Basic Electronics

- Introduction to Electricity, Electronics
- Importance and Application in Computer Science
- Conductors, Insulators, Semiconductors
- Energy Bands
- Conduction in Semiconductors.

Electronic Devices vs Electrical

Comparing these two types of engineering is like comparing the meaning of electric vs electronic.

Electrical devices convert electrical energy into other forms of energy, for example heat, light or sound.

Electronic devices control the flow of electrons in order to perform a task. While electrical engineering is concerned with the large-scale production and distribution of electrical power, electronic engineering focuses on smaller electronic circuits

Electronic Devices and Systems

Electronics may be defined as the science and technology of electronic devices and systems.

Electronic devices are primarily non-linear devices such as diodes and transistors and in general integrated circuits (ICs) in which small signals (voltages and currents) are applied to them.

Resistors, capacitors and inductors existed long ago before the advent of semiconductor diodes and transistors, these devices are thought of as electrical devices and the systems that consist of these devices are generally said to be electrical rather than electronic systems.

With today's technology, ICs are getting smaller and smaller and thus the modern IC technology is referred to as *microelectronics*.

Application of Electronics

Some of its applications included office gadgets like computers, scanners, calculators, FAX machines, projectors etc.

It also includes home appliances like washing machines, refrigerators, microwaves, TVs, vacuum cleaners, video games, loudspeakers etc. and some advanced storage devices such as HDD jukebox, DVDs etc.

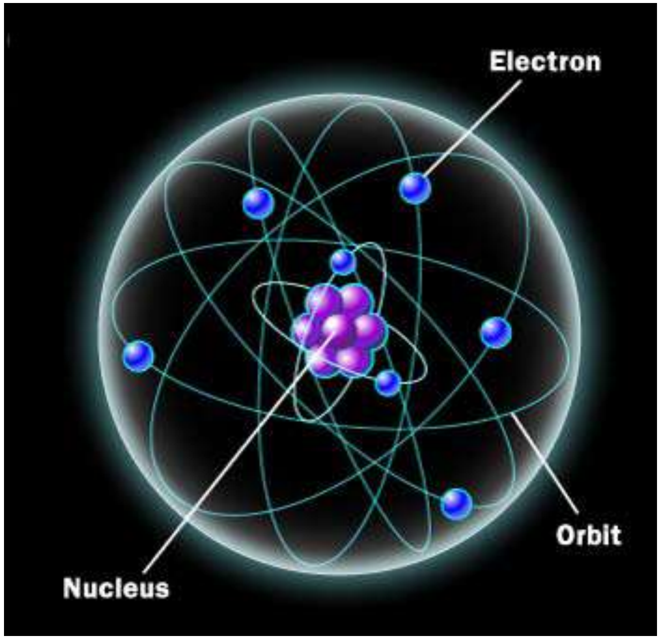
Importance of Electronics in Computer Science

These days we are depending on silicon based electronics to build computers. So, if you learn electronics, you will understand the architecture of computers. Then, you will be able to improve it, even take some other technologies that is not from silicon to build up new architectures.

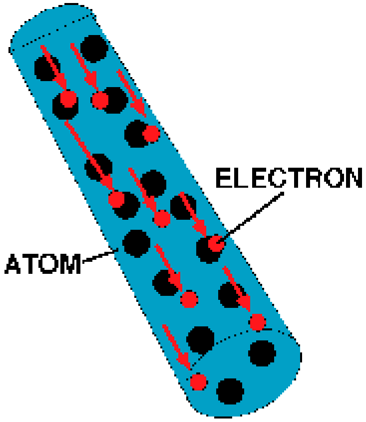
Without electronics there would be no modern computers and without modern computers there would be no need for computer science.

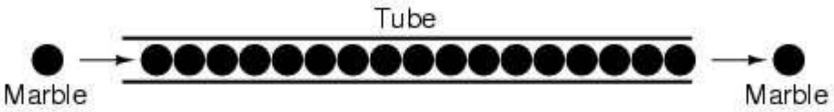
What is Electricity?

- Everything is made of atoms
- There are 118 elements, an atom is a single part of an element
- Atom consists of electrons, protons, and neutrons



- Electrons (- charge) are attracted to protons (+ charge), this holds the atom together
- Some materials have strong attraction and refuse to loss electrons, these are called insulators (air, glass, rubber, most plastics)
- Some materials have weak attractions and allow electrons to be lost, these are called conductors (copper, silver, gold, aluminum)
- Electrons can be made to move from one atom to another, this is called a current of electricity.





Atomic Number

- All elements are arranged in the periodic table of the elements in order according to their atomic number.
- The atomic number equals the number of protons in the nucleus. For example, hydrogen has an atomic number of 1 and helium has an atomic number of 2.
- In their normal (or neutral) state, all atoms of a given element have the same number of electrons as protons; the positive charges cancel the negative charges, and the atom has a net charge of zero, making it electrically balanced

Shells, Orbits, and Energy Levels

- In the Bohr model, electrons orbit the nucleus of an atom at certain distances from the nucleus and are restricted to these specific orbits.
- Each orbit corresponds to a different energy level within the atom known as a shell.
- The shells are designated 1, 2, 3,and so on, with 1 being closest to the nucleus. Electrons further from the nucleus are at higher energy levels.

Principal Quantum Number

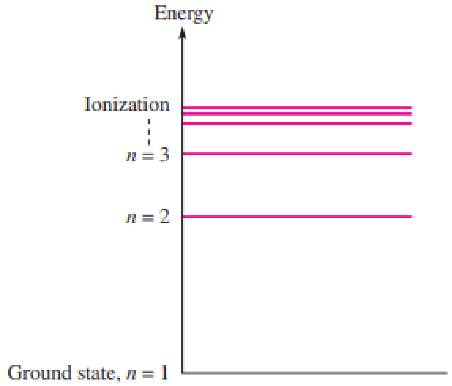
- The idea of discrete energy levels within the atom is still a foundation for understanding the atom, and the wave-mechanics model has been very successful at predicting the energy levels for various atoms.
- The wave-mechanics model of the atom used the shell number, called the principal quantum number, in the energy equation.
- These quantum numbers describe each electron within the atom. All electrons in an atom have a unique set of quantum numbers.
- When an atom is part of a large group, as in a crystal, the discrete energy levels broaden into energy bands. The bands also differentiate between conductors, semiconductors, and insulators.

Valence Shell

- 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 levels 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 they determine the material's electrical properties

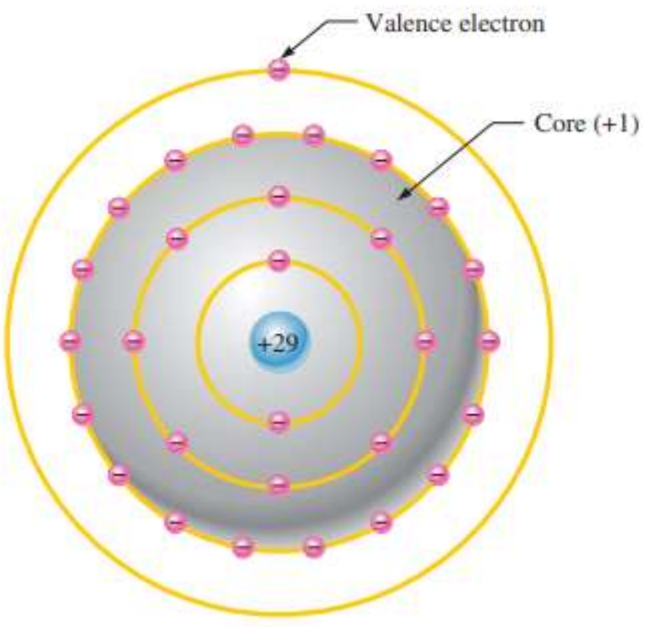
Energy Levels and Ionization Energy

- If an electron absorbs a photon with sufficient energy, it escapes from the atom and becomes a free electron. This is indicated by the ionization energy level in Figure.
- Anytime an atom or group of atoms is left with a net charge, it is called an ion. When an electron escapes from the neutral hydrogen atom (designated H), the atom is left with a net positive charge and becomes a positive ion (designated).
- In other cases, an atom or group of atoms can acquire an electron, in which case it is called a negative ion.



Copper Atom Example

- Copper is the most commonly used metal in electrical applications.
- The copper atom has 29 electrons that orbit the nucleus in four shells.
- The number of electrons in each shell follows a predictable pattern according to the formula, where N is the number of the shell



Categories of Material

Three categories of materials are used in electronics: conductors, semiconductors, and insulators.

Conductors

- Conductors are materials that readily allow current. They have a large number of free electrons and are characterized by one to three valence electrons in their structure.
- Most metals are good conductors. Silver is the best conductor, and copper is next.
- Copper is the most widely used conductive material because it is less expensive than silver.
- Copper wire is commonly used as a conductor in electric circuits

Categories of Material

Three categories of materials are used in electronics: conductors, semiconductors, and insulators.

Semiconductors

- Semiconductors are classed below the conductors in their ability to carry current because they have fewer free electrons than do conductors.
- Semiconductors have four valence electrons in their atomic structures.
- However, because of their unique characteristics, certain semiconductor materials are the basis for electronic devices such as the diode, transistor, and integrated circuit. Silicon and germanium are common semiconductive materials.

Categories of Material

Three categories of materials are used in electronics: conductors, semiconductors, and insulators.

Insulators

- Insulators are nonmetallic materials that are poor conductors of electric current; they are used to prevent current where it is not wanted. Insulators have no free electrons in their structure.
- The valence electrons are bound to the nucleus and not considered “free.”
- Most practical insulators used in electrical and electronic applications are com pounds such as glass, porcelain, teflon, and polyethylene, to name a few.

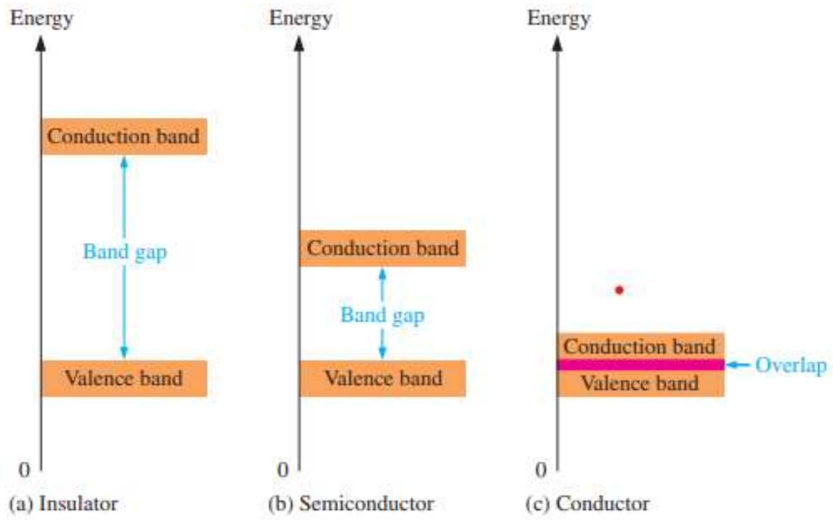
Band Gap

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.

The difference in energy between the valence band and the conduction band is called an energy gap or band gap.

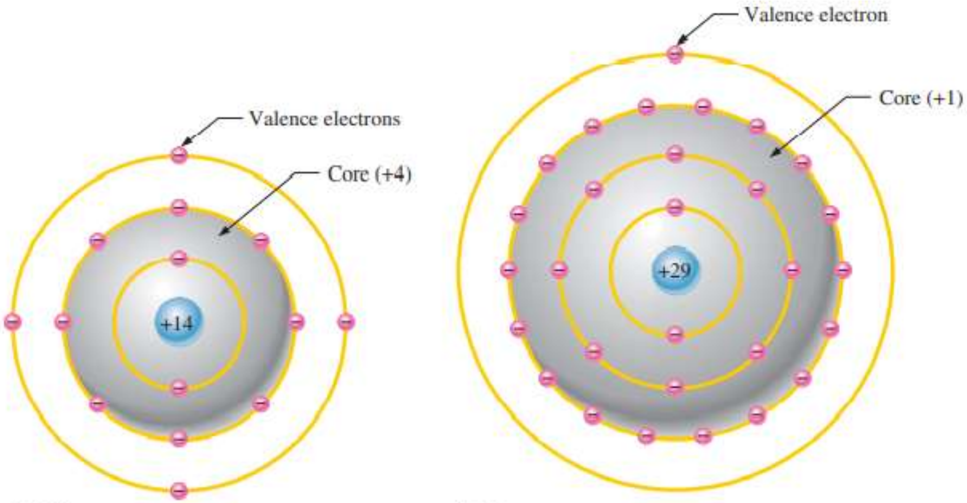
This is the amount of energy that a valence electron must have in order to jump from the valence band to the conduction band. Once in the conduction band, the electron is free to move throughout the material and is not tied to any given atom

Band Gap



Energy
Conduction band
Band gap
Valence band
0
(a) Insulator
Energy
Conduction band
Band gap
Valence band
0
(b) Semiconductor
Energy
Conduction band
Overlap
Valence band
0
(c) Conductor

Comparison of a Semiconductor Atom to a Conductor Atom



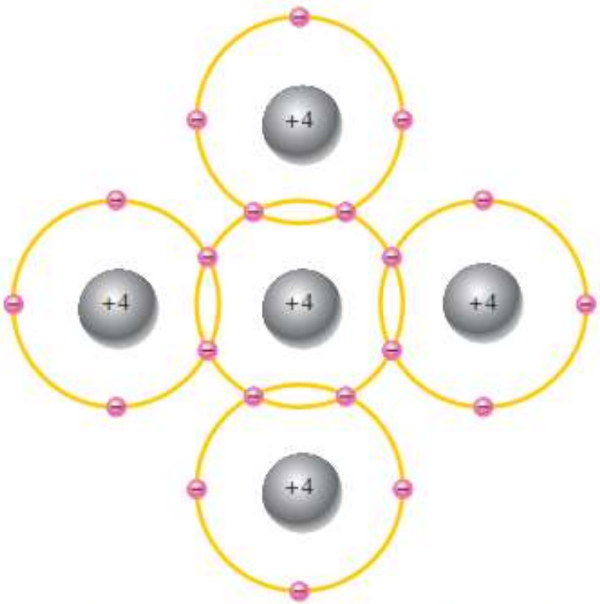
(a) Silicon atom (b) Copper atom

Covalent Bond

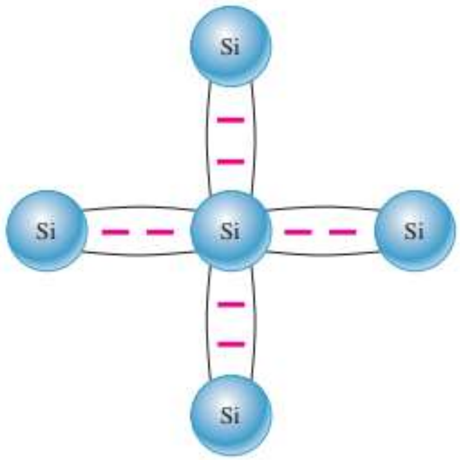
Each silicon atom positions itself with four adjacent silicon atoms to form a silicon crystal. A silicon (Si) atom with its four valence electrons shares an electron with each of its four neighbors. This effectively creates eight shared valence electrons for each atom and produces a state of chemical stability.

Also, this sharing of valence electrons produces the covalent bonds that hold the atoms together; each valence electron is attracted equally by the two adjacent atoms which share it.

Covalent Bond



(a) The center silicon atom shares an electron with each of the four surrounding silicon atoms, creating a covalent bond with each. The surrounding atoms are in turn bonded to other atoms, and so on.



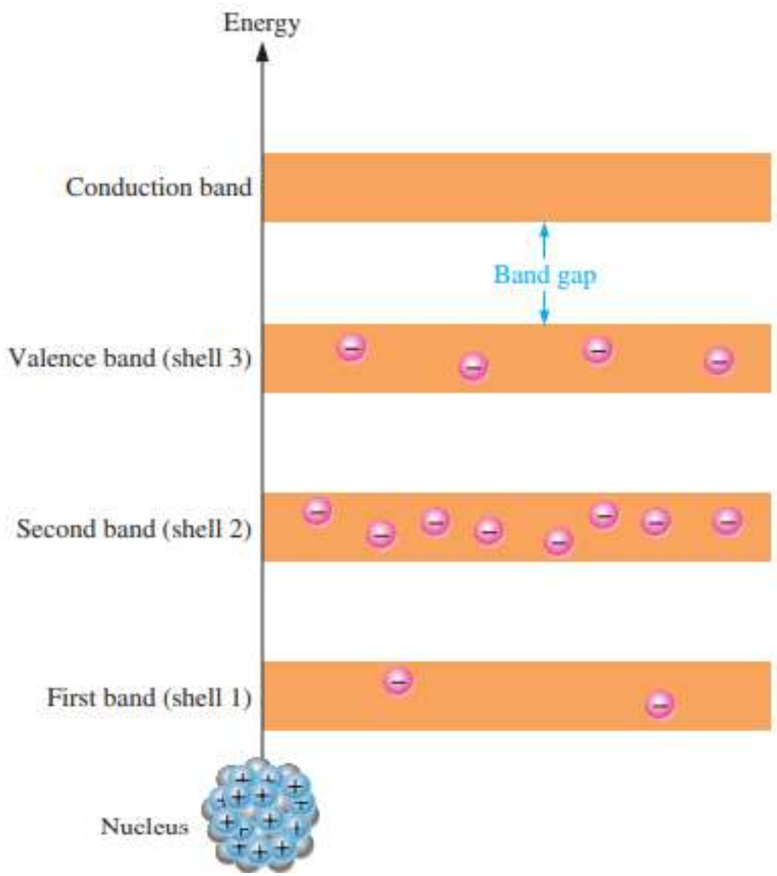
(b) Bonding diagram. The red negative signs represent the shared valence electrons.

Conduction in Semiconductors

The electrons of an atom can exist only within prescribed energy bands. Each shell around the nucleus corresponds to a certain energy band and is separated from adjacent shells by band gaps, in which no electrons can exist.

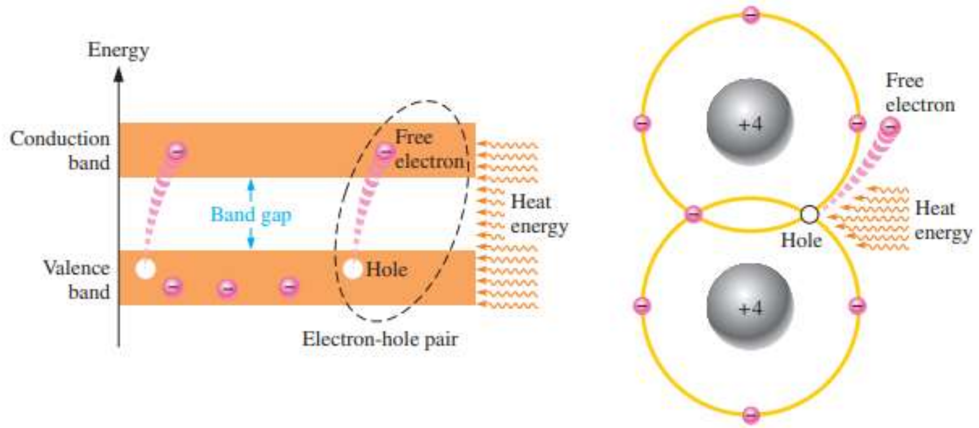
Figure on next slide shows the energy band diagram for an unexcited (no external energy such as heat) atom in a pure silicon crystal. This condition occurs only at a temperature of absolute 0 Kelvin

Conduction in Semiconductors



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

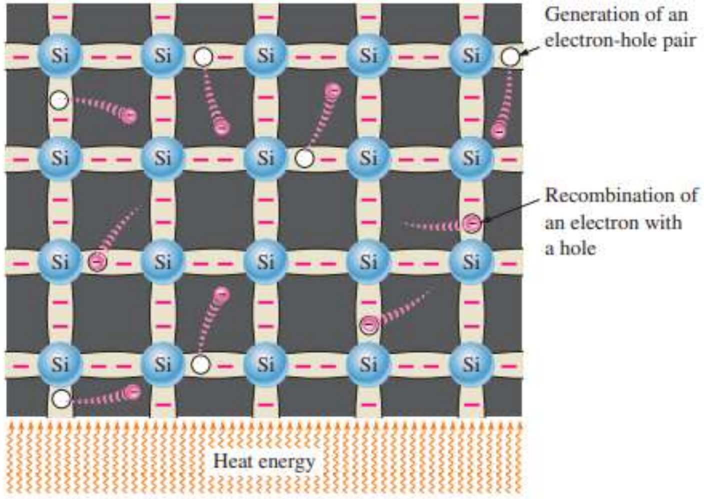
Conduction Electrons and Holes

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

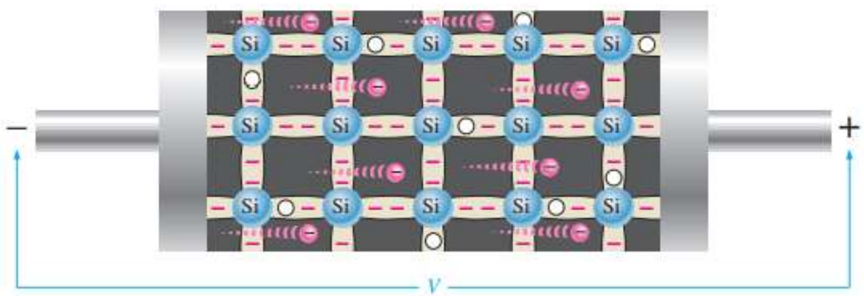
Conduction Electrons and Holes

To summarize, 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.



Electron And Hole 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.



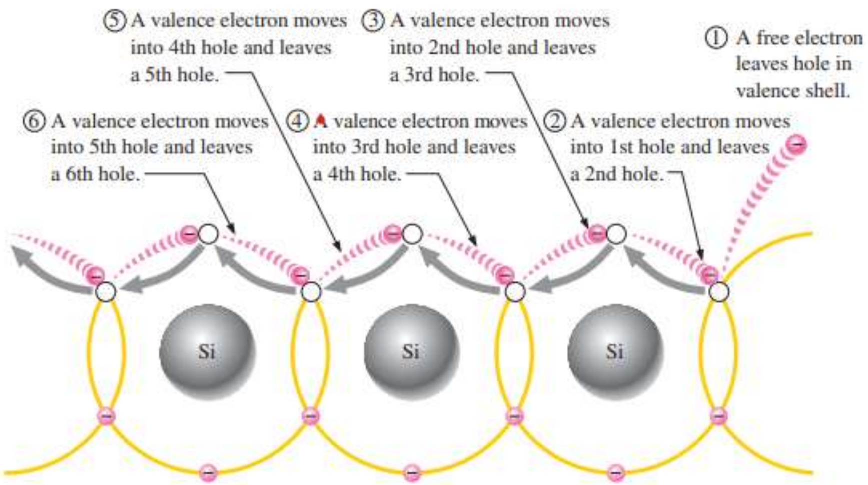
Electron And Hole Current

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

As you have seen, 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.



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.

N-Type and P-Type Semiconductors

Semiconductive materials do not conduct current well and are of limited value in their intrinsic state. This is because of the limited number of free electrons in the conduction band and holes in the valence band. Intrinsic silicon (or germanium) must be modified by

increasing the number of free electrons or holes to increase its conductivity and make it useful in electronic devices. This is done by adding impurities to the intrinsic material.

Two types of extrinsic (impure) semiconductive materials, n-type and p-type, are the key building blocks for most types of electronic devices.

Since semiconductors are generally poor conductors, their conductivity can be drastically increased by the controlled addition of impurities to the intrinsic (pure) semiconductive material. This process, called doping, increases the number of current carriers (electrons or holes). The two categories of impurities are n-type and p-type.

N-Type Semiconductors

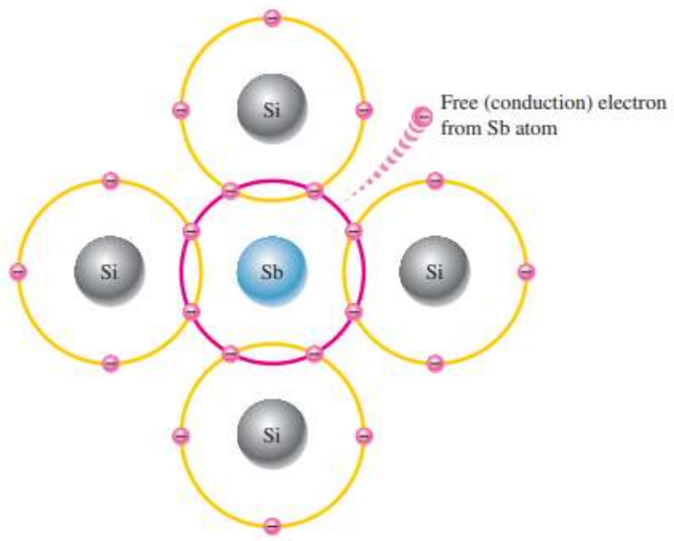
To increase the number of conduction-band electrons in intrinsic silicon, pentavalent impurity atoms are added. These are atoms with five valence electrons such as arsenic (As), phosphorus (P), bismuth (Bi), and antimony (Sb).

As illustrated in Figure, 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.

N-Type Semiconductors

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.



Majority and Minority Carriers

Since most of the current carriers are electrons, silicon (or germanium) doped with pentavalent atoms is an n-type semiconductor (the n stands for the negative charge on an electron). The electrons are called the majority carriers in n-type material.

Although the majority of current carriers in n-type material are electrons, there are also a few holes that are created when electron-hole pairs are thermally generated. These holes are not produced by the addition of the pentavalent impurity atoms. Holes in an n-type material are called minority carriers.

P-Type Semiconductors

To increase the number of holes in intrinsic silicon, trivalent impurity atoms are added. These are atoms with three valence electrons such as boron (B), indium (In), and gallium(Ga).

As illustrated in Figure, each trivalent atom (boron, in this case) forms covalent bonds with four adjacent silicon atoms. All three of the boron atom's valence electrons are used in the covalent bonds; and, since four electrons are required, a hole results when each trivalent atom is added. Because the trivalent atom can take an electron, it is often referred to as an acceptor atom

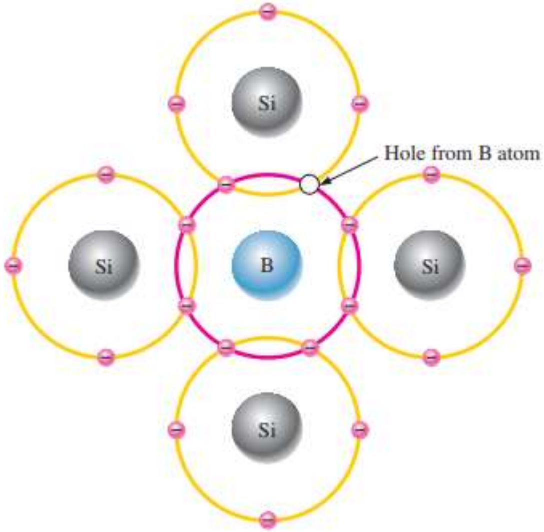
Majority and Minority Carriers

Since 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.

Majority and Minority Carriers

Since 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.

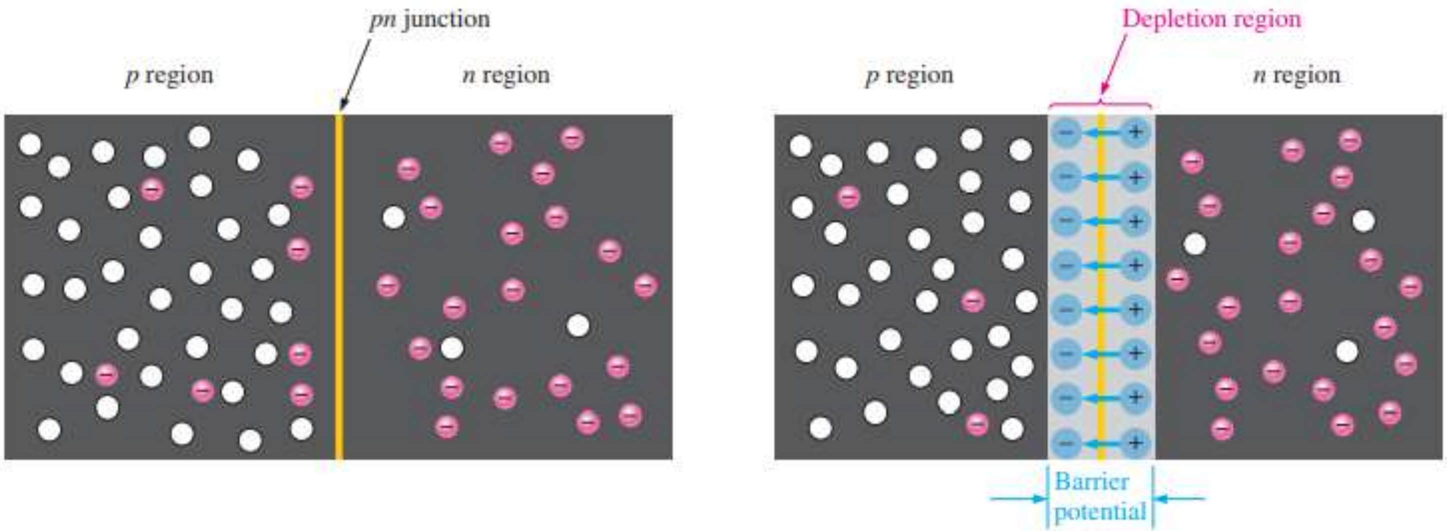


The PN Junction

When you take a block of silicon and dope part of it with a trivalent impurity and the other part with a pentavalent impurity, a boundary called the pn junction is formed between the resulting p-type and n-type portions.

The p region has many holes (majority carriers) from the impurity atoms and only a few thermally generated free electrons (minority carriers). The n region has many free electrons (majority carriers) from the impurity atoms and only a few thermally generated holes (minority carriers).

The PN Junction



(a) The basic silicon structure at the instant of junction formation showing only the majority and minority carriers. Free electrons in the *n* region near the *pn* junction begin to diffuse across the junction and fall into holes near the junction in the *p* region.

(b) For every electron that diffuses across the junction and combines with a hole, a positive charge is left in the *n* region and a negative charge is created in the *p* region, forming a barrier potential. This action continues until the voltage of the barrier repels further diffusion. The blue arrows between the positive and negative charges in the depletion region represent the electric field.

Formation of Depletion Region

Before the pn junction is formed, recall that there are as many electrons as protons in the n-type material, making the material neutral in terms of net charge. The same is true for the p-type material.

When the pn junction is formed, the n region loses free electrons as they diffuse across the junction. This creates a layer of positive charges (pentavalent ions) near the junction.

As the electrons move across the junction, the p region loses holes as the electrons and holes combine. This creates a layer of negative charges (trivalent ions) near the junction.

These two layers of positive and negative charges form the depletion region.

Formation of Depletion Region

After the initial surge of free electrons across the pn junction, the depletion region has expanded to a point where equilibrium is established and there is no further diffusion of electrons across the junction.

This occurs as follows. As electrons continue to diffuse across the junction, more and more positive and negative charges are created near the junction as the depletion region is formed. A point is reached where the total negative charge in the depletion region repels any further diffusion of electrons (negatively charged particles) into the p region (like charges repel) and the diffusion stops.

In other words, the depletion region acts as a barrier to the further movement of electrons across the junction.

Barrier Potential

The potential difference of the electric field across the depletion region is the amount of voltage required to move electrons through the electric field. This potential difference is called the barrier potential and is expressed in volts.

Stated another way, a certain amount of voltage equal to the barrier potential and with the proper polarity must be applied across a pn junction before electrons will begin to flow across the junction.

The barrier potential of a pn junction depends on several factors, including the type of semiconductive material, the amount of doping, and the temperature. The typical barrier potential is approximately 0.7 V for silicon and 0.3 V for germanium at 25’C.