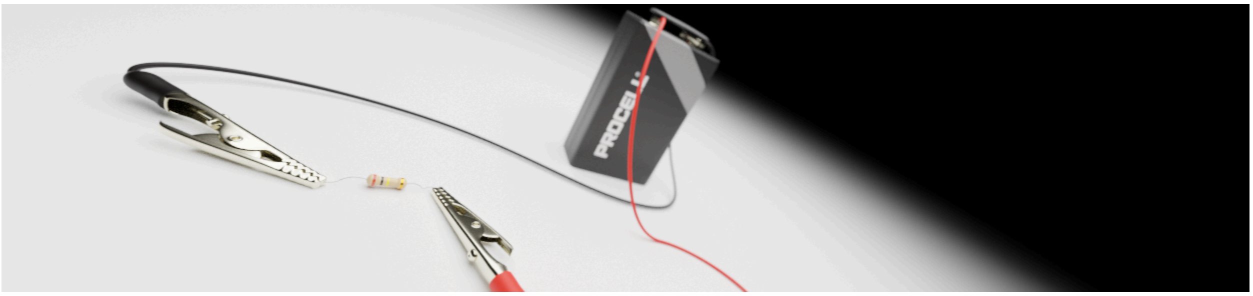
Ohmic Devices & Circuits



OBJECTIVE:

Explore simple circuits and learn about electrical safety.

Background

In the previous lab, you studied equipotential lines - lines along which the electric potential was constant. You learned that positively charged particles (like protons) move from regions of high potential to low potential, and vice versa for negatively charged particles (like electrons). Many charged particles moving together from one region of electric potential to another form an **electric current** (***I***). Thus, in order to produce a current, you need to create a potential difference or voltage (*V*) between two points in space to get the charges moving. A common household item designed to do exactly this is the **battery** - a device that converts *chemical* energy into *electrical* energy, resulting in a potential difference between its positive terminal (**cathode**) and negative terminal (**anode**). When these two terminals are connected to a **conductor** (a material that allows moving charges, such as a copper wire), the electrons in the conductor begin to move from one terminal to the other, generating a current. Such a closed-loop configuration like the (unsafe) one shown in **Figure 1** below is referred to as a **circuit**.

Figure 1 - An (unsafe) closed-loop circuit. All circuits you will be constructing will have insulating material coating the copper wiring.

Note that the wires that you will be working with in this lab are covered in **insulating** material (material that does not allow charges to move), unlike those in the above image, to minimize the risk of electric shock.

The current supplied by a typical 9V battery can sometimes be too much for the purposes of a particular type of circuit, and some circuit components like LEDs can be broken if the current is too high. To remedy this, we can reduce the overall current in a circuit by connecting a **resistor** - a component that decreases the flow of electrons. Any given resistor has a **resistance** (***R***), determined by the resistor's shape and material. For many simple circuits, this resistance relates to the current and electric potential difference via the following:

$$V = IR \tag{1}$$

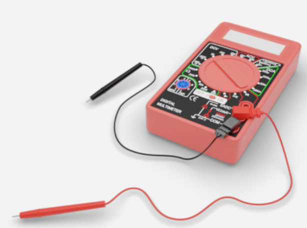
This equation is known as **Ohm's Law**. Ohm's Law is empirical, meaning it is obtained directly from experiments, and not derived via theory from the ground-up (at least, not in this form). This law applies quite well for several circuit components, but there are exceptions. Circuit components that obey equation (1) are referred to as **Ohmic**, while those that do not are called **non-Ohmic**. A good example of a non-Ohmic circuit component is a lightbulb, which generates light by heating a small, thin wire (a filament). As this filament heats, its resistance changes as a function of temperature, thus breaking from Ohm's Law. Most standard resistors, however, are Ohmic to good approximation, so equation (1) will be a cornerstone of this lab.

⚠⚠ SAFETY NOTES ⚠⚠

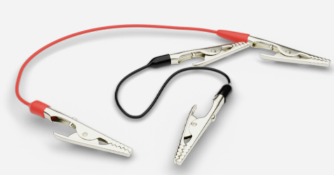
The battery should only be connected in closed circuits for short amounts of time. Disconnect the battery while you're not taking measurements.

Resistors and other circuit components can become hot to the touch, especially if connected incorrectly or for long periods of time. Use caution when handling these components.

EQUIPMENT LIST

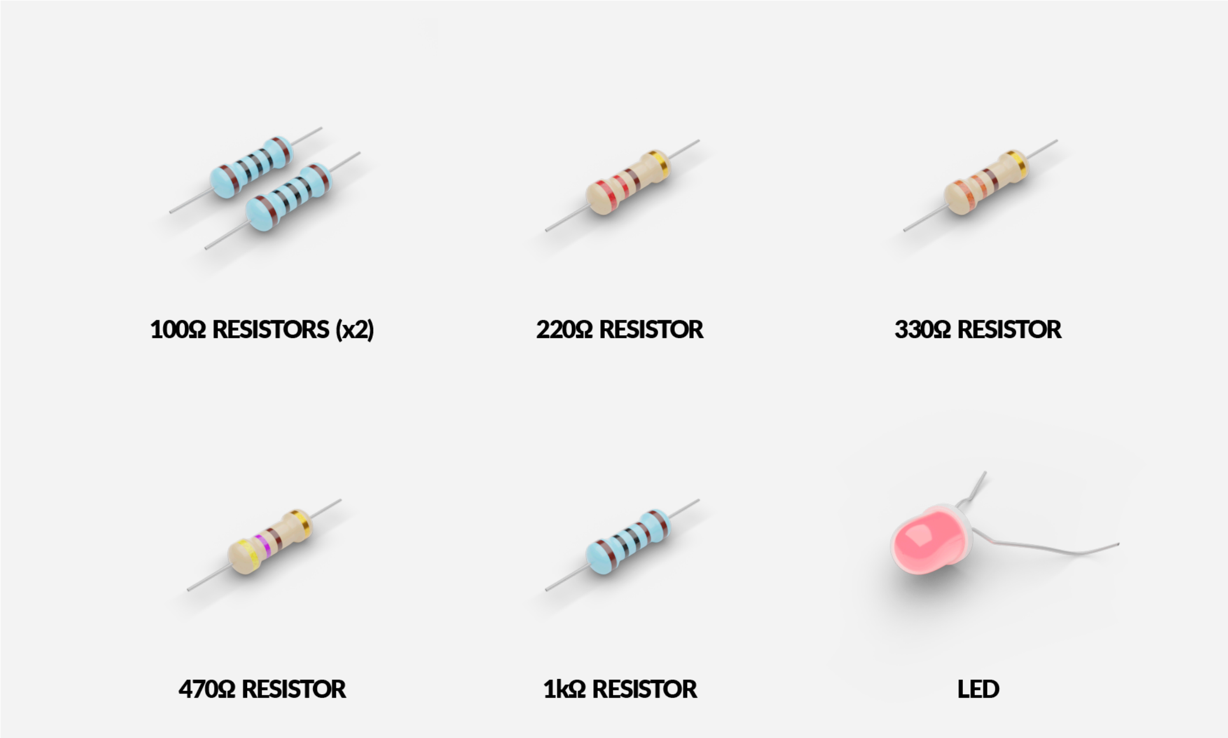


DIGITAL MULTIMETER



ALLIGATOR CLIPS

9V BATTERY



Experiment 1 - Identifying Resistors 2 Ways & Using the DMM as an Ohmmeter

There are two different methods for determining the resistance of a given resistor; the first is to measure the resistance directly using an **ohmmeter**, and the second is to refer to the colored bands in conjunction with the appropriate reference table. Such a table is provided below:

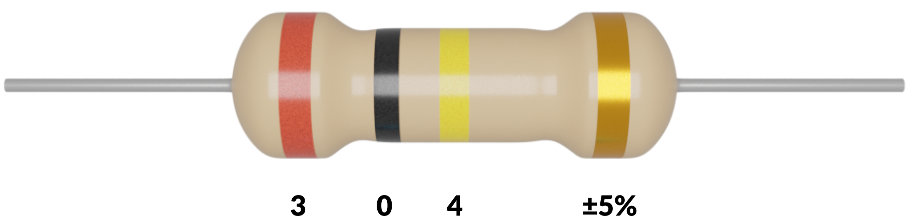
Color	**1st Ring**	**2nd Ring**	**3rd Ring**	**4th Ring**	**5th Ring**
Brown	1	1	1	x10 Ω	± 1%
Red	2	2	2	x100 Ω	± 2%
Orange	3	3	3	x1 kΩ	
Yellow	4	4	4	x10 kΩ	
Green	5	5	5	x100 kΩ	± 0.5%
Blue	6	6	6	x1 MΩ	± 0.25%
Purple	7	7	7	x10 MΩ	± 0.1%
Gray	8	8	8		± 0.05%
White	9	9	9		

Table 1 - Guide to Resistor Color-Coding

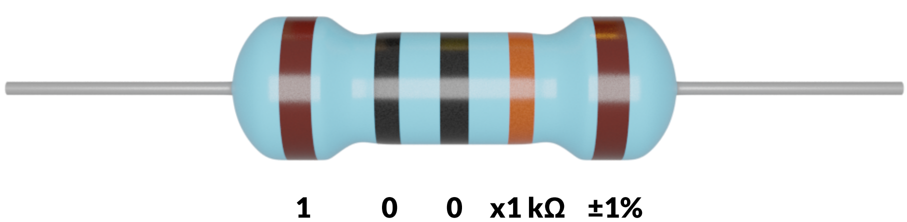
Color	**1st Ring**	**2nd Ring**	**3rd Ring**	**4th Ring**	**5th Ring**
Black	0	0	0	x1 Ω	
Gold				x0.1 Ω	± 5%
Silver				x0.01 Ω	± 10%
No Color					± 20%

Table 1 (cont.) - Guide to Resistor Color-Coding

Reading all of this can be a bit daunting at first, so it's best to start out by looking at a couple examples. Shown below is a typical 4-band resistor; let's find the corresponding entry for each color from the table above, and write them below the rings as follows:



There are only 4 bands on this particular resistor, not 5; note that the last band is taken to be the 5th, with the 4th simply missing. To determine the value of this resistor, we simply read off the entries from left to right as a single value. So, this resistor has a resistance of **304 Ω** (± 5%, so **± 15.2 Ω**). Let's look at a second example, this time with a 5-band resistor:



Again, reading off the entries as a single value, we have a resistance of 100 x 1 kΩ ± 1%. Here, the x1 kΩ is a multiplier, so we multiply 100 by 1 kΩ. Doing this and writing the percentage as a value in Ohms gives **100 kΩ ±** (**1 kΩ**).

This method of reading the rings of resistors to determine their resistance generally works quite well, assuming that any manufacturing mishaps haven't resulted in deviations from these values any greater than their threshold errors. But we can get more precise readings by measuring the resistance directly, as mentioned earlier, via an ohmmeter.

The easiest way to measure the resistance of a resistor is to simply stick it directly into the pertinent inputs on the multimeter, without bringing in any extra wiring. This is shown more clearly in **Figure 2** below, in which a 1 kΩ resistor is being measured:

Figure 2 - The easiest way to measure a resistor using a DMM.

When using the digital multimeter (DMM) as an ohmmeter, it is acting as *both* a **voltmeter** (used to measure voltage) *and* an **ammeter** (used to measure current). The DMM supplies a voltage, measures the current, and then calculates the resistance displayed on the screen using Ohm's Law. Because of this, you must select the appropriate cutoff value for the resistor you're using for the best results. If the Ohm value that the DMM is set to is *smaller* than the resistance of the resistor you're measuring, it will panic and display nonsensical results. As such, you want to start with the lowest Ohm value (200 Ω), and adjust the dial to larger numbers until the display gives a proper reading. For example, in **Figure 2** above, the resistor being measured is roughly 1 kΩ, or 1000 Ω; as such, the 200 Ω setting would be too small, so the dial had to be moved up to the next setting of 2000 Ω. Since 2000 Ω is greater than 1000 Ω, a reasonable reading will be given.

Figure 3 - Resistance cutoff values on the DMM.

Note that when you measure resistors in this way, you must make sure that both ends are making complete contact with the DMM inputs; otherwise, the circuit will be broken and no value will be measured.

Fill out **Table 3** in the first Post-Lab question while completing the following objectives:

1.) Determine the resistance of each of the 6 resistors using the colored rings and the table from earlier.
2.) Determine the resistance of each of the 6 resistors using the DMM.
3.) Calculate the percent difference between the resistances found from both methods for each resistor (formula provided under 'Additional Equations' at the end of this document).

The different methods should produce very comparable results, although they likely will not be exactly the same in each case.

Experiment 2 - Powering an LED & Using the DMM as an Ammeter

To light up an LED, all we need is a battery, two wires, and the LED itself. To light up an LED so that it *doesn't burn out* requires the addition of a resistor to reduce the current in the circuit. Your first couple objectives for this exercise are:

1.) Given that the battery supplies a total voltage of 9V, and there is a 3V drop across the LED, there must be a 6V drop across the resistor for everything to properly balance. Then, assuming a current of 20 mA (0.02 A) and a potential difference of 6V, determine via Ohm's Law which of the 6 resistors you should use in this circuit. (Note: it won't be an exact match, so pick the resistor that is closest to your calculated value).
2.) Using the *exact* value of this resistor (from color code), calculate what the current would be if you were to measure it, again using Ohm's Law.
3.) Using this resistor, construct the circuit shown in **Figure 4** below. Note that in order for the circuit to be complete, you will have to hold the indicated DMM lead in contact with the LED. LEDs have a positive (anode) and a negative (cathode) leg; the positive leg is *longer* than the negative. This longer leg should be connected to the wire coming from the resistor, and the shorter one should connect to the positive (red) lead coming from the DMM, as shown below. If you connect the LED backwards, it will not light up; if this occurs, immediately disconnect it to prevent damage.
4.) Adjust the dial to select the most appropriate direct current amperage (DCA) on the DMM as shown in **Figure 5** - either 20 mA or 200 mA - then turn on the DMM and record the actual current that you measure.
5.) Calculate the percent difference between the measured current and the calculated current. Record this value in Post-Lab question 3.

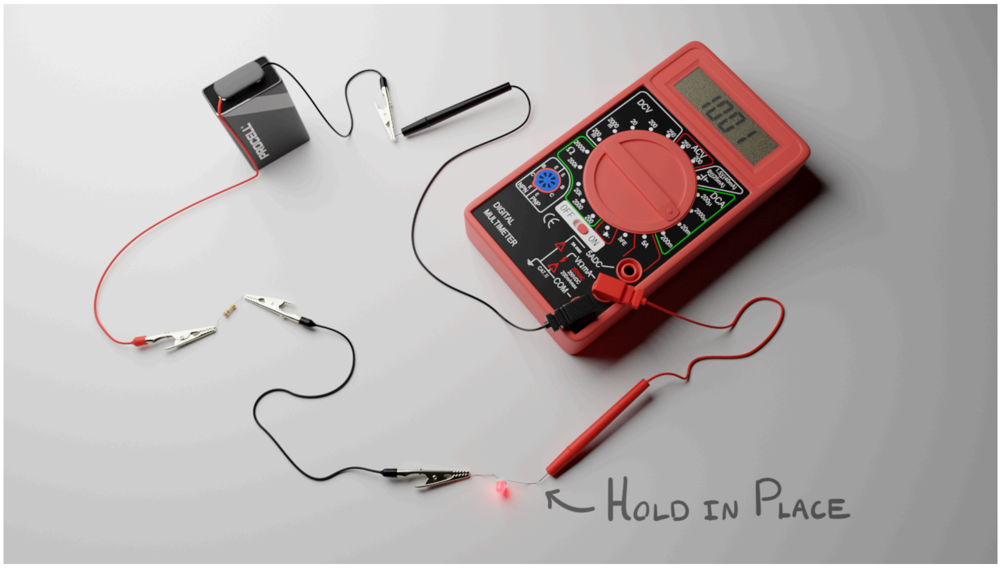


Figure 4 - A simple LED circuit with a resistor to reduce the current.

Figure 5 - Current cutoff values on the DMM.

Note that we have configured the DMM in **series** with the rest of the circuit; this means that the current flowing through the DMM is the *same* as the current flowing through the rest of the circuit. If we hooked up the DMM any other way, it would not give an accurate reading of the current in the circuit.

Experiment 3 - Confirming Ohm's Law & Using the DMM as a Voltmeter

For this last exercise, we want to do two things: check that the battery is indeed a 9V battery, and confirm Ohm's Law for resistor combinations.

We've already used the DMM as an ohmmeter to measure resistance, and as an ammeter to measure current; to check the voltage of the battery, we'll have to use the DMM as a voltmeter. The setup for this is probably about as straightforward as you'd expect, depicted in **Figure 6** below. While this is technically a series configuration (the current through the DMM is the same as the current through the rest of the circuit), it is also a **parallel** arrangement (the voltage between the two inputs on the DMM is the same as the voltage between the terminals of the battery). Hook the DMM up to the battery and adjust the dial to select the most appropriate direct current voltage (DCV) as shown in **Figure 7** - this should likely be the 20 V value, unless the battery is (very) dead. Confirm that the battery is 9V (or very close to 9V), then disconnect it and move on to the next objective.

Figure 6 - The simplest possible circuit configuration for measuring the voltage of a battery.

Figure 7 - Voltage cutoff values on the DMM.

The main part of this exercise is to verify Ohm's Law using multiple resistor pairings. If you change the current flowing through a resistor and measure the voltage across this resistor, the values should be related to each other in the way specified by equation (1). Since we don't have a variable voltage source - just a battery at a fixed voltage - we can adjust the amount of current flowing through a given resistor by combining it with *other* resistors. Your objectives are then as follows:

1.) Copy **Table 2** below onto a separate sheet of paper and include it in Post-Lab question 3.
2.) Construct the circuit shown in **Figure 8** below, with R_1 being one of the 100 **Ω** resistors, and R_2 being any of the other 5 remaining resistors.
3.) Measure the *voltage* V_1 across R_1 and record this voltage value in the table you copied from step 1.

4.) Switch out the resistor you're using as R_2 for a different resistor, and repeat steps 2 and 3. Do this until you have used all of the resistors and completed the table.
5.) Plot V_1 vs. I from the table you've filled out, and fit a trendline to the data.

Figure 8 - A 2-resistor circuit configuration for testing Ohm's Law.

Note that the DMM is connected in parallel with R_1, with each alligator clamp holding one end of R_1 *and* one of the leads from the DMM.

R_1 (Ω)	R_2 (Ω)	I (A)	V_1 (V) (Measured)
100	100	0.045	
100	220	0.028	
100	330	0.021	
100	470	0.015	
100	1000	0.008	

Table 2 - Ohm's Law Data

ADDITIONAL EQUATIONS:

$$\%\text{Difference} = \frac{|a-b|}{(a+b)/2} \times 100 \tag{2}$$

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Post Lab Questions on following page

Post-Lab Questions

1.) Record your resistances from the first step in Experiment 1, as well as the tolerances and your calculated percent differences.

	Resistance (Ω) (Color Code)	Resistance (Ω) (DMM)	Tolerance (%)	% Difference
Resistor 1				
Resistor 2				
Resistor 3				
Resistor 4				
Resistor 5				
Resistor 6				

Table 3 - Resistor Data

2.) In **Table 3** above, does your percent difference indicate that the resistance was within the tolerance value?

3.) What was your percent difference from Experiment 2?

4.) Include your table from Experiment 3.

Post-Lab Questions - continued

5.) Using your table from Experiment 3, make a plot with your voltage values on the vertical axis and the current values on the horizontal axis**.** The slope of this graph will be the resistance of R_1. Using percent difference, compare this to the color code value and measured value from **Table 3.** Include this plot in your submission. Be sure to include proper units and labels for your graph.

6.) In Experiment 3, if Ohm's Law is correct this trendline should have a near-zero volt y-intercept, and a slope roughly equal to 100 **Ω** (the resistance of the resistor through which the current passed). Is this what you observe? If you have a y-intercept, why do you think it is there?