Syllabus – Semiconductor Basics

Atomic structure - Bohr atom model - energy levels - energy bands -important energy band in solids- classification of solids and energy bands - Basics of Semiconductor.

Atomic Structure

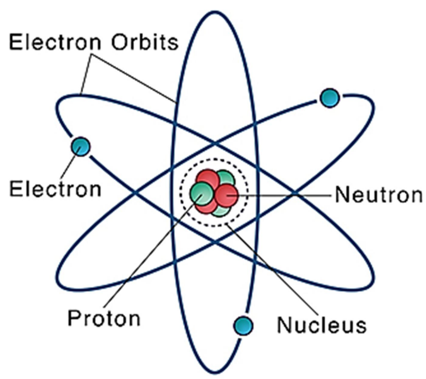
Introduction

Atomic structure is the structure of an atom that consists of a nucleus at the canter containing neutrons and protons, while electrons are revolving around the nucleus.

Atom

Atoms are the building blocks of matter. Atoms are extremely small particles. The term 'atom' was derived from the Greek word 'atomos', meaning 'indivisible'.

Structure of an atom



Subatomic Particles of an Atom

Atom contains the following sub-atomic particles within it that are:

➨Proton ➨Neutron ➨Electron

Protons and Neutrons Combine To Form the Nucleus.

Proton

Ernest Rutherford discovered protons. The proton is a positively charged particle that is located in the nucleus of the atom. The number of protons in an atom referred as the element's atomic number.

Neutron

A neutron is an atom's neutral nucleus with no electric charge and a slightly larger mass than a proton. The number of neutrons in an atom influences its mass and radioactivity. It was discovered by James Chadwick, a British physicist.

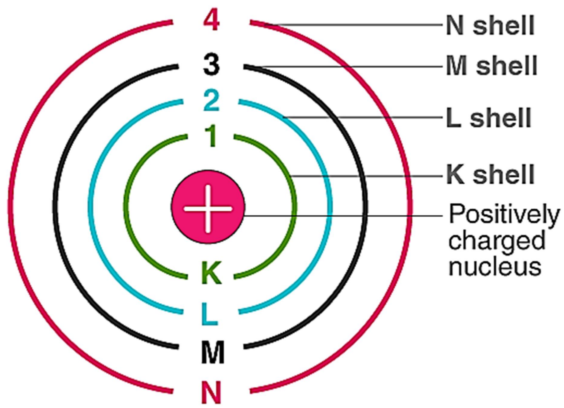
Electron

The electron is a negatively charged particle that revolves around the nucleus. When an atom has the same number of electrons and protons, it is said to be neutrally charged. The positive charge of the protons attracts electrons to the nucleus. Neutrons and protons are much smaller than electrons.

Bohr's atom model

Neils Bohr's devised a model in 1913 in order to overcome the objections that Rutherford's model raised. This atomic model is used to describe the atomic structure of atom which is based on Planck's theory of quantization.

Atomic Model



Postulates

- Electrons revolve around the nucleus in a circular path termed "orbits" or "shells" or "energy level." The orbits are termed as "stationary orbit."
- Electrons can only revolve in certain discrete orbit & orbits with non-radiating energy. Discrete orbits refer to the specific energy levels that electrons occupy in an atom. Non-radiating energy orbits are also called as stationary orbits.
- When an electrons jumps from one energy level to another, it either emits or absorbs an energy equal to the difference in energy between the levels.

  Difference in energy $\Delta E = E_2 - E_1 = hv$

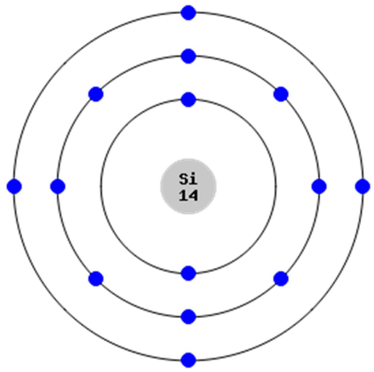
  where, E_1 – Energy of lower orbit, E_2 – Energy of higher orbit

  h = Planck's constant, v = frequency
- As long as the electron remains in an orbit, it neither absorbs nor emits energy.
- The orbits are having different energy levels denoted as K, L, M, N.
- Maximum number of electrons in an orbit = $2n^2$

  Where n=1, 2, 3, 4.

  K can have maximum of 2 electrons. (i.e) $K = 2 \times 1^2 = 2$

  Similarly $L = 2 \times 2^2 = 8$, $M = 2 \times 3^2 = 18$, $N = 2 \times 4^2 = 32$.



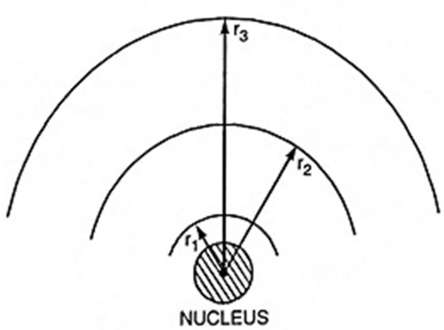
For Ex: **Silicon atom** has 14 electrons
Structure: Silicon atom

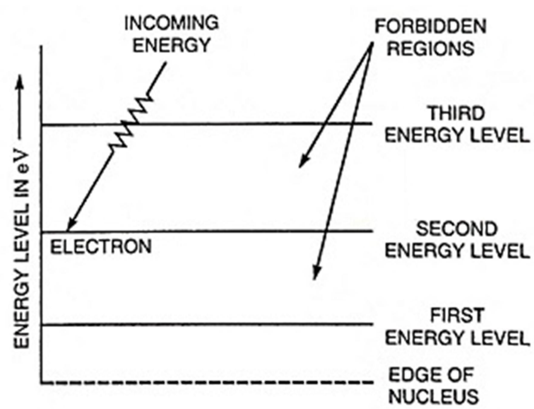
Two electrons revolve in the first orbit
Eight electrons revolve in the second orbit.
Four electrons revolve in the third orbit

Energy levels

An energy level diagram is also known as an energy level scheme or a level diagram. It is a graphical representation of the energy levels of an atom. The level of energy obtainable with different electron orbits can be represented by horizontal lines is known as energy level diagram. The energy level diagram is a useful tool for understanding the behaviour of atoms in different conditions and for predicting their spectroscopic properties.

Energy Level Diagram





Description

The first orbit represents the first energy level; the second orbit represents the second energy level and so on. The larger the orbit of an electron, the greater is its energy. Thus energy level is just another way of representing the orbital radius. The electrons in the shell close to the nucleus are called bound electrons. The energy levels considered above are measured in electron volts (eV). The range of energies possessed by an electron in a solid is known as energy band.

Between each energy level a forbidden region exists. Electrons cannot orbit in forbidden regions. However, they may quickly pass them. If electrons in a particular orbit acquire enough energy from an external electric field or thermal energy, they will jump to a high energy level by passing quickly through the forbidden region. A definite amount of energy is required to be spent in order to remove an electron from its orbit.

Excited electrons are unstable, and they tend to fall back to low energy level by giving up their additional energy. The electrons that do leave their parent atom are termed free electrons.

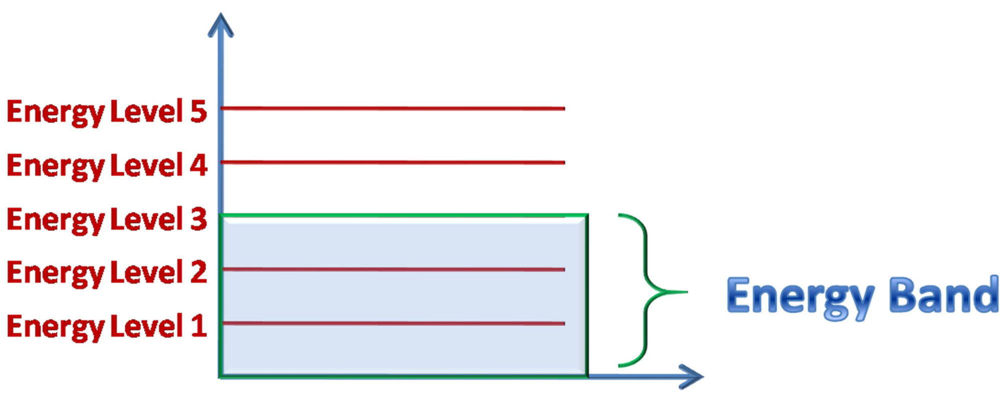
1.

Energy band

The electrons in the same orbit exhibit different energy levels. The grouping of these different energy levels is known as the energy band.

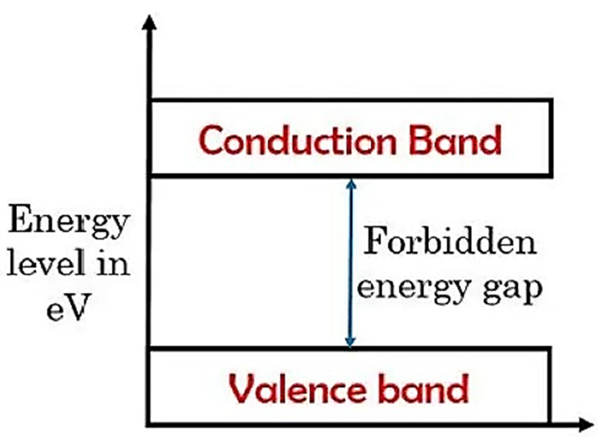
Each orbit has a fixed amount of energy associated with it. The electrons moving in a particular orbit possess the energy of that orbit. The larger the orbit, the greater is its energy. The outer orbit electrons possess more energy than the inner orbit electron. The range of energies possessed by an electron in a solid is known as energy band.

Energy band Structure



Energy Band is a collection of energy levels.

Energy band diagram



An energy band diagram, also known as a band structure, is a graphical representation of the allowed energy levels for electrons in a solid material. It shows the range of energies that electrons are allowed to have within a given material, and how these energy levels are separated by energy gaps. These energy gaps can be used to classify materials as conductors, semiconductors, or insulators.

2.

Important Energy Band in Solids

The energy level of higher orbit electron will leads to formation of energy band. The formation of band mainly depends upon the outermost electrons of atoms therefore these electrons describe the materials properties like electrical conductivity.

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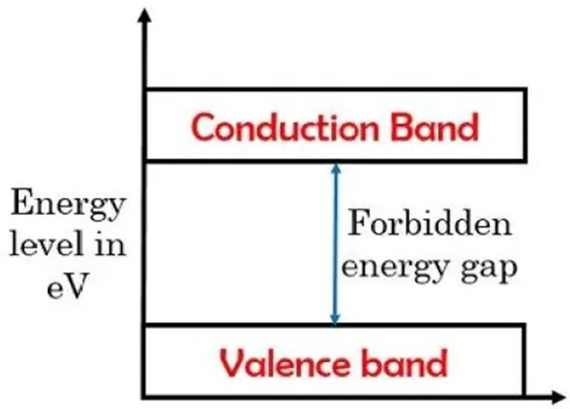
Energy band diagram



Description

Valence Band

Valence Band is defined as the energy band that consists of valence electrons. The electrons in the outer most orbit of an atom are called valence electrons. These valence electrons, when provided with sufficient energy, get changed into free electrons and moves to conduction band thereby causing conductivity. It is at a lower energy level than the conduction band in the energy level diagram. It may be either completely filled or partially filled, but can never be empty.

Conduction Band

A conduction band is defined as that energy band that consists of free electrons that are responsible for conduction. The electrons which have left the valence band are called conduction electrons. This band is above the Fermi energy level i.e. is at higher energy state. Thus the valence electrons require a large amount of excitation energy to reach conduction band thereby giving rise to electric current. It may be either empty or partially filled with electrons.

Forbidden energy gap

The gap between valence band and conduction band is called as **forbidden energy gap**. As the name implies, this band is the forbidden one without energy. Hence no electron stays in this band. The valence electron is going to the conduction band through forbidden energy gap.

The forbidden energy gap if greater means that the valence band electrons are tightly bound to the nucleus. Now, in order to push the electrons out of the valence band, some external energy is required, which would be equal to the forbidden energy gap.

3.

Classification of Solids and Energy Bands

Depending upon the size of the forbidden gap and level of conductivity, the Insulators, the Semiconductors and the Conductors are formed.

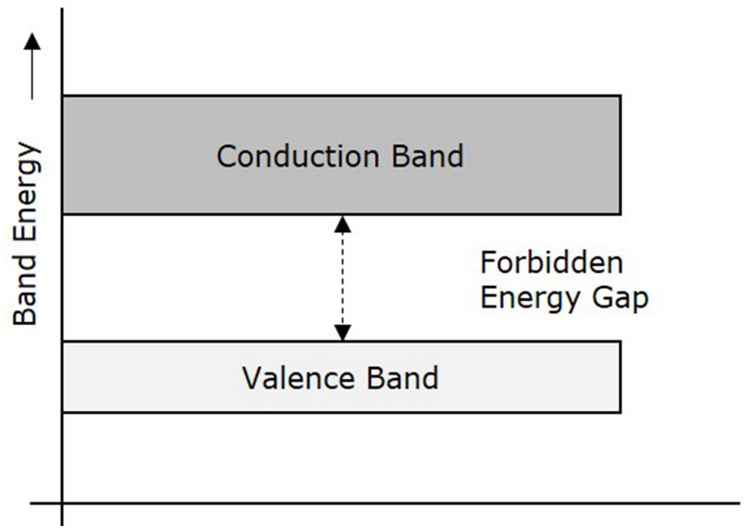
Insulators

Insulators are materials that do not allow electrical current to flow through them easily. It has low conductivity. Since, it offers very high resistance to the flow of electrons; the electrons cannot be travel through these materials. Hence they are known as the insulators, generally, non-metals are the insulators.

Eg. Rubber, Glass, wood, etc.

Insulators are used in making wires, for Electrical appliances like iron, oven, etc.

Structure of Energy Band



Characteristics

- The Forbidden energy gap is very large.
- Valance band electrons are bound tightly to atoms.
- The value of forbidden energy gap for an insulator will be of 10eV.
- For some insulators, as the temperature increases, they might show some conduction.

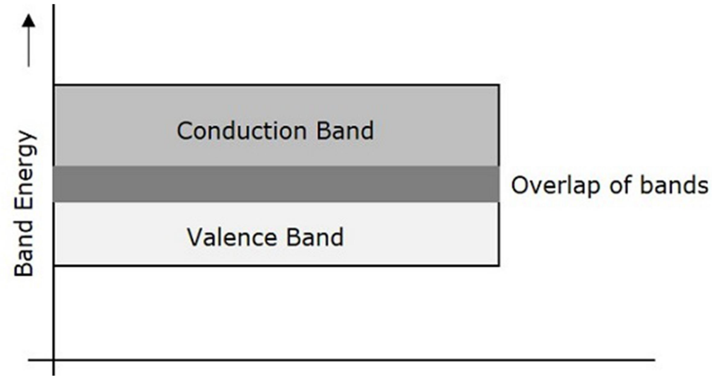
Conductors

A conductor is a material that allows the current to pass through it. Since, it offers very negligible resistance to the flow of electrons, the electrons can be easily travelled through these materials. It has a high conductivity. Generally, metals are the conductors.

Eg. Copper, Silver and gold.

Conductors are mainly used in the Electrical appliances.

Structure of Energy Band



Characteristics

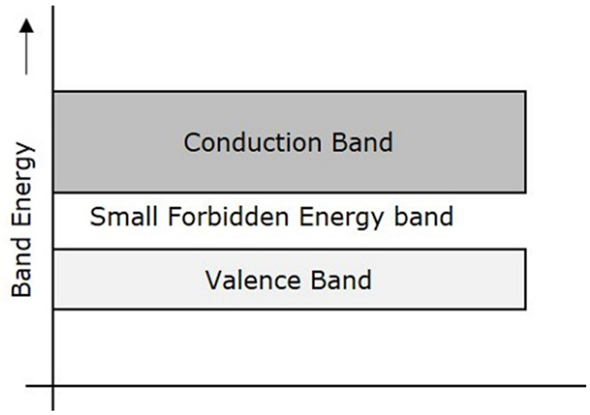
- There exists no forbidden gap in a conductor.
- The valance band and the conduction band gets overlapped.
- The free electrons available for conduction are plenty.
- A slight increase in voltage increases the conduction.

Semiconductors

Semiconductors are known as the 'Brains of Modern Electronics. Semiconductors are materials with conductivity between conductors and insulators. They are partially conducting. These materials have a moderate gap between valence layer and conduction layer.

It is used in electronic devices such as transistors, diodes, and integrated circuits. It also includes materials like silicon and germanium.

Structure of Energy Band



Characteristics

- The Forbidden energy gap is very small.
- The forbidden gap for Ge is 0.7eV whereas for Si is 1.1eV.
- A Semiconductor actually is neither an insulator, nor a good conductor.
- As the temperature increases, the conductivity of a semiconductor increases.

Basics of Semiconductor

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Types of semiconductors

Semiconductors are divided into two types:

- ➨ Intrinsic Semiconductors
- ➨ Extrinsic Semiconductors

Intrinsic semiconductors

A pure semiconductor in which no impurities are added is called an intrinsic semiconductor. It is made up of only a single type of element.

Examples: Germanium (Ge), Silicon (Si), etc.

Extrinsic semiconductors

A semiconductor in an impure form is known as an extrinsic semiconductor. Conductivity can be improved by adding impurities in extrinsic Semiconductors. The method of adding an impurity atom into a pure semiconductor is known as doping.

Extrinsic semiconductors are divided into two categories –

- ➨N-type semiconductor
- ➨P-type semiconductor

N-type Semiconductor

When a small amount of pentavalent impurities like arsenic, phosphorus etc. is added to a pure semiconductor, it is called as n-type semiconductor.

P-type Semiconductor

When a small amount of trivalent impurities like aluminium, gallium, boron etc. is added to a pure semiconductor, it is called P-type semiconductor.

Importance of semiconductors in daily life

Semiconductors are used in

- ➨ designing logic gates, digital circuits, and analogue circuits like oscillators and amplifiers.
- ➨ temperature sensors of air conditioners.
- ➨ Solar plates.
- ➨ 3D printers and microchips.
- ➨ Computers, calculators, mobile phones and other electronic gadgets.