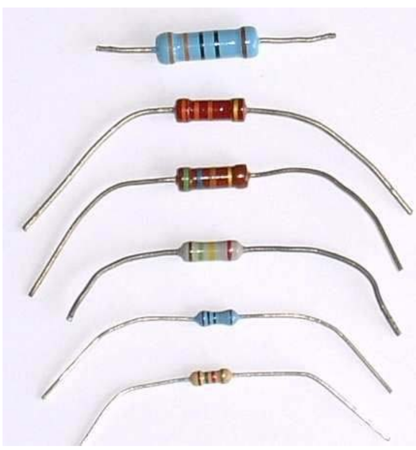
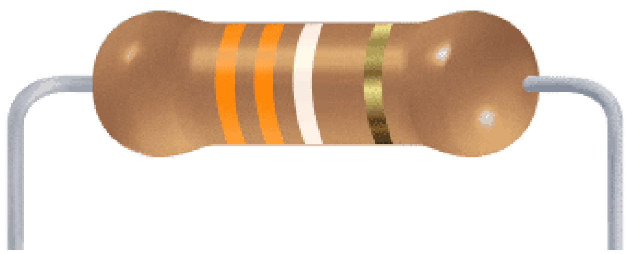
Resistors

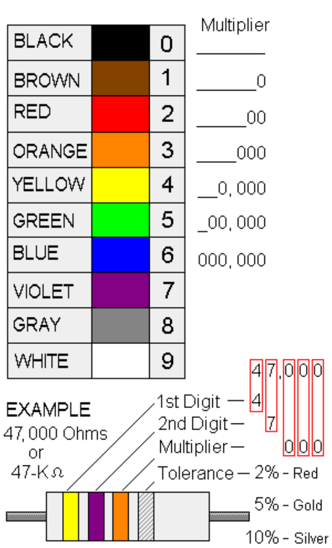
We begin by learning how to read the values of resistors and to measure the values using a digital multimeter (DMM). Resistors are the most common and simplest electrical component. In an electrical circuit diagram, they are indicated using a zig-zag line.

This is only the symbol we use and not what they look like. Resistors come in many forms, but usually look like small pills with colored stripes with a wire coming out of each end.





The colored stripes tell us what the value is of the resistor. Only the first three stripes are used for this purpose. The first two stripes are read like a regular number with each color representing a specific digit.



For the resistor shown above, the first two stripes are orange, which, from the chart at the left, both represent the number 3. Thus the first two numbers are 33. The third stripe is white, which represents the number of zeros we add to the right of 33. Thus, the resistor is 33000000000 Ω which is really, really huge. We will not use resistors this large. We will use a 1000 Ω resistor. This is also called a 1kΩ resistor, since the symbol k represents 1000. The stripes in this case are brown, black, red.

Note that the colors used for the numbers from 2 to 7 correspond to the colors of the rainbow, also known as the colors of visible light. There are many helpful tools online for identifying resistors including: http://www.dannyg.com/javascript/res/resload.htm, http://www.csgnetwork.com/resistcolcalc.html, and http://www.ealnet.com/m-eal/resistor/resistor.htm.

It is good to use one of these tools to confirm that you have read the value of resistors correctly. However, it is still possible to read the colors wrong since some colors fade or print badly when the resistors are being manufactured. To be completely sure that you know the values of the resistors we are going to use today, it is best to measure each one directly to confirm its value. The device we use for this purpose is called a Digital Multi-meter or DMM for short. There are many, many multimeters available for sale, costing anywhere from a few dollars to a few thousand dollars (the more expensive ones are more accurate and have other functionalities). The one we will use is very inexpensive but works well. It is available at Harbor Freight, a great place to buy cheap tools.

Note that there are three places to connect the probe wires. Plug the black lead at the bottom and the red lead in the middle. To use the meter, you must set the function with the dial. To measure resistance values you should turn it to one of the options in the area marked with the Greek letter **Ω**, the symbol for Ohms, the unit of resistance. Select the range to be just larger than the value of your resistor (read from the colored stripes).

If you choose a range that is too small, the meter will think the resistance is too big to measure and will display either just the number 1 or OL. When you see this, adjust the range to a larger value. Before you make any resistance measurements, select the smallest range and measure the resistance of the leads. For this inexpensive meter, this will not be very accurate, but you will see that the resistance is not zero. Also, resistance measurements require that a current be passed through the resistor, so this will use the battery in the meter. If you make too many measurements, especially of small resistors, your battery will no longer work.

Resistance Measurements (Measure all of your resistors, since even those that are labeled the same can be at least a little different)

1st Band Color	2nd Band Color	3rd Band Color	Value from Bands	Measured Value	Percentage Error

Percent Error = 100% x (Value from Bands – Measured Value)/(Value from Bands)

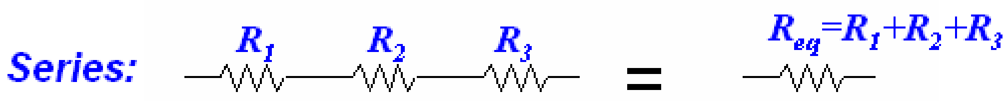
Combining Resistors

Resistors resist the flow of electrical current in the same way that friction resists the motion of physical objects. If, for example, you slide your hand back and forth across the surface of a table (while pushing down on the table top) you will feel friction that forces you to work hard to move your hand. You will also notice that your hand will become warm and your mechanical motion is converted into heat by the friction. If you do not rub on anything, you can much more easily move your hand back and forth (try this without touching the table) and your hand will not heat up. When electrical current flows through a resistor, heat is also produced, although you will generally not notice that the resistor becomes warm since the currents we use are small. However, you should have noticed many times that electrical devices you use become warm when they are on. This is due to resistance in the circuits inside the device.

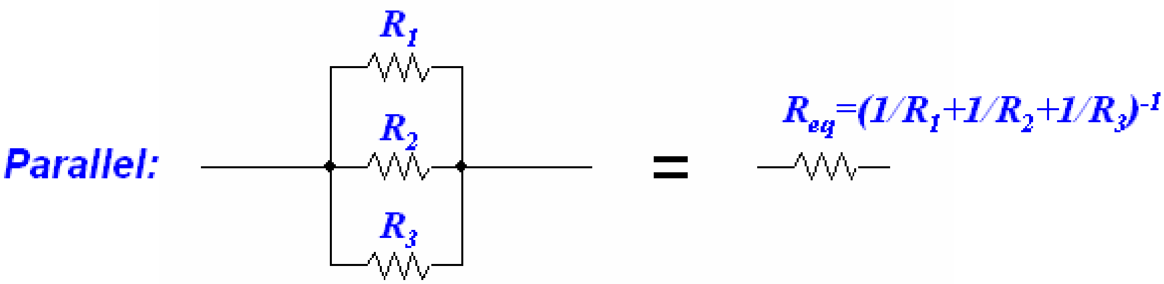
Give two examples of electrical devices that you have personally noticed getting warm when they are turned on.

1.
2.

Since one resistor resists current flow, making the current pass through two resistors connected end-to-end (we call this configuration resistors connected in series) should double the resistance, which is indeed the case. We indicate resistors in series as shown below.



The formula at the right says that resistors add directly in series. Thus, if you have 3 1000Ω resistors (also known as 1kΩ), they will add to 3000Ω. We will do a simple experiment in a minute to show that this is indeed the case. Resistors can also be combined in parallel. That is connecting them together so that the electrical current is given multiple paths to follow rather than just one. When this happens, the current will split up into the parallel resistors.



Adding resistors in series and parallel follows very simple rules that should make sense to us. Resistors in series just add to make a larger resistance. $R = R_1 + R_2 + R_3 + \ldots$ while resistors in parallel add to make a smaller resistance. $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$ This is similar to waiting in line at the grocery store. If there are 16 people waiting in line for one cashier, it takes a long time to get served. If there are 4 cashiers, there will be only 4 people per line and the wait will be much less.

Calculate the resistance of 4 1000Ω resistors in series.

$$R = R_1 + R_2 + R_3 + \ldots = 1000 + 1000 + 1000 + 1000 = ?$$

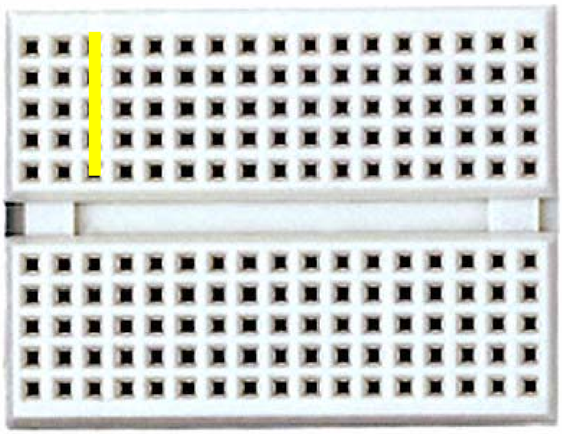
Calculate the resistance of 4 4000Ω resistors in parallel.

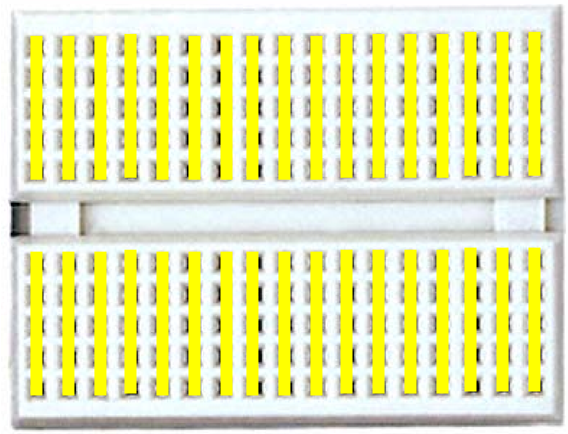
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots = \frac{1}{4000} + \frac{1}{4000} + \frac{1}{4000} + \frac{1}{4000} = ?$$

or $R = ?$

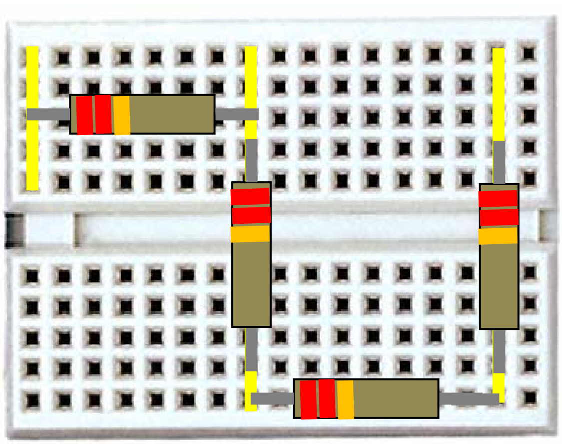
Measuring Combined Resistances

To measure combinations of resistors, we need a simple method to connect them together. For this purpose and for other circuits we will build today, we will use a protoboard (also known as a breadboard). The device we will use looks something like the one shown below.



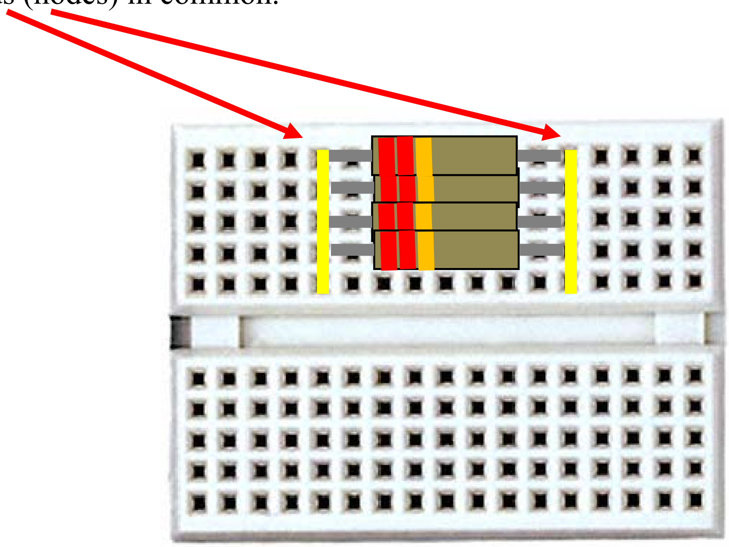


This is a very handy device that permits us to connect electrical components (such as resistors) by pushing wires into the holes on the board. When a wire is pushed into one of the holes on the board, it will be connected to 4 other holes. For example, in the board shown above left, the 5 holes marked with the yellow line are connected together. The board shown above right shows all sets of connected holes (there are 34 sets on this board … the board you use may be different). Note that these yellow lines are not found on the actual board. To connect four resistors in series, one uses a configuration like the one shown below.



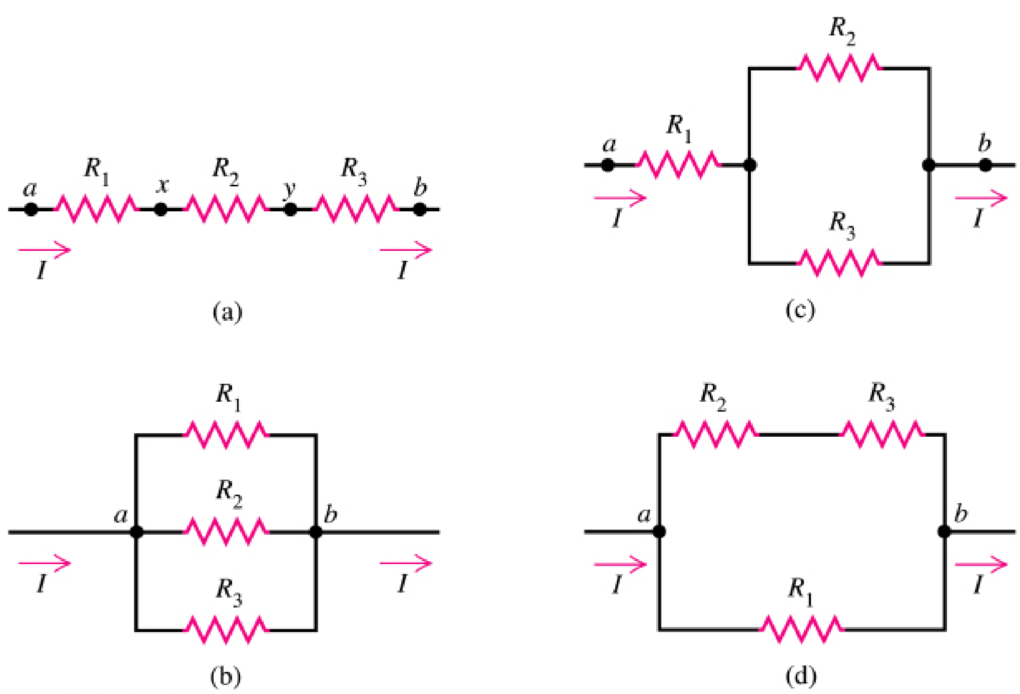
The 1st resistor is inserted in 2 different columns of 5 holes. The 1st wire of the 2nd resistor is connected to the 2nd set of 5 holes used by the 1st resistor. The 2nd wire of the 2nd resistor is inserted into a new set of 5 holes elsewhere on the board. The 3rd and 4th resistors are connected in the same manner. If done correctly, the 4 resistors should now be in series. Following this method, connect 4 1kΩ resistors in series and then use the DMM to measure the total resistance. Your result should agree with your calculation.

Now combine 4 4kΩ resistors in parallel. This is easier than series because one end of each resistor goes in one set of 5 holes and the other goes in the other set. Parallel resistors need to have both ends (nodes) in common.



Measure the combined resistance with the DMM. Again, your result should agree with your calculation.

Shown below are a variety of combinations of resistors that, in general, do not have the same values. We will next consider what happens when we combine two very different resistors.



Two resistors in series: Combine a 1kΩ and a 100kΩ resistor in series on your protoboard. Calculate and measure the combined resistance.

Which of the two resistors dominates the combined value? What can you conclude in general about the combination of two resistors in series where one is very much larger than the other?

Two resistors in parallel: Combine a 1kΩ and a 100kΩ resistor in parallel on your protoboard. Calculate and measure the combined resistance.

Which of the two resistors dominates the combined value? What can you conclude in general about the combination of two resistors in parallel where one is very much larger than the other?

Try the other combinations shown in the figure above with any three resistors and check to see if the calculated values agree with measurements. Note that for the series-parallel circuits, you must first do the calculations in stages.

For your measurements of individual resistors and also of combinations of resistors, you will not obtain perfect agreement with your calculations or with the stripes shown on the resistors. This is because resistor manufacturers only promise to provide components that are close to the indicated value. We do not need resistors to be perfect to build circuits and perfect precision in labeling is expensive. The 4^{th} stripe on each resistor shows how close the manufacturer promises to provide the resistors we have requested. The most common 4^{th} stripe is silver, which indicates 10% tolerance. That is, a resistor with brown, black, orange stripes should be 10,000Ω but with a silver stripe, it might be as low as 9,000Ω or as high as 11,000Ω. The codes for the 4^{th} band are:
silver ±10%, **gold** ±5%, **red** ±2%, **brown** ±1%.
If no 4^{th} band is shown the tolerance is ±20%.

Return to your table for the resistance measurements you made and check to see if all resistors are within the tolerances indicated by the 4^{th} stripe. Note, you should have calculated the percentage error for each of your resistors. For the 1kΩ resistors, what was your largest error?