Resistors

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Resistors

One of the most basic components (parts) used in electronics is the resistor. Resistors are used to control the amount of current that flows in a circuit and to reduce voltage supplied to other components. Some components require specific voltage for proper operation in a circuit, often lower than the voltage supplied by the power source. In this situation a resistor can be used to reduce the voltage supplied by the power source. All electronic components have limits on the amount of current that can flow through them without causing damage and a resistor is commonly used to limit current as a protective measure.

In this exercise you will be using two resistors to explore their effects on current and voltage when connected to a 1.5 volt battery. You will be using Ohm's Law to calculate current in the circuits you build with the resistors. You will also use a multimeter to measure voltage, current and resistance, and compare those results to your calculations using Ohm's Law. You will start to understand how engineers can design electronic circuits on paper using Ohm's Law before they actually start building a test circuit with real electronic components.

The photo of Figure 1 is a close-up view of three typical resistors. You will notice that the bottom one is smaller in size than the other two. A wire is connected to each end of the resistors. Inside the resistors

there is a material that resists the flow of current. The smaller resistor is a lower wattage resistor. The larger resistors are half-watt resistors and I think the smaller one is perhaps a $1/8^{th}$- watt resistor. When you buy resistors, they should be marked on the package with the wattage rating. With experience you can guess at the wattage by their size, but it is better to note the wattage on the package if it is available. In the first lesson we discussed the

Figure 1 Resistors

wattage ratings of electronic components and the importance of not using a component in a circuit unless it has a high enough wattage rating. I also gave you the formula to calculate the wattage of an electrical circuit in lesson 1 (watts = volts X amps).

Most resistors are quite small and it would be difficult to print numbers on them that you could read without a magnifying glass. Instead, resistors are commonly marked with colored bands. The bands are a code for the amount of resistance, in ohms, of the resistor. With my old eyes there is no way to see the colors on the small resistor in Figure 1, but I can tell you the colors on the other two. Reading from the left side the top one is red, red, orange and gold. Using the color code, I know this is supposed to be a 22,000 ohm resistor. The next resistor is: yellow (hard to see), purple, brown, gold (470 ohms). How do we decode the colors? Well, for example, red is the numeral 2, orange 3. Let's decode the first one:

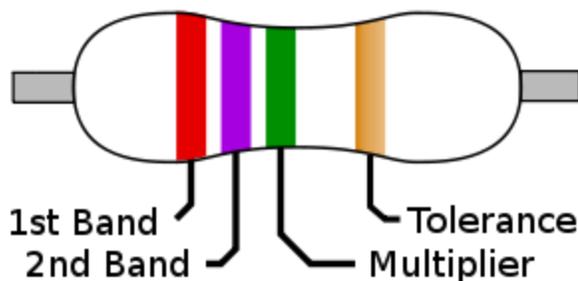red, red, orange. The first two bands we just write down as is, 22. The third band, called the multiplier, is the number of zeroes to add (three for orange). Therefore, the resistance is 22,000 ohms. But what about the gold color? The fourth band of color is the tolerance of the resistor. Tolerance is a measure of how close the true resistance should be to the number given in the code. The color gold represents 5% tolerance. Suppose we had a resistor coded as 100 ohms with a gold fourth band. That resistor should have a true resistance between 95 and 105 ohms. We can find the true resistance by using a multimeter, which you will do in this exercise. You will notice in the diagram in Figure 2 that the tolerance band is supposed to have a greater space between it and the other bands so that you will know the proper end to start reading the bands. But that may not be so clear on actual resistors (see Figure 1). Since most resistors you are likely to work with have 5% tolerance, just look for the gold band and start reading the code from the opposite end. In any case, you should always check resistors with a meter to confirm the resistance.

Figure 2 colored bands on resistor

The Color Code for Resistors

Here is the color code: black = 0, brown = 1, red = 2, orange = 3, yellow = 4, green = 5, blue = 6, purple = 7, grey = 8, white = 9.

Let's decode the resistance of the resistor in figure 2: red 2, purple 7, green 5…. 27 and add 5 zeroes = 2,700,000 ohms. In order to save space in some situations, a large number for resistance can be abbreviated. For a thousand use the letter k and for a million use the letter M. In abbreviated form, 1,000 ohms can be written as **1kΩ** (Ω is the symbol for ohms). And, 2,700,000 ohms can be written as **2.7MΩ**. It is a good idea to learn this now because your multimeter may display resistance in this fashion. For example, suppose you test a resistor with your meter and the display is this: 0.980kΩ. That is the same number as 980 ohms.

Let's start working with real resistors and 1.5 volts from the battery supply on your circuit board (DO NOT USE 3 VOLTS!). You will be given two resistors that contain the labels R1 and R2. When engineers diagram electrical circuits, they label each component with a number for easy reference. For resistors, it is common practice to label them with the letter R followed by a number. So that is what I have done for you. Your first task is to determine the resistance, in ohms, for each resistor. Use the form below to help you read the code on the resistor.

Resistor 1 (R1)

Color of 1st band is _____ and the number for that color is:_____

Color of 2nd band is _____ and the number for that color is:_____

Color of 3rd band is _____ and that is equivalent to how may zeroes: _____

The coded resistance of R1 is _____ ohms (in this case don't abbreviate the number)

You know what the resistance for R1 is supposed to be according to the color code marked on it. But what is the true resistance of that resistor? You must use a meter to find the true resistance.   DON'T FORGET: YOU MUST NEVER TRY TO MEASURE RESISTANCE WITH THE METER IF ELECTRICITY FROM A BATTERY OR OTHER POWER SOURCE IS FLOWING THROUGH THE RESISTOR BECAUSE IT MAY DAMAGE THE METER.

Now measure the resistance of resistor R1 with the meter.

Resistance of R1 measured with the meter is _____ohms.

Look on page two and add here the resistance of R1 according to its color code_____ohms

It is unlikely that your measured resistance for R1 is exactly the same as the resistance marked on it by the color code. There will probably be a small difference between the numbers. The fourth band on the R1 resistor should be gold colored, which indicates a tolerance value of 5%. That means that the resistance measured with the meter should be within 5% of the value coded on the resistor. Does your resistor fall within the 5% tolerance that it should have? You will need to do some calculations to make that determination. You already have all the numbers you need to make the calculation. Here is an example calculation. Suppose your resistor is marked with the code as 100 ohms (by the way, R1 is not 100 ohms). Let's suppose further that you measured the resistance with the meter and found that it is actually 94 ohms. In that case, would the resistor be within the tolerance of 5%? First, multiply 100 ohms by 0.05 to get the answer 5 ohms. That is, 5 ohms is 5% of 100 ohms. Now subtract 5 ohms from 100 ohms, which yields the answer 95 ohms. In order to be within 5% tolerance, the resistor marked as 100 ohms cannot be less than 95 ohms. It also must not be more than 105 ohms. We measured the resistance at 94 ohms, which is less than 95 ohms. Therefore, the resistor is not within the 5% tolerance level. Now, make the calculations to find out if your R1 resistor falls within the marked 5% tolerance.

Value of R1 according to its marked code is _____ohms   X 0.05 =_____ohms

Subtract the 5% value from the marked code value and write the answer here _____also add the 5% value to the marked code value and write the answer here_____. Your R1 resistor must fall within the range of these numbers to be within 5% tolerance.

The measured resistance of R1 is _____ ohms

Is the measured resistance of the R1 resistor within 5% tolerance of its marked code value? _____ yes or no

If your answer is no, then you will need to check your work. Make sure you have decoded the marked value of the resistor properly. Make sure you have properly measured the resistance of the resistor with the meter. If after checking your work, you still find that your resistor is not within the proper

tolerance, then you may have a defective resistor. One of the purposes of measuring the resistance of a resistor and comparing it to the marked value is to confirm that the resistor is in good condition before you actually use it as a component in an electronic circuit.

Now let's work on resistor R2

Resistor R2

Color of 1st band is _____ and the number for that color is:_____

Color of 2nd band is _____ and the number for that color is:_____

Color of 3rd band is _____ and that is equivalent to how may zeroes: _____

The resistance of R2 is _____ ohms according to color coding

The resistance of R2 is _____ ohms according to meter reading

To avoid any confusion, you should always use the resistance measured on your meter for the rest of this exercise. Just to keep that straight, record those values in the space provided below.

Values of resistance measured with the meter:

R1 = _____ ohms

R2 = _____ ohms

Now we are ready to start building electronic circuits with our resistors (go to next page)!

Circuit #1

The circuit you are about to build is just about as simple as possible and is a good place to start. We need to use a resistor of high enough resistance to properly limit current flowing in the circuit and I have selected a resistor for you that will work within safe limits of the components used.

The battery is labeled B1 in the schematic of Figure 3 and the voltage is indicated (1.5 volts).   The symbol for a resistor is a zig-zag line. In this simple circuit it does not matter how we connect the plus and minus terminals of the battery to the resistor, just one to each side. However, we already learned in the last lesson that some electronic components do have "polarity" and a specific wire of the component must be connected to plus on the battery and another specific wire connected to the negative terminal of the battery (for example an LED).
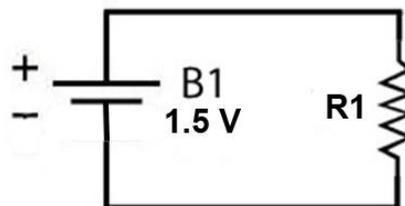

Figure 3 Circuit 1

No go ahead, using Figure 3 for as your example of the circuit, and connect the 1.5 volt battery source of your circuit board to the resistor labeled R1. MAKE SURE YOU DO NOT CREATE A SHORT CIRCUIT. THE CURRENT MUST FLOW THROUGH THE RESISTOR.

While current is flowing in the circuit, it is time now to make a measurement of voltage with your meter. Measure the voltage drop across the resistor R1.

Voltage drop for R1 in circuit one is: _____

In this case you are also measuring the voltage supplied by the battery. It is likely that your measurement is not exactly 1.5 volts. If the battery is new, the voltage will probably be a little more than 1.5 volts. If the battery has been used for a long time, you will probably find that the voltage is well below 1.5 volts. As batteries are used, the voltage they supply becomes less and less. At a certain voltage the battery is no longer useful because it does not supply enough voltage. If the battery is not a rechargeable type, it must be discarded when the voltage is too low.

You already know how much resistance there is in R1 due to a previous measurement. AND KEEP IN MIND MY WARNING THAT YOU SHOULD NEVER TRY TO MEASURE RESISTANCE IN A CIRCUIT THAT IS CARRYING CURRENT. If you tried to measure the resistance of R1 now, while it is connected to the battery, you may damage the meter.

You now know how much voltage is applied to the circuit and how much resistance the circuit has (the wires themselves have almost no resistance to current flow and we can just ignore them in our circuit as sources of resistance). The only significant source of resistance is the resistor.

Remember that there are three important values to keep in mind in our circuit: voltage, resistance and current. We have not measured the current in our circuit yet. We could do that with a meter, but let us

first calculate the expected current according to Ohm's Law. If we know two of three variables we can calculate the third with the law. Recall Ohm's Law:

Current = Voltage/Resistance

Suppose that R1 is 100 ohms (it is not). If R1 was 100 ohms then the current in circuit one would be:

Current = 1.5 volts/100 ohms = 0.015 amps or 15 milliamps

Now calculate the expected current in your circuit using Ohm's Law:

Voltage drop for R1 _____ divided by the measured resistance of R1 _____ equals

_____ amps and multiply by 1,000 equals _____ milliamps

Now that you have calculated the expected current flow in your circuit, you will actually measure the current with the meter. Here you must be very careful because it is easy to damage the meter when making current measurements if you try to measure too much current. Ask an adult to help you with the measurement if you are not sure how to make the measurement. First, determine the direct current (DC) limit of the meter you are using. The maximum amount of current the meter can measure (with the red wire connected to V/Ω/..) is: _____ milliamps

Figure 4 manual meter set to measure current (200 milliamps maximum)

 You must first set the meter to measure direct current (DC). See Figure 4 for an example of the proper dial setting to measure current. Disconnect the red battery wire from the resistor and connect it to the black probe of the meter. Then touch the red probe of the meter to the side of the resistor where you

just removed the battery wire. Current will begin to flow though the meter and your circuit and the meter will display the value for the current. Write down the measured direct current of the circuit.

Measured direct current is _____ milliamps
Calculated current by Ohm's Law _____ milliamps (look on page 6)

Now compare the measured value to the value calculated by Ohm's Law. They should be the same value or close. This confirms that Ohm's Law really can be used to calculate current in a circuit if you know the voltage and resistance. You don't need to measure the current.

Measuring current in electronic devices is usually difficult because you have to break the path of current flow to insert the meter into the circuit. The meter must become a part of the circuit, with the current flowing through the meter. That is not the case when measuring voltage. Remember that when you measured the voltage, you only needed to touch the probes to the wires on both sides of the resistor. You did not need to open the circuit to insert the meter into the path of flow.

Now we should calculate the amount of power our resistor is consuming in circuit one. First let us return to a previous example (100 ohm resistor connected to 1.5 volt battery). Remember that we have already calculated the current when using the 100 ohm resistor (0.015 amps).

Power = Volts X Amps

Power = 1.5 volts X 0.015 amps = 0.022 watts

A 100 ohm resistor would consume 0.022 watts when connected to a 1.5 volt battery. Remember that we are using 0.5 watt resistors. Therefore, we could use a 100 ohm resistor in the circuit because it will consume less power than the rating of the resistor. An engineer would always check to make sure the resistor wattage is sufficient for the circuit.

Now go ahead and calculate the power in watts consumed in your circuit one using the values for current and voltage that you measured with the meter:

Voltage drop for R1 in volts _____   X   measured current in amps_____
equals _____ watts

You will need to convert your current measurement in milliamps to amps. Don't use milliamps in the above calculation. To convert milliamps to amps, divide milliamps by 1,000.

Circuit #2

In this circuit you will connect two resistors "in series." **Electronic components connected in series all have the same amount of current flow through them.** However, the voltage drop across each component depends on its resistance. If you place resistors in a series circuit, it is easy to calculate the total resistance of the circuit. To find the total resistance, just sum the resistances of all resistors. For example, if you place two 100 ohm resistors in series, their combined resistance will be 200 ohms. If all the resistors in a series circuit have the same resistance, then each resistor will have a voltage drop equal to the other resistors in the circuit. Using our same example (a 1.5 volt battery), the voltage drop of each 100 ohm resistor would be 0.75 volt, which is half of 1.5 volts.
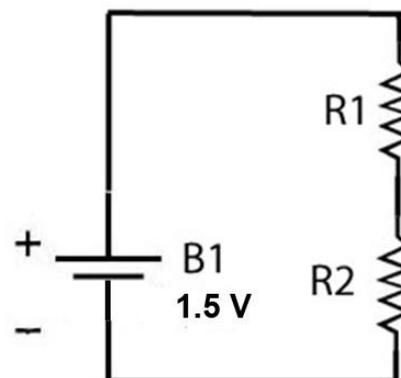
Figure 5 Circuit 2

Using a wire with clips connect the two resistors together on the circuit board and connect 1.5 volts from the battery supply to create the circuit in Figure 5. MAKE SURE YOU DO NOT CREATE A SHORT CIRCUIT.

Current will now flow in the circuit. While current is flowing in the circuit, you will measure the voltage drop of each resistor with your meter.

Set your meter to measure voltage, the same way you did for circuit one.

Touch one meter probe to one wire of R1 and the other probe to the other wire of R1. The meter will now display the voltage drop across R1. Write the voltage drop for R1 here:_____

Touch one meter probe to one wire of R2 and the other probe to the other wire of R2. The meter will now display the voltage drop across R2. Write the voltage drop for R2 here: _____

Resistors R1 and R2 are the only sources of significant resistance in this circuit. If we wish to know the total voltage drop in a circuit that contains only series connected components, then we can just add the voltage drops together.

Voltage drop R1 _____ plus voltage drop R2 _____ = _____ total drop

After you have calculated the total voltage drop above, you can check it with the meter. To measure the total drop touch one meter probe to the red battery wire where it connects to R1 and the other probe to the black battery wire where it touches R2.

Total voltage drop measured by meter is _____ volts.

Are your calculated total voltage drop and measured total voltage drop the same? If not, the values should be nearly the same.

Now you will calculate the current flow through the circuit:

Measured resistance of R1 _____ plus measured resistance of R2 _____ equals _____ ohms total resistance

Total voltage drop equals _____volts

<center>Current = Voltage/Resistance</center>

_____ volts total drop divided by _____ ohms total resistance equals _____ amps current and multiplied by 1,000 equals _____ milliamps

Now you will measure the amount of current flowing in your circuit and compare it with the value you just calculated.

Set your meter to measure DC milliamps. Remove the red battery wire from the resistor and connect it to the black probe. Then touch the red meter probe to the resistor wire where you just removed the red battery wire. Write down the current measured with the meter: _____ milliamps

Your calculated and measured current should be the same or very close. Are your calculated and measured current values the same or nearly the same? _____ yes or no

If you answered no, then please check your work for mistakes.

Have you found that less current flows through circuit 2 than through circuit 1? _____ yes or no

Your answer should be yes. There is more resistance in circuit 2 and both circuits have the same amount of total voltage drop because they utilized the same battery. Since circuit 2 has more resistance, we can expect that less current will flow through it. In fact, we can see that current flow is proportional to the resistance of the circuit. In other words, if we double the resistance in a circuit but keep the voltage the same, then we can expect half as much current flow. Your measurements with the meter confirm that Ohm's Law really does work.

Circuit #3

In this circuit you will connect two resistors "in parallel." Electronic components connected in parallel all experience the same amount of voltage drop but will carry different amounts of current if their resistances are not the same.   If you place resistors in a parallel circuit, you can use the following formula to calculate the total resistance of the circuit.

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}.$$

Don't worry if you don't understand the above formula. Let us just take an example to see how it works. Suppose we have three resistors in parallel with the following resistances: 100 ohms, 200 ohms and 250 ohms. Here is how we would solve the equation.

$$\frac{1}{R_{total}} = \frac{1}{100} + \frac{1}{200} + \frac{1}{250}$$

Now reduce each fraction to a decimal number by dividing the numerator (1) by the denominator and then add the decimal numbers together. In the example the sum is 0.019

$$\frac{1}{R_{total}} = 0.01 + 0.005 + 0.004 = 0.019$$

Below we see the result of calculations on the left. R_{total} is in the denominator and we must rearrange the equation to find the value for total resistance, as in the equation on the right below.

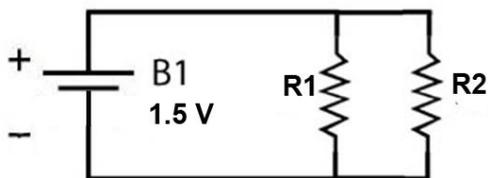$$\frac{1}{R_{total}} = 0.019 \qquad \frac{1}{0.019} = R_{total}$$

Figure 6 diagram for circuit 3

Now to find the total resistance, just divide 1 by 0.019. The result is 53 ohms. You can see the interesting effect of adding resistors in parallel in a circuit. The total resistance of the circuit is less than the lowest value resistor used. This may seem puzzling at first, but let us take a look at the diagram for circuit number three. You can see in the diagram that current can take more than one path when the resistors are arranged in a parallel pattern. Specific electrons in the current have the choice of passing through either R1 or R2, but not both. Since there is more than one path available, the total resistance to flow is less than the resistance of even the lowest resistance resistor. Suppose you needed a 50 ohm resistor for your robot circuit but all you had was a bunch of 100 ohm resistors. Well, no problem, just connect two 100 ohm resistors in parallel and you have a functioning 50 ohm resistor!

Now you will calculate the resistance of R1 and R2 connected in parallel. The measured resistance of R1 is _____ ohms and measured resistance of R2 is _____ ohms.

$$1/R_{total} = 1/R1 + 1/R2$$

$$1/R_{total} = 1/\_\_\_\_ \text{ ohms} + 1/\_\_\_\_ \text{ ohms}$$

Reduce the fractions on the right side of the equation to decimal values (divide one by the value of the resistor)

$$1/R_{total} = _____ \text{ ohms} + _____ \text{ ohms}$$

Sum the decimal values on the right side of the equation

$$1/R_{total} = \text{_____ ohms}$$

Rearrange the equation

$$R_{total} = 1/\text{_____ ohms}$$

Reduce the fraction on the right side of the equation (divide one by the denominator)

$$R_{total} = \text{_____ ohms}$$

Now that you have calculated the value of the resistance for R1 and R2 in parallel, you will compare the value to the resistance determined with the meter. First you need to connect the two resistors together in parallel using two wires with clips. DO NOT CONNECT THE RESISTORS TO THE BATTERY AT THIS TIME. Now measure the resistance of the resistors in parallel with your meter.

   Write here the displayed resistance on the meter: _____ ohms

Your calculated resistance of R1 and R2 in parallel should be the same or nearly the same as the measured resistance. Are the values the same or nearly the same?_____ yes or no

If the values are not the same or nearly the same, then check your work for errors.

Now connect 1.5 volts from the battery to your circuit so that current is flowing through the resistors (MAKE SURE YOU DO NOT CREATE A SHORT CIRCUIT).

Your circuit is now complete and current is flowing through the circuit. You will now measure the voltage drop across both resistors. Set your meter to measure DC volts as you have previously done. Touch one probe of the meter to one of the wires of R1 and the other probe to the other wire of R1. Read the voltage on the meter and write it down here _____ volts drop for R1

Now repeat the procedure to measure the voltage drop for R2 _____ volts drop for R2

Your voltage drop measured for both resistors should be the same or nearly the same. Resistors in parallel have the same voltage drop. However, the current flowing through each resistor will not be the same if they have different resistances. You will now use Ohm's Law to calculate the current flowing through each resistor.

Current = Voltage/Resistance

Measured voltage drop of R1 _____ divided by measured resistance of R1 _____ equals

_____ amps and multiplied by 1,000 equals _____ milliamps

Measured voltage drop of R2 _____ divided by measured resistance of R2 _____ equals

_____ amps and multiplied by 1,000 equals _____ milliamps

Now you will measure the current flowing through each resistor with the meter. Set the meter to measure DC milliamps. Open the circuit in such a way that you only measure the current flowing through resistor R1. Then connect the meter to the circuit.

Record the value of the meter display here: _____ milliamps for R1

Remove the meter from the circuit and restore the wire connection. Now open the circuit in such a way that you only measure the current flowing through resistor R2. Then connect the meter to the circuit.

Record the value of the meter display here: _____ milliamps for R2

Now remove the meter from the circuit and reconnect the wires as they were originally for circuit #3.

Open the circuit is such a way that you will measure the total current flowing through the circuit. Then connect the meter to the circuit.

Record the value of the meter display here: _____ milliamps total current in circuit #3

Now add the measured current flowing through R1 and R2

R1 current _____ plus R2 current _____ equals _____ milliamps total current for circuit #3

Compare your measured total current for circuit #3 with the sum of current for R1 and R2. The values should be the same or very nearly the same. Think about this for a minute. In the last measurement you inserted the meter into the circuit at one of the battery supply wires. All current flowing out of (or in to) the battery was measured by the meter. In the first and second measurements, the meter was inserted into the circuit in such a way that it only measured the current flow through one of the resistors. In this circuit, part of the total current flows through R1 and the remaining part flows through R2. If we add the current flowing through one resistor to the current flowing through the other resistor, then we have calculated the total current flow. Your measurement of the total current flow confirms that the calculation method (adding currents together) is the proper method of calculation.

Congratulations, you have finished this exercise on resistors.