Using Inquiry & Modeling to Study Electrical Resistance

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Math-Science Partnership Grant

www.physicsfirstmo.org
What is the Physics First program?

Physics First is a national movement to teach a year-long Physics course in 9th grade

In Missouri, MO-DESE has funded a partnership led by Columbia Public Schools and Univ. of Missouri-Columbia to develop curriculum and conduct professional development (PD)

Three summers of PD were conducted in 2006, 2007, and 2008 for approx. 70 teachers in 25 Missouri school districts
Curriculum

- Year 1: Uniform and Accelerated Motion, Forces, and Newton’s Laws
- Year 2: Motion in 2D, Energy, Momentum, Astronomy, and Electricity
- Year 3: Electromagnetism, Heat, Light, Waves
- Pedagogy - based on Modeling, Inquiry & 5E

Today - parts of Unit 9: Electrical Resistance
Students’ Beliefs and Big Ideas

What affects resistance – two labs

What causes resistance? – microscopic picture

Figuring out a law that connects voltage, current and resistance
Electric current, resistors, batteries

- Electricity is “used up” by an electrical device
- Electrons in a circuit can be lost and converted into heat or light (no conservation of charge).
- The electron slows down as it travels in the circuit; the lost (kinetic) energy is converted into heat, light, etc.
- Batteries are a reservoir of charge; the charge gets used up to light the lamp, sound the buzzer, run the motor, etc.
- The battery decides the amount of current that flows, not the resistance in the circuit.
Electric current is the flow of charge per unit time.

For charges to move a voltage must be provided.

Voltage is proportional to the electric current and the resistance of the resistor.

The voltage between two points in a circuit is the same for every circuit element(s) connected between those two points (parallel circuit).

The current in a circuit is the same at any two points in a circuit if there are no junctions between those points (series circuit).
What students know about resistance by this time in the unit:

☐ A multimeter can be used to measure the electric current, the voltage and the resistance
☐ Every circuit element has resistance (more or less)
☐ Resistors can have a wide range of resistance
☐ When resistors are connected in series, the total resistance of the group increases
What affects resistance? -1

- Design and conduct an experiment to determine the parameters that affect the resistance of a wire. (DOK4)
- Demonstrate how resistance is measured:
  1. No battery in circuit!
  2. Multimeter set to measure resistance
  3. Connect resistor between Common and Ω terminals
  4. Use alligator clip wires to decrease contact resistance
What affects resistance? -2

- Brainstorm factors that might affect the resistance of a wire

- Temperature
- Amount of wire / Length of wire
- Material that the resistor is made of
- Width of wire
- Copper is good conductor, so its resistance is less
- Shape of wire
- Whether it is wet or dry
- The color of its insulation
Conduct experiments to determine how the length, the diameter, and the material properties of a wire affect its resistance.

- Experiment 1: Use Pencil Lead Resistance Board to investigate the effect of the material, and the effect of the length
- Experiment 2: Use Wire Resistance Board to investigate the effect of wire thickness
Pencil Lead Resistance Board
Resistance of nichrome wire of four different diameters:
Expt. 2: Resistance vs. Gauge, Diameter and Area (nichrome wire)

- Resistance of four gauges of Nichrome wire (16 cm)
- Resistance of Nichrome Wire vs. Diameter
- Resistance of Nichrome Wire vs. Area
- Resistance of Nichrome Wire vs. 1/Area
Optional:

Expt. 2: Resistance vs. Length for Four Gauges of Nichrome Wire

Resistance of Nichrome Wire vs. Length

- 26-gauge
- 28-gauge
- 32-gauge
- 36-gauge

Resistance (Ω) vs. Length (cm)
Outcomes of Pencil Lead and Wire Resistance Labs

- Resistance depends on material, $\rho$
- Relationship between $R$ and $L$
  \[ R \propto L \]
- Relationship between $R$ and $A$
  \[ R \propto \frac{1}{A} \]
- Develop a mathematical expression for resistance
  \[ R = \frac{\rho L}{A} \]
  where $\rho = $ resistivity, typical of material in $\Omega \cdot \text{cm}$
  $L =$ length in cm, $A$ is the cross sectional area in $\text{cm}^2$
So what causes resistance?
Conductors and Insulators

- Metals have loosely bound electrons and are good conductors of electricity. Metals can be made into resistors of low resistance.
- Glass, rubber, or plastic, have tightly bound electrons that do not move easily. They are poor conductors of electricity and are called insulators. Insulators usually have a high resistance.
- Resistance and conductance are inverse terms: high conductance means a low resistance and vice versa.
Electrical resistance is a measure of how well a material resists the flow of current.

In a metal, electrons are loosely bound to their nuclei. They cannot easily escape the atom, but within the metal they run around freely.

As electrons run around they bump into each other, vibrating host atoms, and impurity atoms (for example, oxygen in copper). Collisions deflect the electrons, and their paths zigzag around. They do not "get anywhere" because they go forward as much as they go backward.
Electrons in a wire
When a voltage is applied to a resistor, the positive side of the resistor attracts the electrons. Electrons still go in zigzag paths but travel a little more toward the positive side of the resistor than in other directions. The collisions produce an internal friction or drag -- resistance.
Electrons in a wire when a voltage is applied
A device that resists the flow of current is called a resistor.

The ease with which electrons flow through the resistor is determined by its resistance.

The value of the resistance is a property of the resistor and depends on the length and diameter of the resistor as well as the material the resistor is made of.
Resistors are made of conducting or semiconducting materials. Their resistance can be controlled to provide the desired value.

- Examples - light bulbs, the heater coil in a toaster, a curling iron, the heating element in an electric stove, and carbon resistors in electronic circuits.

- Resistors often have their values printed in a code called the resistor color code.
The resistance of a metal increases as it gets hot. The metal atoms vibrate more when heated, and a traveling electron collides with atoms more frequently. The larger number of collisions generates a larger resistance to electron flow.

Example: the filament of a light bulb is made of a coil of tungsten wire. It heats up and glows when current passes through it. The filament has a higher resistance when it glows than when there is no current going through it.
Resistance increases when a metal is heated
Resistance Changes with Temperature

All four resistors have a resistance of 10 Ω at 20 °C
Investigate whether there is a relationship that connects voltage, current and resistance

Draw three circuits:

- Circuit 1 has a resistor $R_1$ and a 3V battery
- Circuit 2 has the same resistor $R_1$ and a 6V battery
- Circuit 3 has the same resistor $R_1$ and a 9V battery
Make a table and compare (wear your student hats!):

- Total resistance in circuits 1, 2, 3
- Voltage applied across resistors in circuits 1, 2, 3
- Currents through the resistor in circuits 1, 2, 3

<table>
<thead>
<tr>
<th></th>
<th>Circuit 1</th>
<th>Circuit 2</th>
<th>Circuit 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td></td>
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</tr>
</tbody>
</table>

Circuit 1: $R_1$ and 3V battery
Circuit 2: $R_1$ and 6V battery
Circuit 3: $R_1$ and 9V battery
Design an experiment to obtain a relationship between current, voltage and resistance

- IV- voltage; DV- current for a given resistor
- Measure current through the resistor and voltage across the resistor at the same time.
- Make measurements for several voltages
- After obtaining one current vs. voltage curve for a given resistor, repeat the measurement for several resistors.
Experimental setup

Measuring current with 3V battery

Measuring current and voltage with 3V battery
Measuring current and voltage with 6V battery

Experimental setup...

1.5V, 3V and 6V batteries can produce several combinations
Voltage-Current graph for four resistors

Slope of lowest line:
\[
\frac{\text{rise}}{\text{run}} = \frac{(4.38 - 0)V}{(20 - 0) \times 10^{-3} A} = 219 \left[ \frac{V}{A} \right] = 219\Omega
\]

Next, read off current at 4.4V for each resistor

<table>
<thead>
<tr>
<th>R (Ω)</th>
<th>Current at 4.4V (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>217</td>
<td>20</td>
</tr>
<tr>
<td>528</td>
<td>8.5</td>
</tr>
<tr>
<td>1486</td>
<td>2.79</td>
</tr>
<tr>
<td>4630</td>
<td>0.95</td>
</tr>
</tbody>
</table>
Analysis for fixed voltage:

**Current vs. Resistance for a Fixed Voltage of 4.4V**

<table>
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<th>Resistance (Ω)</th>
<th>Current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>217</td>
<td>20</td>
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<tr>
<td>4630</td>
<td>0.95</td>
</tr>
</tbody>
</table>

**Current vs. 1/R for 4.4V**

<table>
<thead>
<tr>
<th>1/R</th>
<th>Resistance (Ω)</th>
<th>Current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0046</td>
<td>217</td>
<td>20</td>
</tr>
<tr>
<td>0.0019</td>
<td>528</td>
<td>8.5</td>
</tr>
<tr>
<td>0.0007</td>
<td>1486</td>
<td>2.79</td>
</tr>
<tr>
<td>0.0002</td>
<td>4630</td>
<td>0.95</td>
</tr>
</tbody>
</table>

\[ I (A) = 4.36/R \]
A mathematical relationship between voltage, current and resistance:
Ohm’s law: \( V = IR \) or \([\text{volts}]=[\text{amps}].[\text{ohms}]\) or \([V]=[A].[\Omega]\)

For a resistor, the greater the voltage, the greater the current.
The resistor dictates the amount of current in a circuit, given a certain battery.
Ohm’s law applies to resistors, not to all electronic devices.
Ohm’s law can be applied to individual resistors, to strings of resistors, or a whole circuit of resistors.
The current-voltage graph for an ohmic device is a straight line.
The slope of a current-voltage graph (rise/run) has units of \([A]/[V]\). These units translate to \([\Omega]\).
Ohmic and non-Ohmic devices
Students conduct experiments to investigate the factors that affect the resistance of a wire-shaped object:

\[
\text{Resistance} = \frac{\text{Resistivity of material} \times \text{Length}}{\text{Cross-sectional area}}
\]

Students conduct an experiment to determine the connection between voltage, current and resistance, Ohm’s Law:

\[
\text{Voltage across resistor} = \text{Current through resistor} \times \text{Resistance}
\]
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