

Chapter 06: Electricity

Physical Science, Tillery, 13th ed.

Lab 09: DC Circuits

DUE: 01 July 2024

Introduction

The concept of electrical resistance is both simple and complicated. The simple part: not everything is equally easy to push electrons through. Well, we know this. We already know that some materials are good conductors (like copper wire), and some are pretty terrible (like the plastic insulation covering the wire). It's obvious to us that the copper has a lower resistance to electrical current, and the insulation has a higher resistance. The more complicated part is explaining exactly why copper (or any other good conductor of electricity) has low resistance.

We have observed that for a given light bulb, increasing the voltage increases the current (and the brightness). Now that we know a little about circuits, we can quantify this relationship. Ohm's Law states:

$$V = IR$$

We will measure the voltage and current in a circuit and establish that this relationship is valid.

Objectives

- Learn to use the DC Circuits simulator
- Correctly construct DC circuits based on schematic diagrams
- Demonstrate Ohm's Law quantitatively
- Learn to use the color-band system to identify standard resistors
- Distinguish between ohmic and non-ohmic behavior using a graphical representation

Equipment

- Internet-capable device with the ability to run a browser
- Paper, pencil, calculator
- Scientific Calculator

Procedure

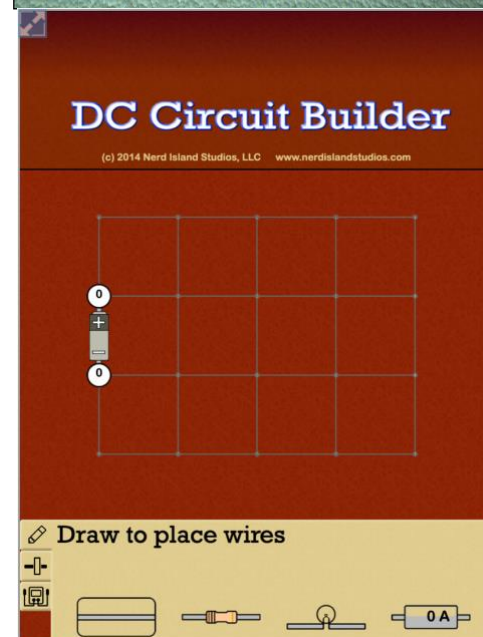
1. Read this handout completely before you try to dive in. It will save you time and frustration later. If you are able to print it, you will not have to tab between windows—you can look at this and the circuit simulator at the same time.
2. Do you have paper and pencil handy? Go get it, I'll wait. Don't forget your calculator.
3. In a browser window, navigate to the [DC Circuit Builder Interactive](#). Don't try to start doing the lab yet! Just verify that the interactive opens properly. Unfortunately, this particular sim does not have a downloadable App for your phone.
4. The figure on the right shows what the interface looks like on the web page. You can pull on the lower right corner to re-size the window and make it bigger.
5. Notice what you can control: From the top tab, you can grab and place wire segments, resistors, light bulbs, and ammeters on the grid. The middle tab lets you adjust the voltage of the battery (its position is fixed) or the resistance of your resistors. The bottom tab has a voltmeter and ammeter to analyze just a portion of the circuit you build.
6. To construct a complete circuit, you must always have a closed path from the positive to the negative terminal of the battery. Spend a minute practicing placing the wires and resistors without worrying about numbers; just make sure you can manipulate the various elements. Change the voltage. Change the resistance.
7. Have you got your paper and pencil? I recommend answering the questions on paper while you run the sim. Trying to navigate between the sim, the handout, and the Google form will not be easy. Wait until you have answered the questions on paper, double-checked them, and are satisfied with your answers before filling in the Google form and submitting it.

Band 1	Band 2	Band 3	Band 4
VALUE	VALUE	MULTIPLIER	TOLERANCE
BROWN 1	BROWN 1	BROWN x10 or +1 zero	BROWN ±1%
RED 2	RED 2	RED x100 or +2 zeros	RED ±2%
ORANGE 3	ORANGE 3	ORANGE x1k or +3 zeros	
YELLOW 4	YELLOW 4	YELLOW x10k or +4 zeros	
GREEN 5	GREEN 5	GREEN x100k or +5 zeros	GREEN ±5%
BLUE 6	BLUE 6	BLUE x1M or +6 zeros	BLUE ±25%
VIOLET 7	VIOLET 7		VIOLET ±1%
GREY 8	GREY 8	GOLD x.1	GOLD ±5%
WHITE 9	WHITE 9	SILVER x.01	SILVER ±10%
VALUE	VALUE	MULTIPLIER	TOLERANCE

Band 1	Bands 2 & 3	Band 4	5 - BAND	Band 5
VALUE	VALUE	MULTIPLIER		TOLERANCE
BROWN 1	BLACK 0	BLACK x1 or no zeros		BROWN ±1%
RED 2	RED 2	RED x100 or +2 zeros		RED ±2%
ORANGE 3	ORANGE 3	ORANGE x1k or +3 zeros		
YELLOW 4	YELLOW 4	YELLOW x10k or +4 zeros		
GREEN 5	GREEN 5	GREEN x100k or +5 zeros		GREEN ±5%
BLUE 6	BLUE 6	BLUE x1M or +6 zeros		BLUE ±25%
VIOLET 7	VIOLET 7			VIOLET ±1%
GREY 8	GREY 8	GOLD x.1		GOLD ±5%
WHITE 9	WHITE 9	SILVER x.01		SILVER ±10%
VALUE	VALUE	MULTIPLIER		TOLERANCE

Reading Resistor Color Bands

7 5 000 = 75,000Ω ±2%

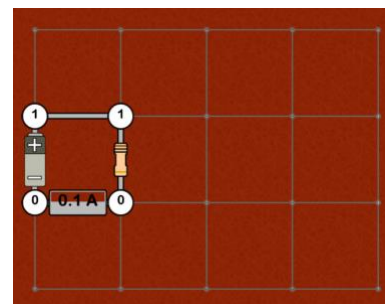


Simple Circuits

Build a simple circuit with one resistor and the ammeter. The ammeter reads the current in amps. Click on the middle tab, then the battery. Adjust the voltage to $V = 1V$. Now click the resistor and verify that the resistance $R = 10\Omega$.

- Notice that the Sim shows positive charges moving to indicate current. *Really?*
 - Yes. Protons are literally pouring out of the (+) terminal and marching toward the (-).
 - No! The charges in motion are electrons, which are (-). However, the sign convention for current is defined (for historical reasons) by positive charge.
- Swap the wire segment and the ammeter so that the meter is on top and the wire is on bottom. Does the ammeter reading change? Yes or no?

Complete the table below by adjusting only the voltage. Record the value of the current for each value of voltage. The initial current when $V = 1V$ should be $I = 0.1A$ (as shown above).



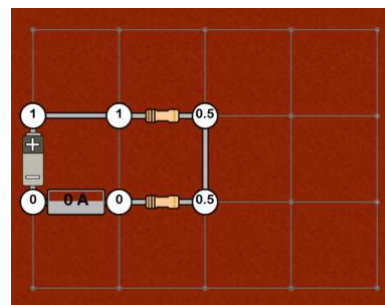
QUESTION	VOLTAGE V (V)	CURRENT I (A)	RATIO $R = \frac{V}{I} (\Omega)$	QUESTION	VOLTAGE V (V)	CURRENT I (A)	RATIO $R = \frac{V}{I} (\Omega)$
	1	0.1	$(1/0.1) = 10$	4	6		
3	3			5	12		

- What is the current when $V = 3V$?
 - $I = 0.1A$
 - $I = 0.2A$
 - $I = 0.3A$
 - $I = 0.4A$
 - $I = 0.5A$
 - $I = 0.6A$
- What is the current when $V = 6V$?
 - $I = 0.2A$
 - $I = 0.4A$
 - $I = 0.6A$
 - $I = 0.8A$
 - $I = 1.0A$
 - $I = 1.2A$
- What is the current when $V = 12V$?
 - $I = 0.2A$
 - $I = 0.4A$
 - $I = 0.6A$
 - $I = 0.8A$
 - $I = 1.0A$
 - $I = 1.2A$
- Calculate the ratio $R = \frac{V}{I}$ for each trial. Notice anything?
 - No. The ratio is random.
 - Yes. The ratio is constant.
 - Yes. The ratio increases as voltage increases.
 - Yes. The ratio decreases as the voltage increases.
- Now adjust the voltage so that $V = 10V$. Compare the current drawn when $R = 10\Omega$ to $R = 20\Omega$.
 - Double the resistance results in twice as much current.
 - Double the resistance results in $\frac{1}{2}$ as much current.
 - As long as the voltage remains constant, the current is unaffected!

Series Circuits

Congratulations! You have just demonstrated Ohm's Law for a simple circuit. The ratio you found is the electrical resistance (R , measured in Ohms, Ω) of the single resistor in the circuit. What happens when we add more resistors? Build a circuit with two resistors as shown on the right, where $R_1 = R_2 = 10\Omega$. Notice that there is only one possible path for the current to follow, so this is called a series circuit.

Now notice the number in the white circles. They represent the voltage. So, our 1-volt battery has (+1) at the (+) terminal and (0) at the (-) terminal. Think of the voltage as the energy available to do work (push electrons across the resistor). So, we have (+1), and when we get to the resistor, we use some of that energy to get across R_1 . According to the figure, we used $V_1 = 1 - 0.5 = 0.5V$. Then, at R_2 , there is $V_2 = 0.5V$ remaining, and that's the energy we use to push the charge through the second resistor. (We are assuming the ammeter has zero resistance. It's not quite perfectly true, but it has a small enough resistance to ignore.) One more observation: because there is only one pathway, the current is the same for R_1 and R_2 : $I_1 = I_2 = I$.

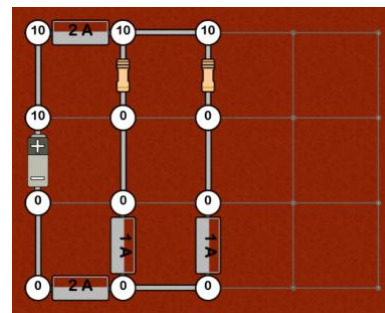


- Make sure the voltage is still $V = 10V$ and $R_1 = R_2 = 10\Omega$. What is the current through this circuit?
 - $I = 0A$
 - $I = 0.5A$
 - $I = 1.0A$
 - $I = 5.0A$
 - $I = 10A$
 - $I = 50A$
- Apply Ohm's Law to the circuit: $V = IR$, where V is the battery voltage, and I is the ammeter reading. What is your calculated value for the resistance R ?
 - $R = 0.1\Omega$
 - $R = 0.2\Omega$
 - $R = 1\Omega$
 - $R = 2\Omega$
 - $R = 10\Omega$
 - $R = 20\Omega$
- In a series circuit, the equivalent, or total, resistance is defined as the sum of all the resistors. In this case, $R = R_1 + R_2$. What is the equivalent resistance of the circuit you just built?
 - $R = 0.1\Omega$
 - $R = 0.2\Omega$
 - $R = 1\Omega$
 - $R = 2\Omega$
 - $R = 10\Omega$
 - $R = 20\Omega$
- True or false:** Two resistors in series will draw the same amount of current as a single resistor having $R = R_1 + R_2$.
- True or false:** Three resistors in series will draw more current than two resistors in series.
- True or false:** If you remove one resistor from a series circuit (click to remove!), the other one keeps working and still draws current.

Parallel Circuits

Now let's build a different type of circuit. We want the ability to have more than one device in the circuit, and switching any one of them off or on doesn't affect the other devices. Sound impossible? Well, that's how buildings are wired. When you're in the kitchen, you can turn on the toaster without having to turn anything else on. Switching off the light doesn't turn the microwave off. The devices are all independent.

Construct the circuit shown on the right, starting with $V = 10V$, and resistors $R_1 = R_2 = 10\Omega$. The first thing you notice is that the voltage across each of the resistors is exactly the same, and $V_1 = V_2 = 10V$. This is true for all devices in parallel. Also notice the ammeters! We intentionally put a lot of them in place to show clearly how the total current I leaving the battery splits between the separate branches I_1 and I_2 , then comes back together and back to the battery: $I = 2A = I_1 + I_2 = 1A + 1A$.



14. Click on one of the resistors (either one) to remove it from the circuit. What happens?
- Current flow through that branch stops, but the current through the second resistor is uninterrupted.
 - The entire circuit is broken. Current cannot flow through either resistor if one is removed.

Put the resistor you removed back into the circuit. Make sure that $R_1 = 20\Omega$ and $R_2 = 10\Omega$. Complete the table below to answer Questions 15–19.

QUESTION	BATTERY VOLTAGE V (V)	TOTAL CURRENT I (A)	RESISTOR 1 R_1 (Ω)	VOLTAGE V_1 (V)	CURRENT I_1 (A)	RESISTOR 2 R_2 (Ω)	VOLTAGE V_2 (V)	CURRENT I_2 (A)
	10	2	10	10	1	10	10	1
15-19	10		20			10		

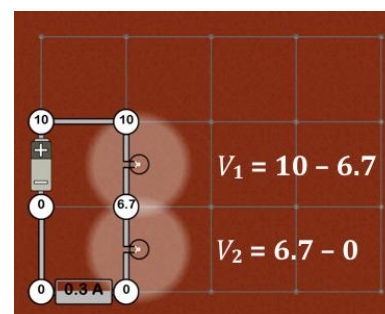
15. What is the total current I ?
- $I = 0.25A$
 - $I = 0.50A$
 - $I = 0.75A$
 - $I = 1.00A$
 - $I = 1.25A$
 - $I = 1.50A$
16. What is the voltage V_1 across Resistor 1?
- $V_1 = 0.25V$
 - $V_1 = 0.50V$
 - $V_1 = 2.5V$
 - $V_1 = 5.0V$
 - $V_1 = 7.5V$
 - $V_1 = 10V$
17. What is the current I_1 through Resistor 1?
- $I_1 = 0.25A$
 - $I_1 = 0.50A$
 - $I_1 = 0.75A$
 - $I_1 = 1.00A$
 - $I_1 = 1.25A$
 - $I_1 = 1.50A$
18. What is the voltage V_2 across Resistor 2?
- $V_2 = 0.25V$
 - $V_2 = 0.50V$
 - $V_2 = 2.5V$
 - $V_2 = 5.0V$
 - $V_2 = 7.5V$
 - $V_2 = 10V$
19. What is the current I_2 through Resistor 2?
- $I_2 = 0.25A$
 - $I_2 = 0.50A$
 - $I_2 = 0.75A$
 - $I_2 = 1.00A$
 - $I_2 = 1.25A$
 - $I_2 = 1.50A$
20. Use Ohm's Law ($V = IR$) to calculate the equivalent resistance in this circuit, where V is the battery voltage and I is the total current. The equivalent resistance R is
- $R = 1.5\Omega$
 - $R = 6.67\Omega$
 - $R = 8.5\Omega$
 - $R = 10\Omega$
 - $R = 15\Omega$
 - $R = 30\Omega$

Does this result surprise you? You can double-check your answer if you don't believe it by using the formula for equivalent resistance of devices in parallel:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}, \quad \text{or } R = \frac{R_1 R_2}{R_1 + R_2}$$

21. So, now that you have verified your equivalent resistance R , can you explain it?
- What is there to explain? Exactly like a series circuit, the total resistance is the sum of all the resistors.
 - When you add devices in parallel, every device loses some of its resistance. Each device only has 22% of its original resistance.
 - When the branches are independent, more current flows through the circuit. The true resistance of each device stays the same.

Let's switch from the resistors to lightbulbs. Build a circuit with two bulbs in series. Adjust the resistance of each bulb so that $R_1 = 10\Omega$ and $R_2 = 20\Omega$. Leave the voltage at $V = 10V$. Note that the 'glow' of the bulbs may change, but you cannot use it to make quantitative comparisons! Verify the voltage directly by using the voltmeter on the bottom tab: drag the red probe to the circle before the bulb and the black probe to the circle after the bulb you want to test.



22. Calculate the power of each bulb using $P = IV$. The same current flows through each, but note the voltage difference. The bulb with the highest power is the brightest. Which bulb is brighter, the 10Ω bulb or the 20Ω bulb? (The 'glow' doesn't help you here!)

Now wire the same two bulbs in parallel. Use the same voltage, $V = 10V$, and resistances, $R_1 = 10\Omega$ and $R_2 = 20\Omega$. Surprised?

23. Calculate the power of each bulb using $P = IV$. The power is
- $P_1 = 1W$ and $P_2 = 0.5W$
 - $P_1 = 10W$ and $P_2 = 5W$
 - $P_1 = 15W$ and $P_2 = 30W$
 - $P_1 = 100W$ and $P_2 = 200W$

