Properties of Electrical Resistors

Purpose: Students will become familiar with electrical resistance and electrical resistors.

Introduction:

If you have ever untangled a garden hose, you're somewhat familiar with resistance. If the hose is bent too sharply, the water doesn't come out very well. You can even stop the water flow entirely by bending the hose intentionally. The bend in the hose restricts the flow of water. Something like this happens in electrical circuits. Every garden hose, water pipe, artery, or vein resists the flow of fluid. Every circuit element (wire, lamp, motor, transistor, integrated circuit, etc.) has some electrical resistance that limits the flow of current. They only exceptions are electrical superconductors and superfluids, which are special substances that lose all resistance at temperatures that are usually near absolute zero.

In this lab, you will investigate some of the properties of various types of electrical resistors. You'll also see what happens when resistors are combined in series and parallel.

Experiment 1: Exploring Resistance (no more than 5 minutes)

You will need three or four drinking straws and a few short pieces of tape. The straws are "resistors." The air pressure from your lungs is the "voltage,"and the flow of air is the "current."

- Put one end of a straw in your mouth and breathe through it gently. Then pinch the middle of the straw with your fingers so that it is partially closed. Observe the increase in effort required to breathe through the pinched straw. Try it again, this time blowing air through the open, then pinched, straw. Notice that to maintain a constant flow of air ("current"), you have to blow harder (increase the "voltage") when the straw is pinched. In electrical terms, this relationship between current, voltage, and resistance is called "Ohm's Law." $I = \dfrac{V}{R}$
- Put one end of a straw in your mouth and breathe through it gently. Then place a second straw in your mouth so that the two straws are side by side. In electrical terms, the two straws are in "parallel." Try breathing through the combination of two parallel straws. Add more straws if you like. Record your observations in the Analysis Questions at the end of the lab. Do it NOW. You need to think about this before moving on with the lab.
- Put one end of a straw in your mouth and breathe through it gently. Using tape, attach a second straw to the end of the first straw to make a longer straw. Observe the change in resistance. If you like, add a third or fourth straw to make a really long straw and observe again. Record your observations in the Analysis Questions at the end of the lab. Do it NOW.
- Put the straws in the trash receptacles. You don't need them any more.

Experiment 2: Using the DMM (Digital Multimeter) (no more than 5 minutes)

The DMM is a versatile tool for measuring voltage, current, resistance, and more, depending on the individual meter's features. Read the following and familiarize yourself with the DMM. To use the DMM:

- Turn the POWER switch on. **Note:** These DMM's automatically turn themselves off after 30 minutes. **To reset, turn the power switch OFF, <u>wait five seconds</u>, then turn the meter back on.**

- Plug one probe into the COM (common) port. This probe is traditionally black. The electrons don't care what color it is.

- What do you want to measure? Voltage? Resistance? Current? Usually, you will plug the other probe (traditionally red) into the port labeled "**VΩ**". If you want to measure currents, use the ports labeled "mA" or "A", depending on the size of the currents you want to measure. IN THIS CASE, YOU WANT RESISTANCE (labeled **Ω**) which is the right-most plug.

- Put the "AC/DC" switch on DC. AC stands for "alternating current" and DC stands for "direct current." In this lab, you will only work with DC circuits. Make sure that the "HOLD" and "REL" buttons are off.

- Turn the DMM knob to the setting for what you want to measure. In this lab, you want resistance (labeled **Ω**).

Fig. 1: Extech Model MT310 Digital Multimeter (DMM)

- Your meter should automatically choose its range. The range shows the highest value that can be measured. In general, if you have a choice of ranges (such as 200V, 100V, 20V, 10V, 2V), start with the highest range and work your way down to the most appropriate setting. WARNING: Measuring a current that is too high for your setting will blow the meter's internal fuse. Start high, and work your way down!

- About the ± sign: If you are measuring voltage or current, the minus sign appears when the polarity of the non-COM (traditionally red) probe is negative.

- Pay attention to the UNITS on the display. There's a difference between Ω, kΩ, and MΩ!

- About error: For the purposes of this lab, you may assume that the error of the DMM is no greater than **2% of the meter's reading**. In reality, each range on the meter has its own measurement uncertainty. If you need to know about the DMM's measurement uncertainty in more detail, please refer to the manufacturer's data sheet for the DMM or the sheet posted on the bulletin board in the lab. (Most are Extech Digital Multimeter Model MT310)

Your turn!

Set the DMM to measure ohms (Ω). The DMM should read "0L" (or overload) when the free ends of the probes aren't connected to anything. "0L" simply means that the resistance is too high for the meter to measure. Touch the two probes together firmly. The DMM should read 0Ω. If the meter isn't working, ask your TA or instructor for assistance.

Experiment 3: Measuring the resistance of the human body (5 minutes, max)

This is a very short experiment. Moisten your fingers and firmly hold the "business end" of a DMM probe in each hand. Answer the Analysis Questions for this experiment. No, you won't get shocked. The DMM produces a low voltage from a 9V battery, which is mostly harmless.

Your resistance won't be steady, so take a reading whenever you feel lucky. EACH PERSON in your lab group should try this. Compare notes with other students in the lab to get a sense of what values are typical, and what variations are normal.

Experiment 4: What is the relationship between resistance and the length of a wire? (15 minutes, maximum)

You have a clear plastic block containing a wire. This is a special wire made from a metal with unusually high electrical resistance.

- Use the DMM to measure the resistance between one end of the wire and the other four points.
- Measure the lengths of the wires with a ruler. When you measure length, ignore the parts of the wires that are in contact with the sockets.
- Record your data on the Data Sheet and plot a graph of resistance vs. length in Graphical Analysis. Before you print, make sure that the point protectors are visible, that the color is dark, and that "Connect Points" is unchecked in Graph Options. Fit a straight line to your data.
- Answer the Analysis Questions (NOW, please) and attach a copy of the graph to your lab report.
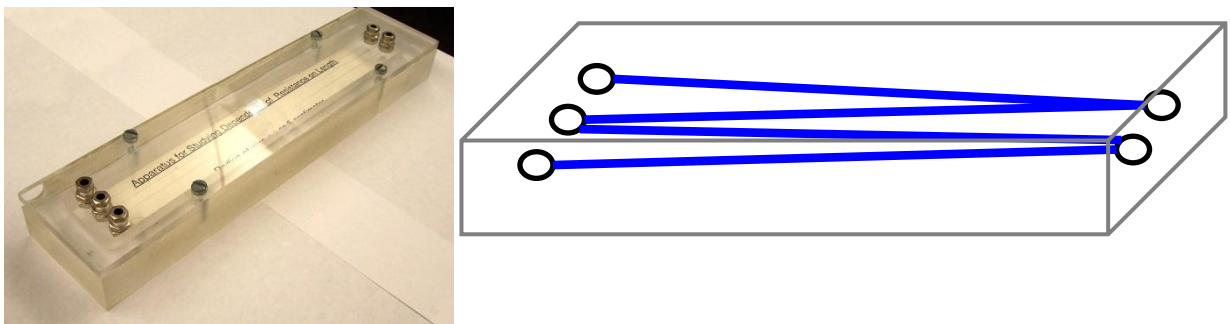
Your apparatus is shown below.

Fig. 2: Apparatus for measuring the resistance of a wire. The wire zigzags from the top left connector to the bottom left. Left: photograph. Right: sketch, showing the wire.

Experiment 5: What is the effect of temperature on the resistance of a wire?

(Allow 20 minutes for this experiment. You may do Experiments 6 or 7 first, if you wish.)

You have a resistor made from a wire wrapped on a core to make a small coil. This "wire-wound" resistor has a resistance of approximately 600 Ω at room temperature.
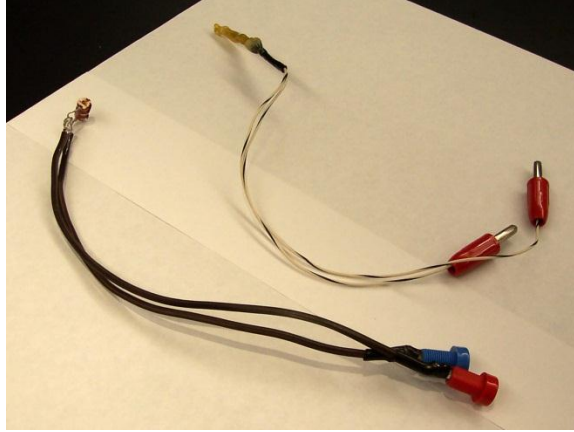

Fig. 3: The wire-wound resistor for Experiment 5 is on the left. The thermistor for Experiment 6 is on the right.

These measurements are brief. Simply take the DMM and coil over to the containers at the sides of the room and measure its resistance at several different temperatures. Perform your measurements there. **Do not attempt to take the containers to your table.** Dip just the coil into each temperature bath, taking care not to get much of the connecting wires wet or cold. Record your data in the table at the end of the lab. Your temperatures are:

- Room temperature (measure temperature and ohms)
- Hot tap water (dip only the coil in the water, measure the temperature and ohms)
- Ice water (0°C, dip only the coil into the water, no need to measure temperature)
- A mixture of dry ice and alcohol (-78.5°C) Do NOT attempt to measure the temperature! It's too cold for the thermometer to measure.
- Liquid Nitrogen (-196°C) Be very gentle with the coil and its wires, since these are easily damaged while frozen. Do NOT attempt to measure the temperature, as this may damage the thermometer.

Analysis:

- Plot a graph of resistance vs. temperature in Graphical Analysis.
- Fit a straight line to your data, omitting the liquid nitrogen point. Clicking and drag on the graph to select the data thay you want to fit.
- Make sure that "Connect Points" in Graph Options is unchecked, the color of the data is dark, and that the ±2% error bars and fitted line are visible before you print your graph.
- Answer the Analysis Questions for Experiment 5.

Experiment 6: Thermistors (15 minutes, maximum)

A thermistor is a tiny piece of semiconductor made so that its resistance changes a lot over some temperature range. Most digital thermometers sense temperature with thermistors, then convert resistance into temperature with a look-up table in the thermometer's microprocessor. (A microprocessor is a basically a tiny computer.)

You have a bare thermistor. **Your job:** Measure its electrical resistance at several temperatures, then plot the resistance vs. temperature curve for your thermistor.

To do this, put the thermistor and the digital thermometer in a small beaker of water at the same time. Start with hot water from the faucet, then gradually add ice. Take at least six to eight readings at different temperatures between "hot water" and 0°C. Don't try to get evenly spaced numbers like 20°C or 35°C. That's a waste of time. "Weird" numbers like 23.6°C or 17.5°C are fine. It is more important to get each temperature and resistance reading at the same time.

Record your data on the data sheet. Plot it in Graphical Analysis, and answer the Analysis Questions.

If you want to know more about thermistors, try http://en.wikipedia.org/wiki/Thermistor

Experiment 7: Series and Parallel Resistors

You have a board on which four carbon resistors are mounted. Carbon resistors used to be commonly used in electronics. The nominal values of the resistance can be determined by the colors of the stripes on the resistors. Starting at the stripe nearest one end of the resistor, the first stripe gives the first digit. The second stripe gives the second digit of the resistance. The third stripe gives the number of zeros (power of ten), and the fourth stripe is the tolerance. If the fourth stripe is silver, the nominal resistance should be within 10% of the actual value. If the fourth stripe is gold, the tolerance is 5%. The colors are easy to remember if you think "black, brown, rainbow, gray, white." A "Meg" is a megaohm, or 10^6 Ω

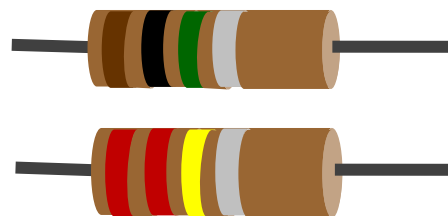| Color	Number	Multiplier
Black	0	0
Brown	1	10
Red	2	100
Orange	3	1000 = 1k
Yellow	4	10^4 = 10k
Green	5	10^5 = 100k
Blue	6	10^6 = 1Meg
Violet	7	10^7 = 10 Meg
Gray	8	10^8 = 100 Meg
White	9	10^9 = 1000 Meg

Fig. 3: Resistors.

Top: Brown-Black-Green-Silver is 10×10^5 Ω = 10^6 Ω = 1 Megohm ±10%.

Bottom: Red-Red-Yellow-Silver is 22×10^4 Ω = 220 kΩ ± 10%

When resistors are manufacured, there's some variation in the actual resistance. To make matters worse, the actual resistance depends somewhat on temperature, and can change as a result of using the resistor in a circuit. Circuit designers know that all resistances are only approximate. The "nominal value" of a resistor is what's painted on it. The "actual value" is what you measure with your DMM. The "tolerance" is a statement about the measurement uncertainty in the nominal value.

Your job:

- Determine the individual nominal resistances and tolerances by reading the color codes of the resistors.

- Measure the individual actual resistances, using the DMM, and record these in your data table.

- Compare the actual resistances with the nominal resistances to determine whether your resistors are within their tolerances.

Please do all of this NOW.

Next, recall Experiment 1 at the start of this lab. Two or more resistors are in series if they are connected end-to-end. Two or more resistors are in parallel if they are connected side-by-side.

Note that connecting resistors in series is like stringing two garden hoses together. All of the current must pass through both resistors, one after the other. When resistors are connected in parallel, it's like passing through a set of toll booths on the highway. The current flow divides so that some current flows through one resistor, and some through the other(s).
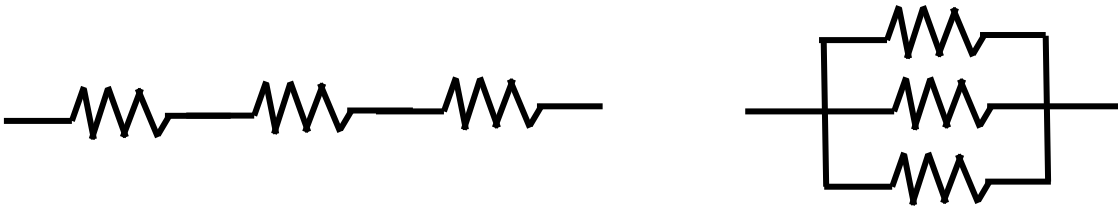

Fig. 4: The three resistors on the left are connected in series. The three resistors on the right are connected in parallel.

Your job: Make series and parallel combinations of resistors. PREDICT, then measure the actual resistances of your combinations.

- Connect two different pairs of resistors in series. Predict the resistance of the combination, then measure and record the actual value. DO NOT CHANGE YOUR PREDICTION! If your prediction turned out to be wrong, state what was wrong with it. This is how you learn! Resistances in a series combination simply add together: $R_{total}=R_1+R_2+R_3+\cdots$.

- Connect two different pairs of resistors in parallel. Predict the resistance of the combination, then measure and record the actual value. DO NOT CHANGE YOUR PREDICTION! If your prediction turned out to be wrong, state what was wrong with it. This is how you learn!

In a parallel combination, add the reciprocals of the resistances: $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$.
Don't forget to take the reciprocal of the result to get R_{total}!

- If you have the time and energy, make any combinations of resistors that you like. Predict and test the final resistance, then comment on the result of your test.

Clean-Up:

- Please empty water, wipe up spills, and leave the tables and apparatus clean and dry.
- Disconnect all wires.
- Turn off the DMM and digital thermometer.
- Place all trash and recyclables in the proper containers.

For more information and practice:

There is an excellent Java applet that lets you build DC circuits, observe how they work, and even measure voltages, resistances, and currents. The web address is:
http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc

Lab Section: _____   T.A.'s _____

Today's Lab Partners: _____

Properties of Resistors

Data Sheets

Analysis Questions for Experiment 1:

1. (circle one) Does the resistance INCREASE, DECREASE, or STAY THE SAME when you put straws in parallel?

2. (circle one) Does the resistance INCREASE, DECREASE, or STAY THE SAME when you put straws in series?

3. (circle one) When you pinched the straw, you decreased its cross-sectional area. When you added straws in parallel, you effectively increased the cross-sectional area. Is resistance DIRECTLY or INVERSELY proportional to the cross-sectional area of the tube or tubes?

4. (circle one) Is resistance DIRECTLY or INVERSELY proportional to the length of the tube?

Analysis Questions for Experiment 3:

5. What is the approximate electrical resistance of your human body? _____

6. Compare your number with those of a few other people in the room. What did you find out about the measured values?

7. The ohmmeter function of the DMM works by applying 9V to the resistor, then measuring the current. A few milliamperes is all it takes to confuse the heart into fibrillation. Using Ohm's Law (V=IR), how much current passed through your body when you checked your resistance? (Most of this current did not pass through your heart.)

ANSWER: _____   Please show your work below.

Data for Experiment 4:

Construct your own data table below. Don't forget the units!

Analysis Questions for Experiment 4:

8. Based on your results from Experiment 1, what did you expect to happen?

9. What did your graph reveal about the relationship between the length of a wire and its electrical resistance?

10. Based on your graph, what would be the resistance of a 35 cm long section of this wire?

11. Wires with high electrical resistance tend to get hot when large currents pass through them. What does this experiment tell you about the common practice of connecting extension cords end-to-end to make a longer cord?

Data for Experiment 5:

Temp. Bath	Temperature (°C)	Resistance (Ohms)
Hot water		
Room temperature		
Ice water	0	
Dry Ice/Alcohol	-78.5	
Liquid Nitrogen	-196	

Analysis Questions for Experiment 5:

12. What does your graph tell you about the relationship between temperature and the resistance of a wire?

13. All physical laws come with "fine print." Many laws are true only under certain conditions. You might have observed that the point for liquid nitrogen is not in line with the other data points. That's physics. The relationship between temperature and resistance is not linear at very low temperatures. Is the resistance of the coil in liquid nitrogen higher or lower than you would expect, basing your expectations on the other data points?

14. (Answer this outside of class) The equation for the resistance of a wire as a function of temperature is $R=R_o[1+\alpha(T-T_o)]$ where α is the coefficient of resistivity for the material. R_o and T_o are constants representing the values of resistance and temperature at some convenient starting point. usually 20°C. Because R_o and T_o are constants, this actually is the equation of a straight line. Use the slope of your graph to find the value of α for your coil. Use your room temperature data as R_o and T_o. Show your work below. Add pages or use the back if you need more room.

Answer:
α = _____ Ω/°C

Name: _____

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Data for Experiment 6:

Create your own table here:

Analysis Question for Experiment 6:

15. What does your graph tell you about the relationship between resistance and temperature for a thermistor? Discuss this in some detail.

Data for Experiment 7:

Table 1: Nominal and actual resistances

Individual Resistor	Nominal Resistance (from color code)	Tolerance (from color code)	Actual Resistance (DMM)	δR (DMM Error)
R_1				
R_2				
R_3				
R_4				

Remember, δR is 2% of the DMM's reading.

P31220 Lab   Name: _____

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Table 2: Series and parallel combinations

Combination (for example, R_1 and R_2 in series)	Predicted R_{total} (show calculations below)	Measured R_{total}	% difference % diff= $\frac{(predicted-measured)}{measured}$

Measure at least two series combinations and two parallel combinations. You may do more if you like. Use the actual (measured) values of the individual resistors when you make your predictions.

Lab Section: _____   T.A.'s _____

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Analysis Questions for Experiment 7:

16. How well did your predictions match your actual measurements? (This is an invitation to consider experimental error)

17. What mistakes did you make, and how did you correct them? (This is actually important. Most, if not all, scientific progress comes from figuring out why predictions failed.)

18. What are your final thoughts and impressions about this lab?

List of graphs to turn in with your data sheets:
- Experiment 4: Resistance vs. Length of a Wire
- Experiment 5: Resistance vs. Temperature for a Wire
- Experiment 6: Resistance vs. Temperature for a Thermistor