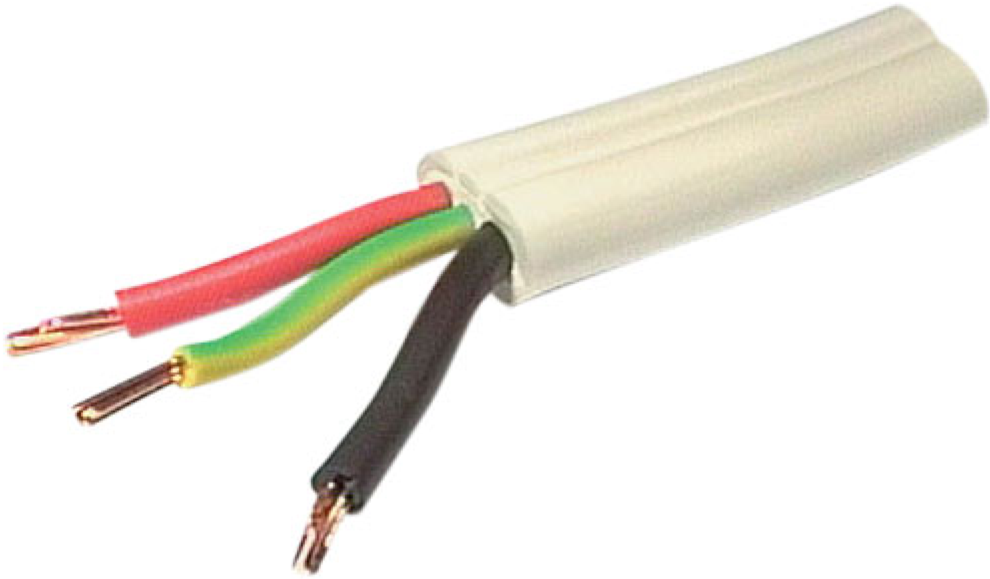
EE3103
conductors, insulators and semiconductors assignment 2



Student name

Notes for “Conductors, Insulators and Semiconductors”

Edited 28.01.19 Chris Meehan

Introduction

Conductors are usually metal, insulators a non-metal and semiconductors modified insulators that act as poor conductors.

Conductors are essentially used to transport electricity and are chosen so that the heat produced within them is appropriate to its purpose.
Eg: A cable is required to conduct with a minimal lose of energy through it, in the form of heat, but a heater element will dissipate a set amount of energy.

Conductors vary in their uses from superconducting cables (cooled close to –273 degrees Celsius), to heater elements. Miniature tracks on circuit boards to semiconducting devices that change their mind at a very fast rate.

Insulators on the other hand are used to contain, control or block that flow of electricity and are used in combination with conductors.

Semiconductors fall between the two and with a bit of coaxing can change their mind to behave as either a poor conductor or a poor insulator.

Many other factors are considered also to determine the choice of a conductor, insulator or semiconductor for a certain task.

As electricity is the flow of electrons through these materials we need to look into their atoms to understand why certain materials behave differently.

Atomic theory

Atoms are centred on a nucleus containing neutrons and protons. This is where almost all the mass or matter is found.
Orbiting this positively charged centre mass are the negatively charged electrons.
The large positive mass in the centre exerts a pull on the orbiting electrons stopping them from flying away.
Although the electrons are weightless by comparism with the nucleus, they are moving at an incredible speed. This high orbital speed stops the electrons falling back into the centre mass of the atom.
This model is similar to the moon orbiting the earth but the electrons move very much faster.

The electrons orbit at set distances from the nucleus and these distances depend on the atoms total number of electrons. This total number of electrons equals the total number of protons making the atom electrically balanced or neutral. The neutrons have no charge and their presence has no electrical effect.

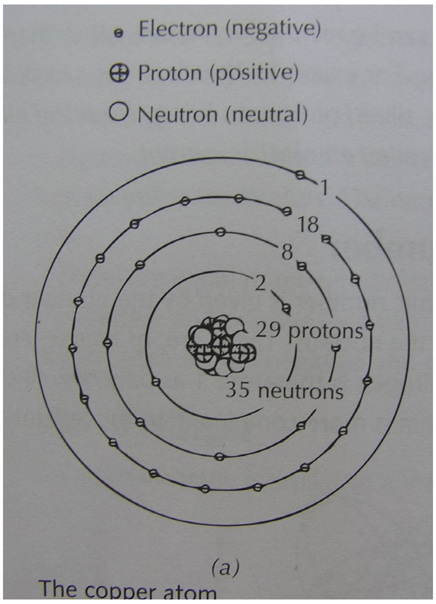
When an atom loses an electron it becomes electrically positive and will want to attract a replacement from any passing electron.
When an atom is holding an extra electron in its outer shell it becomes slightly negatively charged and can easily lose it to a passing atom, especially to an atom slightly positively charged.
We call these types of atoms ions or charged particles.

Atoms endeavour to restore their electric charge to a neutral state and in doing so can pass the electrons along to other atoms in a line. This is the essence of an electric current.

Each element is characterised by its atom having a definite number of protons and electrons.
Copper for example has an atomic number of 29. There are 29 protons and 29 electrons orbiting the nucleus.

Electrons orbit the atoms nucleus in set layers called shells.
When each shell fills up to its maximum number of electrons, it then starts filling up the next shell further out from the nucleus.
The outermost shell is called the valence shell and the electrons there are termed valence electrons.
This shell and the quantity of electrons found there give the particular atom its electrical characteristics.

Using a copper atom as an example we can show how the electron shells are constructed.



Note the valence shell has only one electron. This means that it has a loose hold on it and can easily be lost to another atom.

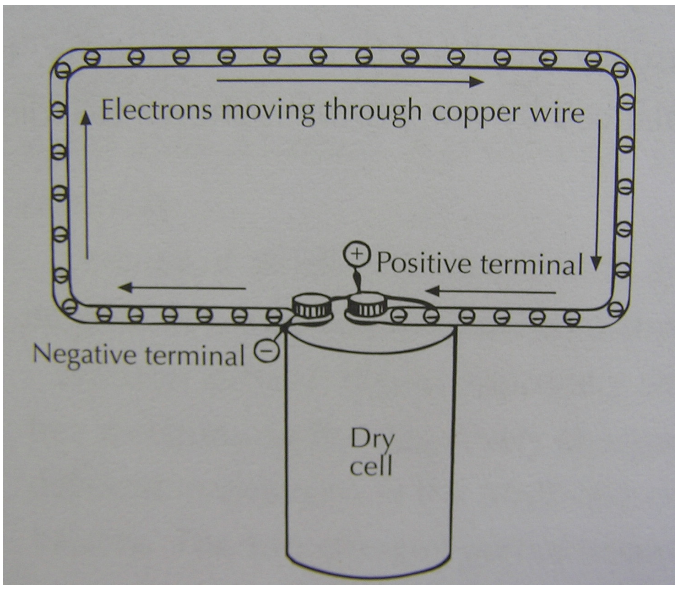
This may happen if energy is applied as heat or a greater attractive force lures this vulnerable electron away.

These electrons can wander freely and randomly around a group of copper atoms.

This situation describes a **good conductor**

If we now connect a battery to this copper conductor we find that the positive terminal of the cell would attract these free electrons in the conductor, with the negative terminal providing its excess electrons. These electrons would flow along the copper conductor.

This illustration shows the direction of electron flow from negative to positive, however we have traditionally shown current flow as positive to negative. This is termed as conventional current and is the accepted current flow.



If we now consider an atom where the outer shell is complete, we would have a situation where the atom is most reluctant to allow any of its electrons to escape its influence.

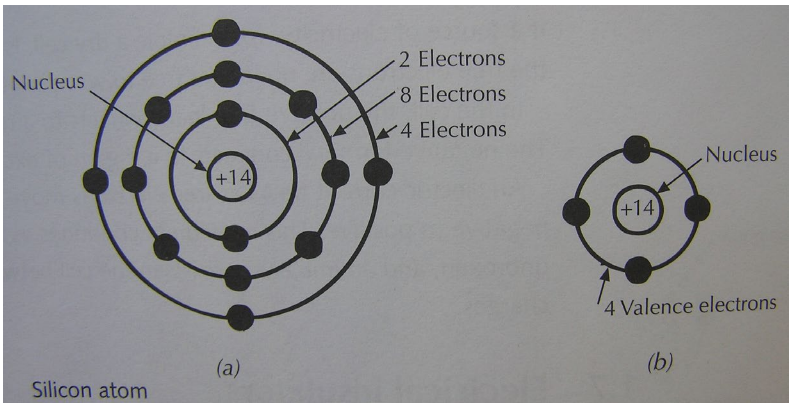
This would define a **<u>good insulator</u>** as there would be few electrons free to allow an electric current to flow. This is because the *valence electrons are tightly bound.*

Between these two extremes lies the variable world of semi-conductors. These materials make neither a good conductor or insulator but can be manipulated to alter their electrical properties.

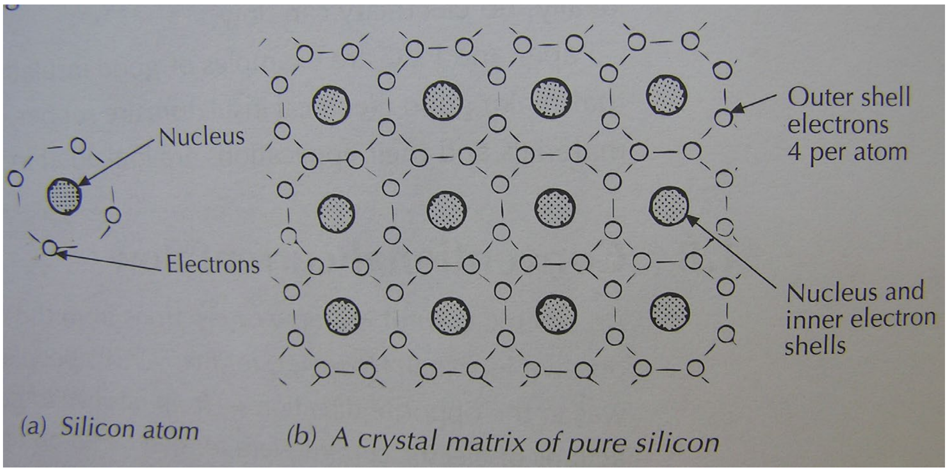
<u>Semiconductors</u>

Remember a good conductor will have one electron in its outer shell.
A good insulator will have a full valence shell.
But a semiconductor would have a half full valence layer, say 4 electrons in an 8 electron shell.

A good example of this would be silicon.

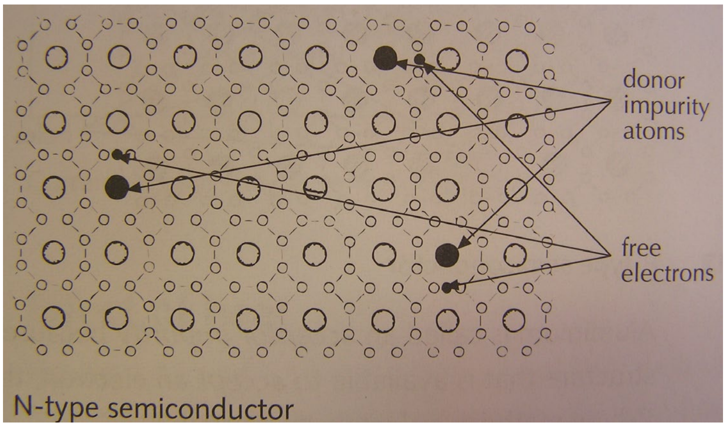


Silicon atoms tend to form a crystal matrix where they share their 4 outer electrons with other silicon atoms in such a way that they all end up with 8 electrons in the outer shell.

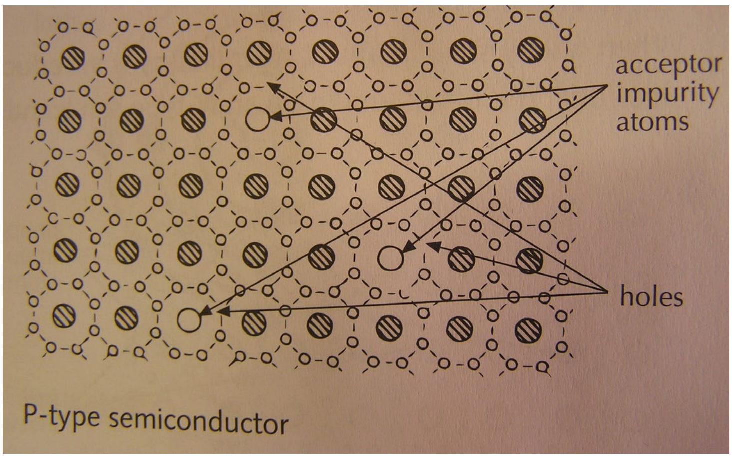


In this pure configuration silicon behaves as an insulator .

By adding a minute “ doping “ of another atom, say **antimony (Sb)**, which has 5 valence electrons, we can make the silicon matrix behave as a poor conductor with extra electrons and is shown **below** as an **N type** semiconductor.



Doping in this case is the controlled contamination of 1 part in 10 million of doping atoms.



We can separately construct a **P type** matrix, by adding an impurity atom, which has 3 valence electrons, such as **aluminium (Al)**

Instead of having an excess of electrons as the N type has in the matrix, there would be **gaps or holes** in the structure

Although silicon is the most commonly used semiconductor base material, germanium and selenium are elements that are used in more specialist roles as well.

Other doping agents include indium, gallium and boron.

Altering the quantities of impurities or the level of doping will change the electrical characteristics of these semiconductors enabling them to perform various different tasks. (i.e. diode to zener diode with more doping)
This is discussed in greater detail when we study semiconductor diodes.

Resistivity

How well a material conducts current or resists the flow of current can be measured. When we compare different materials we can use a table of resistivity which shows their comparative values for the same size piece. The bigger the number of ohms the greater the resistance.

Resistivity table

Silver	$16.3 \times 10^{-9}\ \Omega m$	good conductor
Copper	$17.2 \times 10^{-9}\ \Omega m$	
Gold	$24.4 \times 10^{-9}\ \Omega m$	
Aluminium	$28.3 \times 10^{-9}\ \Omega m$	
Brass	$46 \times 10^{-9}\ \Omega m$	
Steel (tungsten)	$55 \times 10^{-9}\ \Omega m$	
Tin	$110 \times 10^{-9}\ \Omega m$	
Lead	$207 \times 10^{-9}\ \Omega m$	
Nichrome	$1100 \times 10^{-9}\ \Omega m$	
Carbon	$35000 \times 10^{-9}\ \Omega m$	
Silicon	$0.8\ \Omega m$	semi-conductor
Germanium	$0.9\ \Omega m$	
Ceramic	$10^{10}\ \Omega m$	
Rubber	$10^{13}\ \Omega m$	
PVC	$10^{14}\ \Omega m$	good insulator
Glass	10^{10} to $10^{14}\ \Omega m$	
Mica	10^{13} to $10^{17}\ \Omega m$	

Conductor and Insulator properties and uses

Conductors are used to convey electricity and signals. A good conductor will in general have a low resistance, be mechanically strong, flexible and be corrosion resistant.

Some common uses include;
High voltage transmission lines.
Motor windings.
Telephone and data lines.
Lighting and power cables.
Heating elements.
Circuit board tracks.

Insulators are used to contain current flow in the conductors and appear as;
Glass insulators on pylons.
Varnish on motor windings.
Rubber, PVC and silicone on cables.
Oil in transformers.
Mica, ceramics and plastics in electronics.

And now looking more closely at specific materials

Conductors

Gold - A good performing conductor, very resistant to oxidation and corrosion. Used as connectors in electronics as low contact pressure provides a low resistant contact. Prohibited by cost for other than specialist uses.

Silver - The best conductor. Oxidation can be an issue and is also expensive by comparism to say copper. Will withstand 300°C.

Copper - The best all rounder. Relatively cheap, flexible and mechanically strong. Used extensively for general wiring with cables and busbars and motor windings.
Soft annealed for flexibility in cables and hard drawn for aerial cables.

Aluminium - Mass per metre, aluminium conducts better than copper even when you consider it is only 60% as conductive than copper per square area. Used for pylon cables to reduce mechanical loading. Non-conductive oxidation is a real issue and special jointing procedures are needed on terminations. It is not as flexible as copper.
Can operate below 150°C.

Nichrome - An alloy used as a higher resistance heater element. Will operate red hot at 800 to1100°C.

Tungsten - Higher resistance still. Can operate white hot at temperatures around 2000 to 2500°C making it ideal for use as light bulb filaments.

Brass - A good conductor and a hard material, which makes it an ideal choice for motor commutators. Can be brazed to easily to join conductors and is resistant to corrosion. It is 50% harder than copper and can stand higher temperatures. Not flexible

Carbon - Conducts well if mixed with other better conducting material in a cast form. Soft and self-lubricating making it an ideal choice for motor brushes. Prone to moisture absorption. Will withstand 1000°C.

Lead - A low melting point makes lead an ideal metal to join conductors together as solder. It has vibration damping properties which assist the mechanical strength on these joins. Corrosive resistant properties see lead used for underground cable sheaths and its high density makes it ideal for screening against electromagnetic radiation. Used extensively in lead acid cells.

Tin - Used as a protective coating on steel as an alternative to zinc. When mixed with lead creates a stronger solder joint. Brass has tin as one of it's alloy elements and used in bushed bearing alloys.

Insulators

Rubber - Natural rubber is unstable so insulating rubber has sulphur added to become vulcanised rubber. The sulphur however is corrosive to copper so a layer of pure rubber must shield the two. Very flexible and ideal for cords. Damaged easily with heat, UV exposure and oil contamination.
Silicone rubber as a variant can stand higher temperatures of 212°C and is very corrosion resistant.

PVC - Strong and flexible. Non hydroscopic (waterproof) and reasonably flexible. Used for most general purpose cables. Has a low melting point, insulation damage can occur at around 160°C. Toxic gases are released if burnt (hydrogen chloride)
Operating temperature of 75 to 90°C.

Mica - A silicate material, naturally occurring or reconstituted with additives. Can withstand 600°C and is used in capacitors, resistors, stoves toasters and commutator insulators.

Glass - Made from silica sand producing an excellent insulator, however very brittle. Has been superseded mostly now in uses as high voltage insulators on pylons. Can be spun for cable insulation tape.

Oil - An excellent totally flexible insulator able to dissipate heat well.Used in contained transformers and can be hydroscopic.

Ceramics - Non metallic materials permanently hardened by firing at high temperatures. Good heat and chemical resistance, with the added advantage of being mouldable. Applications include spark plug insulators, high voltage switchgear mouldings and electronic components.

EE3103 conductor insulator or semiconductor assignment

1) What does valence mean in terms of shells?

2) What does valence mean in terms of electrons?

3) What group of atoms are usually conductors?

4) How many electrons are found in the outer shell of a good conductor?

5) What is the unit of resistivity?

6) Is an electron positively charged?

7) What charge is a neutron?

8) What is an ion?

9) How cold is absolute zero?

10) What element has an atomic number of 29?

11) Loosely bound electrons refer to what group of elements?

12) Define conventional current.

13) How does the valence shell appear in a silicon atom.

14) Is silicon a base material or a donor material?

15) Define an acceptor material.

16) What does p type mean?

17) What does doping mean?

18) Name a pentavalent material.

19) Define PTC.

20) Where are covalent bonds found?

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21) Is carbon PTC or NTC

22) What is Nichrome?

23) Where is tungsten used in the electrical industry?

24) Why is copper so popular in the electrical industry?

25) Why is aluminium not used as much as copper for conductors?

26) Why are rubber cables being replaced with PVC?

27) Why is carbon good for brush material in rotating machines?

28) Varnish usually covers what conductor in which application?

29) Name a fluid insulator commonly used in the electrical industry.

30) Name the most common insulator used for cables in buildings.