm's Law)?

5 pts

4.8 Be prepared to demonstrate your working circuit to a TA.

⚠ **Do NOT take your circuit apart yet! You will need it for lab checkoff!**