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Student Handout.

Conductors, Insulators & Semiconductors.

Electron Theory of Matter.

Atomic Structure:

- Electrons –ve
- Protons +ve
- Neutrons nil

Matter: It has mass and occupies space.

Molecules: The smallest part of a substance that is recognisable as that substance i.e. H2O Water.

Ionisation: The normal atom has an equal number of protons and electrons, which in turn means the atom is neutral and has no apparent electrical charge. When a normal atom looses or gains a electron it is ionised or electrical charged

Loss of electrons = +ve charged atom
Gain of electrons = -ve charged atom

Electron Theory: Is the assumption that all matter is composed of minute –ve and +ve charged particles and assumes that all electrical effects (i.e. electrical energy) is due to the ordered movement of 'free electrons' from atom to atom or put another way, there are to many or to few electrons in a particular atom.

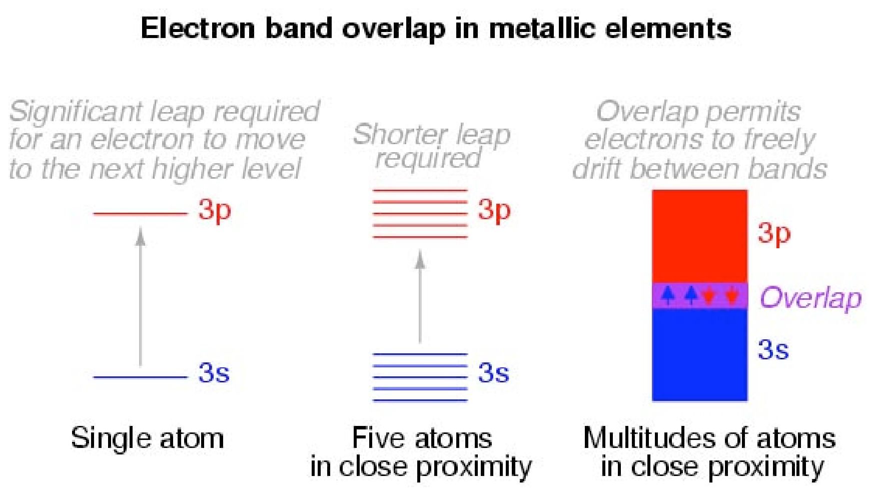
The electrons of different types of atoms have different degrees of freedom to move around. With some types of materials, such as metals, the outermost electrons in the atoms are so loosely bound that they chaotically move in the space between the atoms of that material by nothing more than the influence of room-temperature heat energy. Because these virtually unbound electrons are free to leave their respective atoms and float around in the space between adjacent atoms, they are often called free electrons.

Valence, *What determines the valence of an atom?*

The number of electrons in the outermost shell determines the valence of an atom. For this reason, the outer shell of an atom is called the VALENCE SHELL; and the electrons contained in this shell are called VALENCE ELECTRONS. The valence of an atom determines its ability to gain or lose an electron, which in turn determines the chemical and electrical properties of the atom. An atom that is lacking only one or two electrons from its outer shell will easily gain electrons to complete its shell, but a large amount of energy is required to free any of its electrons. An atom having a relatively small number of electrons in its outer shell in comparison to the number of electrons required to fill the shell will easily lose these valence electrons. The valence shell always refers to the outermost shell.

Band theory of solids

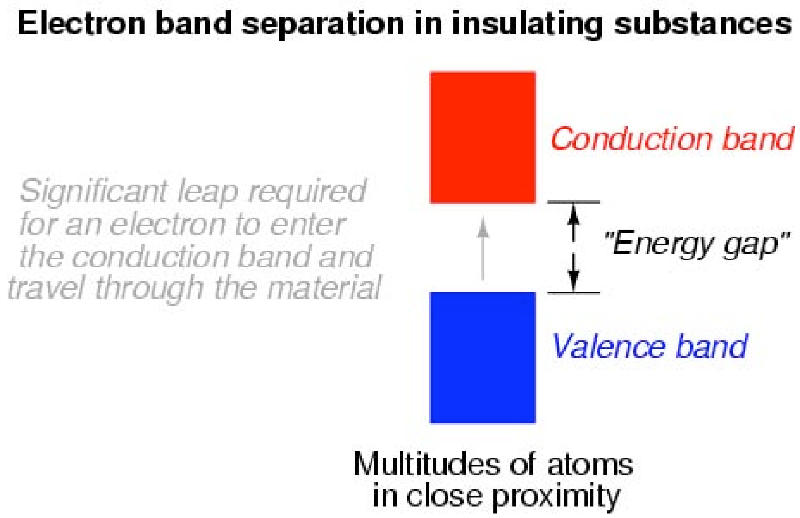
A useful way to visualize the difference between conductors, insulators and semiconductors is to plot the available energies for electrons in the materials. Instead of having discrete energies as in the case of free atoms, the available energy states form bands. Crucial to the conduction process is whether or not there are electrons in the conduction band. In insulators the electrons in the valence band are separated by a large gap from the conduction band, in conductors like metals the valence band overlaps the conduction band, and in semiconductors there is a small enough gap between the valence and conduction bands that thermal or other excitations can bridge the gap. With such a small gap, the presence of a small percentage of a doping material can increase conductivity dramatically.



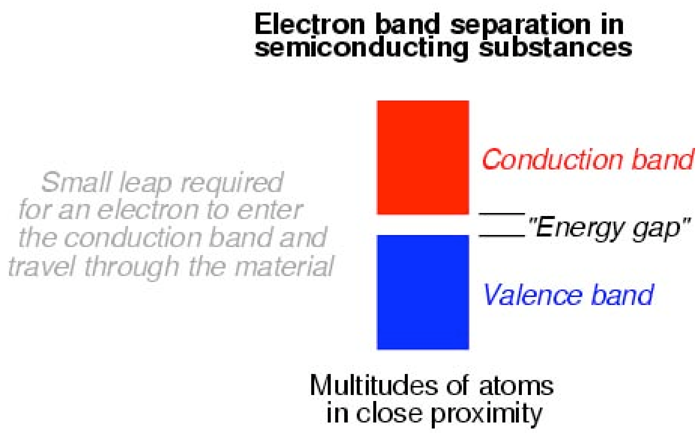
When atoms combine to form substances, the outermost shells, sub shells, and orbitales merge, providing a greater number of available energy levels for electrons to assume. When large numbers of atoms exist in close proximity to each other, these available energy levels form a nearly continuous band wherein electrons may transition.

It is the width of these bands and their proximity to existing electrons that determines how mobile those electrons will be when exposed to an electric field. In metallic substances, empty bands overlap with bands containing electrons, meaning that electrons may move to what would normally be (in the case of a single atom) a higher-level state with little or no additional energy imparted. Thus, the outer electrons are said to be "free," and ready to move at the beckoning of an electric field.

Band overlap will not occur in all substances, no matter how many atoms are in close proximity to each other. In some substances, a substantial gap remains between the highest band containing electrons (the so-called valence band) and the next band, which is empty (the so-called conduction band). As a result, valence electrons are "bound" to their constituent atoms and cannot become mobile within the substance without a significant amount of imparted energy. These substances are electrical insulators:



Materials that fall within the category of semiconductors have a narrow gap between the valence and conduction bands. Thus, the amount of energy required to motivate a valence electron into the conduction band where it becomes mobile is quite modest:



At low temperatures, there is little thermal energy available to push valence electrons across this gap, and the semiconducting material acts as an insulator. At higher temperatures, though, the ambient thermal energy becomes sufficient to force electrons across the gap, and the material will conduct electricity.

It is difficult to predict the conductive properties of a substance by examining the electron configurations of its constituent atoms. While it is true that the best metallic conductors of electricity (silver, copper, and gold) all have outer s sub shells with a single electron, the relationship between conductivity and valence electron count is not necessarily consistent:

Element	Specific resistance (ρ) at 20° Celsius	Electron configuration
Silver (Ag)	9.546 Ω·cmil/ft	$4d^{10}5s^1$
Copper (Cu)	10.09 Ω·cmil/ft	$3d^{10}4s^1$
Gold (Au)	13.32 Ω·cmil/ft	$5d^{10}6s^1$
Aluminum (Al)	15.94 Ω·cmil/ft	$3p^1$
Tungsten (W)	31.76 Ω·cmil/ft	$5d^4 6s^2$
Molybdenum (Mo)	32.12 Ω·cmil/ft	$4d^5 5s^1$
Zinc (Zn)	35.49 Ω·cmil/ft	$3d^{10}4s^2$
Nickel (Ni)	41.69 Ω·cmil/ft	$3d^8 4s^2$
Iron (Fe)	57.81 Ω·cmil/ft	$3d^6 4s^2$
Platinum (Pt)	63.16 Ω·cmil/ft	$5d^9 6s^1$

Likewise, the electron band configurations produced by compounds of different elements defies easy association with the electron configurations of its constituent elements.

In other types of materials such as glass, the atoms' electrons have very little freedom to move around. While external forces such as physical rubbing can force some of these electrons to leave their respective atoms and transfer to the atoms of another material, they do not move between atoms within that material very easily.

This relative mobility of electrons within a material is known as electric conductivity. Conductivity is determined by the types of atoms in a material (the number of protons in each atom's nucleus, determining its chemical identity) and how the atoms are linked together with one another.

Here are a few common examples of conductors and insulators:

* **Conductors:**
* Silver
* Copper
* Gold
* Aluminium
* Iron
* Steel
* Brass
* Bronze

* **Insulators:**
* glass
* rubber
* Polyvinyl Chloride (PVC)
* porcelain
* ceramic
* (dry) cotton
* (dry) paper
* (dry) wood
* Plastic
* Air
* Pure water

Semiconductors

* Galena
* Selenium
* Silicon
* Germanium

It must be understood that not all conductive materials have the same level of conductivity, and not all insulators are equally resistant to electron motion.

For instance, silver is the best conductor in the "conductors" list, offering easier passage for electrons than any other material cited. Dirty water and concrete are also conductors, but these materials are substantially less conductive than any metal.

Conductor Environmental Uses.

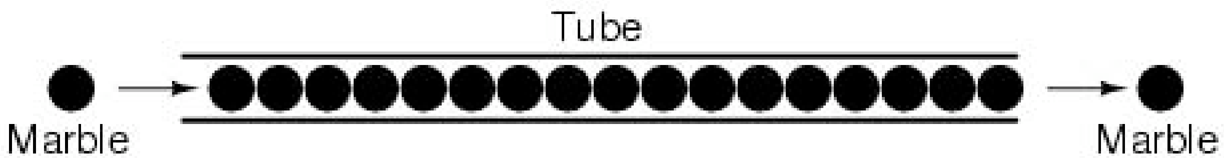
Material\Condition	Heat	Moisture	Corrosion	Dust	Tension	Compression	Vibration
Copper	good	good	Poor	Good	Poor	Good	Ok
Silver	Good	Good	Good	Good	Good	Good	Good
Aluminium	Good	Good	Good	Good	Ok	Good	Good
Tungsten	vgood	Good	vgood	Poor	Ok	Ok	Ok
Carbon	Good	Poor	Good	Poor	Poor	Good	Poor
Nichrome	vgood	Poor	Poor	Poor	Poor	Poor	Ok
Brass	Good	Good	Good	Good	Poor	Good	Ok

Copper is by far the most common conductor material and is in general use in every day domestic and commercial power reticulation. In some situations conductors need to be of a material that will resist corrosion better than copper such as gold and silver but as these conductor materials are very expensive there use is generally restricted to switching contacts and high-risk areas such as would be found in Rotorua. Other conductors such as aluminium being lighter and easier to handle can be more useful in large feeder conductors carrying high ranges of currents and distribution of heat such as in power room 'buzz bars'.
Physical dimension also impacts conductivity. For instance, if we take two strips of the same conductive material -- one thin and the other thick -- the thick strip will prove to be a better conductor than the thin for the same length. If we take another pair of strips -- this time both with the same thickness but one shorter than the other -- the shorter one will offer easier passage to electrons than the long one. This is analogous to water flow in a pipe: a fat pipe offers easier passage than a skinny pipe, and a short pipe is easier for water to move through than a long pipe, all other dimensions being equal.

It should also be understood that some materials experience changes in their electrical properties under different conditions. Glass, for instance, is a very good insulator at room temperature, but becomes a conductor when heated to a very high temperature. Gases such as air, normally insulating materials, also become conductive if heated to very high temperatures. Most metals become poorer conductors when heated, and better conductors when cooled. Many conductive materials become perfectly conductive (this is called superconductivity) at extremely low temperatures.

While the normal motion of "free" electrons in a conductor is random, with no particular direction or speed, electrons can be influenced to move in a coordinated fashion through a conductive material. This uniform motion of electrons is what we call electricity, or electric current. To be more precise, it could be called dynamic electricity in contrast to static electricity, which is an unmoving accumulation of electric charge. Just like water flowing through the emptiness of a pipe, electrons are able to move within the empty space within and between the atoms of a conductor. The conductor may appear to be solid to our eyes, but any material composed of atoms is mostly empty space! The liquid-flow analogy is so fitting that the motion of electrons through a conductor is often referred to as a "flow."

A noteworthy observation may be made here. As each electron moves uniformly through a conductor, it pushes on the one ahead of it, such that all the electrons move together as a group. The starting and stopping of electron flow through the length of a conductive path is virtually instantaneous from one end of a conductor to the other, even though the motion of each electron may be very slow. An approximate analogy is that of a tube filled end-to-end with marbles:

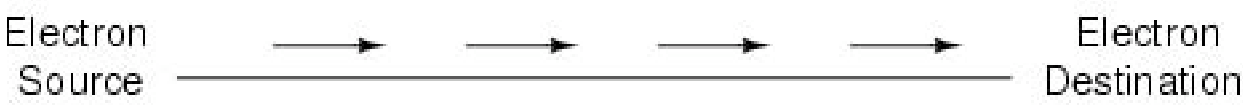


The tube is full of marbles, just as a conductor is full of free electrons ready to be moved by an outside influence. If a single marble is suddenly inserted into this full tube on the left-hand side, another marble will immediately try to exit the tube on the right. Even though each marble only travelled a short distance, the transfer of motion through the tube is virtually instantaneous from the left end to the right end, no matter how long the tube is. With electricity, the overall effect from one end of a conductor to the other happens at the speed of light: a swift 186,000 miles per second!!! Each individual electron, though, travels through the conductor at a much slower pace.

If we want electrons to flow in a certain direction to a certain place, we must provide the proper path for them to move, just as a plumber must install piping to get water to flow where he or she wants it to flow. To facilitate this, wires are made of highly conductive metals such as copper or aluminium in a wide variety of sizes.

Remember that electrons can flow only when they have the opportunity to move in the space between the atoms of a material. This means that there can be electric current only where there exists a continuous path of conductive material providing a conduit for electrons to travel through. In the marble analogy, marbles can flow into the left-hand side of the tube (and, consequently, through the tube) if and only if the tube is open on the right-hand side for marbles to flow out. If the tube is blocked on the right-hand side, the marbles will just "pile up" inside the tube, and marble "flow" will not occur. The same holds true for electric current: the continuous flow of electrons requires there be an unbroken path to permit that flow. Let's look at a diagram to illustrate how this works:

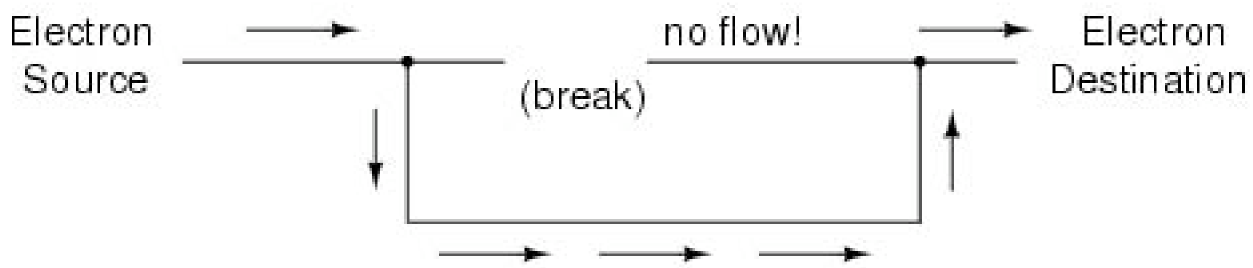
A thin, solid line (as shown above) is the conventional symbol for a continuous piece of wire. Since the wire is made of a conductive material, such as copper, its constituent atoms have many free electrons that can easily move through the wire. However, there will never be a continuous or uniform flow of electrons within this wire unless they have a place to come from and a place to go. Let's add a hypothetical electron "Source" and "Destination:"



Now, with the Electron Source pushing new electrons into the wire on the left-hand side, electron flow through the wire can occur (as indicated by the arrows pointing from left to right). However, the flow will be interrupted if the conductive path formed by the wire is broken:

Since air is an insulating material, and an air gap separates the two pieces of wire, the once-continuous path has now been broken, and electrons cannot flow from Source to Destination. This is like cutting a water pipe in two and capping off the broken ends of the pipe: water can't flow if there's no exit out of the pipe. In electrical terms, we had a condition of electrical continuity when the wire was in one piece, and now that continuity is broken with the wire cut and separated.

If we were to take another piece of wire leading to the Destination and simply make physical contact with the wire leading to the Source, we would once again have a continuous path for electrons to flow. The two dots in the diagram indicate physical (metal-to-metal) contact between the wire pieces:



Now, we have continuity from the Source, to the newly made connection, down, to the right, and up to the Destination. This is analogous to putting a "tee" fitting in one of the capped-off pipes and directing water through a new segment of pipe to its destination. Please take note that the broken segment of wire on the right hand side has no electrons flowing through it, because it is no longer part of a complete path from Source to Destination.

It is interesting to note that no "wear" occurs within wires due to this electric current, unlike water-carrying pipes which are eventually corroded and worn by prolonged flows. Electrons do encounter some degree of friction as they move, however, and this friction can generate heat in a conductor. This is a topic we'll explore in much greater detail later.

Insulators:

Materials with high electron mobility (many free electrons) are called conductors, while materials with low electron mobility (few or no free electrons) are called insulators.

There are many materials that can act as insulators. If we consider most cables need insulation to protect the conductors from shorting to each other and to protect users from electric shock. The most common cable insulator is PVC (Polyvinyl Chloride) as it has a high dielectric strength and is very mailable but it has the disadvantage of giving of poisonous gasses when burnt. In a high-risk fire situation an insulator like fire resistant cables used in plenum (pronounced PLEH-nuhm, from Latin meaning full) spaces in buildings these cables could be insulated with Teflon or Mica. Rubber one of the oldest insulator materials in commercial use still has uses where flexibility is crucial such as protective insulated clothing and stress points in electrical appliance leads.

Insulator Environmental Uses.

Material\Condition	Heat	Moisture	Corrosion	Dust	Tension	Compression	Vibration
Glass	Good	Good	Good	Good	Poor	Good	Poor
Mica	vgood	vgood	vgood	vgood	Poor	Poor	Poor
Oil	Poor	Poor	vgood	Poor	Poor	Poor	Good
Ceramics	vgood	vgood	vgood	vgood	Ok	Ok	Ok
Rubber	Ok	Good	vgood	Poor	Ok	Ok	Good
PVC	Poor	Good	vgood	Good	Ok	Poor	Good
Teflon	vgood	Good	vgood	Good	Ok	Poor	Good

REVIEW:

- In conductive materials, the outer electrons in each atom can easily come or go, and are called free electrons.
- In insulating materials, the outer electrons are not so free to move.
- All metals are electrically conductive.
- Dynamic electricity, or electric current, is the uniform motion of electrons through a conductor.
- Static electricity is an unmoving, accumulated charge formed by either an excess or deficiency of electrons in an object.
- For electrons to flow continuously (indefinitely) through a conductor, there must be a complete, unbroken path for them to move both into and out of that conductor.

Student Assessment Questionnaire.

Note: This part of the assessment is open book and 100% is the required result.

1. **Name three conductors and state their resistivity.**
    - ____________
    - ____________
    - ____________
2. **Name three insulators and state their resistivity.**
    - ____________
    - ____________
    - ____________
3. **Name two semiconductors.**
    - ____________
    - ____________
4. **Name three uses for conductors.**
    - ____________
    - ____________
    - ____________
5. **Name three uses for insulators.**
    - ____________
    - ____________
    - ____________

6. **Name three uses for semiconductors.**
    - ___________
    - ___________
    - ___________

7. **Fill in the blanks in the following Table.**

Conductor Environmental Uses.

Material\Condition	Heat	Moisture	Corrosion	Dust	Tension	Compression	Vibration

8. **Fill in the blanks in the following Table.**

Insulator Environmental Uses.

Material\Condition	Heat	Moisture	Corrosion	Dust	Tension	Compression	Vibration

9. What is an electrical conductor?

a. anything that prevents electricity from flowing
b. anything that transmits electricity
c. anything that transmits heat
d. none of the above

10. Which one of the following metals is the best electrical conductor?

a. silver
b. copper
c. aluminum
d. tungsten

11. Which one of the following is not a characteristic of copper?

a. flexible
b. good corrosion resistance
c. reasonable cost
d. light weight

12. Which of the following is used to make light bulb filaments?

a. copper
b. aluminum
c. silver
d. tungsten

13. How is the function of wires identified?

a. labels
b. colors
c. position
d. symbols

14. What prevents electricity from jumping from one conductor to another in a cable?

a. insulation
b. fiber optics
c. paper
d. oil fill

15. A group of wires enclosed in a metal, rubber, or plastic sheet is called?

a. insulation
b. fiber optics
c. cable
d. bundle

Name: ________________________________

Course: ________________________________

Date: ________________________________

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Tutors Signature: ___________________________