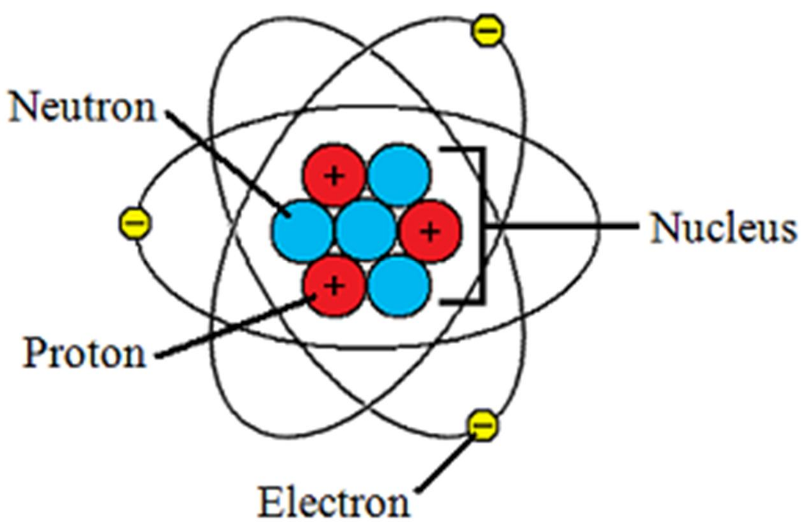
Chapter One
Basics Atomic Structure

1.1: The Atom

All matter **is composed of atoms**; all atoms consist of **electrons**, **protons**, and **neutrons** except **normal hydrogen**, which does not have a neutron.
∴ **Atoms** are the basic building blocks of all matter.
∴ **EVERYTHING** on Earth is made of atoms…even the air and your body.



Each element in the periodic table has a unique atomic structure, and all atoms within a given element have the **same** number of protons.

NOTE:
At first, the atom was thought to be a tiny indivisible sphere. Later it was shown that the atom was not a single particle but was made up of a small dense nucleus around which electrons orbit at great distances from the nucleus, similar to the way planets orbit the sun.

1.2: The Bohr Model

An atom: **it is the smallest particle of an element** that retains the characteristics of that element.

Each of the known **118** elements has atoms that are different from the atoms of all other elements.

This gives each **element** a unique atomic structure.

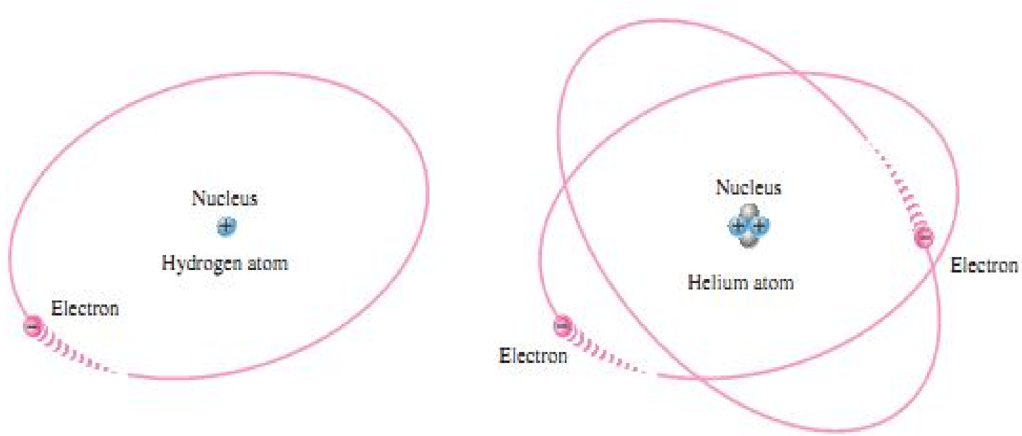
According to the classical Bohr model, **atoms** have a **planetary type** of structure that consists of a central nucleus surrounded by orbiting electrons,

The **nucleus** consists of **positively charged** particles called **protons** and **uncharged particles** called **neutrons**. The basic particles of **negative charge** are called **electrons**.

∴ Atoms are made of three particles:

- Protons (+)
- Neutrons (N)
- Electrons (e-)

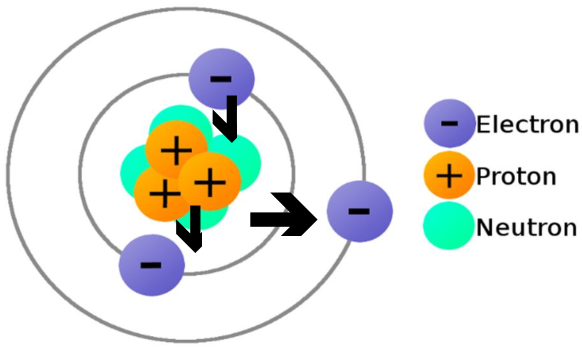
Each type of atom has a certain number of electrons and protons that distinguishes it from the atoms of all other elements.
For example, the **simplest atom** is that of hydrogen, which has one proton and one electron. As another example, the helium atom, has two protons and two neutrons in the nucleus and two electrons orbiting the nucleus.



NOTE:
This view shows that the electrons in the same orbit do not follow the same orbital path. They are both equidistance from the nucleus, though, so they are in the same shell.

Q1: What force holds all the parts of an atom together?

Answer: It is the **electromagnetic force** of attraction between the positive protons in the nucleus and the negative electrons orbiting around the nucleus that holds the atom together.



1.3: Atomic Number

All elements are **arranged** in the periodic table of the elements in order according to their atomic number.
It is **used to IDENTIFY the element from the Periodic Table**.
All known elements can be found on the periodic table.
Elements contain one or more of the **same** types of atoms!
It can be used **like** a social security number for people.

The atomic number **equals** the number of protons in the nucleus, which is the **same** as the number of electrons in an electrically balanced (neutral) atom.
∴ The **atomic number is the number of PROTONS in the atoms of an element**.

For example, hydrogen has an atomic number of 1 and helium has an atomic number of 2.

Periodic table

Group	1	2	3		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Alkali metals	Alkaline earth metals														Pnicto-gens	Chalco-gens	Halogens	Noble gases
Period 1	Hydro-gen 1 H																		Helium 2 He
2	Lithium 3 Li	Beryl-lium 4 Be												Boron 5 B	Carbon 6 C	Nitrogen 7 N	Oxygen 8 O	Fluorine 9 F	Neon 10 Ne
3	Sodium 11 Na	Magne-sium 12 Mg												Alumin-ium 13 Al	Silicon 14 Si	Phos-phorus 15 P	Sulfur 16 S	Chlorine 17 Cl	Argon 18 Ar
4	Potas-sium 19 K	Calcium 20 Ca	Scan-dium 21 Sc		Titanium 22 Ti	Vana-dium 23 V	Chrom-ium 24 Cr	Manga-nese 25 Mn	Iron 26 Fe	Cobalt 27 Co	Nickel 28 Ni	Copper 29 Cu	Zinc 30 Zn	Gallium 31 Ga	Germa-nium 32 Ge	Arsenic 33 As	Selenium 34 Se	Bromine 35 Br	Krypton 36 Kr
5	Rubid-ium 37 Rb	Stront-ium 38 Sr	Yttrium 39 Y		Zirco-nium 40 Zr	Niobium 41 Nb	Molyb-denum 42 Mo	Tech-netium 43 Tc	Ruthe-nium 44 Ru	Rhodium 45 Rh	Pallad-ium 46 Pd	Silver 47 Ag	Cad-mium 48 Cd	Indium 49 In	Tin 50 Sn	Anti-mony 51 Sb	Tellur-ium 52 Te	Iodine 53 I	Xenon 54 Xe
6	Caesium 55 Cs	Barium 56 Ba	Lan-thanum 57 La	*	Hafnium 72 Hf	Tantalum 73 Ta	Tungsten 74 W	Rhenium 75 Re	Osmium 76 Os	Iridium 77 Ir	Platinum 78 Pt	Gold 79 Au	Mercury 80 Hg	Thallium 81 Tl	Lead 82 Pb	Bismuth 83 Bi	Polonium 84 Po	Astatine 85 At	Radon 86 Rn
7	Francium 87 Fr	Radium 88 Ra	Actinium 89 Ac	**	Ruther-fordium 104 Rf	Dubnium 105 Db	Sea-borgium 106 Sg	Bohrium 107 Bh	Hassium 108 Hs	Meit-nerium 109 Mt	Darm-stadtium 110 Ds	Roent-genium 111 Rg	Coper-nicium 112 Cn	Nihon-ium 113 Nh	Flerov-ium 114 Fl	Moscov-ium 115 Mc	Liver-morium 116 Lv	Tenness-ine 117 Ts	Oga-nesson 118 Og
				*	Cerium 58 Ce	Praseo-dymium 59 Pr	Neo-dymium 60 Nd	Prome-thium 61 Pm	Sama-rium 62 Sm	Europ-ium 63 Eu	Gadolin-ium 64 Gd	Terbium 65 Tb	Dyspro-sium 66 Dy	Holmium 67 Ho	Erbium 68 Er	Thulium 69 Tm	Ytter-bium 70 Yb	Lutetium 71 Lu	
				**	Thorium 90 Th	Protac-tinium 91 Pa	Uranium 92 U	Neptu-nium 93 Np	Pluto-nium 94 Pu	Ameri-cium 95 Am	Curium 96 Cm	Berkel-ium 97 Bk	Califor-nium 98 Cf	Einstei-nium 99 Es	Fermium 100 Fm	Mende-levium 101 Md	Nobel-ium 102 No	Lawren-cium 103 Lr	

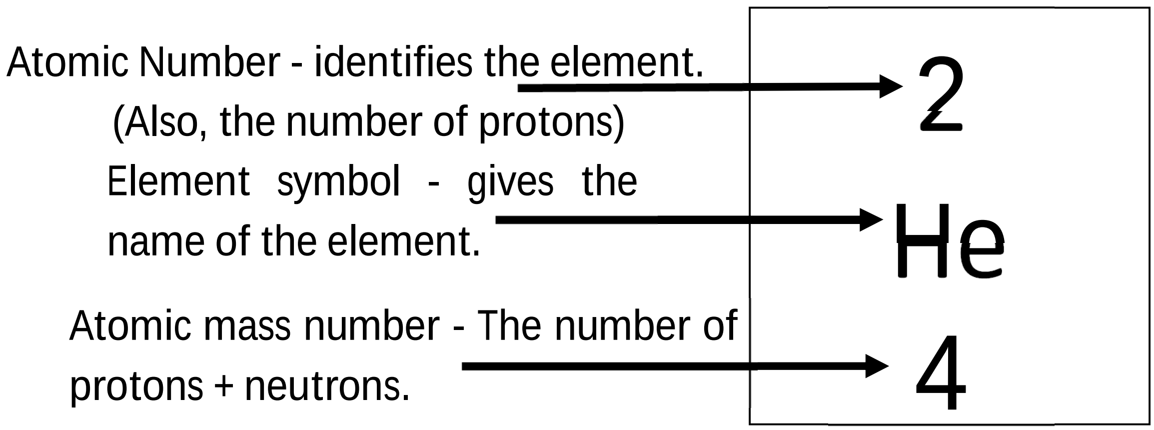
1.4: Atomic Mass Number

The **atomic mass number** includes the number of protons and neutrons, since they are the two largest particles in the atom.

∴ **Atomic Mass Number** = **protons** + **neutrons**.

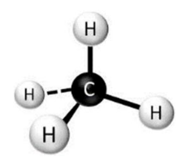
Since they are both located in the nucleus, the mass of the atom is located in the nucleus.

Example of using the Periodic Table:



1.5: Compounds

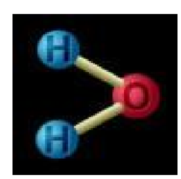
Compounds contain **more than one type of atom**!



Example of organic compound:

A compound with carbon and hydrogen atoms:

Methane (natural gas) – CH_4 (1 atom of carbon and four atoms of hydrogen).



Example of inorganic compound:

A compound without carbon and hydrogen atoms:

Water – H_2O (2 atoms of hydrogen and one atom of oxygen).

1.6: Ions

- An ion **is an atom or group of atoms with a positive or negative charge**!
- A **particle with a neutral charge** has the same number of protons and electrons.
- An **ion** does not have the same number of electrons and protons.

Examples of ions:

- H^+ - A hydrogen atom that is missing one electron. The atom has one more proton than electron, and must have a positive charge.
- CO_3^{2-} - Carbonate has two more electrons than protons.

H.W (Home Work): Q2: TRUE/FALSE QUIZ

1. An atom is the smallest particle in an element.
2. An electron is a negatively charged particle.
3. An atom is made up of electrons, protons, and neutrons.
4. Electrons are part of the nucleus of an atom.

H.W: Q3:

1. Every known element has
   (a) the same type of atoms (b) the same number of atoms
   (c) a unique type of atom (d) several different types of atoms
2. An atom consists of
   (a) one nucleus and only one electron (b) one nucleus and one or more electrons
   (c) protons, electrons, and neutrons (d) answers (b) and (c)
3. The nucleus of an atom is made up of
   (a) protons and neutrons (b) electrons
   (c) electrons and protons (d) electrons and neutrons

H.W: Q4: If the atomic number of a neutral atom is 6, how many electrons does the atom have? How many protons?

Solution:

1.7: Atomic and Electron Theories

To **understand** how transistors and other semiconductors work, you should have a good knowledge of **atomic and electron theories**. The following is a review of their principles. As you know, **all matter** is composed **of compounds or elements**.

The **elements** are the basic materials found in nature. When elements are combined to form a new material, we have a **compound**.

The **smallest particle that a compound can be reduced to and still retain its properties is a molecule**.

The **smallest particle that an element can be reduced to and still retain its properties is called an atom**.

When elements are combined to form compounds, the atoms of the elements join to form the **compound molecules**.

There are thousands of compounds, but there are only 118 elements, from which all matter is made. The elements are listed in the table with their atomic number called Periodic Table.

1.8: Atomic Particles

Although the atoms of the different elements have different properties, they all contain the same **subatomic** particles. There are a number of different subatomic particles, but only three of these are of interest in basic electronics: **proton, electron**, and **neutron**. The only way that an atom of one element differs from the atom of another element is in the **number** of subatomic particles that it contains. You will learn more about this later.

The protons and neutrons are contained in the center, or **nucleus** of the atom, and the electrons **orbit** around the nucleus. Proton is small but very heavy; it is difficult to dislodge from the nucleus. **Electron is smaller than the proton**. It is about **1836** times lighter and is easy to move.

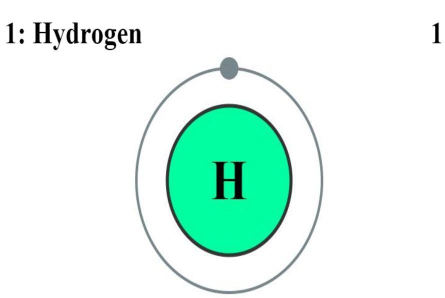
Electrons and protons are the particles that have the electrical properties. **Electron** has a **negative** electrical charge, and the **proton** has a **positive** electrical charge. These charges are **equal** and **opposite**. The law of electrical charges states that particles with **like** charges **repel** each other, and those with **unlike** charges **attract** each other. This is what keeps the electrons in orbit. The nucleus of the atom contains the positive protons, and so has a positive charge that attracts the negative electrons. The **centrifugal force** of the orbiting electrons counteracts the attraction of the nucleus to keep the electrons orbiting. Since electrons have like charges, they repel each other, and cause themselves to be spaced **equidistant** from one another.

Neutrons have no electrical charge; they are **neutral**. They are sometimes thought of as protons and electrons combined, but they are actually different particles. Usually, atoms have the same number of electrons and protons, and so they are electrically neutral. **If an atom does have more electrons, it is called a negative ion. If it has more protons, it is called a positive ion**.

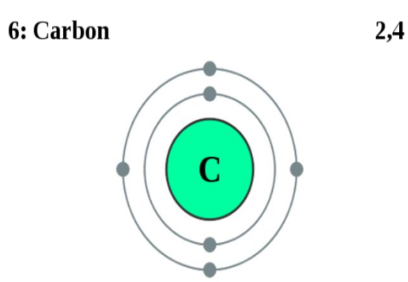
1.9: Orbital Shells

Actually, what differentiates an atom of one element from an atom of another element is the number of protons the atom has in its nucleus. This is what the **atomic number** refers to. **And since a neutral atom has the same number of electrons as protons**, an atom with 29 **protons** should have 29 **electrons** orbiting around its nucleus.

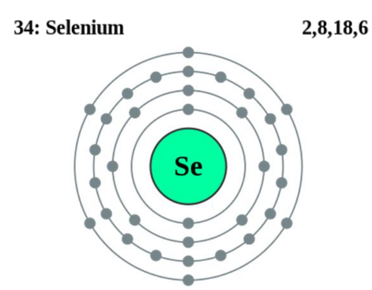
These electrons orbit in groups called shells. Actually, each electron has its own individual orbit, but certain orbits are grouped together to produce what is called a shell. For convenience, all the electrons on one shell are shown on diagrams as though they follow the same orbit.



Hydrogen atom has one Shell

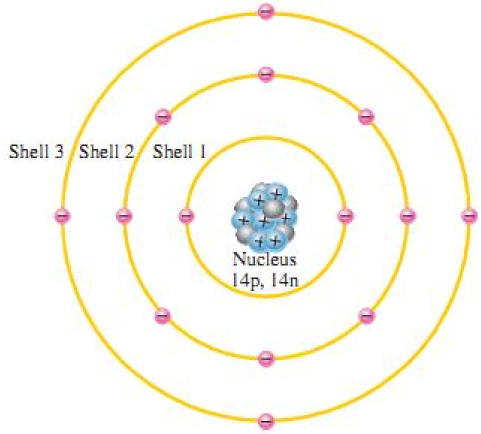


Carbon atom has two Shells



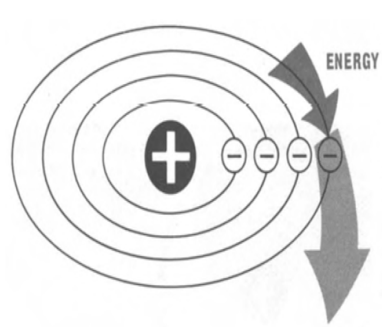
Selenium atom has four Shells

In an atom, the orbits are grouped into energy levels known as **shells**.
A given **atom** has **a fixed number of shells**.
Each **shell** has **a fixed maximum number of electrons**.
The shells (energy levels) are designated 1, 2, 3, and so on, with 1 being closest to the nucleus.
The **Bohr model of the silicon atom** is shown in this figure. Notice that there are 14 electrons and 14 each of protons and neutrons in the nucleus.



1.10: Energy Levels

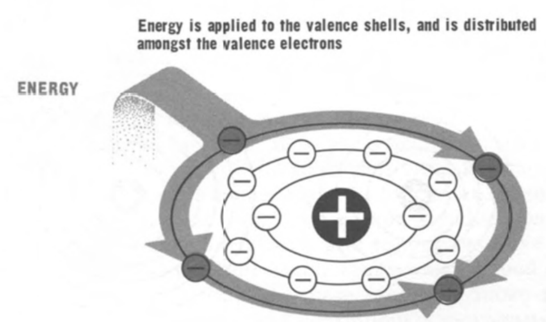
Although every electron has the **same negative charge**.
Not all electrons have the **same energy levels**.
Electrons that orbit **close** to the nucleus have **less energy** than those that orbit farther away. The **farther** electron orbit from the nucleus, the **grater** energy it contains.
Actually, the energy contained by the electron determines how far it will orbit. Therefore, if we could add energy to an electron in an inner orbit, we can move it out of that orbit to a higher orbit.
And, if enough energy is added to a valence electron, it can be moved out of its orbit; and since there is no higher orbit, the **electron will be freed from its atom**.



If enough energy is added to a valence electron, it will move out of the atom.

For the sake of simplicity, all the inner electrons are not shown in the figure.

When energy is applied to an atom, by heat or voltage or by other ways, the shell that first receives the energy is the valence shell. Therefore, valence electrons are the ones most easily removed from an atom. This is easy to understand when you consider that valence electrons are also farthest from the attraction of the nucleus, and so are easier to set free.



1.11: The Maximum Number of Electrons in Each Shell

The **maximum number of electrons (N_e)** that can exist in each shell of an atom is a fact of nature and can be calculated by the formula, $N_e = 2n^2$. Where *n* is the number of the shell.

For all of the known elements;

- There can be up to **seven shells** in an atom.
- Each shell can only hold a certain **number of electrons** in orbit.
- The **first shell**, closest to the nucleus, cannot hold more than **2 electrons**.
  For inner most shell the number of electrons is equal to:
  $$N_e = 2(1)^2 = 2 \text{ electrons}$$
- The second shell cannot hold more than 8 electrons; the third no more than 18.
  $$N_e = 2(2)^2 = 8 \text{ electrons} \quad \text{and} \quad N_e = 2(3)^2 = 18 \text{ electrons}$$
- The fourth, no more than 32; and so on.
  $$N_e = 2(4)^2 = 32 \text{ electrons} \quad \text{and} \quad N_e = 2(n)^2 \text{ electrons}$$

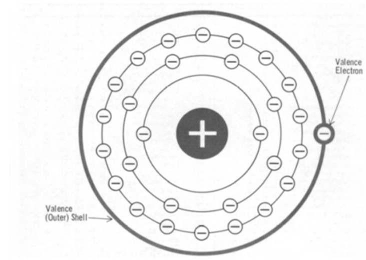
H.W: Q5: What is the maximum number of electrons that can exist in the 3rd shell of an atom?

Solution:

1.12: The Valence Shell

The outer most shell of an atom is called the valence shell. The word valence is a Greek word meaning **hook**, it came into use when an old chemical theory considered that atom had hooks that held them to other atoms. Since we now know that it is the electrons in the outermost shell that enable atoms to join, the word valence was carried over as the name of the outer shell. **Electrons that orbit in the outer shell are also known as valence electrons**.

NOTE:
The outer shell of any atom cannot hold any more than 8 electrons. This rule is important because it shows which atoms make up good conductors, Insulators, or semiconductors, as you will soon learn.



1.13: Electron Configuration Table

Element	K	L	M	N	O	P	Q
	1	2	3	4	5	6	7
	s^2	s p^6	s p d^{10}	s p d f^{14}	s p d f	s p d f	s

Example 1.1: Using the atomic number from the periodic table, describe a Nitrogen (N^7) atom using an electron configuration table.

Solution:

NOTATION	EXPLANATION
$1s^2$	2 electrons in shell 1, orbital s
$2s^2$ $2p^3$	5 electrons in shell 2: 2 in orbital s, 3 in orbital p

Example 1.2: Using the atomic number from the periodic table, describe a silicon (Si) atom using an electron configuration table.

Solution:

NOTATION	EXPLANATION
$1s^2$	2 electrons in shell 1, orbital s
$2s^2$ $2p^6$	8 electrons in shell 2: 2 in orbital s, 6 in orbital p
$3s^2$ $3p^2$	4 electrons in shell 3: 2 in orbital s, 2 in orbital p

H.W: Q6: Develop an electron configuration table for the germanium (Ge) atom in the periodic table. **Solution:** Answers can be found at www.pearsonhighered.com/floyd.

1.14: Stable and Unstable Atoms

The tendency of an atom to give up its valence electrons depends on **chemical stability**. When an atom is stable, it resists giving up electrons, and when it is unstable, it tends to give up electrons.

The **level of stability** is determined by the number of valence electrons. Because the atom strives to have its outer or valence shell completely **filled**.

If an atoms valence shell is more than half filled, that atom tends to fill its shell. So, since **8** is the most electrons that can be held in the valence shell.

Elements with **5 or more valence electrons** make good ***insulator***, since they tend to take on rather than give up electrons.

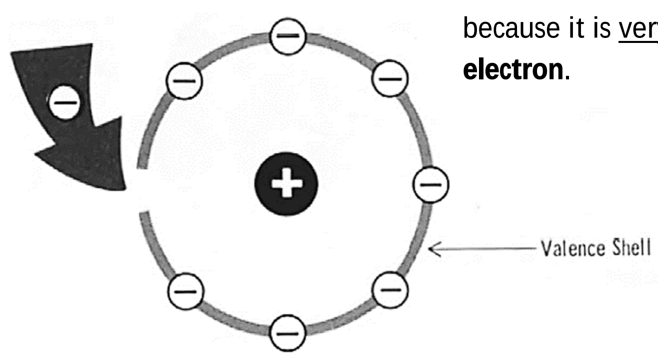
Atoms with **less than 4 valence electrons** tend to give up their electrons to empty the valence shell; this would allow the **next shell**, which is already filled, to be the outer most shell. These atoms make the best ***electrical conductors***.

An atom with **8 valence electrons is completely stable**, and will resist any sort of activity. These are the **inert gases** (atomic numbers 2, 10, 18, 36, 54 and 86), and are the ***best insulators***.

Atoms with **only 1 valence electrons** are the ***best conductors***.

As you probably have gathered by now, ***semiconductors*** **have 4 valence electrons**, and are neither *conductors* nor good *insulators*.

These atoms make ***good insulators*** because it is very difficult to **free an electron**.



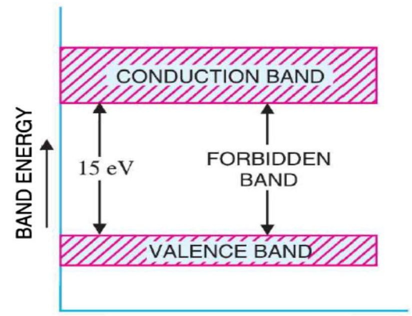
An atom that is ***more than half filled***, but has **less than 8 electrons**, tries to become stable by ***filling*** its **valance shell**.

1.15: Energy Band Theory

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**. When atoms combine to form **substances**, the outermost shells, subshells, and orbitals merge, providing a greater number of available energy levels for electrons to assume. When large numbers of atoms are close to each other, these available energy levels form a nearly **continuous band** wherein electrons may move.

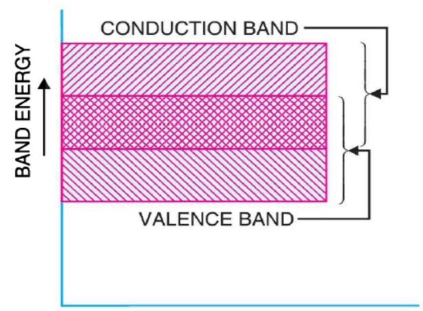
It is crucial to the conduction process is **whether or not** there are **electrons** in the **conduction band**.

In insulators the **electrons** in the valence band are separated by a **large gap** from the conduction band.



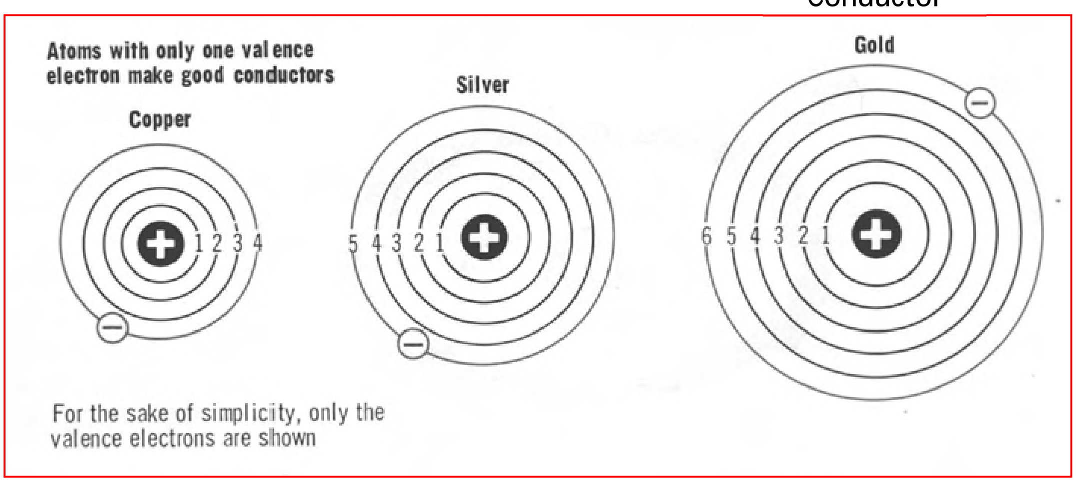
Insulator

In conductors like **metals** the valence band overlaps the conduction band.
In terms of the band theory of solids, **metals** are unique as **good conductors of electricity**.



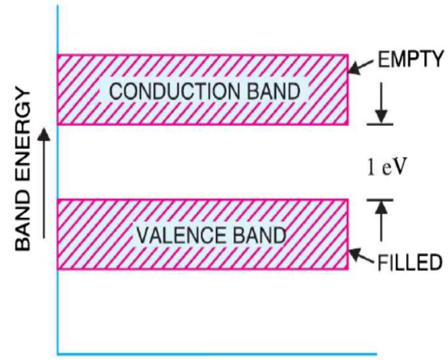
Conductor

Think about this diagram!!!



H.W: Q7: Write the Name three of best conductive materials.
Solution:

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**. (Doping procedure will be discussed in chapter 2 in details).



Semiconductor

For **intrinsic semiconductors** like ***silicon*** and ***germanium***, the Fermi level is essentially halfway between the **valence** and **conduction bands**.

An important parameter in the band theory is the **Fermi level**, the top of the available electron energy levels at **low temperatures**.
The **position** of the Fermi level with the relation to the conduction band is a crucial factor in determining **electrical properties**.

Although **no** conduction occurs at 0 K, at higher temperatures a finite number of electrons can reach the conduction band and provide some current. In doped semiconductors, extra energy levels are added.
The increase in **conductivity with temperature** can be **modeled** in terms of the **Fermi function**, which allows one to calculate the **population of the conduction band**.

H.W: Q8: How many valance electrons does a semiconductor have?
Solution:

H.W: Q9: What is the basic difference between conductors and insulators?
Solution:

H.W: Q10: How many valance electrons does a conductor such as copper have?
Solution:

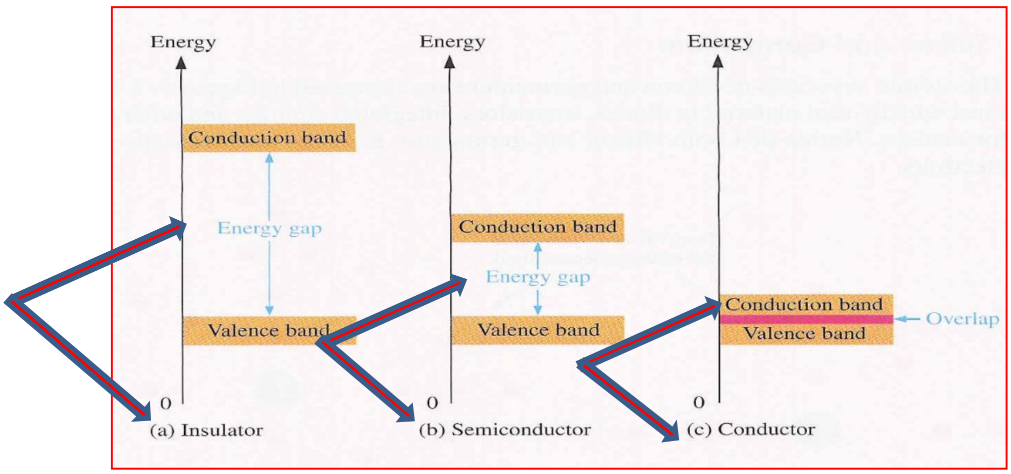
H.W: Q11: What is the most widely used semiconductive material?
Solution:

H.W: Q12: A certain atom has four valence electrons. What type of atom is it?
Solution:

1.16: Energy Band Diagrams

Since it is easy to force a valence electron from an atom of a ***good conductor***, it takes only little energy to do this.
And, similarly since it is difficult to free an electron from an atom of an ***insulator***, it takes more energy to do this.
Semiconductors require less energy than insulators, but more than conductors.

Actually, the energy required to release **electrons** in the three different types of material falls in to a certain band called the **conduction band**, and can be shown on energy band diagrams to indicate how easy or difficult it is to free an electron to start **electrical conduction**.



Energy diagrams for the three types of materials

- The **valence band** in each diagram stands for the energy level of the valence electron.
- The **conduction band** stands for the energy level that must be reached for the valence electrons to be freed from the valence shell.
- The **forbidden band**, *when it exists*, is the **energy gap** between the other two bands. If only enough energy is added to a valence electron so that its total energy lies in the forbidden band, the valence electron will not be freed; it will stay in the valence shell.
  - The diagrams show ***insulators*** have a **high forbidden band**.
  - ***Semiconductors*** have a thinner forbidden band.
  - And, ***conductors*** have no forbidden band.
- The **valence and conduction bands** in ***good conductors*** overlap, so that valence electrons in these materials move randomly from one energy level to the next, and continuedly move out of the valence shell of one atom in to that of another; that is why it is **very easy to cause current flow** in *conductors*.

H.W: Q2+: TRUE/FALSE QUIZ

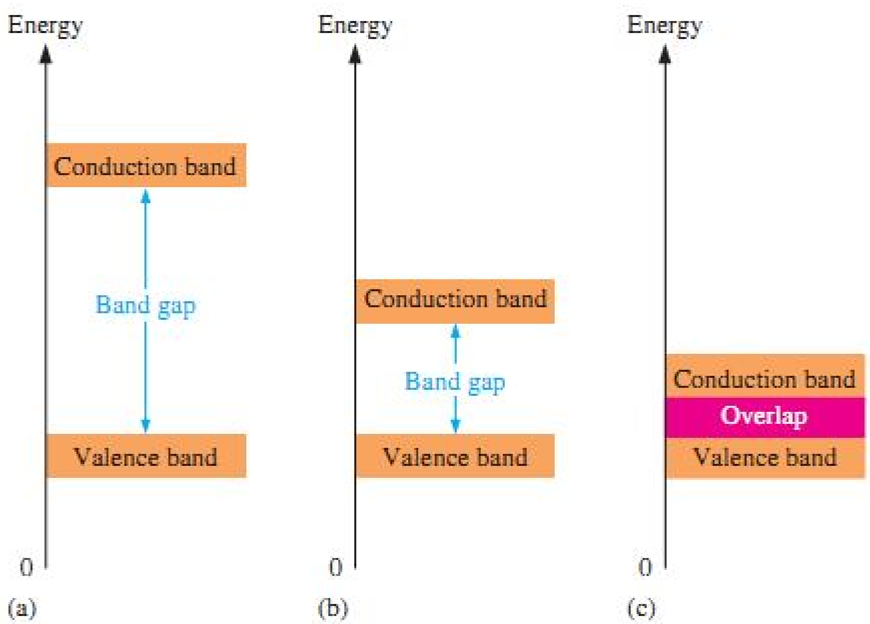
5. Valence electrons exist in the outer shell of an atom.
6. Silicon is a conductive material.

H.W: Q3+:

4. Valence electrons are
   - (a) in the closest orbit to the nucleus
   - (b) in the most distant orbit from the nucleus
   - (c) in various orbits around the nucleus
   - (d) not associated with a particular atom
5. A positive ion is formed when
   - (a) a valence electron breaks away from the atom
   - (b) there are more holes than electrons in the outer orbit
   - (c) two atoms bond together
   - (d) an atom gains an extra valence electron
6. The most widely used semiconductive material in electronic devices is
   - (a) germanium (b) carbon (c) copper (d) silicon
7. The difference between an insulator and a semiconductor is
   - (a) a wider energy gap between the valence band and the conduction band
   - (b) the number of free electrons
   - (c) the atomic structure
   - (d) answers (a), (b), and (c)
8. The energy band in which free electrons exist is the
   - (a) first band (b) second band (c) conduction band (d) valence band
9. In a semiconductor crystal, the atoms are held together by
   - (a) the interaction of valence electrons
   - (b) forces of attraction
   - (c) covalent bonds
   - (d) answers (a), (b), and (c)
10. The atomic number of silicon is
    - (a) 8 (b) 2 (c) 4 (d) 14
11. The atomic number of germaniums is
    - (a) 8 (b) 2 (c) 4 (d) 32
12. The valence shell in a silicon atom has the number designation of
    - (a) 0 (A) (b) 1 (K) (c) 2 (L) (d) 3 (M)
13. Each atom in a silicon crystal has
    - (a) four valence electrons
    - (b) four conduction electrons
    - (c) eight valence electrons, four of its own and four shared
    - (d) no valence electrons because all are shared with other atoms

14. Which of the following are called valence electrons?
    (a) The electrons which are present inside the nucleus.
    (b) The electrons present in the outermost shell of an atom.
    (c) The electrons which have no electric charge.
    (d) The electrons present in the innermost shell of an atom.

H.W: Q13: For each of the energy diagrams in this Figure, determine the class of material based on relative comparisons.



Solution: