Lecture (01) Introduction to Electronics

By:

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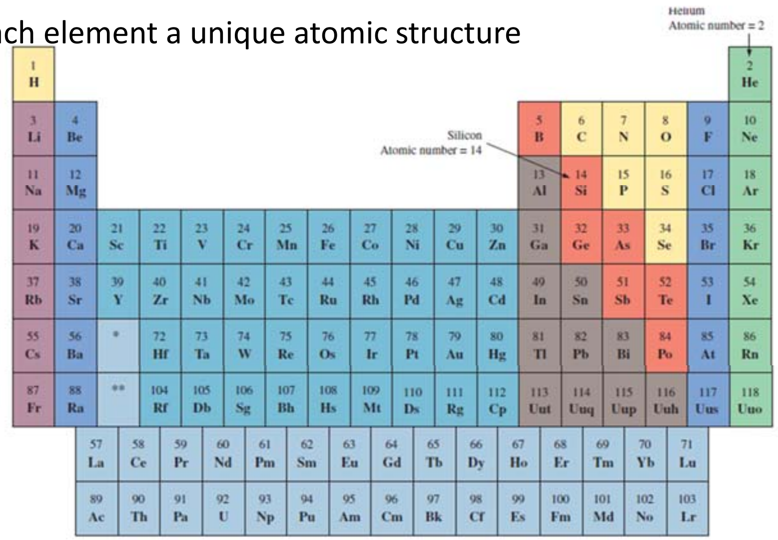
Agenda

1. Atom
2. Materials used in Electronics
3. Current in semiconductors/conductors

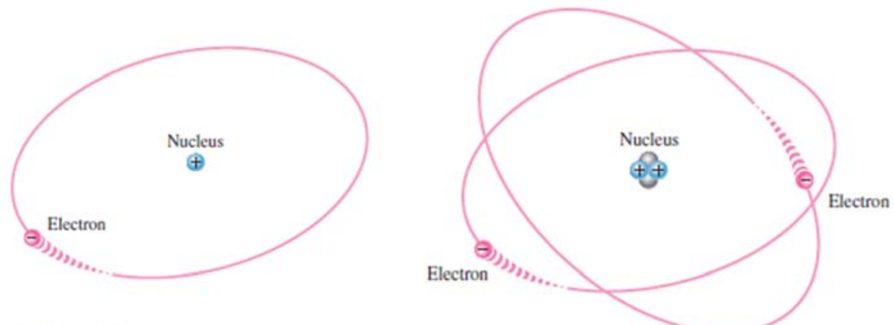
1. The Atom

- Number of elements is 118
- each element a unique atomic structure



Bohr Model

- Central <u>nucleus</u>
  - +ve particles called <u>proton</u>
  - -uncharged particles called <u>neutrons</u>
- Surrounded by –ve particles called <u>electrons</u>

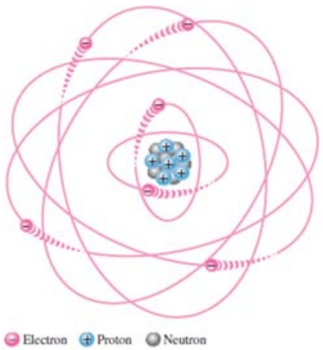


(a) Hydrogen atom

(b) Helium atom

Atomic number

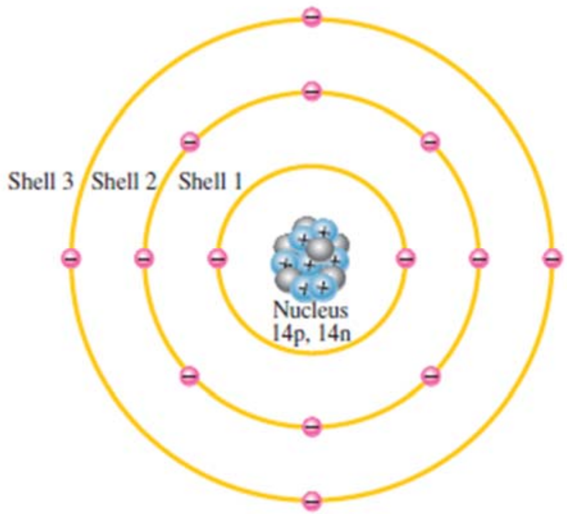
- Elements are arranged in periodic table according to atomic number
- The **atomic number** equals the number of protons in the nucleus, which is the same as the number of electrons in an electrically balanced (neutral) atom.



Electrons and Shells

- Electrons orbit the nucleus of an atom at certain distances from the nucleus.
- electrons orbit only at discrete distances from the nucleus.
- Each discrete distance (**orbit**) from the nucleus corresponds to a certain energy level.
- orbits are grouped into energy levels known as **shells**
- atom has a fixed number of shells, are designated 1, 2, 3, and so on

- Silicon atom



- The maximum number of electrons (*Ne*)

$$N_e = 2n^2$$ where n is the number of the shell

- The maximum number of electrons that can exist in the innermost shell (shell 1) is

$$N_e = 2n^2 = 2(1)^2 = 2$$

- The maximum number of electrons that can exist in shell 2 is

$$N_e = 2n^2 = 2(2)^2 = 2(4) = 8$$

- The maximum number of electrons that can exist in shell 3 is

$$N_e = 2n^2 = 2(3)^2 = 2(9) = 18$$

- The maximum number of electrons that can exist in shell 4 is

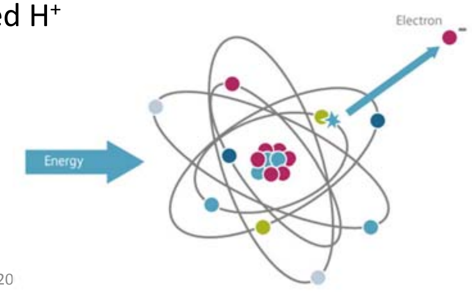
$$N_e = 2n^2 = 2(4)^2 = 2(16) = 32$$

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
- Electrons with the highest energy exist in the outermost shell of an atom and are relatively loosely bound to the atom
- outermost shell is known as the **valence** shell and electrons in this shell are called *valence electrons*
- 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.

Ionization

- When an atom absorbs energy from a heat source or from light, the valence electrons can jump to higher energy shells.
- *ionization energy : the amount of absorbed energy by atom to make* valence electron escape (free electron) from outer shell, which turn atom to positive ion
- the chemical symbol for hydrogen is H. when atom loses its valence electron, it is designated H^+



- The reverse process can occur in certain atoms when a free electron collides with the atom and is captured, releasing energy
- The atom that has acquired the extra electron is called a *negative ion*.

- The ionization process is not restricted to single atoms. In many chemical reactions,
- a group of atoms that are bonded together can lose or acquire one or more electrons.
- As ion is more stable than the neutral atom because it has a filled outer shell.

The Quantum Model

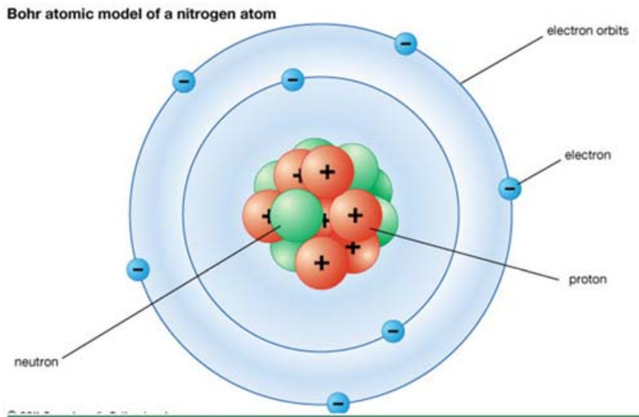
- The quantum model, a more recent model than Bohr 's model, is considered to be more accurate.
- Like the Bohr model, the quantum model has a nucleus of protons and neutrons surrounded by electrons.
- Unlike the Bohr model, the electrons in the quantum model do not exist in precise circular orbits as particles.
- Two important theories underlie the quantum model:
  - the wave-particle duality
  - the uncertainty principle.

- *Wave-particle duality :*
- Just as light can be both a wave and a particle **(photon),**
- electrons are thought to exhibit a dual characteristic.
- The velocity of an orbiting electron is considered to be its wavelength,
- which interferes with neighboring electron waves by amplifying or canceling each other

- *Uncertainly principle:*
- *As* wave is characterized by peaks and valleys.
- electrons acting as waves cannot be precisely identified in terms of their position
- *Heisenberg* said: it is impossible to determine simultaneously both the position and velocity of an electron with any degree of accuracy or certainty
- That produces the *probability clouds; which is a* mathematical description of electrons location

- In the quantum model, each shell or energy level consists of up to four subshells called **orbitals**, which are designated *s*, *p*, *d*, and *f.*
- Orbital ***<u>s</u>*** can hold a maximum of **<u>two</u>** electrons,
- orbital ***<u>p</u>*** can hold **<u>six</u>** electrons,
- orbital ***<u>d</u>*** can hold **<u>ten</u>** electrons,
- and orbital ***<u>f</u>*** can hold **<u>fourteen</u>** electrons.

- Nitrogen 7



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*

- In the quantum picture, each shell in the Bohr model is a three dimensional space surrounding the atom that represents the mean (average) energy of the electron cloud.
- The term **electron cloud** (probability cloud) is used to describe the area around an atom's nucleus where an electron will probably be found.

EXAMPLE

- describe a silicon $(Si)_{14}$ atom using an electron configuration table.

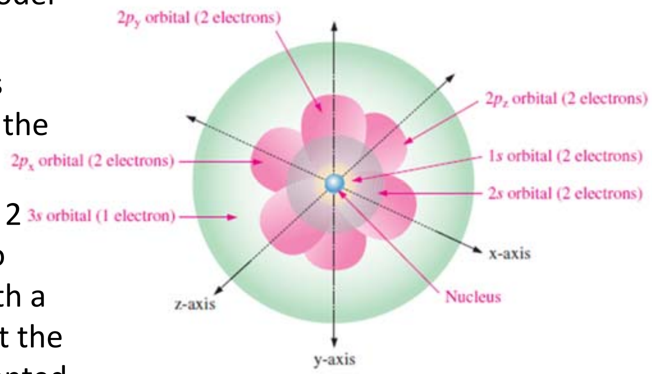
EXAMPLE

- describe a silicon $(Si)_{14}$ atom using an electron configuration table.

Bohr Model	
shell	Number of electrons
1	2
2	8
3	4

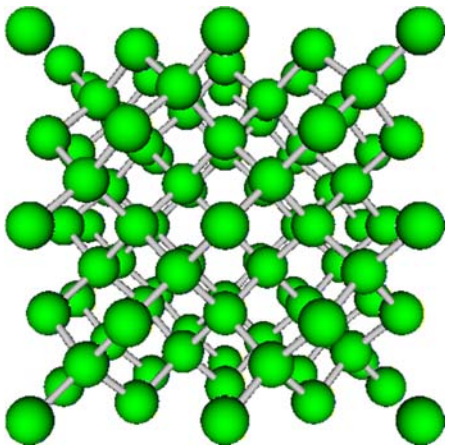
Quantum model	
orbitals	Number of electrons @ shell
$1S^2$	2
$2S^2$ $2P^6$	8
$3S^2$ $3P^2$	4

- In a 3d quantum model
- the *s*-orbitals are shaped like spheres with the nucleus in the center
- A *p*-orbital for shell 2 has the form of two ellipsoidal lobes with a point of tangency at the nucleus; One is oriented on the *x*-axis, one on the *y*-axis, and one on the *z*-axis.



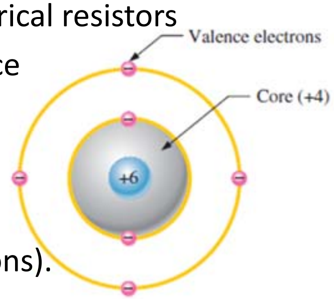
2. Materials used in Electronics

- materials can be classified (electrical properties) into
  - conductors,
  - semiconductors,
  - Insulators
- atoms combined and arrange in a symmetrical pattern to form a solid, crystalline material (crystal structure)
- They held together by covalent bonds, by the interaction of the valence electrons of the atoms



Insulators, Conductors, and Semiconductors

- Carbon (C_6) is used in some types of electrical resistors
- As atom can be represented by the valence shell and a **core** that consists of all the inner shells and the nucleus
- The core has a net charge of +4 (+6 for the nucleus and for the -2 inner-shell electrons).



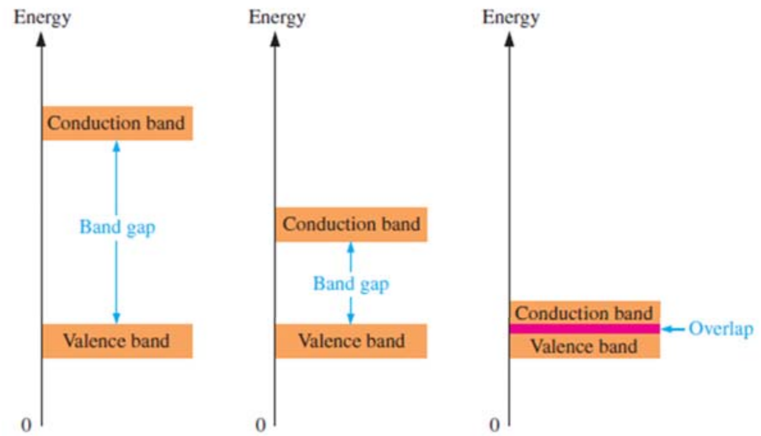
- ***Insulators***
- material that does not conduct electrical current
- Most good insulators are compounds of many materials
- have very high resistivity
- Valence electrons are tightly bound to the atoms
- Examples; rubber, plastics, glass, mica, and quartz.

- ***Conductors***
- easily conducts electrical current
- Most metals are good conductors.
- best conductors are single-element materials
- valence electrons (free electrons) are very loosely bound to the atom
- such as copper (Cu), silver (Ag), gold (Au), and aluminum (Al),

- ***Semiconductors***
- between conductors and insulators in its ability to conduct electrical current.
- characterized by atoms with four valence electrons.
- Single-element semiconductors are silicon (Si), and germanium (Ge).
- Compound semiconductors such as gallium arsenide, indium phosphide, gallium nitride, silicon carbide, and silicon germanium

- **Band Gap**
- When an electron acquires enough additional energy, it can leave the valence shell, become a *free electron,* and exist in what is known as the *conduction band; in which* electron is free to move throughout the material and is not tied to any given atom.
- *energy gap* or **band gap :**
  - **t**he energy difference in between the valence band and the conduction band
  - The amount of energy that a valence electron must have in order to jump from the valence band to the conduction band.

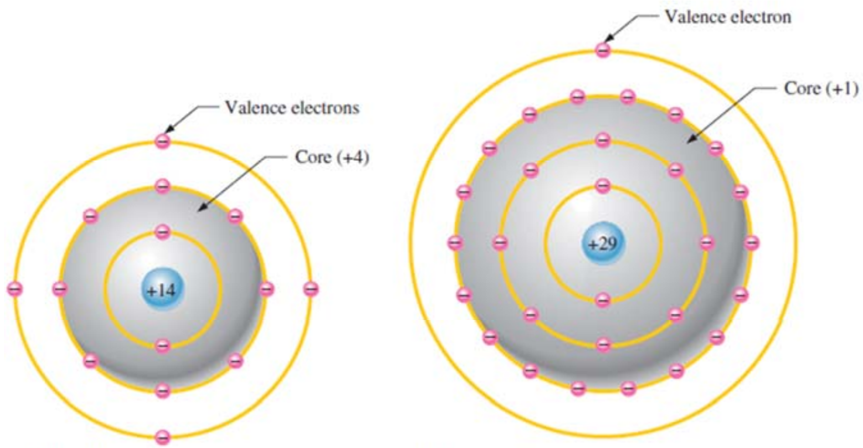
- Figure shows energy diagrams for insulators, semiconductors, and conductors



(a) Insulator (b) Semiconductor (c) Conductor

- The energy gap or band gap is the difference between two energy levels that makes valance electron escape from atom.
- It is a region in insulators and semiconductors where no electron states exist, Although an electron can “jump” across it under certain conditions.
- For insulators, gap can be crossed when breakdown conditions, applying very high voltage
- In semiconductors the band gap is smaller, valance electron can jump is it absorbs a photon.
- In conductors, the conduction band and valence band overlap, valence electrons can move freely into the conduction band, so there are always electrons available as free electrons.

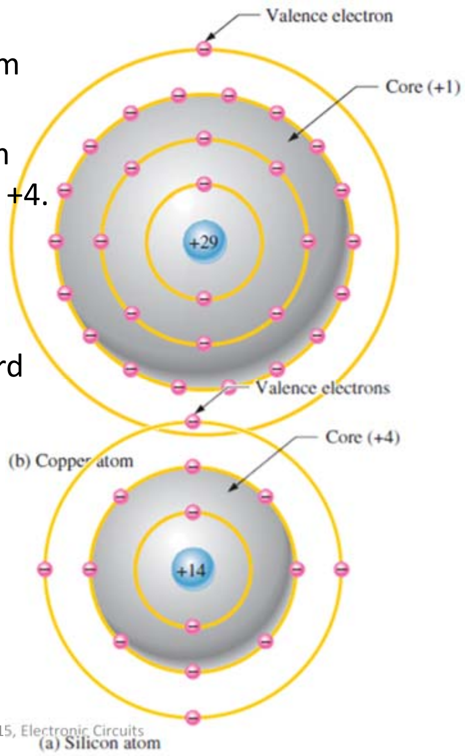
- **Comparison of a Semiconductor Atom to a Conductor Atom** Silicon is a semiconductor and copper is a conductor.



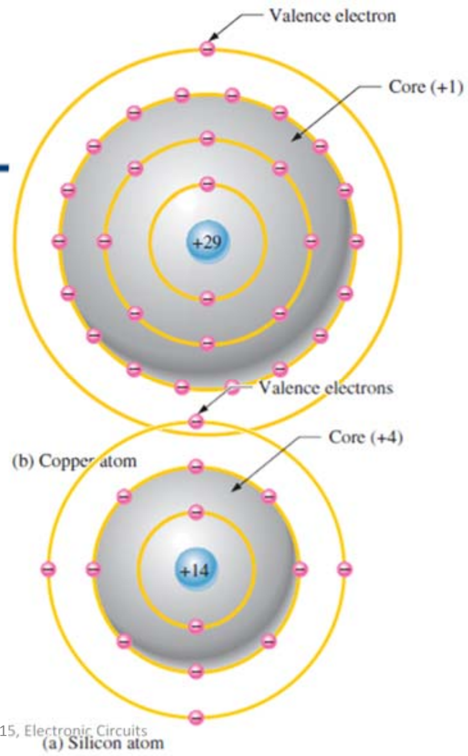
(a) Silicon atom (b) Copper atom

- The core includes everything except the valence electrons
- the core of the silicon atom has a net charge of +4 (+14 protons -10 electrons)
- the core of the copper atom has a net charge of +1 (+29 protons -28 electrons)

- valence electron in the copper atom "feels" an attractive force of +1
- valence electron in the silicon atom which "feels" an attractive force of +4.
- 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; so The valence electron in copper has more energy than the valence electron in silicon.
- easier for valence electrons in



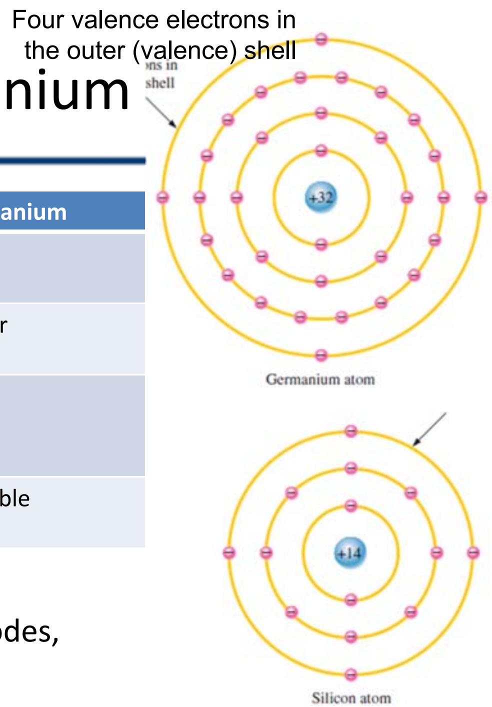
- copper to acquire enough additional energy to escape from their atoms and become free electrons than it is in silicon
- large numbers of valence electrons in copper already have sufficient energy to be free electrons at normal room temperature



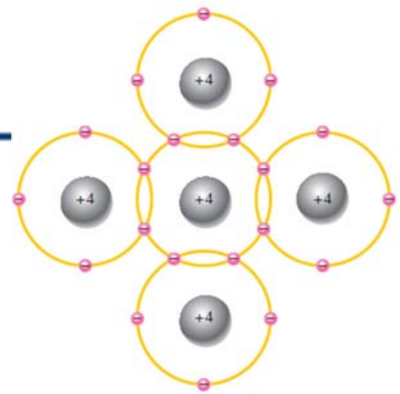
Silicon and Germanium

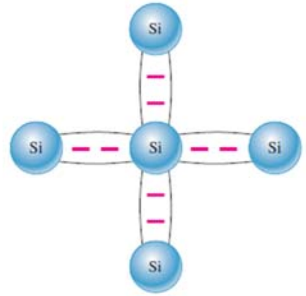
item	Silicon	Germanium
Valence electron shell	3rd	4th
Valence electrons energy	lower	higher
Acquired energy to make valence electrons escape	higher	lower
Stability @ high temp	stable	unstable

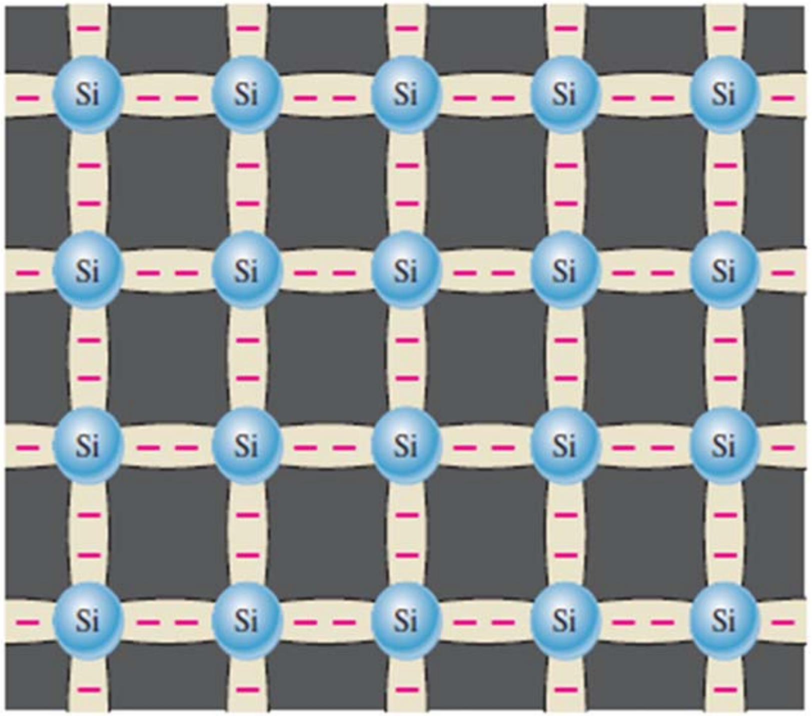
- silicon is a more widely used semiconductor devices like diodes, transistors, ICs.



- ***Covalent Bonds***
- silicon **crystal** formed from four adjacent silicon atoms
- A silicon (Si) atom with its four valence electrons shares one electron wit four neighbor atoms, This effectively creates eight shared valence electrons for each atom and produces a state of chemical stability
- Sharing create covalent bonds that holds atoms together







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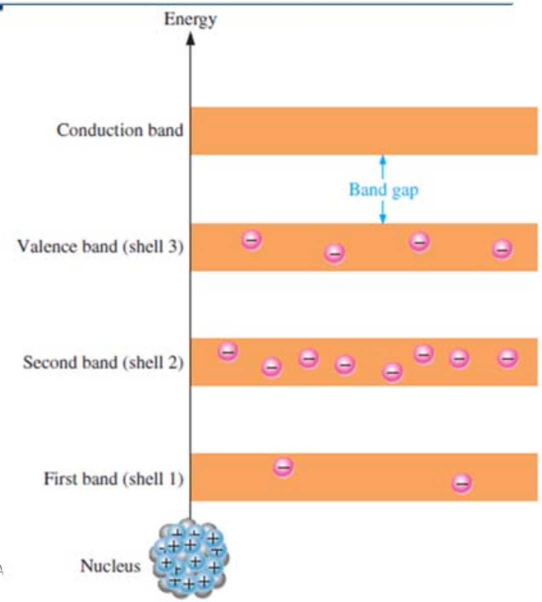
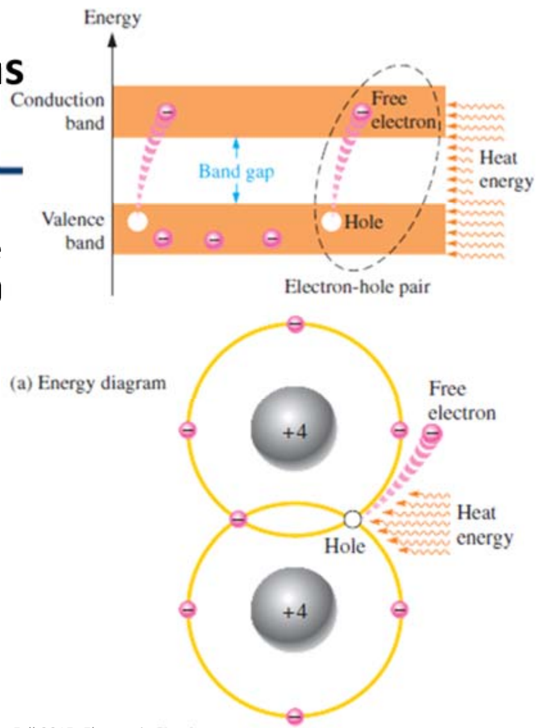
3. Current in semiconductors

- Atom electrons exists on certain shell around the atom each shell has a prescribed energy bands.
- Adjacent energy bands (between atoms) are separated by band gaps
- Figure shows the energy band diagram for an unexcited atom in a pure silicon crystal



Conduction Electrons and Holes

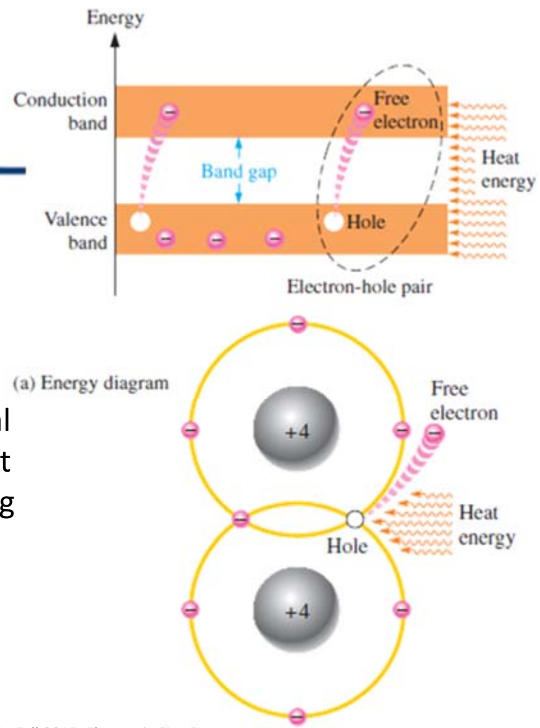
- An intrinsic (pure) silicon crystal at room temperature has sufficient heat (thermal) energy for some valence electrons to jump the gap from the valence band into the conduction band, becoming free electrons
- Free electrons are also called **conduction electrons.**



(a) Energy diagram

(b) Bonding diagram

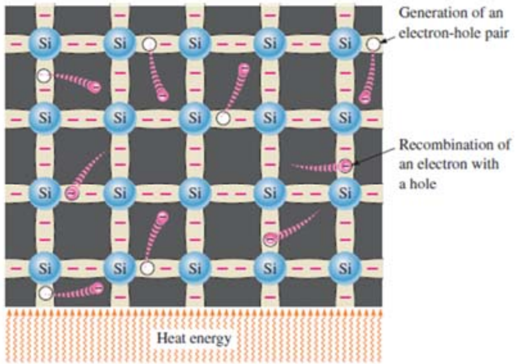
- When an electron jumps to the conduction band, it leaves a hole in valence band
- every electron raised to the conduction band by external energy, there is one hole left in the valence band, creating what is called an **electron-hole pair.**



(a) Energy diagram

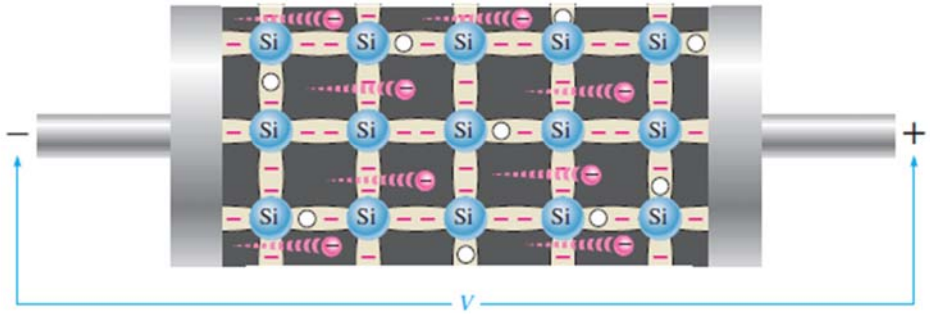
(b) Bonding diagram

- **Recombination** occurs when a conduction-band electron loses energy and falls back into a hole in the valence band.
- *Electron-hole pairs in a silicon crystal is;* Free electrons are being generated continuously while some recombine
- with holes.

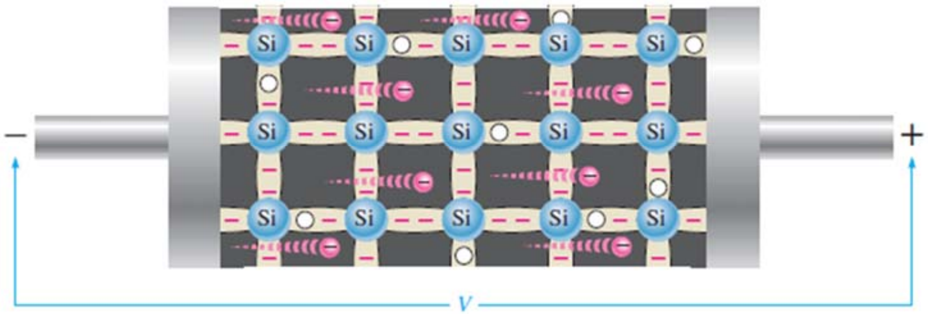


Electron and Hole Current in semi conductors

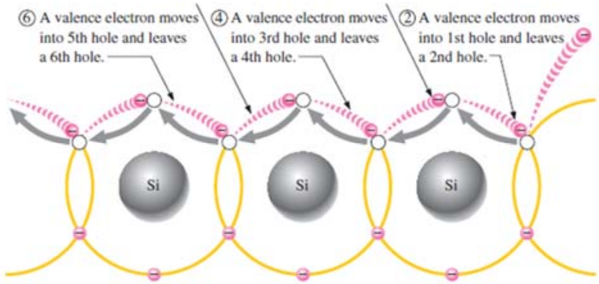
- When a voltage is applied across a piece of intrinsic silicon
- Applied voltage cause thermal energy
- Thermal energy generates free electrons in the conduction band,
- Free electrons are free to move randomly in the crystal structure,



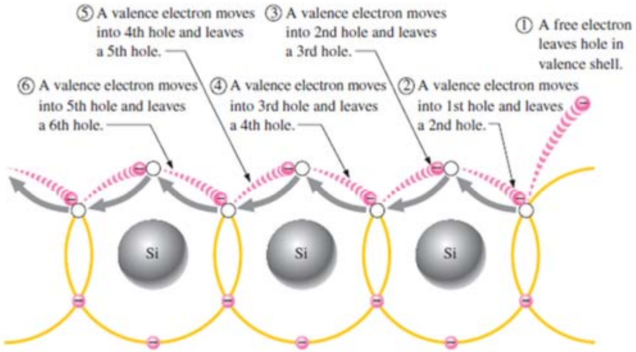
- Free electrons are now easily attracted toward the positive end.
- This movement of free electrons is one type of **current** in a semi conductive material and is called ***electron current*** *(occurred in conduction band)*



- Agreed that holes are created by the free electrons exist atoms
- Other valence Electrons remains attached to the atom and can't move to conduction band
- But these valence electron can move into a nearby hole with little change in its energy, leaving another hole where it came from



- Effectively the hole has moved from one place to another in the crystal structure,
- Current in the valence band is produced by valence electrons, it is called ***hole current*** (*occurred in valence band*).

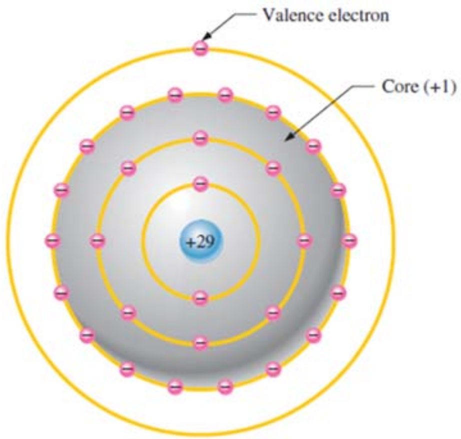


When a valence electron moves left to right to fill a hole while leaving another hole behind, the hole has effectively moved from right to left. Gray arrows indicate effective movement of a hole.

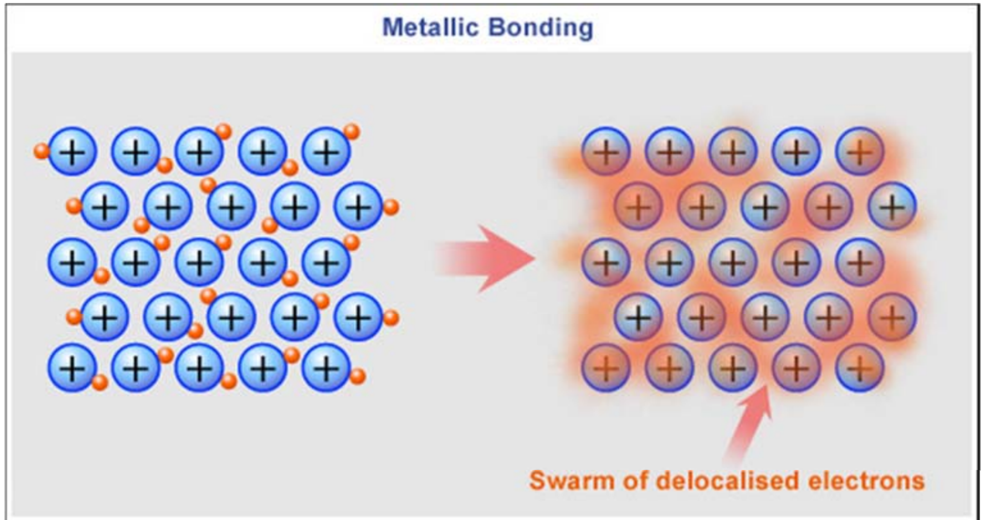
- conduction in semiconductors :
  - Movement of free electrons in the conduction band
  - movement of holes in the valence band,
  - the movement of valence electrons to nearby atoms, creating hole current in the opposite direction

Electron Current in conductors

- Copper atoms crystal, atoms consist of a "sea" of positive ion cores (no covalent bond), atoms are stripped of their valence electrons.
- valence electrons are attracted to the positive ions, keeping the positive ions together and forming the metallic bond.
- The valence electrons do not belong to a given atom, but to the crystal as a whole

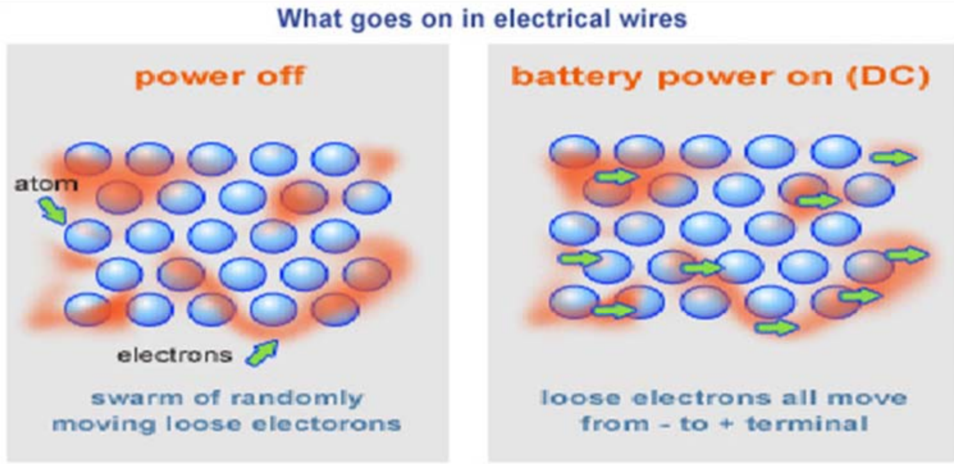


(b) Copper atom



The outer electrons are so weakly bound to metal atoms that they are free to roam across the entire metal. Having 'lost' their outer electrons, individual metal atoms are more like positive ions in a swarm of communal electrons.

- Since the valence electrons in copper are free to move, the application of a voltage results in current.
- There is only one type of current—the movement of free electrons—because there are no “holes” in the metallic crystal structure.



If you could see what’s going on at the atomic level inside a wire, it’d look something like this. Like all metals, wire is made of rigid framework of atoms with a swarm of loose electrons buzzing around them. Hook a wire up to a battery (DC) and the electrons all move forwards in synch.