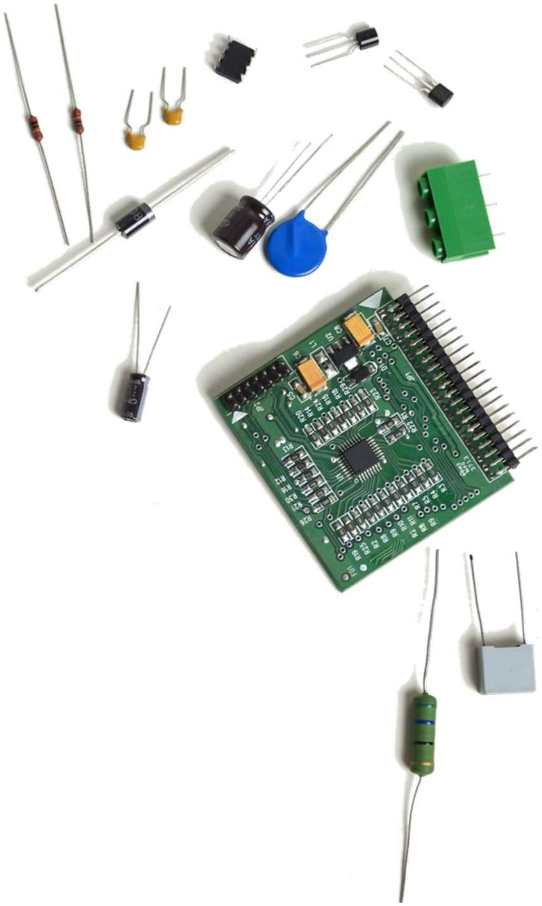
104010 : BASIC ELECTRONICS ENGINEERING



UNIT I
Introduction to Electronics

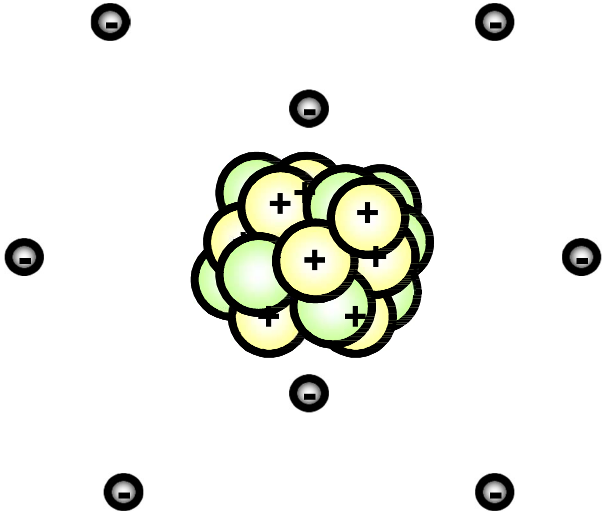
(Images taken from the internet)

Matter

- Anything that has mass and takes up space (volume)
  - Examples:
    - A brick has <u>mass</u> and <u>takes up space</u>
    - A desk has <u>mass</u> and <u>takes up space</u>
    - A pencil has <u>mass</u> and <u>takes up space</u>
    - Air has <u>mass</u> and <u>takes up space</u>

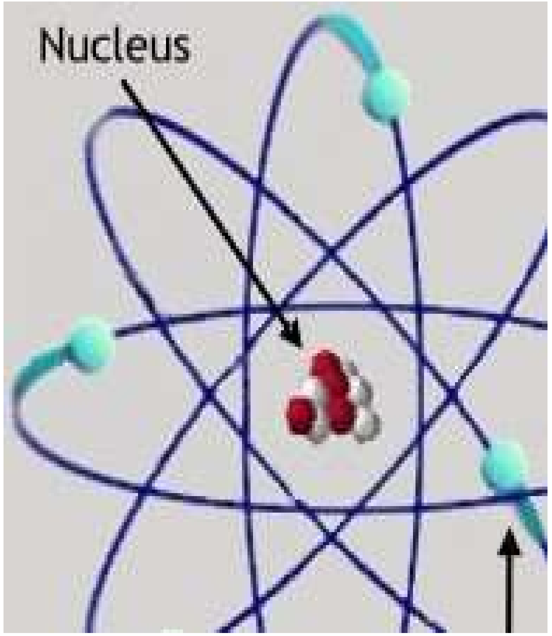
All of the above examples are considered matter because they have mass and take up space. Can you think of anything that would not be considered matter?

The Building Blocks of Matter: *Atoms*

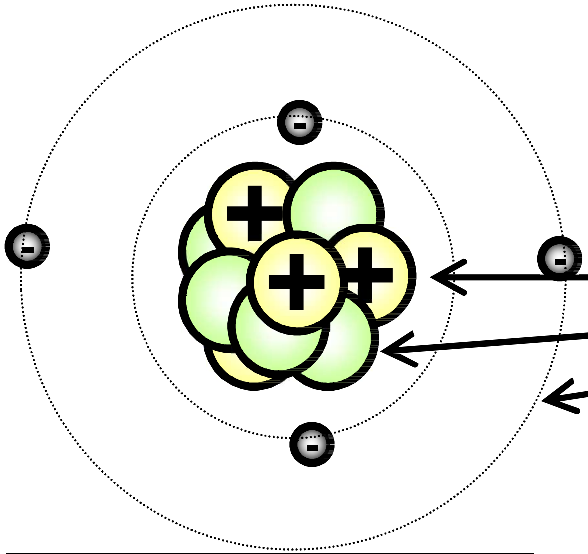


What is An Atom?

- The smallest unit of an element.
- Consists of a central nucleus surrounded by one or more electrons.



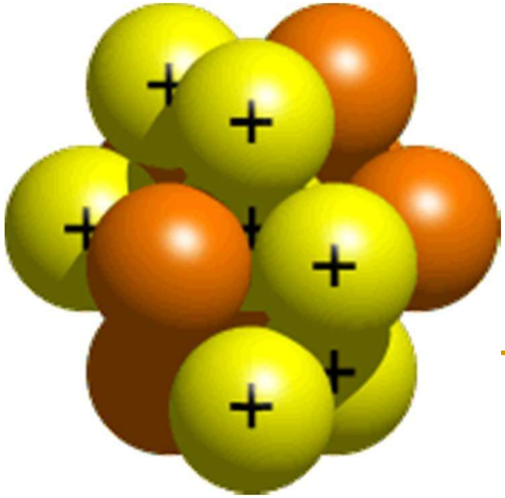
Atoms



- Smallest possible unit into which matter can be divided, while still maintaining its properties.
- Made up of:
  - protons
  - neutrons
  - electrons
- The solar system is commonly used as an analogy to describe the structure of an atom

For example, what is the smallest possible unit into which a long essay can be divided and still have some meaning?

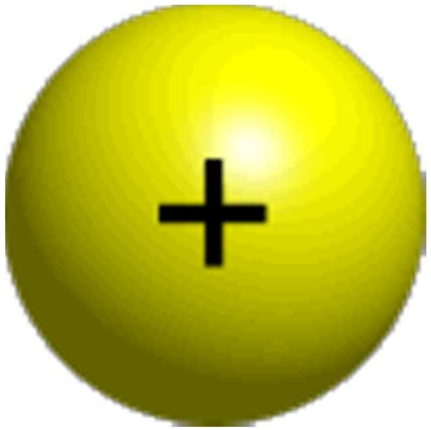
What is The Nucleus?



- The central part of an atom.
- Composed of protons and neutrons.
- Contains most of an atom's mass.

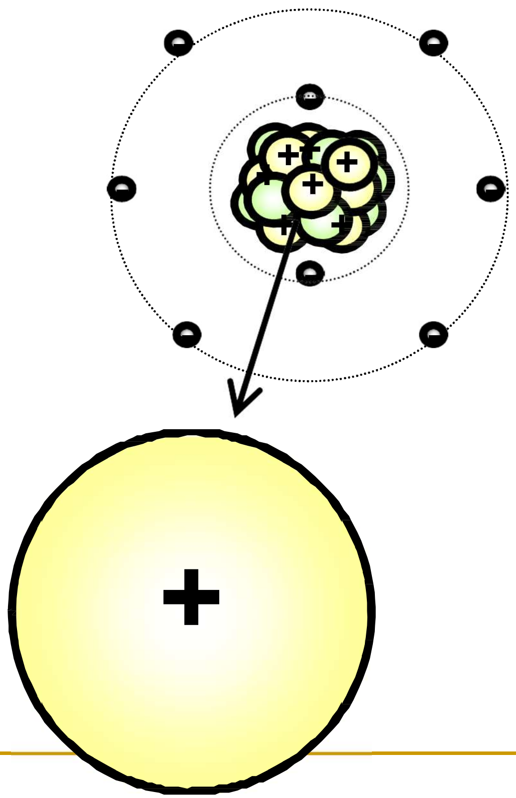
What is A Proton?

- Positively charged particle.
- Found within an atomic nucleus.

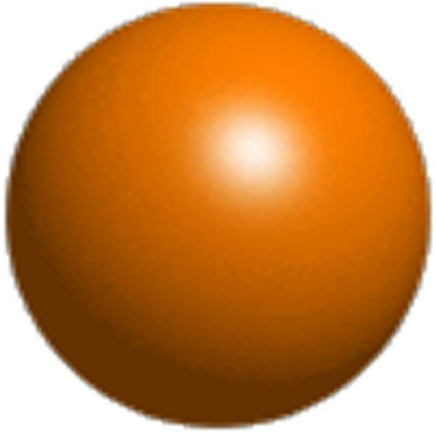


Protons (+)

- Positively charged particles
- Help make up the nucleus of the atom
- Help identify the atom (could be considered an atom's DNA)
- Equal to the atomic number of the atom
- Contribute to the atomic mass
- Equal to the number of electrons

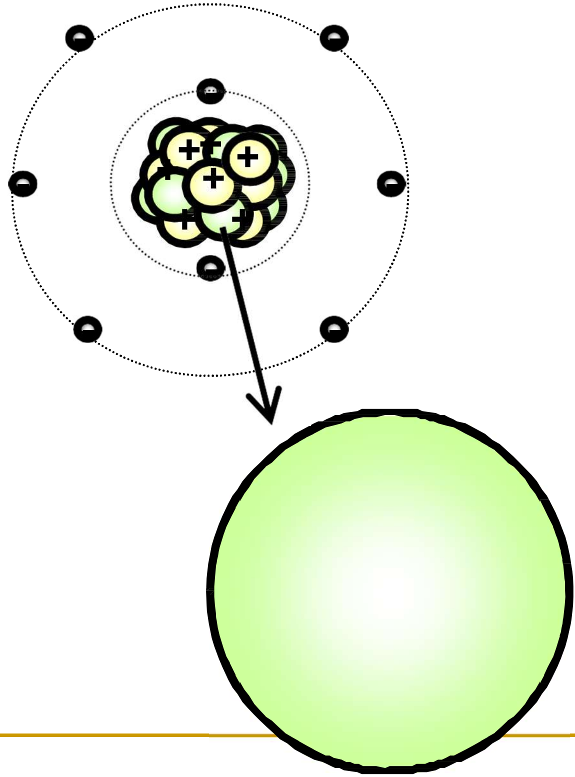


What is A Neutron?



- Uncharged particle.
- Found within an atomic nucleus.

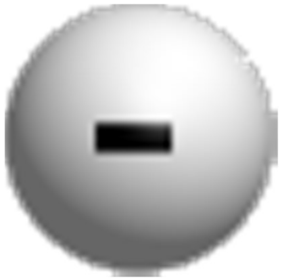
Neutrons



- Neutral particles; have no electric charge
- Help make up the nucleus of the atom
- Contribute to the atomic mass

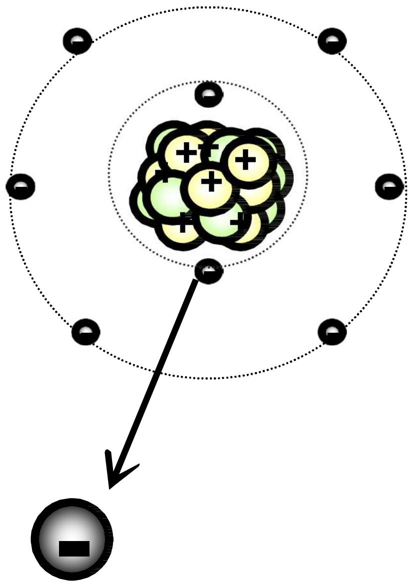
What is An Electron?

- Negatively charged particle.
- Located in shells that surround an atom's nucleus.



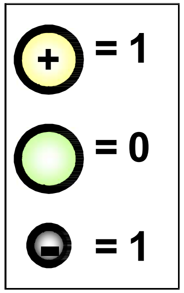
Electrons (-)

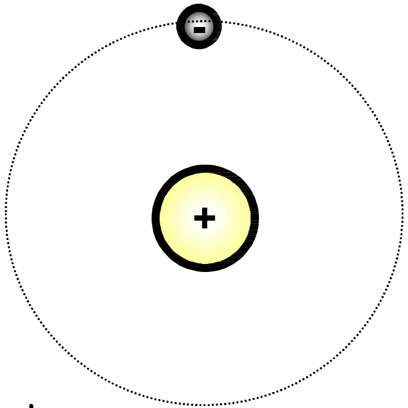
- Negatively charged particles
- Found outside the nucleus of the atom, in the electron orbits/levels; each orbit/level can hold a maximum number of electrons (1^{st} = 2, 2^{nd} = 8, 3^{rd} = 8 or 18, etc…)
- Move so rapidly around the nucleus that they create an electron cloud
- Mass is insignificant when compared to protons and neutrons
- Equal to the number of protons
- Involved in the formation of chemical bonds



Hydrogen (H) Atom

- Notice the one electron in the first orbital



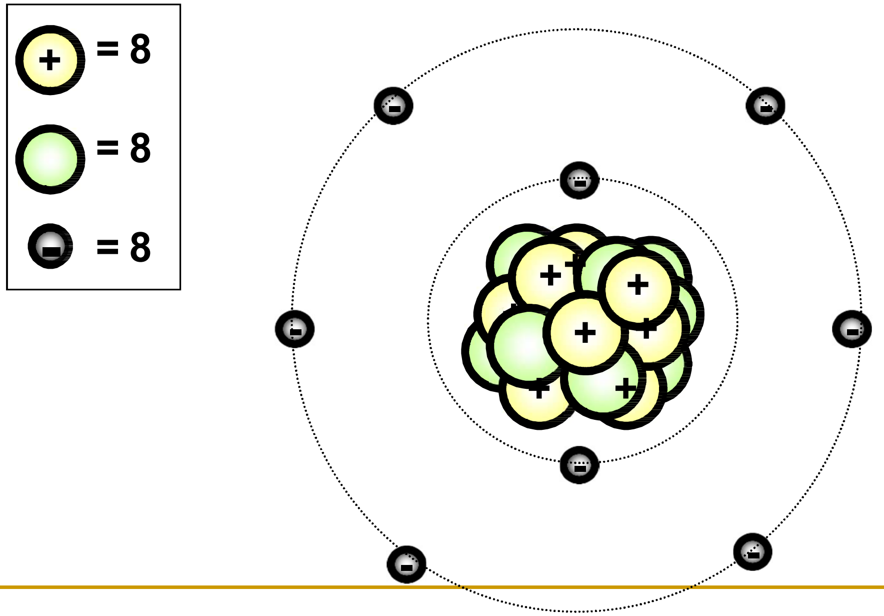


How many more electrons can fit in the 1st orbital/ level?

Even though there are no neutrons present, Hydrogen is still considered an atom

Oxygen (O) Atom

- Notice the two electrons in the first orbital/level and the six in the second



How many more electrons can fit in the 2nd orbital/ level?

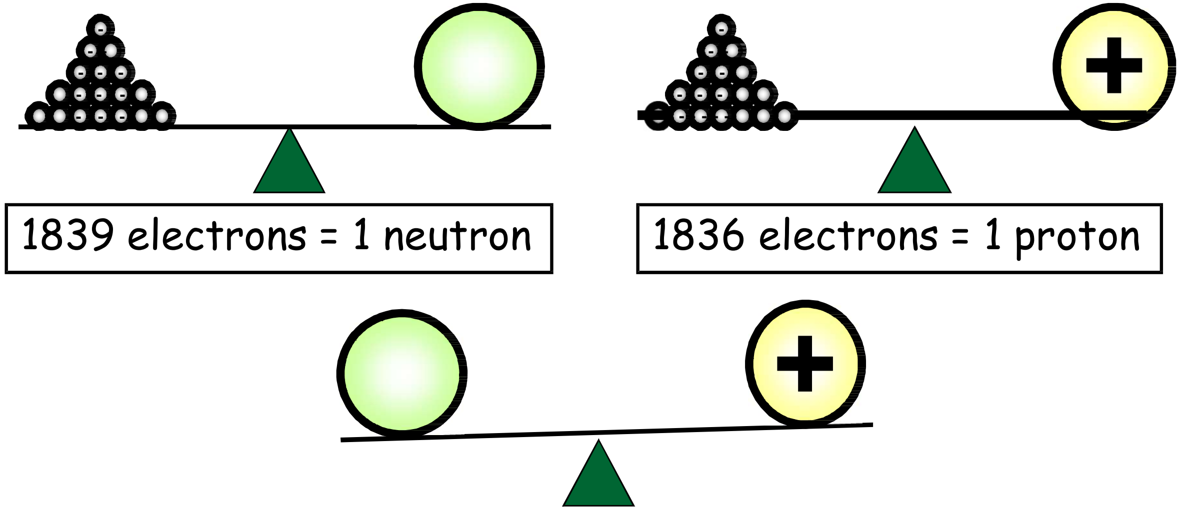
Sub-Atomic Particles

Weight Comparison

(protons, neutrons, electrons)

How do you think the mass of a neutron compares to that of a proton?

Neutron = 1.6749286 $\times 10^{-27}$ kg
Proton = 1.6726231 $\times 10^{-27}$ kg
Electron = 9.1093897 $\times 10^{-31}$ kg



1839 electrons = 1 neutron

1836 electrons = 1 proton

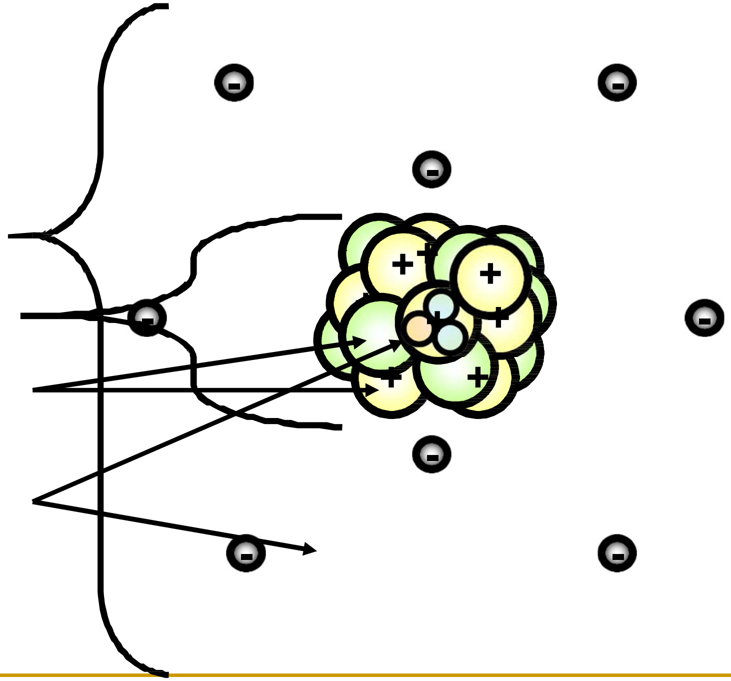
1 neutron ≈ 1 proton

Sub-atomic Particles

Size Comparison

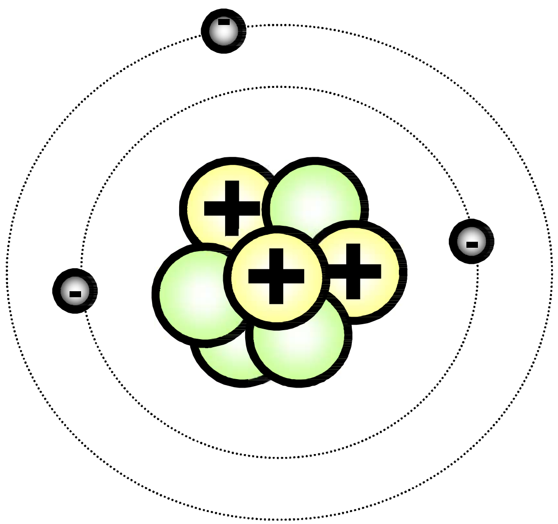
(protons, neutrons, electrons, & quarks)

	Size in atoms	Size in meters (m)
Atom	1	10^{-10}
Nucleus	$\frac{1}{10,000}$	10^{-14}
Proton or Neutron	$\frac{1}{100,000}$	10^{-15}
Electron or Quark	$\frac{1}{100,000,000}$	10^{-18} (at largest)



Atomic Number

- The number of protons in the nucleus of an atom

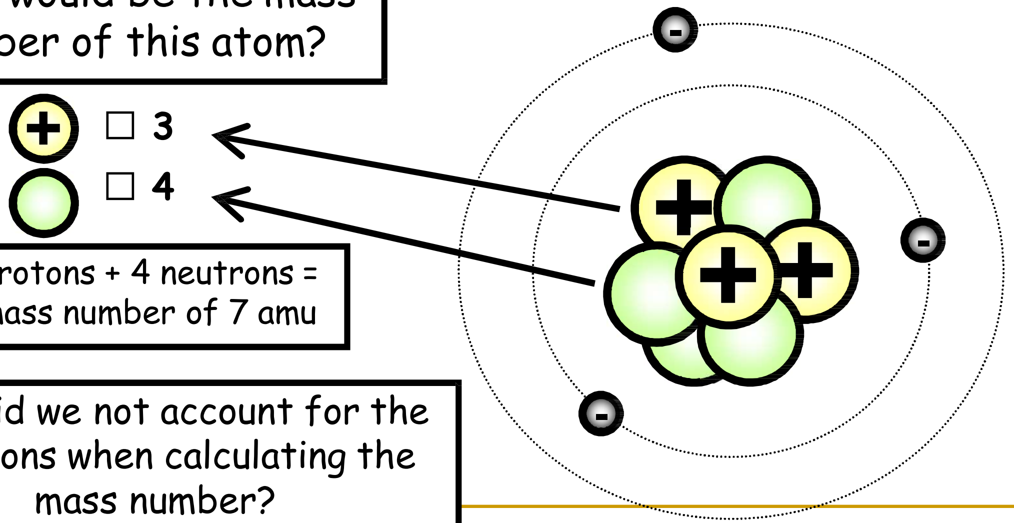


What would be the atomic number of this atom?

Mass Number

- The total number of protons and neutrons in an atom's nucleus
- Expressed in <u>A</u>tomic <u>M</u>ass <u>U</u>nits (amu)
  - Each proton or neutron has a mass of 1 amu

What would be the mass number of this atom?



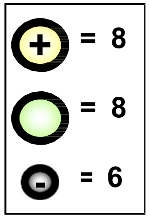
3 protons + 4 neutrons = a mass number of 7 amu

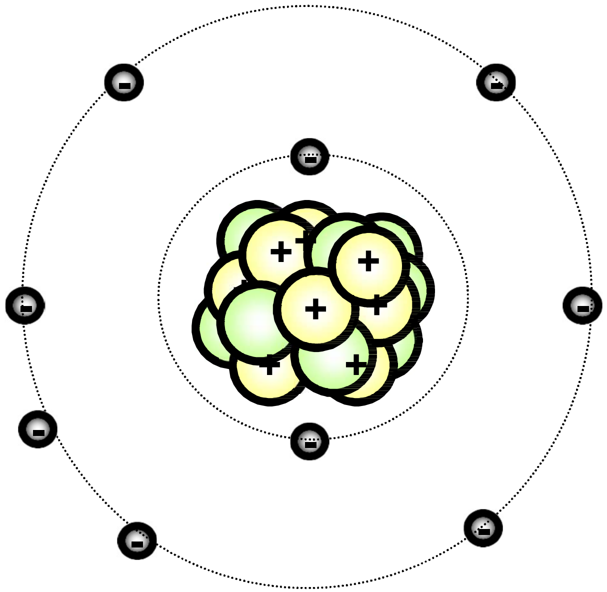
Why did we not account for the electrons when calculating the mass number?

Ion

- Charged particle that typically results from a loss or gain of electrons
- Two types:
  - <u>Anion</u> = negatively charged particle
  - <u>Cation</u> = positively charged particle

Currently, this atom of oxygen is neutral because it has an equal number of electrons (8) and protons (8).



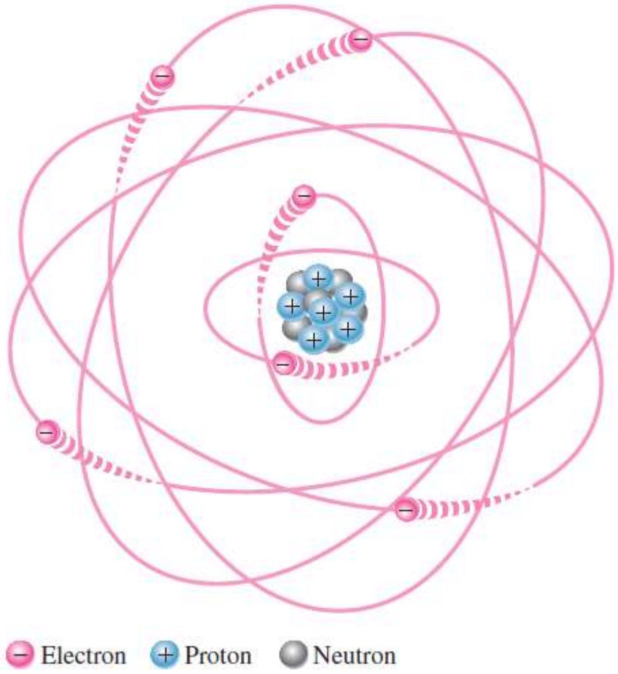


Now that this atom of oxygen just gained an electron, it is no longer neutral or an atom. It is now considered an ion (anion). This ion has more electrons (9) than protons (8).

Symbol = O

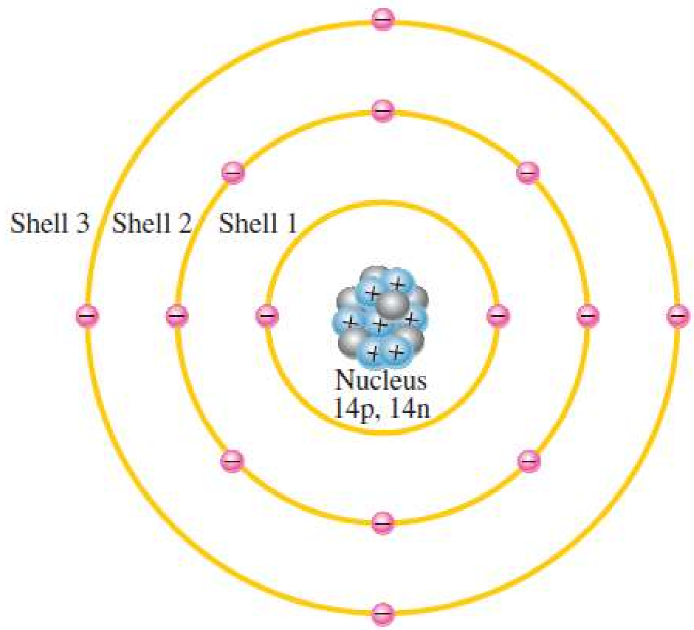
Bohr's Model of Atom

- The **nucleus** consists of positively charged particles called **protons** and uncharged particles called **neutrons.**
- The basic particles of negative charge are called **electrons**.
- Each type of atom has a certain number of electrons and protons that distinguishes it from the atoms of all other elements.



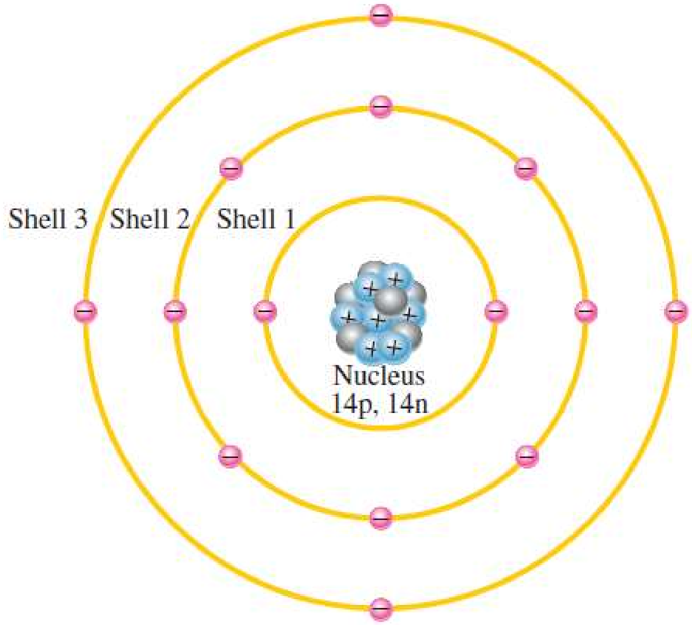
Electrons and Shells

- ***Energy Levels*** Electrons orbit the nucleus of an atom at certain distances from the nucleus.
- Electrons near the nucleus have less energy than those in more distant orbits.
- Only discrete (separate and distinct) values of electron energies exist within atomic structures.
- Electrons must orbit only at discrete distances from the nucleus.



Electrons and Shells

- Each discrete distance (**orbit**) from the nucleus corresponds to a certain energy level.
- 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.
- There are 14 electrons and 14 each of protons and neutrons in the nucleus in the figure.



Electrons and Shells

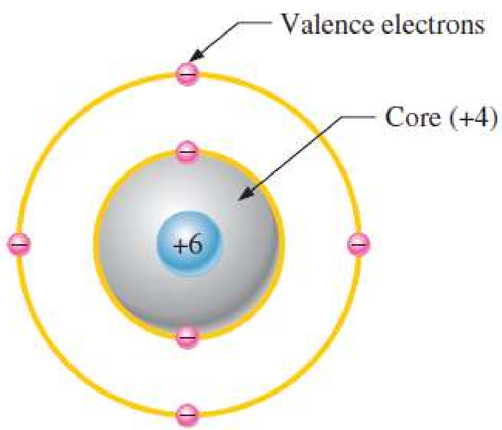
- The Maximum number of electrons in each shell : $2n^2$
- **Valence Electrons**
  - Electrons that are in orbits farther from the nucleus have higher energy and are less tightly bound to the atom than those closer to the nucleus.
  - This is because the force of attraction between the positively charged nucleus and the negatively charged electron decreases with increasing distance from the nucleus.
  - Electrons with the highest energy exist in the outermost shell of an atom and are relatively loosely bound to the atom.
  - This outermost shell is known as the **valence** shell and electrons in this shell are called *valence electrons.*
  - These valence electrons contribute to chemical reactions and bonding within the structure of a material and determine its electrical properties. When a valence electron gains sufficient energy from an external source, it can break free from its atom. This is the basis for conduction in materials.

Electrons and Shells

- An atom absorbs energy from a heat source or from light, electron's energy is raised.
- The valence electrons possess more energy and are more loosely bound to the atom.
- Easily jump to higher energy shells when external energy is absorbed by the atom.
- Valence electron acquires enough energy, called *ionization energy,* can actually escape from the outer shell and the atom's influence.
- The departure of a valence electron leaves a previously neutral atom with an excess of positive charge (more protons than electrons).
- The process of losing a valence electron is known as **ionization**, and the resulting positively charged atom is called a *positive ion.*
- The escaped valence electron is called a **free electron**.
- The reverse process :The atom that has acquired the extra electron is called a *negative ion*.

Materials in Electronics

- Valence and Core



Insulators

- An **insulator** is a material that does not conduct electrical current under normal conditions.
- Most good insulators are compounds rather than single-element materials and have very high resistivities. Valence electrons are tightly bound to the atoms; therefore, there are very few free electrons in an insulator.
- Examples of insulators are rubber, plastics, glass, mica, and quartz.

Conductors

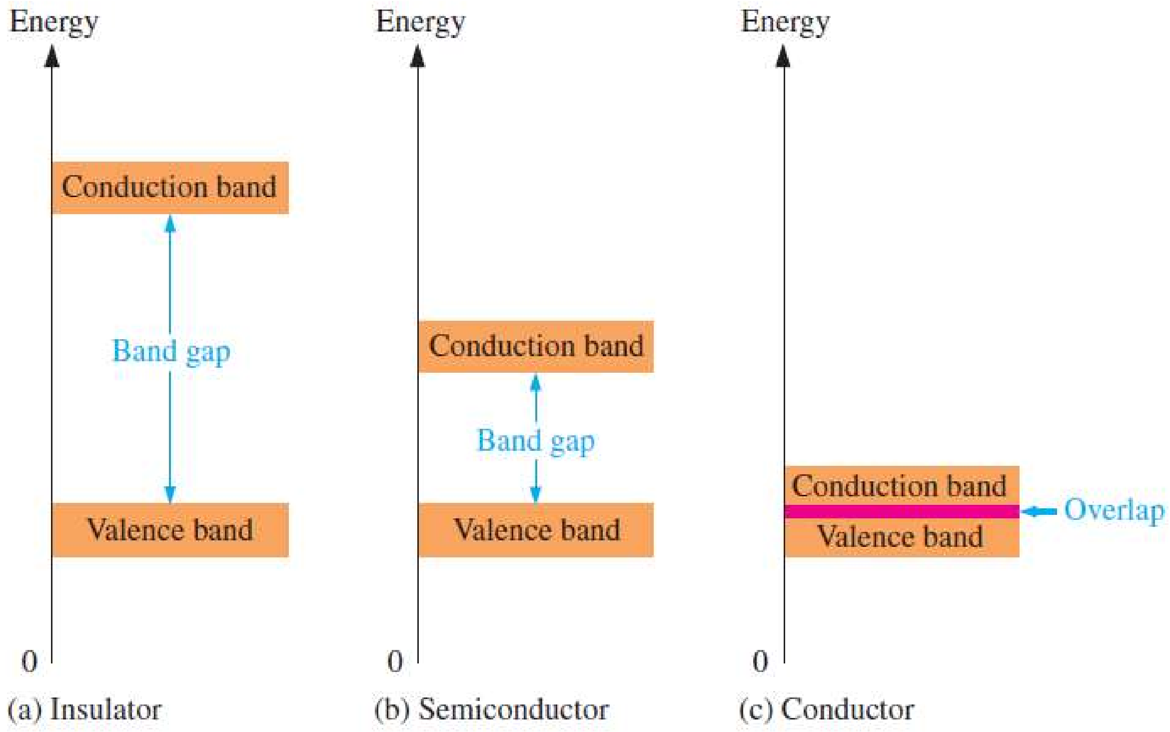
- A **conductor** is a material that easily conducts electrical current.
- Most metals are good conductors.
- The best conductors are single-element materials: copper (Cu), silver (Ag), gold (Au), and aluminum (Al), which are characterized by atoms Only one valence electron very loosely bound to the atom.
- These loosely bound valence electrons become free electrons. Therefore, in a conductive material the free electrons are valence electrons.

Activity

Semiconductors

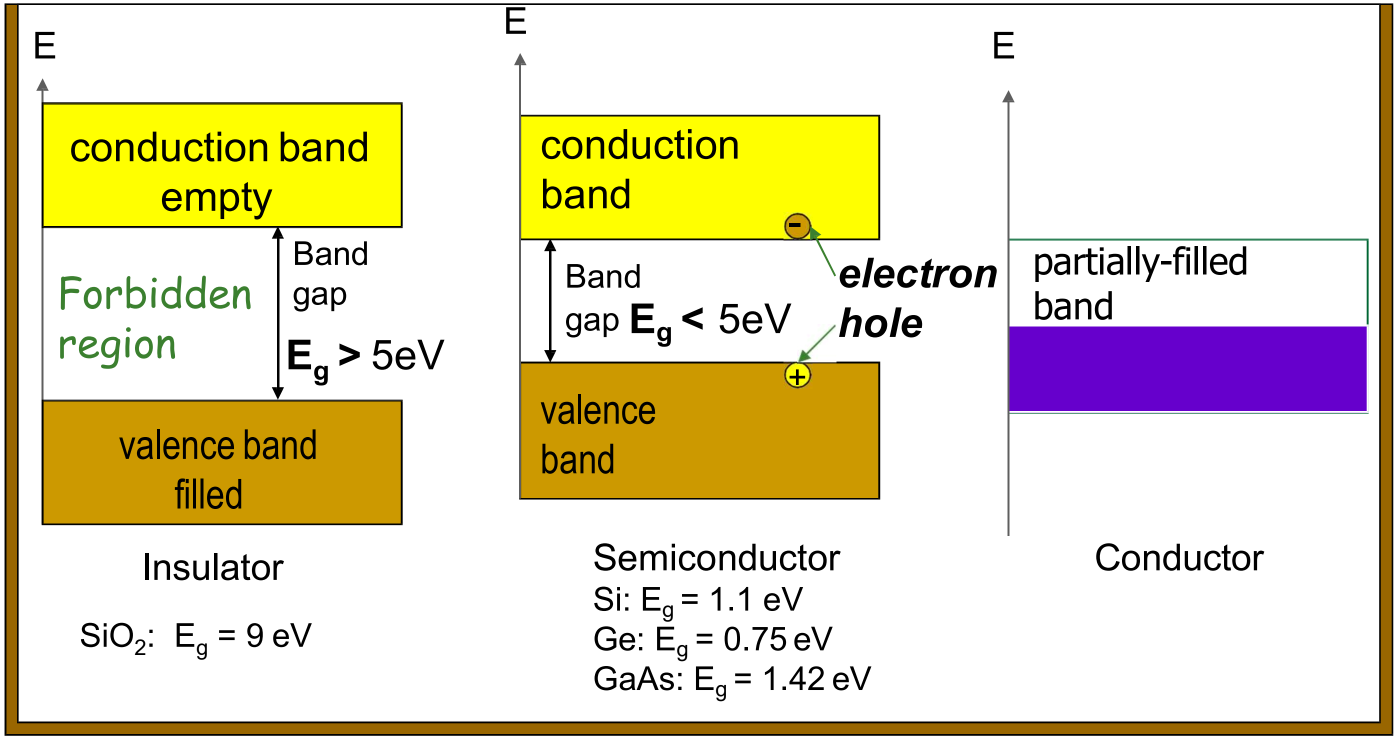
- A **semiconductor** is a material that is between conductors and insulators in its ability to conduct electrical current.
- A semiconductor in its pure (intrinsic) state is neither a good conductor nor a good insulator.
- Single-element semiconductors are antimony (Sb), arsenic (As), astatine (At), boron (B), polonium (Po), tellurium (Te), silicon (Si), and germanium (Ge).

Insulators, Conductors, Semiconductors

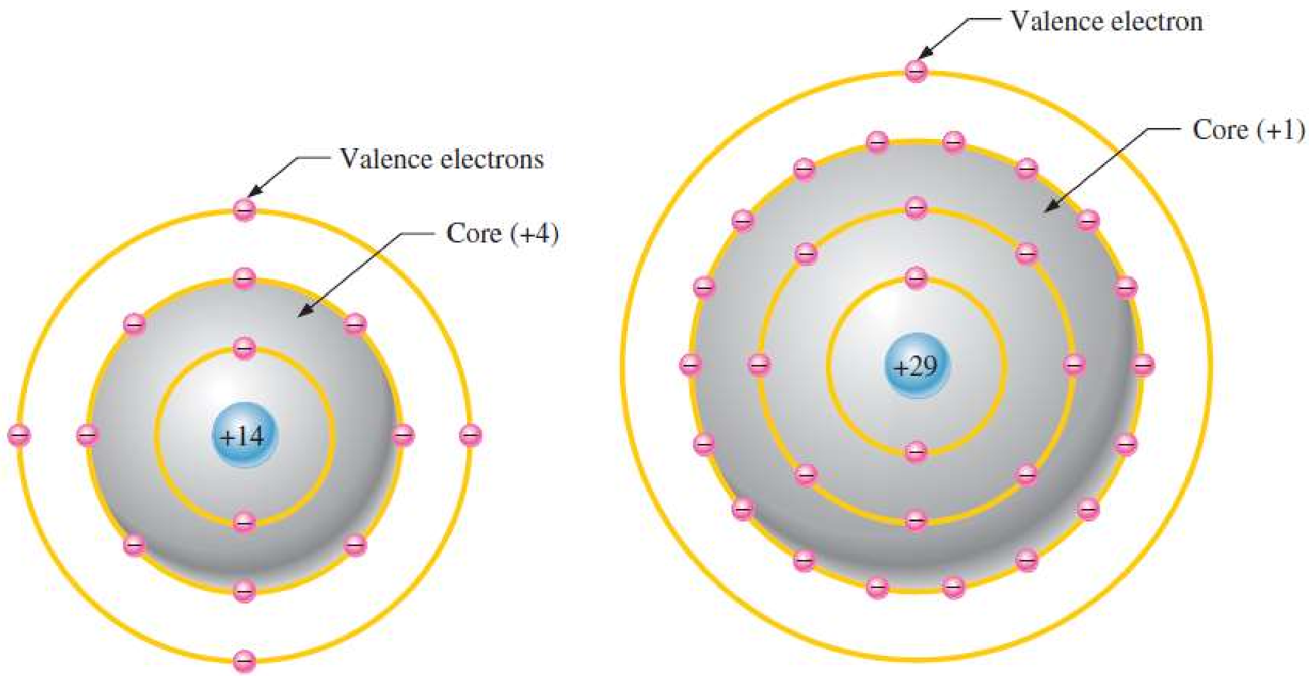


Insulators, Conductors, Semiconductors

from energy band structures



Conductors, Semiconductors

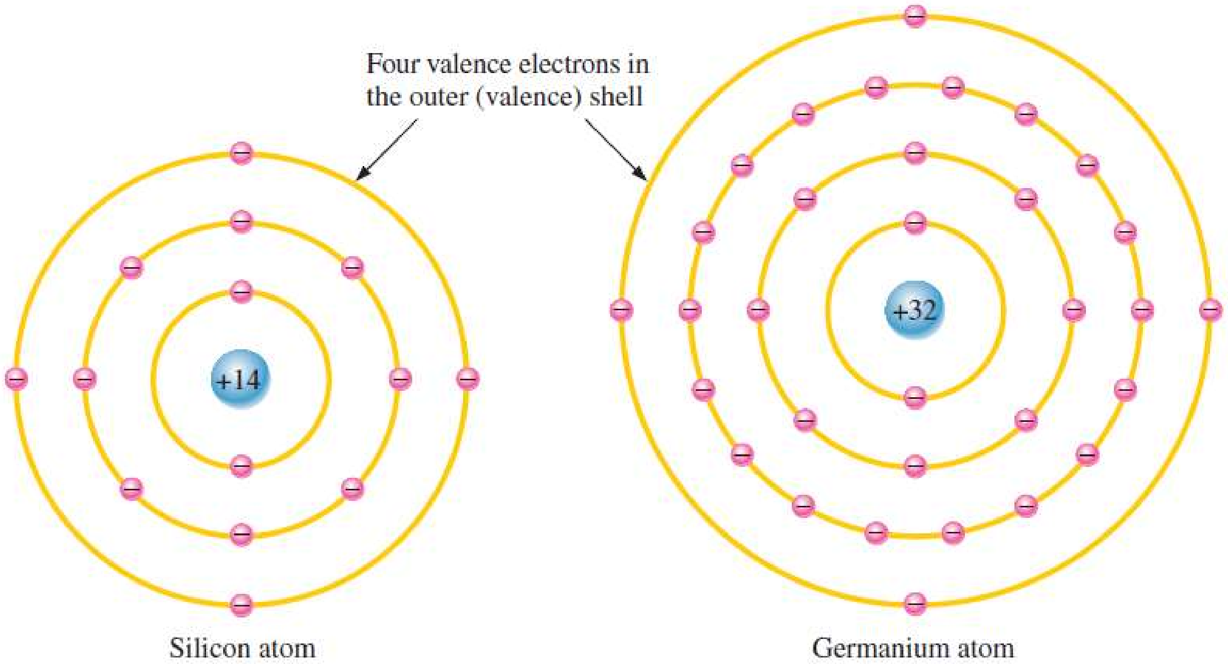


(a) Silicon atom (b) Copper atom

Conductors, Semiconductors

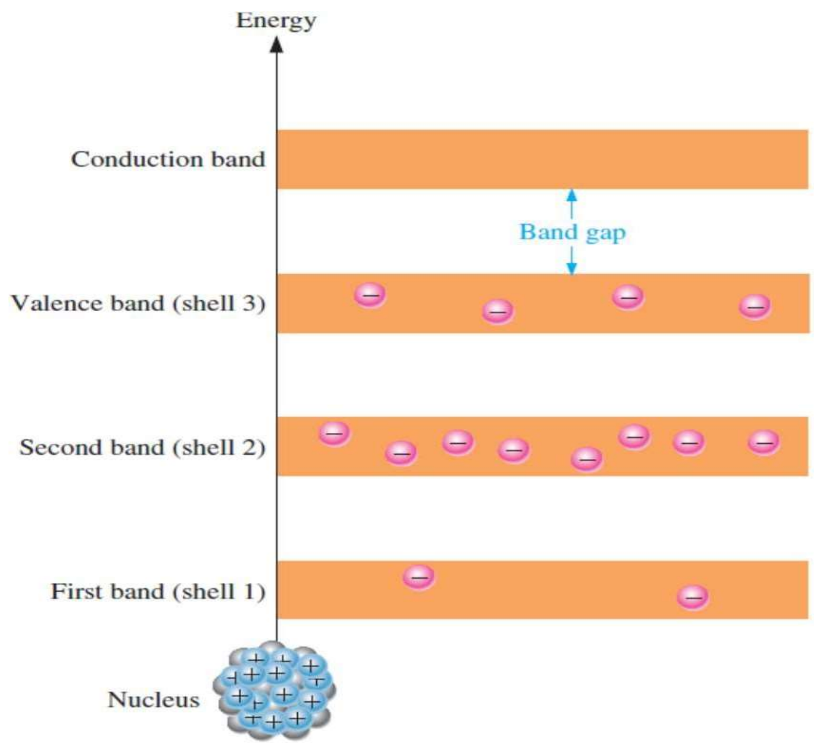
- The valence electron in the copper atom “feels” an attractive force of 1 compared to a valence electron in the silicon atom which “feels” an attractive force of 4.
- More force trying to hold a valence electron to the atom in silicon than in copper.
- The copper’s valence electron is in the fourth shell, which is a greater distance from its nucleus than the silicon’s valence electron in the third shell.
- Electrons farthest from the nucleus have the most energy.
- The valence electron in copper has more energy than the valence electron in silicon.
- This means that it is easier for valence electrons in copper to acquire enough additional energy to escape from their atoms and become free electrons than it is in silicon.
- In fact, large numbers of valence electrons in copper already have sufficient energy to be free electrons at normal room temperature.

Silicon and Germanium

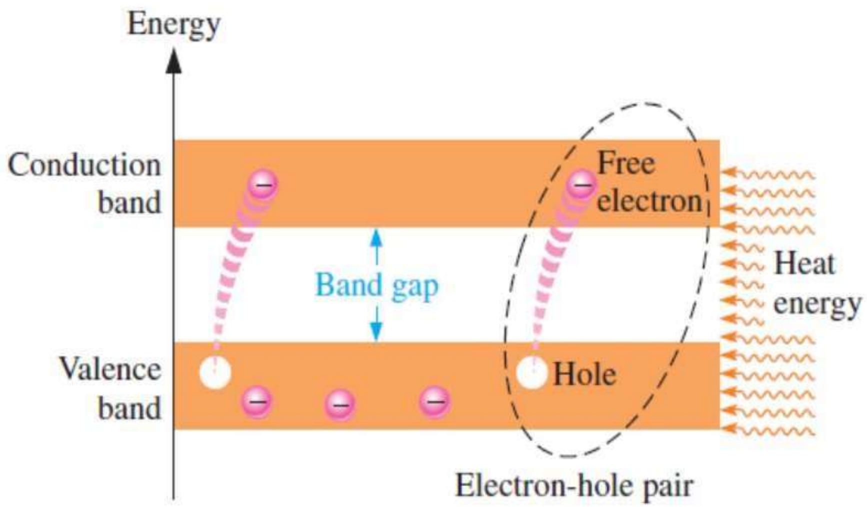


Energy Band Diagram

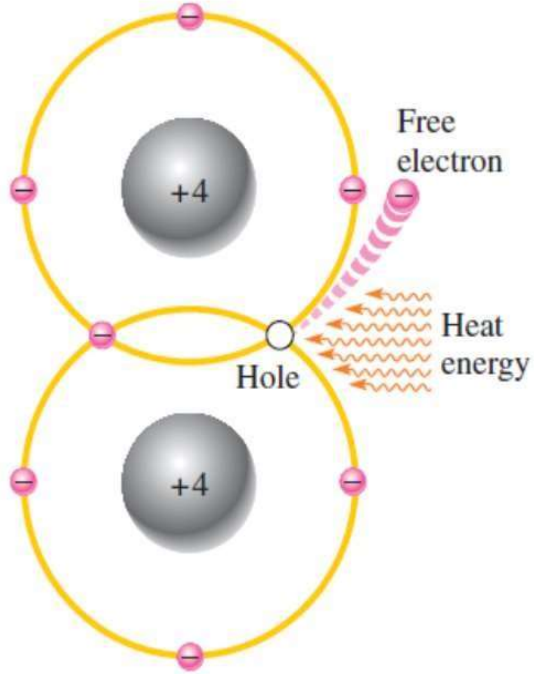
- Energy band diagram for an unexcited atom in a pure (intrinsic) silicon crystal.
- There are no electrons in the conduction band.



Conduction Electrons and Holes



(a) Energy diagram



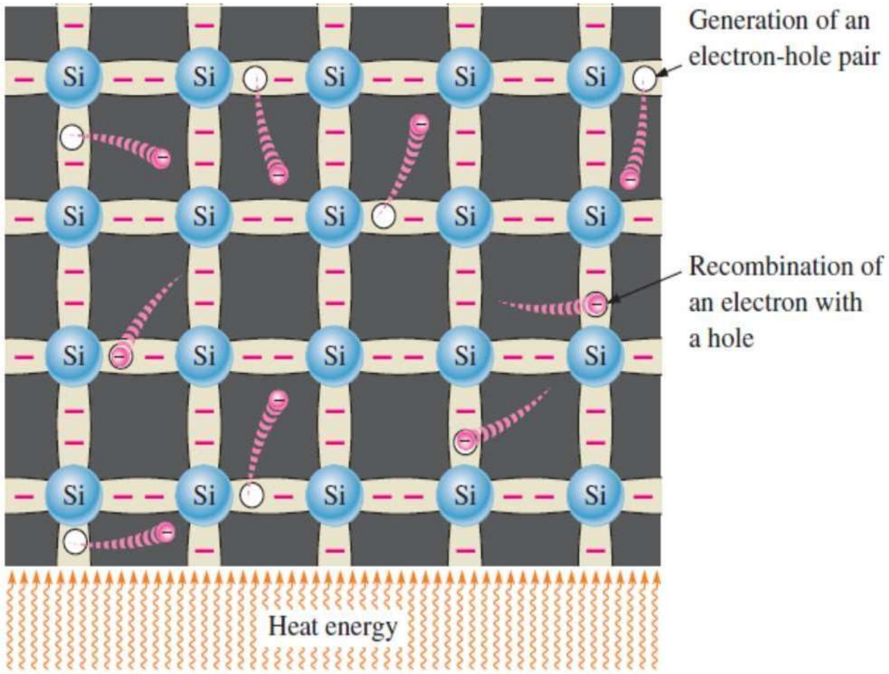
(b) Bonding diagram

Conduction Electrons and Holes

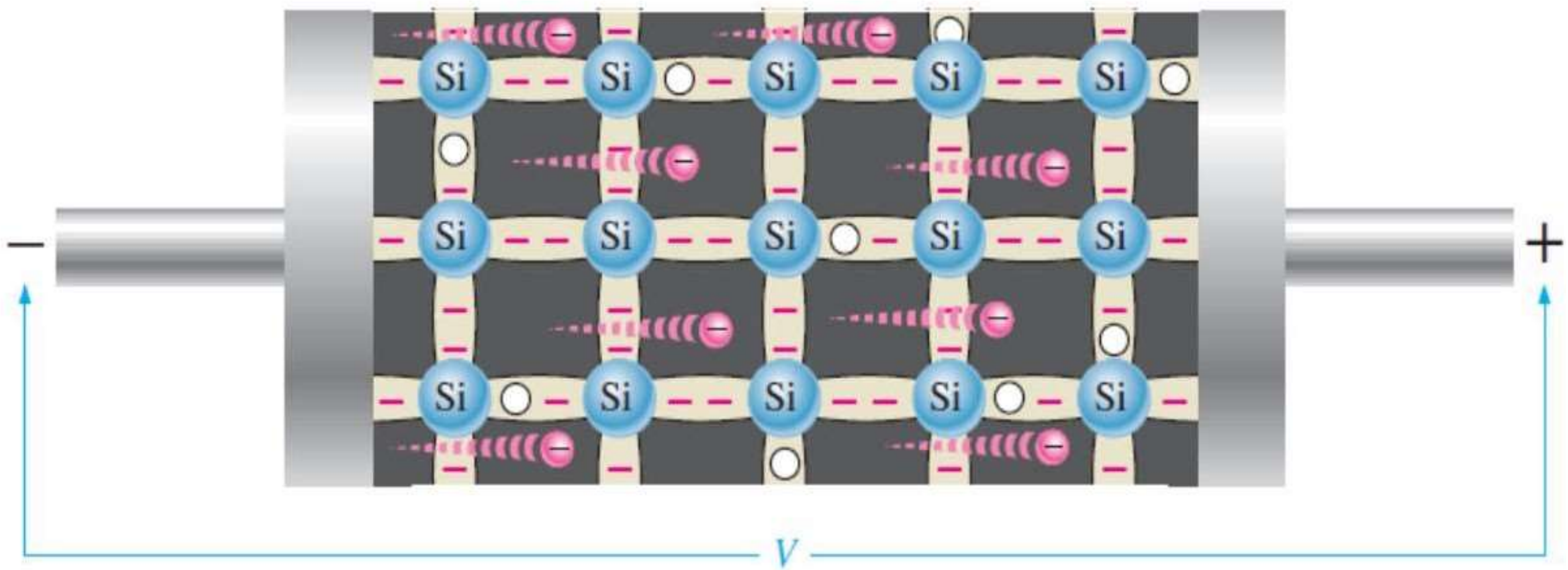
- An intrinsic (pure) silicon crystal at room temperature has sufficient heat (thermal) energy for some valence electrons to jump the gap from the valence band into the conduction band, becoming free electrons.
- Free electrons are also called **conduction electrons.**
- When an electron jumps to the conduction band, a vacancy is left in the valence band within the crystal. This vacancy is called a **hole**.
- For every electron raised to the conduction band by external energy, there is one hole left in the valence band, creating what is called an **electron-hole pair.**
- **Recombination** occurs when a conduction-band electron loses energy and falls back into a hole in the valence band.

Conduction Electrons and Holes

- A piece of intrinsic silicon at room temperature has, at any instant, a number of conduction-band (free) electrons that are unattached to any atom and are essentially drifting randomly throughout the material.
- There is also an equal number of holes in the valence band created when these electrons jump into the conduction band.
- This is illustrated in Figure.



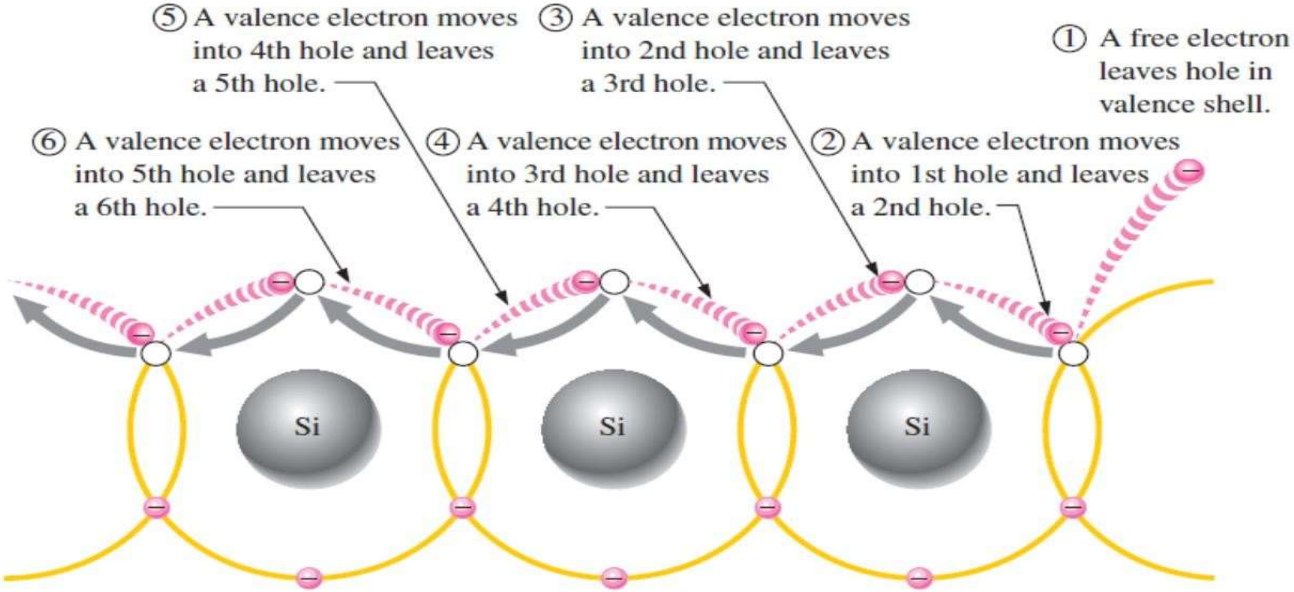
Electron Current



Electron Current

- When a voltage is applied across a piece of intrinsic silicon, the thermally generated free electrons in the conduction band, which are free to move randomly in the crystal structure, are now easily attracted toward the positive end.
- This movement of free electrons is one type of **current** in a semiconductive material and is called *electron current.*

Hole Current



When a valence electron moves left to right to fill a hole while leaving another hole behind, the hole has effectively moved from right to left. Gray arrows indicate effective movement of a hole.

Hole Current

- Another type of current occurs in the valence band, where the holes created by the free electrons exist.
- Electrons remaining in the valence band are still attached to their atoms and are not free to move randomly in the crystal structure as are the free electrons.
- However, a valence electron can move into a nearby hole with little change in its energy level, thus leaving another hole where it came from.
- Effectively the hole has moved from one place to another in the crystal structure.
- Although current in the valence band is produced by valence electrons, it is called *hole current* to distinguish it from electron current in the conduction band.

Electron and Hole Current

- Conduction in semiconductors is considered to be either the movement of free electrons in the conduction band or the movement of holes in the valence band, which is actually the movement of valence electrons to nearby atoms, creating hole current in the opposite direction..

Hole Current

- At what energy level does hole current occur?
  - Germanium it is 0.66 eV; for Silicon it is 1.1 eV; Gallium Arsenide is 1.42 eV at room temperature, to name a few common substrates.
  - This is the minimum energy level for the electrons to cross the depletion layer in the semiconductor and fill the empty holes, enabling hole current to flow.

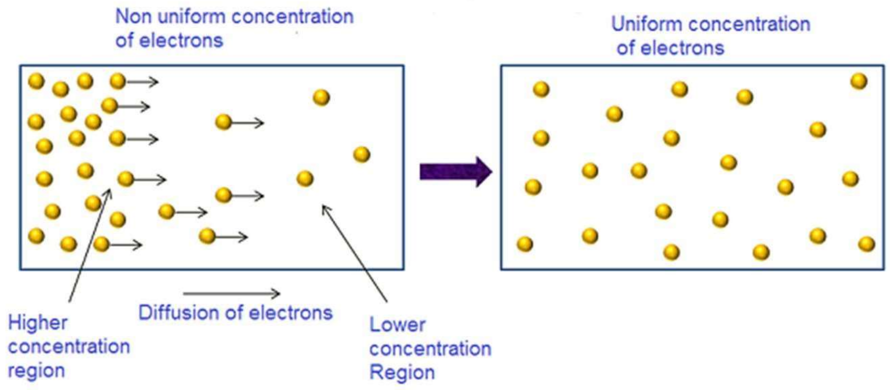
Drift Current

- Drift is, by definition, charged particle motion in response to an applied electric field.
- When an electric field is applied across a semiconductor, the carriers start moving, producing a current.
- The positively charged holes move with the electric field, whereas the negatively charged electrons move against the electric field.
- Drift current in a semiconductor is the resultant of carrier drift.
- Drift current also depends on the ability of the carriers to move around in the semiconductor, or the electron and hole mobility.

Diffusion Current

- Diffusion is the process of particles distributing themselves from regions of high concentration to regions of low concentration.
- Diffusion does not need external forces to act upon a group of particles.
- The particles move about using only thermal motion.
- If we let the particles be carriers, so as they move around they take charge with them.
- The moving of charge will result in a current.
- We call this *current due to diffusion*.

Diffusion Current

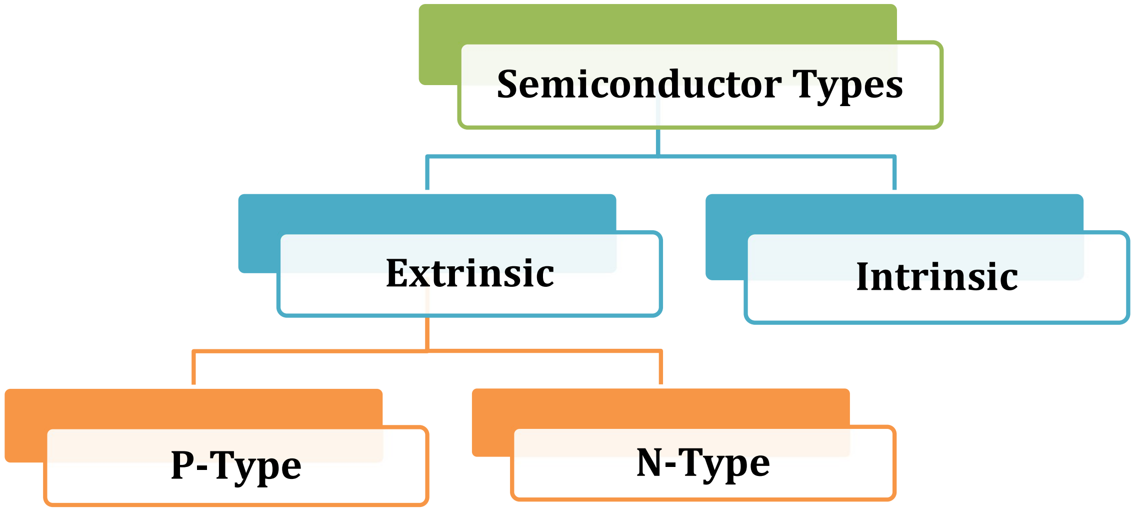


Drift Current and Diffusion Current

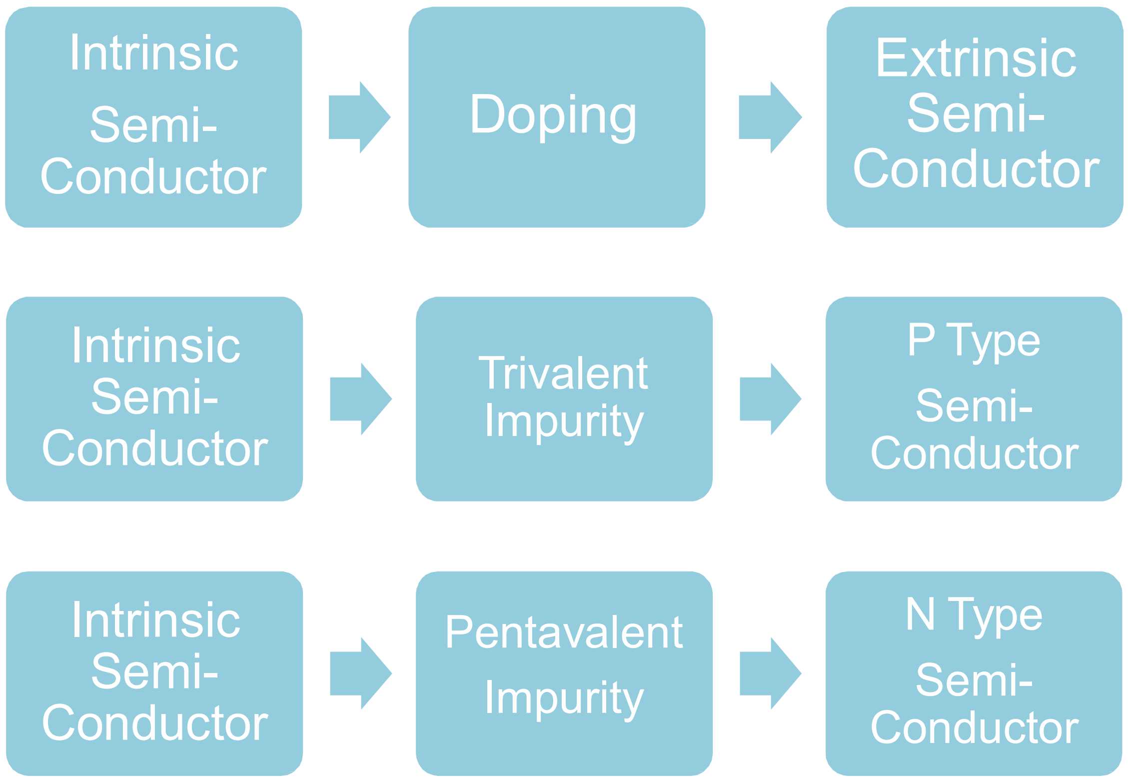
- The difference between drift current and diffusion current is that drift current depends on the electric field applied.
- The other difference between drift current and diffusion current, is that the direction of the diffusion current depends on the change in the carrier concentrations, not the concentrations themselves.
- Total current in a semiconductor is the sum of drift and diffusion current.

Introduction to Semiconductor Physics

Parameter	Conductor	Semi Conductor	Insulator
No. of Valance Electrons	3 or less than 3	4	5 or more than 5
Conductivity	High	Medium	Negligible



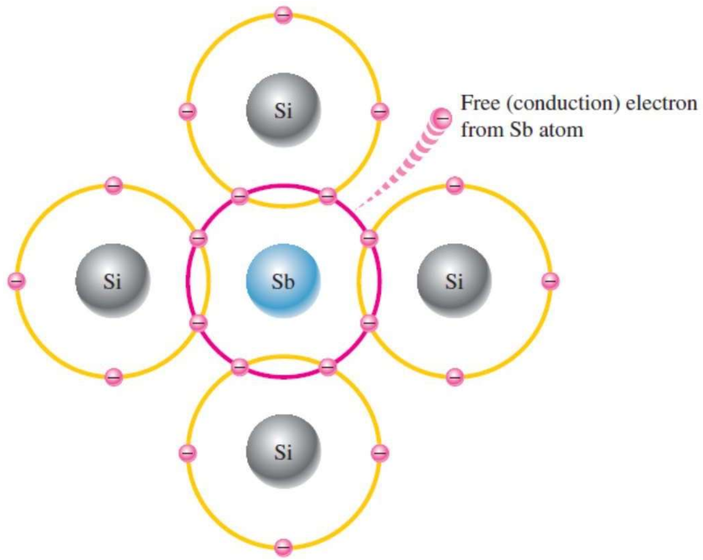
Semi-Conductor Types



Doping

- Semiconductors are generally poor conductors.
- Controlled addition of impurities to the intrinsic (pure) semiconductive material is **Doping.**
- **Doping**, increases the number of current carriers (electrons or holes).
- The two categories of impurities are *n*-type and *p*-type.

N-type Semiconductor



- Pentavalent
  - (Donor) impurity
  - Arsenic (As)
  - Phosphorus (P)
  - Antimony(Sb)
  - Bismuth(Bi)

N-type Semiconductor

- Each pentavalent atom (antimony, in this case) forms covalent bonds with four adjacent silicon atoms.
- Four of the antimony atom's valence electrons are used to form the covalent bonds with silicon atoms, leaving one extra electron.
- This extra electron becomes a conduction electron because it is not involved in bonding.
- Because the pentavalent atom gives up an electron, it is often called a *donor atom.*
- The number of conduction electrons can be carefully controlled by the number of impurity atoms added to the silicon.
- **A conduction electron created by this doping process does not leave a hole in the valence band because it is in excess of the number required to fill the valence band.**

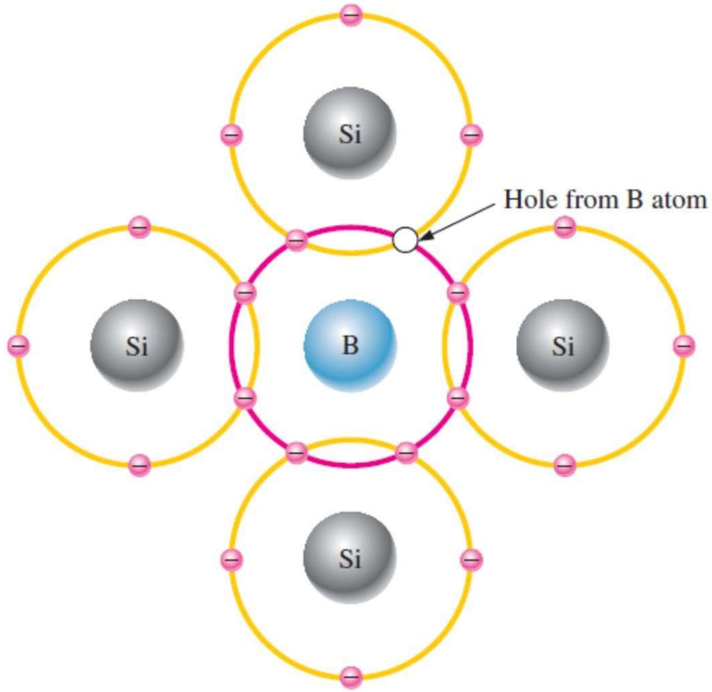
N-type Semiconductor

- Majority and Minority Carriers

- Most of the electrons are free since doping is with pentavalent material leaving one electron by each atom.
- These free electrons contribute to the current, called majority carriers.
- Few holes that are created when electron-hole pairs are thermally generated.
- These Holes are called minority carriers, *Not* produced by the addition of the pentavalent impurity atoms.

P-type Semiconductor

- Trivalent
  - (Acceptor) impurity
  - Boron (B)
  - Indium (In)
  - Gallium(Ga)



P-type Semiconductor

- Each Trivalent atom (Boron, in this case) forms covalent bonds with four adjacent silicon atoms.
- Three of the Boron atom's valence electrons are used to form the covalent bonds with silicon atoms, leaving one extra hole.
- This extra hole becomes a conduction electron because it is not involved in bonding
- Because the trivalent atom can take up an electron, it is often called a *acceptor atom.*
- The number of holes can be carefully controlled by the number of impurity atoms added to the silicon.
- **A hole created by this doping process is *not* accompanied by a conduction (free) electron.**

P-type Semiconductor

- Majority and Minority Carriers
- Most of the current carriers are holes, silicon (or germanium) doped with trivalent atoms is called a *p*-type semiconductor.
- The holes are the majority carriers in *p*-type material.
- Although the majority of current carriers in *p*-type material are holes, there are also a few conduction-band electrons that are created when electron-hole pairs are thermally generated.
- These conduction-band electrons are *not* produced by the addition of the trivalent impurity atoms.
- Conduction-band electrons in *p*-type material are the minority carriers.

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1. Electronic Devices, Thomas L. Floyd
2. Web Resources

Thank You..