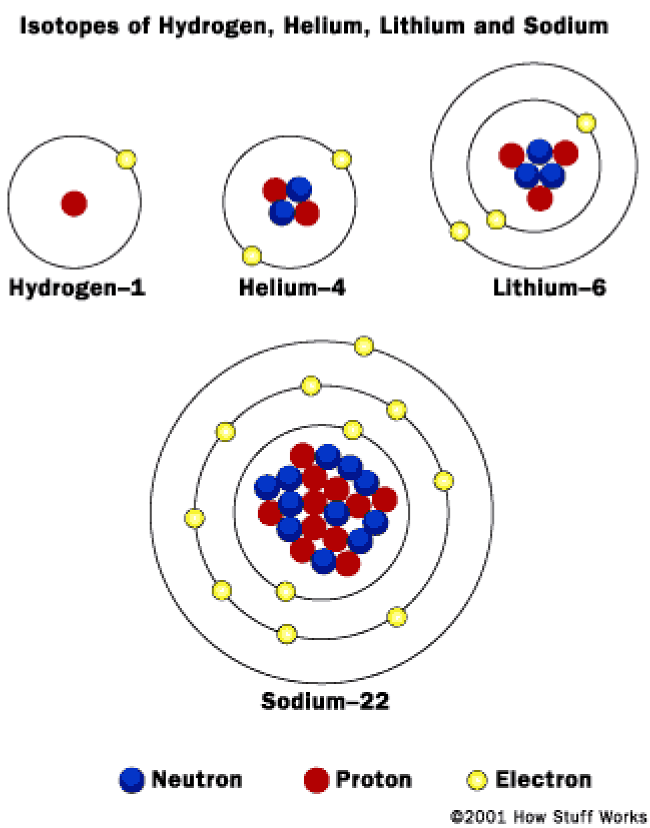
Structure of Matter
The objective of the first two hours is to cover the material that would otherwise require two years of college level electronics. Since we are not interested in a general electronics background we can cut this material down to basic that are important to our industry, specifically. The advantage of a college class is a change in the student's perspective. We want the student to view the universe from an understanding of how matter and energy exist and interact. We want the student to understand what electricity is and what characteristics it has, not just "memorize a bunch of phrases for the test Friday". We want you to learn and understand the material.
Bear with me, please, this won't take more than an hour or two, and it won't hurt a bit.

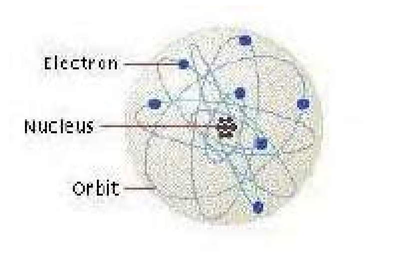
Everything around us is made of atoms. Each atom consists of an inner nucleus of Protons and Neutrons. Encircling this nucleus we have layers of Electrons in shells. We normally have an equal number of Electrons and Protons. Electrons have a negative electrical charge. Protons have a positive electrical charge. Neutrons have no electrical charge. A Neutron may be considered to be a Proton and Electron that have combined. Electrons may be imagined as a cloud of electromagnetic energy, having very little mass (only about 1/1800th that of a Proton or Neutron). Protons and Neutrons have all the meaningful mass of the atom.



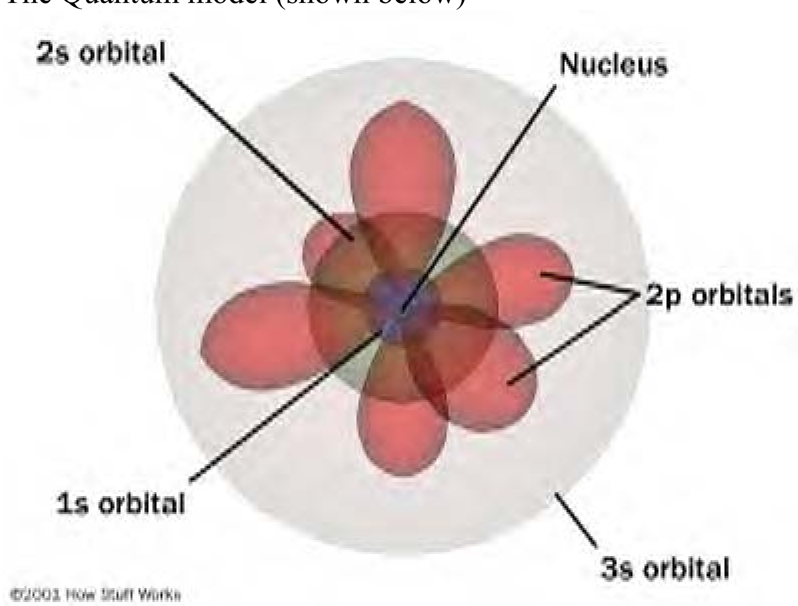
It is only the structure of these particles that makes one element different from another. Hydrogen has one Proton and one Electron circling around it. This is the simplest form of an atom and is given the "Atomic Number" of "1" (having only one Proton and one

Electron). Hydrogen has an "Atomic Mass" of "1" (having only one Proton in the nucleus). In a perfect world, this would be the whole truth. Alas creation is not perfect. Every element has a percentage of impurities in it that have an abnormal number of Neutrons in the nucleus. The different structures of any given element that have a different number of neutrons are called “isotopes”. The most popular isotope of Hydrogen has no neutrons. There is a rare isotope of Hydrogen that has one neutron. The chemical and electrical properties are the same, but the atomic weight differs.
The next larger element, Helium, has two Electrons, two Protons, and two Neutrons. Helium has the Atomic Number of "2" (two Protons), and an Atomic Weight of "4" (two Protons plus two Neutrons).
We draw them, for the sake of clarity alone, as shown above. A more realistic picture may look more like the following.

The Rutherford model (shown at the right)
This is a fairly old concept of what an atom looks like. The electrons are considered to be in spherical layers around the nucleus. Each layer has a maximum number of electrons.



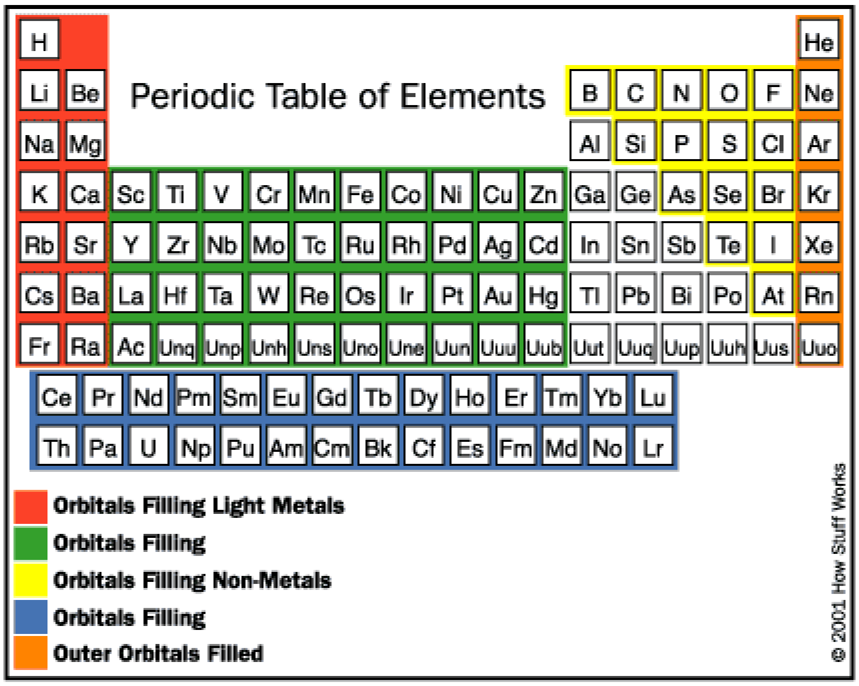
The Quantum model (shown below)



In the Quantum model the electrons are not all spherical in character. It is suggested that the inner layer of electrons take elliptical orbits around the nucleus. With only one electron, we have a spherical orbit. When we add the next electron the two electrons, being the same electrical charge, tend to repel one another, giving us a shape somewhat like an hourglass. A third electron would take an orbit somewhat like a doughnut around the center of the hourglass.
Which of these stories is true? Probably none. But the Quantum model is most likely closer to the truth. Man has been theorizing the atom for centuries, and every century’s developments in science proves the last century’s concept to be incomplete or incorrect.

It is very likely that someone a hundred years from now will look back on our concept of the atom and smile as we look back at the pre-Einstein concept of the atom as being like a raisin muffin, with the electrons being the embedded raisins.
By any description of the atom, we can say our theories are sufficient enough to form working concepts. We still come to the conclusion that everything that has the same Electron and Proton structure is the same element. (Yes, that story falls apart in the heaver elements, but this is just basics, so let's keep the descriptions basic.)

We can uniquely identify all one hundred, or so, distinct elements, and arrange them on a chart called a Periodic Table.



The Appendix has a more complete description of the elements. We will not bother to go into details here. It isn't that important to the explanation of electricity, only that you understand the concept of atomic structure.

The outer layer of electrons is what determines many characteristics of the element. This shell is called the Valence Shell, and the electrons in it are called Valence Electrons. It is this structure that determines if the element will be a metal or non-metal. It determines what other elements will readily bond with this element. Most important to this discussion, it determines whether or not this element will conduct electricity readily, or not.

As a general statement, if the valence shell has only one or two electrons, it will readily conduct electricity. These are usually metals. If the outer shell has seven or eight electrons (there are never more than eight), it will not readily conduct electricity. These two types of elements are called Conductors and Insulators of electricity.

In between these two extremes we have a group of elements that have three, four, or five electrons in their valence shell. These are neither good conductors, nor are they good insulators. We call these semiconductors.
Conductors (metals) we use to carry electricity from one place to another. Insulators we use to prevent electricity from going where we don't want it. Semiconductors we use as the creativity of our imagination and the laws of physics allow us to.

So what is electricity?

The electrons that we mention are constantly in motion around the nucleus at the speed of light. About 186,000 Miles per Second, or 300,000 Kilometers per Second, if you prefer. The electrons are constantly being shared between the atoms. This sharing of electrons is what bonds atoms together. Normally this sharing is going on with no particular pattern, and appears random.

If we apply a voltage across a conductor we can get these electrons to move in an organized fashion, away from the Negative side of the voltage, and toward the positive side of the voltage. This flow of electrons is electrical current, and this is the main topic we will discuss here. We will come back to more on this later.

The Six Basic States of Matter

Condensed, solid, plastic, liquid, gas, and plasma are the six states in which matter may exist. Material substances, whether solid, liquid, or gas, are conceived as being composed of very large numbers of molecules and atoms. A molecule is the smallest portion of a compound that cannot be divided further without losing its characteristic material properties. A compound is composed of multiple atoms. Atoms are the smallest portions of a basic element that retains the characteristics of that element. We have identified about a hundred unique elements. These elements combine together in different arrangements to form the molecules that make up the countless substances the world is made of.

Matter may exist in up to six identifiable states, each having a unique characteristic. There are three states of matter mentioned in basic chemistry. These are Solid, Liquid, and gas. The solid state may have two notable conditions. At very low temperatures matter may drop into a condensed state. In this state we have an absence of notable energy characterized by no atomic or molecular vibration. It is at this temperature we get super conduction in various compounds. Above this temperature most matter is solid. The atoms and molecules of all matter above absolute zero and are in rapid continuous vibration, exchanging energy. As various atoms release energy and contract, their neighbors absorb the energy and expand. If these atoms are near the surface, this energy may radiate as heat or light in the form of a photon. Between atoms and molecules this energy is released as a phonon. There is no difference between photonic and phononic energy. It is a matter of where it is at that makes the difference in definition.
In solids the bonding between atoms or molecules is relatively strong, and the material exhibits hardness and rigidity. As we add energy to this material the bonding between

molecules, or atoms, becomes weakened, and the material softens to the plastic state. The material is less rigid and may be deformed with applied force. The material retains the form after the force is removed. For the purpose of electronics, this plastic state is worth noting. We must be conscious of solder in this plastic state. Material in the plastic state will not flow, like a liquid. Compounds often have a wider plastic state over a given temperature range than pure elements.

If we add more energy to our material we move from plastic to liquid. The material flows, following gravity, heat, or other environmental effects. Liquids conform to the shape of their vessel, altered by gravity. If we add more energy we reach the vapor temperature of the material where it changes from liquid to gas. In the gaseous state matter conforms to the shape of the vessel with less effect by gravity. Matter is less dense than in the liquid state. Solids and liquids are not easily compressed. Gases compress easily, and make wide swings in volume depending on energy (temperature, pressure and gravity).

In gases the atoms are still intact. If we add significant more energy we get to the plasma state. In plasma the electrons and nuclides are dissociated with one another, and the material becomes a sea of disconnected electrons and nuclides. At even higher temperatures the nuclides them selves start to unravel and the plasma becomes a stew of subatomic particles. This is the condition we find in the center of a star where fusion becomes possible. The extremes of gravity and pressure make our rules for chemical recombination incomplete.

When we talk about the chemistry of stars we must consider all six states of matter and keep our rules inclusive of Temperature, Pressure, and Gravity. We must also keep these rules in mind when we consider manufacturing processes in micro gravity. Molten metals, and all things liquid, conform to the shape of the vessel. We do not have the separation of heavier metals to the bottom of the pot (a requirement for separating metals). We do not have the separation of gases, as we expect in refining fuels at normal gravity. Lighter gases do not rise to the top. There is no top in micro gravity. Our dream of mining asteroids in space is unrealistic for this, and other reasons.

Caveats

Not all elements and compounds will experience all six states. Many gases will only go down to the liquid state at zero Kelvin. Zero Kelvin is not experienced in real space around solar systems, and perhaps not in the voids between solar systems, either. Since matter is energy, as long as we have matter present we will be above absolute zero. Some compounds go directly from solid to gaseous states, often with a great release of energy (an explosion).

Concept comments for these papers

These papers deal with subjects of science. As such they represent our present state of what we suspect reality around us to be like. We look back at what we called science one or two hundred years ago and smile, if not laugh, at what we thought to be true. We once thought the world was flat. We once considered electrons on atoms to be as raisins on a muffin. As we get more questions answered, we learn even more questions. We assume our present state of knowledge is not the whole truth, but just the best workable theory we have at this time. Science is not a religion to be believed. Science is to be understood, and perhaps has no ultimate conclusions.

That someone will someday, a hundred years from now, look back on our sciences of today and smile or laugh, is, in my opinion, a given reality.

Direction of future papers

The objective of these earlier courses is to get you to view the world around you at the sub-atomic, atomic and molecular level. We will try to present to you what electricity is, and what is happening, at the atomic, and sub-atomic level. The goal is to get you to understand the subjects, not just memorize the phrases.

When you say, “current is the number of electrons in motion”, I want you to picture in your mind a sea of electrons, and a flow of a current made of electrical charges in motion.

When you say, “voltage is the electrical pressure that causes current to flow”, I want you to visualize what is going on within the atoms, and between the atoms that causes the electrons to move from one atom to the next.

When you say, “resistance is the opposition to the flow of current”, I want you to have in mind how the construction of the atom or molecule determines how much force will have to be applied before a given level of current will flow.

In keeping with this concept, I want you to have some degree of insight into the chemistry aspect of electricity. The rules that apply in what makes metals conduct apply to what makes chemicals conduct, also.

Atomic bonding

Substances appear to be hard because the atoms share electrons in a covalent bond. The outer-most shell of electrons, valence electrons, determines which elements will bond with which elements. Atoms have an affinity to seek an outer shell of eight electrons. Atoms that have six valence electrons will attract to other elements that have two valence electrons, or to two elements that have one valence electron. For example, Oxygen, with six valence electrons, will attract two atoms of Hydrogen to form a stable molecule called H_2O, water.

Valence electrons bond with other valence electrons in a covalent bond, where atoms next to one another share electrons. As an electron leaves one atom, it attracts an electron from a neighboring atom. This perpetual sharing of electrons bonds atoms together to give a substance apparent hardness. The more covalent bonds shared, the harder the substance is. Diamond, the crystalline form of Carbon, has all four valence electrons in tight bond to four other neighboring atoms, making it one of the hardest substances we know.

Acids and pH level

These covalent bonds that bind atoms together to make molecules have certain strengths in their bonding. In chemical reactions, these bonds are altered, changing the molecular content of the substance. Some Hydrogen based liquids have a very strong attracting force on other atoms. An acid molecule has an outer shell comprised of Hydrogen atoms. Hydrogen atoms on the outer surface of the atom present a strong positive force, an exposed proton, attracting an electron. The more Hydrogen atoms on the outer surface of the atom, the higher strength we have presented to attract other atoms. An acid's strong attractive force rips the covalent bonds that hold neighboring molecules together.

This strength is measured in the number of protons from Hydrogen (pH).

Batteries

A battery is a chemically generated source of electrons. Typically, we have two chemical compounds separated by a barrier that will only allow charges to pass in one direction. We have a substance with an abundance of electrons on one side (negative charge) of this barrier, and a substance with a deficiency of electrons on the other side (positive charge). The barrier will not allow electrons to pass through. In order for the electrons to pass from one side to the other an electrical path must be provided around the outside of the battery.

Once the excess electrons have left the negative terminal, traveled through the circuit, returned to the battery at the positive terminal, the battery has depleted itself of charges, and the battery is dead. Inside the battery, the positive charges have passed through the barrier, completing the circuit.

This discharging is accomplished by a chemical reaction. In some types of batteries, this chemical reaction is reversible. Applying an electrical charge reverses the chemical reaction, charging up the battery again.

Atoms, Molecules and Electronics

Bear in mind that this a simplified discussion of the elements. Reality is a bit more complicated. Our intention here is to study of the behavior of electrons. This study we call electronics. Like most books on basics, we will stretch the truth a little bit to keep the story simple.

Everything around us that has substance is made of atoms. If we take a chunk of Aluminum and start breaking it apart into smaller and smaller pieces, the smallest thing we could break it into, and still have something identifiable as Aluminum, would be an

atom of Aluminum. All atoms of Aluminum are identical in size and structure. We cannot break Aluminum down into any other identifiable materials. This makes Aluminum a basic element.
We have identified about one hundred basic elements that make up everything around us. Water, for instance, is made of Hydrogen and Oxygen. If we take water apart into smaller and smaller units, the smallest unit that would be identifiable as water would be a group of one atom of Oxygen and two atoms of Hydrogen, designated H2O. This is one molecule of water. Groups of atom like this are called molecules, and these substances are called compounds.

Atoms and molecules are the smallest objects we can identify. Molecules break down into atoms, but once we break an atom apart we cease to have anything we can identify as a substance. All atoms are made of a central core, called a nucleus, surrounded by a shell of electrons. Electrons from an Aluminum atom are the same as electrons from Hydrogen or Oxygen atoms.

The nucleus is made of Protons and Neutrons. All protons are identical. All Neutrons are identical. The only thing that makes Aluminum different from Oxygen or Hydrogen is the number of Electrons, Protons, and Neutrons that make of the atoms.

Hydrogen, for example, is the most basic element. An atom of Hydrogen has a nucleus of one proton with one electron circling around it. All hydrogen atoms are made this way, and everything made this way must be hydrogen atoms.

The next heaviest element is Helium, which has two protons in the nucleus, surrounded by two electrons. All Helium atoms are made this way, and everything made this way must be Helium.

An atom is made of an inner nucleus of positively charged Protons and neutrally charged Neutrons, with an outer shell of negatively charged Electrons. The protons and neutrons are mostly matter and make up most of the mass of the atom. An electron is mostly energy. Most of the weight and mass of the atom is in the nucleus of the atom, in the protons and neutrons. A proton or neutron is roughly about the same size as an electron, but weighs about 1800 times as much.

Each unique element has a unique quantity of Electrons, Protons, and Neutrons. The makeup of these Electrons, Protons and Neutrons defines the characteristics the element will have. Usually there is one Electron for every Proton. Neutrons only affect the mass of the atom.

Elements are referred to by this number of Protons (or electrons) as the atomic number of that element. Atomic number covers a range from one to over one hundred, but atomic diameter varies much less. Hydrogen, the smallest of the elements, (at STPG) has a diameter of 0.53 Angstroms. Francium, the largest element I have data for, with an atomic number of 87 only has a diameter of 2.7 Angstroms. Only five times the diameter of Hydrogen.

The normal atom, having an equal number of negative electrons and positive protons, has no electrical charge. It is this characteristic we will alter as we discuss electricity. If we remove an electron from an atom, it now has more positively charged protons than negatively charged electrons, and the atom becomes a positive ion, a charged atom.

Likewise, if we force an extra electron onto an atom it now has more electrons than protons, and becomes a negative ion.

The electrons are layered in predictable shells and subshells. It is the outer shell of electrons that is of particular interest to us in the study of electronics. If the outer shell has only one or two electrons, they may be pulled away and move to a neighboring atom with relative ease. This is what makes an element a good conductor of electricity. These are primarily metals.

For our purposes, we are concerned with the outer shell of electrons. An electron is mostly energy with very little mass. Electrons move around the nucleus is loosely defined shells at extremely high speeds (186,000 miles per second, or 300,000 kilometers per second). The structure of these shells defines many characteristics the element will have.

If the outer shell is complete and stable, the electrons are not readily pulled out of place. These elements are insulators, and do not conduct electricity well.

These last two statements are true whether we are talking about an element or a molecule. If a molecule has one or two loosely bonded electrons, it will be a good conductor. If it has no unbonded electrons, it will be a good insulator.

In between the extremes of conductors and insulators are a group of elements (or molecules) that have four or five electrons in the outer shell. These are semiconductors. They are neither good conductors, nor good insulators. By controlling the specific characteristics of these elements we can get some very creative results. This is the realm of Solid State Electronics.

Conductors, like metals, are used to carry electricity from one point to another. Insulators are used to prevent the flow of electricity where we don't want it to go. Semiconductors are used to specifically manipulate the flow of electricity in detail.

Some popular semiconductors are elements like Carbon, Selenium, Silicon, and Germanium, or compounds like Cadmium Sulfide, and Gallium Arsenide. The list of useful molecular compounds is extensive. By including various elements, we can get unique characteristics that cause light to be emitted (Gallium Arsenic, or Gallium Arsenic Phosphide), or cause the compound to react to the presence of light (Cadmium Sulfide). We can create substances that change shape on the application of electricity, or create electricity by the application of physical pressure.

What we have said concerning what makes an atom a conductor or insulator also applies to molecules. While a metal, like Iron, mixes with Oxygen to make iron oxide, the result is an insulator. The outer (valence) electrons of the Iron atoms are tied up in bonds to the Oxygen atoms. Rust (iron oxide) is a poor conductor because the electrons are no longer free to move, producing an electrical current.

We manipulate atoms and molecules to get the performance we desire. The possibilities are limited only by the laws of physics, our understanding of the elements and the imagination we apply in manipulating the laws of physics.