As you have seen in lecture, lab and pre-recitation problem, it is useful to think of electric current as a flow; more specifically, the flow of charged particles through the wires, light bulbs, and other materials that make up a circuit.

I. Visualizing resistance and resistivity

As charged particles move through matter, they encounter “obstacles” along the way. Materials with more obstacles have a larger resistivity.

Use your phone or computer to search for “phet resistivity,” and open the simulation. The simulation is called “Resistance in a Wire” and is at the URL https://phet.colorado.edu/en/simulation/resistance-in-a-wire.

For the pre-recitation assignment you already played with the simulation. Therefore you should have a feel for what is going on.

A. Thinking in terms of analogies

Think of water flowing through a pipe as an analogy to the scenario in the PhET simulation. You may also want to look at the last problem (for practice) in Homework 4.

Discuss the analogy with your partner. Try to make it as “tight” as possible by connecting each aspect of the analogy to a corresponding aspect of the flow of charge through a wire. Some initial questions to consider: in the water through a pipe analogy, what corresponds to the electrons and what corresponds to the wire? Once you have worked out your analogy:

1. Describe in words the change in the analogy system that corresponds to an increase in cross-sectional area.

2. Describe in words the change in the analogy system that corresponds to an increase in resistivity.
B. Resistivity, resistance and Ohm’s law

Resistivity is a property of a particular material, which characterizes how that material conducts electricity. It does not depend on the dimensions and external geometry of the sample. It is, for that reason, called a material property. Remember, however, material properties depend on the temperature of the said material. To understand further, please answer the following questions:

1. Does resistivity depend on temperature? Explain in words.

2. Imagine two cylindrical rods that are made up of Aluminum and have the same cross-sectional area. Both of the rods are kept at the same temperature however one rod is longer than the other. Do the rods have equal or unequal resistivity? Do the rods have equal or unequal resistance? Explain in words.

3. From above question, is the resistance dependent on the geometry of the rod? Is resistance a material property? Explain in words.

Dirty metals, that is metals that have sufficient concentration of impurities (as you saw in the PhET simulation) usually obey Ohm’s law (for small enough current and potential difference). This means that the voltage-drop ($V$) across a metallic wire is proportional to the current flowing through the wire. Please remember voltage-drop and potential difference are one and the same thing!

4. In the proportionality of voltage-drop across a metallic wire to current flowing through the wire, what is the proportionality constant called? What is the unit of the proportionality constant?

5. Write down Ohm’s law explicitly for a metallic resistor. Assume the voltage-drop across the resistor is $V$, $R$ gives the resistance of it, and the current flowing across the resistor is $I$. 
II. Quantitative analysis of resistors in parallel

Two resistors, \( R_1 = R_2 = R \), are connected in parallel in a circuit. A portion of the circuit is shown at right. It is given that a current \( I \) flows through point A. Note that the amount of current will get divided into two parts at the junction (denoted as a big solid black dot after point A); one of the parts will enter the \( R_1 \) branch, whereas the other part enters the \( R_2 \) branch.

1. How much current will go towards point B? How much current will go towards point C? \([\text{Hint: One can apply charge conservation at point A, which later will come to be known as the Kirchhoff's junction rule. How do the resistances of the two branches compare?}]\)

2. How much current will flow through points D and E?

3. How much current will flow through point F? \([\text{Hint: Was any charge gained or lost along these paths?}]\)

4. Rank the currents at the labeled points \((A - F)\).

5. Is the voltage-drop \( V_1 \) across \( R_1 \) greater than, less than, or equal to the voltage drop \( V_2 \) across \( R_2 \)? Explain in words and equations.

6. If this network were connected directly to a 4.0 V battery and \( R_1 = R_2 = 8 \ \Omega \), what current would flow through each of the labeled points? Show your work and provide correct units. \([\text{Hint: What is the equivalent resistance of the circuit? Does this entire current flow through point A? Does this entire current flow through points B and C?}]\)
III. Quantitative analysis of resistors in series

Two resistors, $R_1 > R_2$, are connected in series in the following circuit.

1. Rank the currents $I$ at the labeled points (A – C). Explain. [Hint: Think back to questions 1-4 from part III. Does this entire current flow through point A? Does this entire current flow through points B and C?]

2. Is the voltage drop across $R_1$ greater than, less than, or equal to the voltage drop across $R_2$? Use Ohm’s law to support your answer. Explain in words and equations. [Hint: How do the resistances compare? How does the current through $R_1$ compare to $R_2$?]

3. If this network were connected directly to a 4.0 V battery and $R_1 = R_2 = 8 \, \Omega$, what current would flow through each of the labeled points? Show your work and provide correct units. [Hint: What is the equivalent resistance of the circuit?]
IV. Resistors in series and parallel (OPTIONAL)

Two pools of water are draining from water tank 1 to water tank 2 with different drain pipe configurations as shown in the figures. In Configuration 1 the drain pipes are attached end to end, and in Configuration 2 the pipes are side-by-side. A constant pressure difference ($\Delta P$) is maintained between tank 1 and 2 by using pumps. We neglect the effect of gravity.

1. In which configuration will it be easiest for the water to flow from the tank 1 to the tank 2? Explain in words.

2. In which configuration will the amount of water that flows in a given unit of time (say, one second) be greatest? Explain in words.

3. Compare this analogy to problem 6 of section II and problem 3 of section III. Both circuits have equal ideal batteries and resistors, with the only difference being that the resistors are arranged in parallel or in series. In which circuit will electrons flow the easiest? Which circuit has a greater net current out of the battery? Is this consistent with your answers for numbers 1 and 2 above? Explain in words.

4. In the water analogy shown in Configurations 1 and 2, pressure difference created by the pumps is the driving factor that causes the water to drain from one tank to the other. What property of the electric circuits is the best analogy to pressure difference’s role in Configurations 1 and 2 above? (circle one)

- resistance
- current
- potential difference
- wire length
- wire resistivity
- Ohm’s Law