Important Concepts in E&M: Conductors, Insulators, & Semiconductors

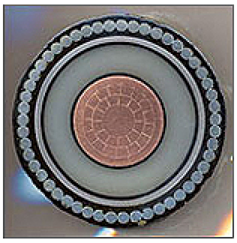
Most materials naturally fall into the category of conductors or insulators. A special group of materials fall into an intermediate category called semiconductors. Some semiconducting materials include silicon, germanium, and carbon.

Conductors

In a conductor, electrons are bound very loosely and are free to move around. These so-called free electrons can move freely through the material and respond to nearby positive and negative charges. Conductors have low resistance and transfer electric current well. Metals are generally good conductors, the best of which are:

1. silver
2. copper
3. gold
4. aluminum

Silver is the best conductor (used on the electronics board in the image) and gold, due to the fact that it doesn't corrode, is often used as a coating in extremely important circuitry. Copper is the most widely used conductor in wires due to cost limitations. Aluminum is actually a better conductor than copper for the same weight of material, however, aluminum has some other characteristics that make it less desirable in household wiring. For example, aluminum tends to thermally contract or expand differently than other materials found in fixtures or connectors. Use of aluminum in household wiring has lead to electrical fires. Aluminum is very good to use for long distance power lines, however, as its light weight makes it possible to create very long, light wires with low resistance.



The image to the right shows a cross-section of a high voltage power line that will run underwater between Oahu, Lanai, and Molokai. This power line is most likely intended to carry power generated by wind farms on Lanai and Molokai to Oahu. This image and information came from The Hawaii Clean Energy Initiative Website.

Other conductors include solutions of salts and all plasmas.

Insulators

In an insulator, electrons are bound very tightly to the atoms or molecules that make up the material, making it impossible to transfer charge from one place to another within the material. Insulators, also called dielectrics, have a high resistance and do not pass an electric current. Some of the best insulators, in order of higher resistivity, are:

1. Quartz
2. Mica
3. Glass

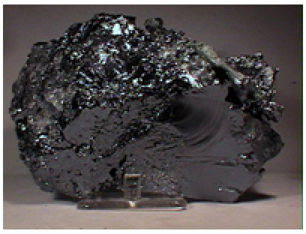
Plastics, ceramics, rubber, wood, and paper are all good insulators.

If you take a good look at an electrical pole on the street, you'll see that the high voltage wires that carry our power aren't attached directly to the pole. Why not? Wood is a decent insulator. But what about when it rains and the wood gets wet? Water is a conductor! Or perhaps you have metal poles carrying power lines through your town. If the power lines were connected directly to the metal, all of our precious electricity would run into the ground and anyone who took a break and leaned against the pole wouldn't live to do it again. That is why power lines are connected to very good insulators which are then connected to our wooden or metal telephone poles. This keeps the electricity in the lines and not in the poles. Modern high voltage insulators are typically made of porcelain or composite polymer materials. Prior to the 1960s, many insulators were made of glass.

Semiconductors

Semiconductors have a small number of free electrons available and pass a limited amount of electrical current. Semiconductors are extremely important in modern electronics because they can be used to *control the amount of current in an electrical system*. Semiconductors can be "doped" or mixed with different types of materials to change their conductive properties.

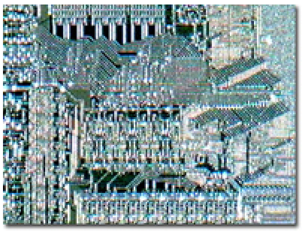
Some semiconductor materials, shown in order below, include silicon, graphite (a form of carbon), germanium, and gallium arsenide phosiphide seen as the little plates inside the clear plastic LED. Different forms of gallium arsenide phospide glow red, orange, or yellow when a current passes through them, making the substance widely used in older light-emitting diodes (LEDs).




Semiconductors are generally crystalline solids like silicon and graphite (carbon). Devices made with semiconductor materials include:

- Solar cells
- Transistors
- Diodes, like LEDs
- Microprocessor Chips which run your computer (like Intel Pentium, Celeron, AMD, etc)

Anything that is computerized or uses radio waves depends on semiconductors. Solar cells, like those shown below, are often made out of silicon doped with phosphorous. The second image below shows an Intel 8088 microprocessor (via http://micro.magnet.fsu.edu/optics/olympusmicd/galleries/chips/intel8088a.html). The image looks strange because the structures you see are extremely tiny - at the micron (10^{-6} m) level. The base is a tiny sliver of silicon packed with 29,000 transistors (also made of semiconductor materials).

On the Web

The following website provides a fun online web application that allows users to play with a light bulb in a circuit. Items such as a coin, rubber eraser, piece of chalk, key, etc, can be placed into the circuit to see what happens to the light bulb. Suggested for younger students or as fun science-y entertainment. http://www.sciencekids.co.nz/gamesactivities/circuitsconductors.html

This page on PBS’s website gives a nice metaphor to describe conductors, insulators, and semiconductors: http://www.pbs.org/transistor/science/events/semics.html

PBS has a webpage called "Transistorized!" that describes the history and discovery of the transistor. The website interface is a transistor radio. The first "station" labelled *Electron* simply goes to a timeline, but the other "stations" lead to stories about what was going on with transistors through time.
http://www.pbs.org/transistor/

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