

**Resistors in Series and Parallel:  
Developing and Explaining Equivalent Resistance Laws**

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**Goal:** This lesson is relatively unusual as an inquiry lab as it was designed with three goals in mind:

- a) students develop equivalent resistance laws for resistors in parallel and series configurations using experimental evidence,
- b) students develop and test hypotheses that explain why the resistance laws work the way they do, and
- c) students identify and test assumptions inherent in the hypotheses.

**Student Performance Objects:**

- Experimentally identify rules for adding resistors in series and parallel.
- Explain the reasons for the series and parallel resistance rules.
- Identify the facts that energy (properly defined) and current are conserved in series and parallel circuits respectively.
- Correctly know, comprehend, and apply associated terms and concepts: series, parallel, current, ampere, resistance, ohm, volt, voltage, Ohm's law, addition rules, etc.
- Use the above information to solve problems associated with series and parallel circuits.

**Time Required:** This is a four-day lesson. The first day will deal with series circuits; the second and third days will deal with parallel circuits. On day 4 students will apply what they have learned by experience to problems provided by the course instructor.

**Student Background:** This lesson assumes that students know how to use a multimeter to measure voltage and current, and that they have previously developed via experimental inquiry Ohm's law ( $V = IR$ ). It would be good earlier to have had students experimentally determine the factors that affect resistance (e.g.,  $R = \rho L/A$  and/or  $R = f(\text{temperature})$ ) before completing this lesson so that they will also know how to measure resistance.

**Special Considerations:** Students will probably have had little to no experience developing and testing assumptions and hypothesis. Therefore, the instructor probably will have to provide students with considerable assistance in the corresponding steps of day 1 activities. By day 3 students will go through these same steps again without instructor assistance.

**Day 1 Steps:**

- 1) Give students 3 resistors of different but similar values (e.g., 30, 75, and 110 ohms), multimeter, and connecting wires.
- 2) Give students the charge to develop an experiment to convincingly show what the law is for equivalent resistance when adding resistors in series. They should arrive at the following conclusion:  $R_{Total} = R_1 + R_2 + \dots + R_n$
- 3) Give students the charge to use their knowledge of Ohm's law to explain why this relationship is of the form it is. That is, why equivalent resistances are the sum of individual resistances. Set students to working in cooperative groups. They should eventually come up with a hypothetical explanation and assumption that approximates the following:

Because  $V = IR$ , then  $R = V/I$ . Substituting this into the equivalent resistance for series resistors equation results in:

$$\frac{V_{Total}}{I_{Total}} = \frac{V_1}{I_1} + \frac{V_2}{I_2} + \dots$$

Students should then, if necessary, be prompted to examine this relationship for constant terms (e.g.,  $I_{Total} = I_1 = I_2$ ) to see if anything will cancel. They should test this assumption experimentally (thereby testing and rejecting the very common preconception that current is “used up”). Student then should develop a hypothesis that the equivalent resistance law for series circuits is the way it is due to the conservation of potential. That is,  $V_{Total} = V_1 + V_2 + \dots$  Students should then test to see if voltage drops around a series circuit do indeed sum to the voltage impressed on the circuit providing experimental support for this hypothesis.

### Day 2-3 Steps:

- 1) Give student groups each a single but different “fixed” resistor and a decade resistor box (variable resistor) along with multimeter and connecting wires.
- 2) Give students the charge of developing an equivalent resistance law for two resistors wired in parallel. They should arrive at the following conclusion for this combination:

$$\frac{1}{R_{Total}} = \frac{1}{R_1} + \frac{1}{R_2}$$

- 3) Give students the charge to use their knowledge of Ohm’s law to explain why the equivalent resistance for parallel resistors relationship is of the form it is similar to the earlier process used for series resistors. Set students working in cooperative groups. They should eventually come up with a hypothetical explanation and assumption that approximates the following:

Because  $V = IR$ , then  $1/R = I/V$ . Substituting this into the equivalent resistance form of the parallel resistors equation results in:

$$\frac{I_{Total}}{V_{Total}} = \frac{I_1}{V_1} + \frac{I_2}{V_2}$$

Students should again look for constant terms (e.g.,  $V_{Total} = V_1 = V_2$ ). This should lead the students to hypothesize that current flowing through the various legs of a parallel circuit are also conserved (e.g.,  $I_{Total} = I_1 + I_2$ ).

Notes: (a) Students’ attention should be drawn to the fact that individual resistances in parallel circuits do not sum up to impressed voltage as they do in series circuits, but that potential difference over a pair is conserved. (b) Some assistance probably will have to be given to students who attempt to curve fit data. Because the data appears to reach an asymptote, suggest to students that they might want to graph inverses on both axes. (c) Have students whiteboard results from parallel circuit work following step two. It is important for everyone to see that the intercept of the double inverse graph is the reciprocal of the resistance of the fixed resistor.

### Day 4 Steps:

Provide students with a number of circuit diagrams and have them resolve problems associated with them.

- 1) Using equivalent resistance laws, find equivalent resistance for resistors in series and parallel circuits.
- 2) Using Ohm’s law, find voltage drops for various resistors in a circuit.
- 3) Using Ohm’s law, find current through various sections of a circuit.