Lab D06&07: Combinations of Resistances

(2/6/02)

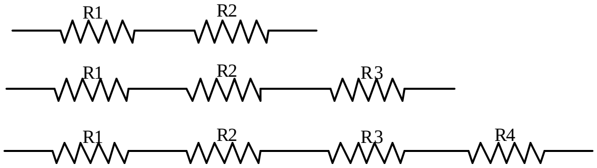
Equipment: each pair of people should have...

breadboard	multimeter	access to a box of various resistors
battery pack	4 alligator clips	various colored highlighter pens

Part A: Exploring Resistances in Series

1) Gather four **different** resistors such that the largest resistance is about 3 or 4 times the smallest, and all are larger than 150 Ω less than 15 kΩ. Measure and record the resistance of each of your resistors. Assign the resistors "labels" R_1-R_4 in order of increasing size for bookkeeping purposes. Naturally, you should put all these data in a table.

2) a. Measure and record the equivalent resistance of two, three, and four different resistors strung together as symbolically shown in the three examples below (called resistors in series). Use the breadboard to put the resistors in series--do not twist the resistor wires together. Be sure to hold the resistor wires close to the breadboard when inserting and removing the resistors on the board or the wires will kink. **Do not mangle the resistor wires**!



b. You should see a trend in how the measured equivalent resistance relates to the individual resistance values. From the trend you observed, write down a sentence describing the trend (qualitative words only, no math). Your sentence should be something like: "As the number of resistors in a series increases, the equivalent resistance of the combination...."

c. Write a general formula for the equivalent resistance ($R_{EQ,s}$) of N resistors (R_1, R_2, R_3,...,R_N) in series. Make sure your formula obeys the sentence you wrote above.

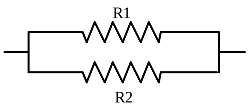
3) a. To test your formula, put resistors R_2 and R_3 in series. **Before** you do any measuring **predict** (i.e. calculate) the equivalent resistance of these two resistors in series.

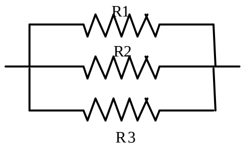
b. Now measure the equivalent resistance of the series combination. Did your expression for the equivalent resistance of two resistors in series work for this new combination? Try some other new series combinations to convince yourself--organize and clearly document your work.

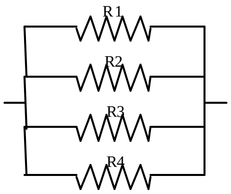
4) Use the fact that the length of the (hypothetical) equivalent resistor for the series is equal to the sum of the lengths of the individual resistors to derive mathematically the formula you guessed in part 2c. You may assume that all the resistors are made of the same material and have the same cross-sectional area. Then explain <u>why</u> the equivalent resistance is larger than any individual resistance in the series. (Hint: use the resistance-resistivity formula $R=\rho L/A$, which is the formula in the Cutnell + Johnson handout). **Call teacher over to check at this point.**

Part B: Exploring Resistances in Parallel

1) a. Measure and record the equivalent resistance of two, three, and four different resistors strung together as symbolically shown in the three examples below (called resistors in parallel). Use R_1-R_4 to make these combinations. Use the breadboard to put the resistors in parallel--do not twist the resistor wires together. Be sure to grasp the resistor wires right up against the breadboard when inserting and removing the resistors on the board or the wires will kink. **Again, do not mangle the resistor wires!**







b. Again, you should see a trend in the measured resistance values. From the trend you observed, write down a sentence describing the trend (qualitative words only, no math). Your sentence should be something like: "As the number of resistors in parallel increases, the equivalent resistance of the combination...." Write a second full sentence describing how the equivalent resistance always compares to the smallest individual resistance in the parallel combination.

c. Now, hypothetically imagine that all of your resistors were the same value, what would be the relationship between the equivalent resistance, the number of resistors, and the resistance of each resistor. Write down this formula.

2) a. To test your ideas, put resistors R_3 and R_4 in parallel. **Before** you do any measuring again **predict** the equivalent resistance of these two resistors in parallel. You should be able to estimate this (e.g. it should be less than 100 ohms, but not as little as 50 ohms, because …)

b. Now measure the equivalent resistance of the parallel combination. Does your estimation method that worked for the equivalent resistance of two resistors in parallel work for this new combination? Try some other new parallel combinations to convince yourself—organize and clearly document your work. If you find your predictions are not working, write another and test again.

3) Using the fact that the cross-sectional area of the (hypothetical) equivalent resistor for the parallel circuit is equal to the sum of the cross-sectional areas of the individual resistors, derive mathematically the formula for equivalent resistance that you guessed in part 1c. You may assume that all the resistors in parallel are made of the same material and have the same length. Explain *why* the equivalent resistance is smaller than any individual resistance in the parallel combination. (Hint: look at figure 20.21 on p. 601 of C&J, and use the resistance-resistivity formula again!). **Call teacher over to check at this point**.

Part C: Exploring Resistors in Both Parallel and Series

Obtain any **three** of your four resistors and record their resistance values. Using all three of these resistors, construct four **different** combinations (series, parallel and two new ones), each with a distinct circuit diagram, so that had the resistors been all the same they would still have a unique equivalence resistance (i.e. the diagrams should differ not simply by switching resistor values). Draw the resistor pattern of each different combination; predict/calculate the equivalent resistance of each pattern (work carefully and neatly); then measure the equivalent resistance directly with the multimeter and compare (% diff.) to the calculated values. Either you or your partner should keep up with these resistors until this entire lab is complete. **Check with teacher at this point.**

Find a battery and measure its voltage difference. Then predict the current flowing *into* and *out of* the battery ($I_{b\ in}$ and $I_{b\ out}$ respectively, yes they should be the same), for each resistor combination. Measure each current and compare (% difference) them with your predictions. Record these data.

Part D: Exploring Kirchhoff's Rules

These are also often called the *Loop Rule* and the *Junction Rule,* though they are really **conservation of energy** and **conservation of charge**, respectively. You will investigate these rules for 4 resistor combinations using the same 3 resistors from the last *part*. This is an alternative, and more fundamental, way of investigating the combinations of resistors than the idea of equivalent resistance.

In the following, use the same combination of resistors as in part C.

1. Draw the circuit diagram (it should take up half a page); label the resistors R_1, R_2, R_3 and the battery voltage, ΔV_b. Appropriately label all currents and voltage drops in the diagram.
2. Build the circuit, but do not measure any currents or voltages yet.
3. Using the junction rule (i.e. charge is a conserved quantity), write down an equation for each junction. Now measure the current(s) flowing into, and out of, each junction to test this equation. You will need to design a data table, and find a %-difference, and write a short conclusion about the validity of the junction rule, as determined by your measurements.
4. Identify each loop in the circuit that includes the battery, using appropriate labels. Write down the loop rule (i.e. the electric force is conservative), for each loop. Design an appropriate table for each loop to record the voltage changes across every component of the loop. Measure and record all the voltage changes around each loop. Be sure to record the correct sign of every voltage difference (remember how the multimeter defines voltage difference). Below each table, add up separately all the voltage rises and all the voltage drops. Calculate the %-difference between these values. Write a short conclusion about the validity of the loop rule as determined by your measurements.
5. Now energy is conserved too, therefore the power produced by the battery must be the same as the power dissipated by all the resistors. Design a data table with the following columns: circuit component, current, voltage difference, power. Record the appropriate currents and voltages, then calculate the power for each component. Discuss and compare the total power flowing into and coming out of the system. Write a short conclusion about conservation of energy, where energy comes from and where it goes to in your system.

Once you have finished this section, **CALL OVER YOUR INSTRUCTOR** and be prepared to discuss intelligently each of these 4 circuits. Make sure that you did not leave out any junctions or loops.

Part E: Post-lab

Kirchhoff's rules are usually used to find the current flowing through each resistor in a complex circuit. They are very important, because they are fundamental rules that can be used in any circuit with any device.

As a post-lab exercise, assume that you know two things about the circuits above:

- The voltage drop across the battery.
- The resistance of each resistor.

Now find the current flowing through each resistor and the voltage drop across each resistor, using Ohm's law (V=IR), and the loop and junction rules, but do not use any equivalent resistance formulas.

Now referring back to part D, compare (%-difference) the currents and voltage drops that you calculated with the ones you measured in the lab.

Naturally, you will write an overall conclusion for this lab.