Nanotechnology in Electronics
An Introduction to the units on LEDs, Thermistors, and Transistors

The purpose of the following group of lab units is to illustrate properties associated with nanotechnology and the electronics industry through utilization of semiconductors. By using macro-examples of actual nano-circuitry, students will understand what is happening on the small-scale. Semiconductors and nano-sized particles have similar properties different from the metals and nonmetals often studied in a typical high school physics or chemistry class.

By tracing the history of the semiconductor industry from start, straight through to today's emerging technology, the advantages of nanotechnology and limitations of old technology can be understood.

Semiconductors can be modified to be more conductive or insulating depending on the application. For this purpose they are used as a conducting device and allow for the flow of electrons. Ohm's Law governs the relationship between potential difference (V), current (I) and resistance (R) for standard metals in the solid state. Equation 1 is Ohm's Law stated mathematically. According to Ohm's Law, a linear relationship exists between the potential difference and the current. Semiconductors, nanoparticles, nanotubes, and some metals under certain conditions do not obey Ohm's Law.

$$R = \frac{V}{I} \qquad \text{Eqn 1.}$$

The lab entitled "Ohm's Law with Light Bulbs & LEDs" compares a resistor, incandescent light bulb, and an LED. Students will graph current (I) vs. potential difference (V). The resistor will follow Ohm's law and the inverse slope of the line will yield the resistance. Theoretically, the resistance will be the same regardless of the potential difference applied across the resistor. When a potential difference is applied across an incandescent light bulb it reaches high temperatures because heat dissipates rapidly through the tiny tungsten filament. At high temperatures the tungsten becomes more resistant to the flow of current because of the increased kinetic energy of the atoms that make up the filament. An LED is made of a semiconductor that does not produce heat when it is lit. LEDs are more efficient than incandescent light bulbs because there is no energy loss associated with heat loss. Semiconductors are nonohmic, but not because of heat, but rather its chemical makeup.

On the nano-scale researchers at Oak Ridge National Laboratory are using carbon nanotubes and magnetic nanowires as electrodes for polymer- based organic LEDs (OLEDs) to enhance the light emission. These OLEDs are nanosized, made of thin films of polymers or organic molecules. Currenty OLEDs are found in cell phone and digital camera displaces, but the goal is to use them on a grander scale. Evident Technologies Inc. announced in September 2008 that it uses

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nanotechnology to create LEDs of any color. Traditional LEDs can only produce light in the standard colors such as blue, green, and red.

To show a difference between LEDs and resistors in a circuit, "LED Circuit Combination" can be used in conjunction with teaching circuit analysis. When the potential difference is greater, more current is produced which in turn makes the LED brighter. The more electrical energy available the more light energy is produced. The LED is less resistant and needs less current. Electrons and holes within the LED combine and release energy in a process that is the reverse of the photoelectric effect. An LED works on the principle of quantum mechanics and not classical physics, just as nanostructures do.

To apply this theory to a real world application both "Thermistor Circuit" and "Effect of Temperature on Electrical Resistance Properties of a Thermistor" explore semiconductor variable resistance. When temperature changes so does the resistance. Students by now have been exposed to and know that increased temperature means increased resistance. But, instead if an NTC (Negative Temperature Coefficient) thermistor is used, the resistance decreases with increased temperature. This is another example of how materials exist that do not follow Ohm's law.

All of these labs build to the "Transistors as Switches and Amplifiers" lab. Nanotechnology in electronics is trying successfully year after year to decrease the size of transistors. Transistors exist in just about all electronic devices. A computer alone holds more than 42 million transistors. As these devices get smaller and smaller the cost increases exponentially to manufacture them. Alternatives to semiconductor transistors include hybrids (semiconductors and molecular) transistors and carbon nanotubes. Scientists have discovered that a single nanotube acts as a transistor. When two nanotubes are crossed they can create a logic structure. By looking at a macro-example, students will be better able to envision a world they can't see with their own eyes. At the time this document, was written the tiniest transistor created was 10 atoms by 1 atom wide made of graphene. Reportedly, larger versions of this grapheme transistor have performed 10 times faster than traditional silicon transistors.

Introducing LEDs, Thermistors, and Transistors: *A lesson in five consecutive parts.*

- **Lesson 1:** Ohm's Law With Light Bulbs and LEDs. The purpose of this activity is to illustrate ohmic and non-ohmic materials in a simple series circuit.
- **Lesson 2:** The Effect of Temperature on the Electrical Resistance Properties of a Thermistor.
  A thermistor is a semiconductor, a group of materials classified as having properties of both conductors and insulators. This experiment illustrates how temperature affects electrical resistance of a semiconductor.
- **Lesson 3:** Thermistor Circuit. The purpose of this activity is to show a thermistor's usefulness within a circuit. This activity will introduce thermistors in a circuit so that future activities may build upon this idea to conclude with micro/nano-circuits.

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- **Lesson 4:** LED Circuit Combination. The purpose of this activity is to show an LED in a circuit. This activity will introduce diodes in simple circuits so that future activities may build upon this idea to conclude with micro/nano-circuits.
- **Lesson 5:** Transistors as Switches and Amplifiers. The purpose of this activity is to become familiar with transistors and their uses as switches and amplifiers.

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