Lecture 4

Electrical Basics

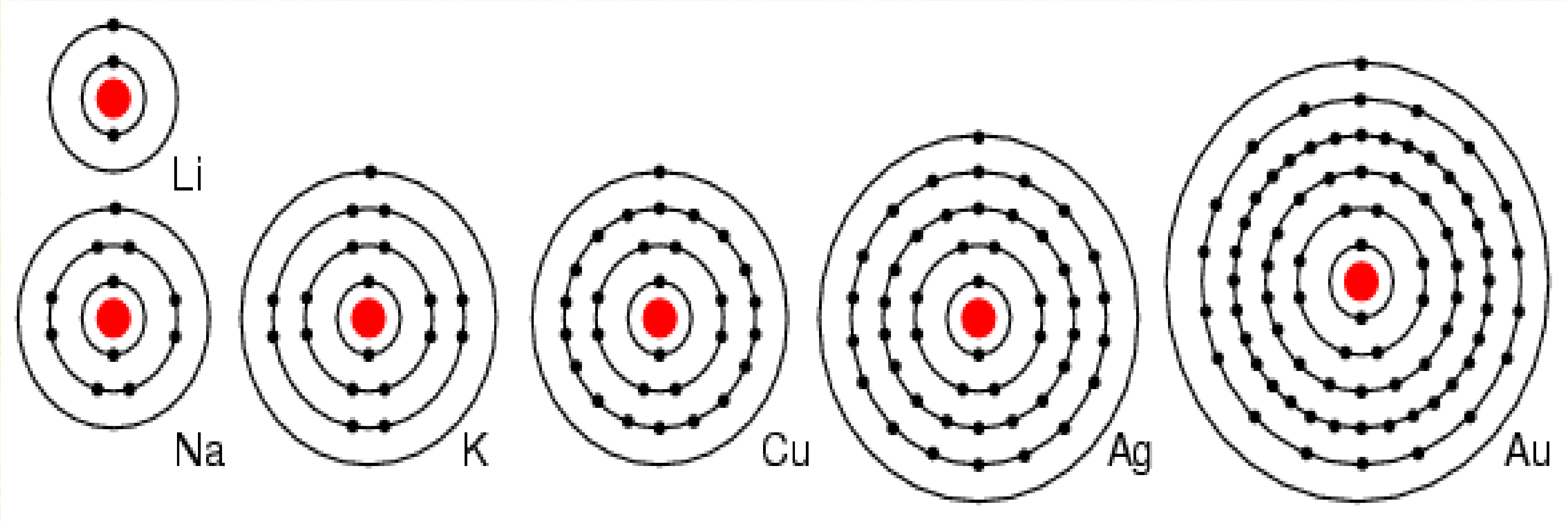
Semiconductor

Diode

Transistors

Semiconductor

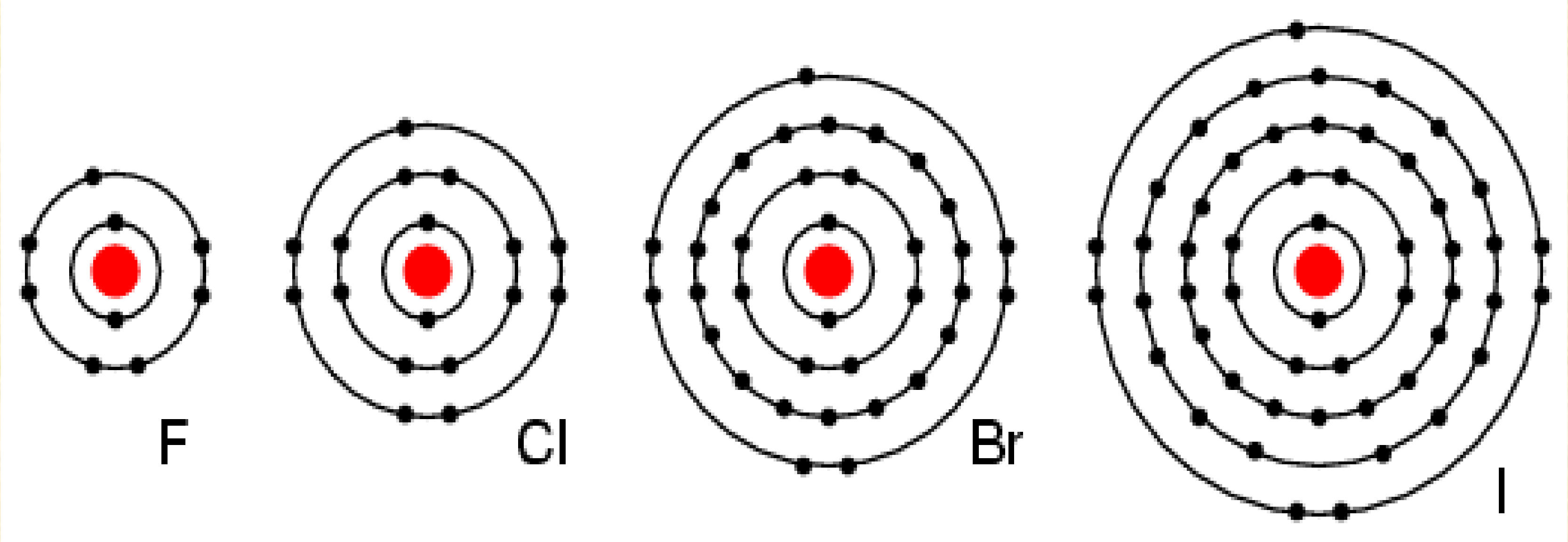
Conductors



Li, Na, K, Cu, Ag, and Au have a single valence electron. These elements all have similar chemical properties. These atoms readily give away one electron to react with other elements. The ability to easily give away an electron makes these elements excellent conductors.

Semiconductor

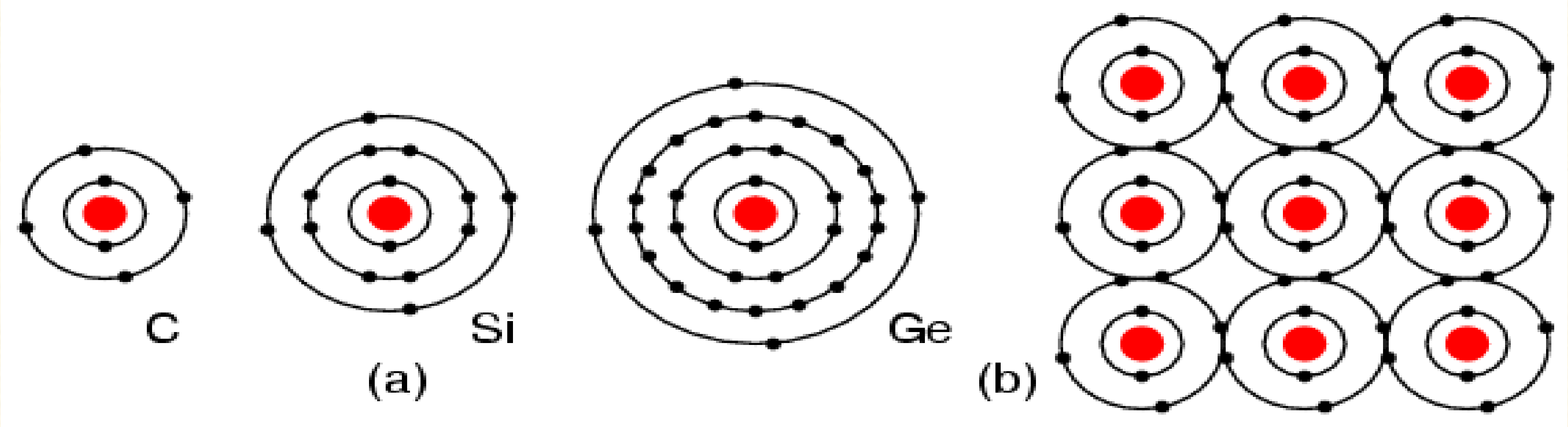
Insulators



Fl, Cl, Br, and I all have 7 electrons in the outer shell. These elements readily accept an electron to fill up the outer shell with a full 8 electrons. If these elements do accept an electron, a negative ion is formed from the neutral atom. These elements which do not give up electrons are insulators.

Semiconductor

Semiconductors

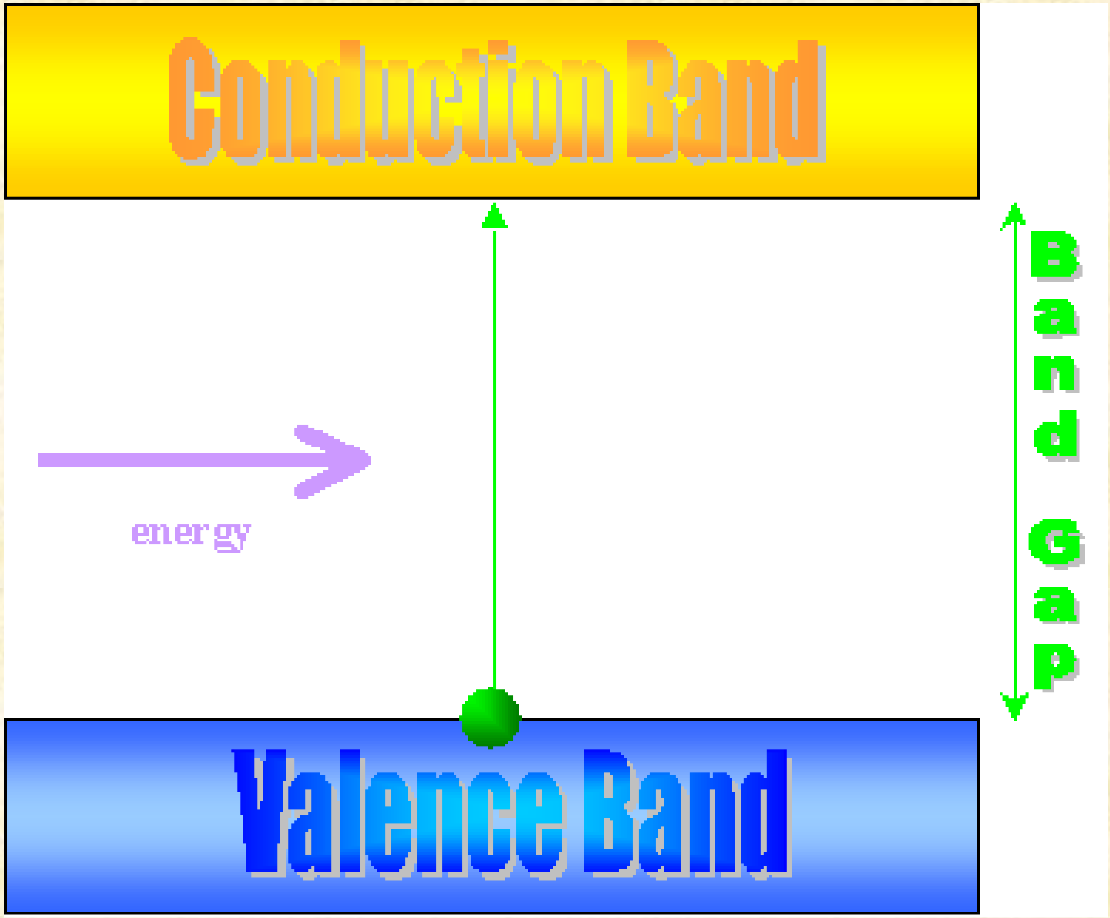


C, Si, Ge, having 4 electrons in the valence shell, form compounds by sharing electrons with other elements without forming ions. This shared electron bonding is known as covalent bonding.

Semiconductors are materials that contain exactly four electrons in the outer orbit of their atom structure and are, therefore, neither good conductors nor good insulators.

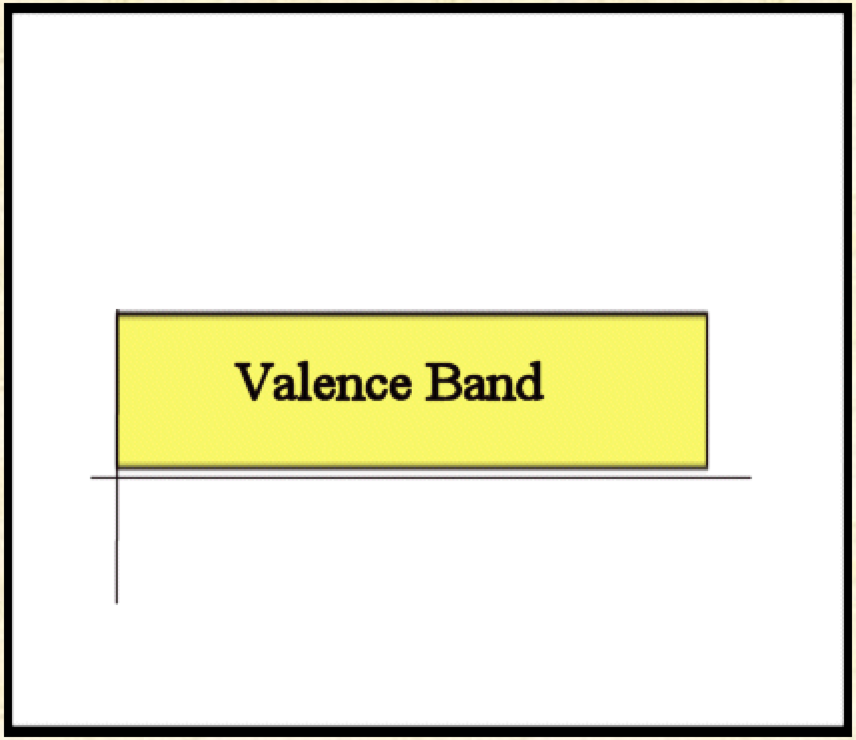
Semiconductor

Scientific Principle of Conduction



Semiconductor

Valence Band

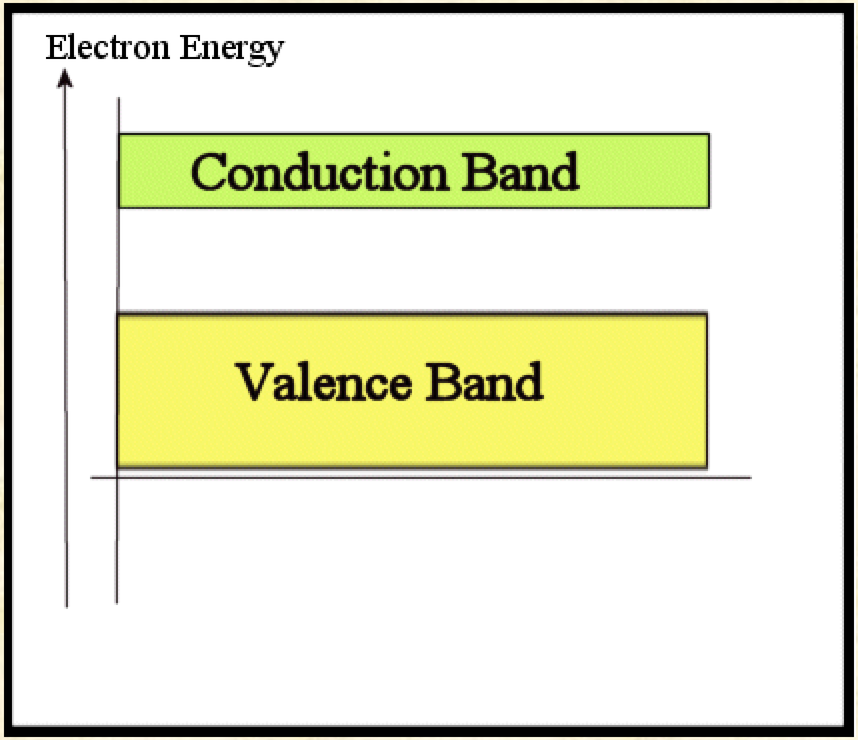


The highest occupied energy band is called the valence band.

Most electrons remain bound to the atoms in this band.

Semiconductor

Conduction Band

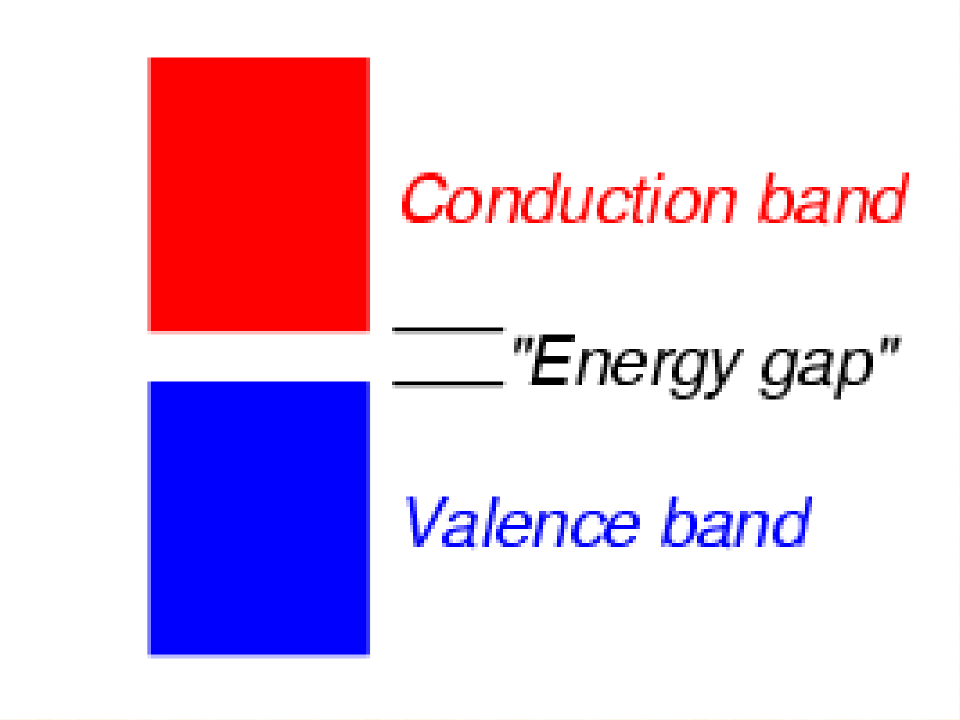


The conduction band is the band of orbitals that are high in energy and are generally empty.

It is the band that accepts the electrons from the valence band.

Semiconductor

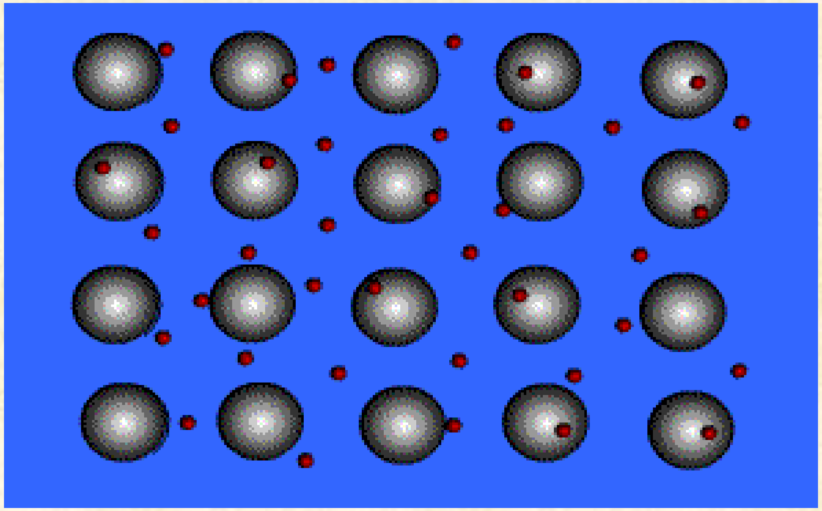
Energy Gap

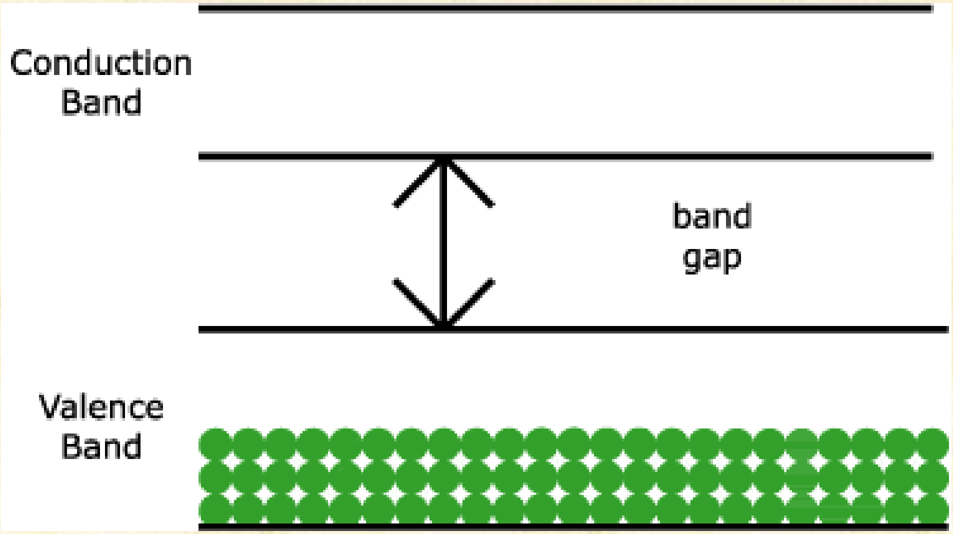


The “leap” required for electrons from the Valence Band to enter the Conduction Band.

Semiconductor

Conductors





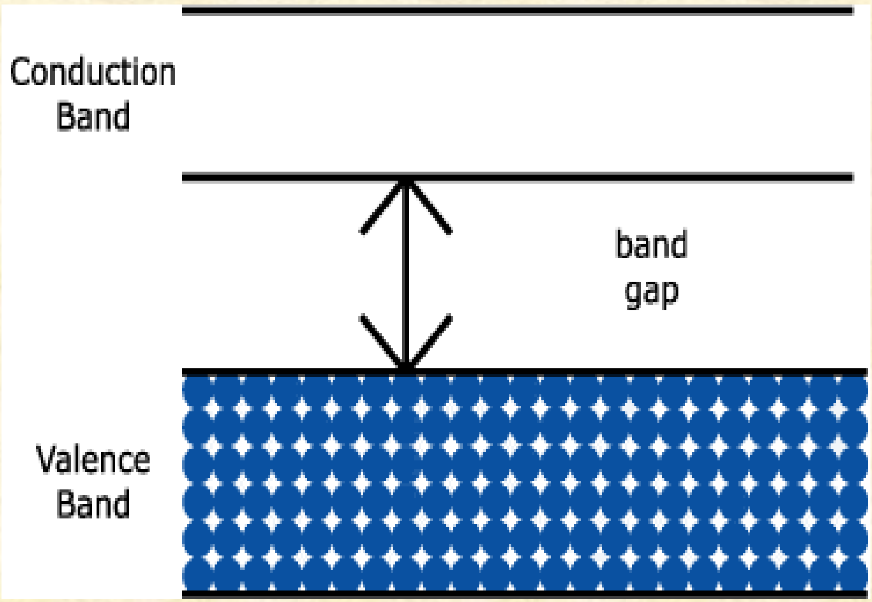
In a conductor, electrons can move freely among these orbitals within an energy band as long as the orbitals are not completely occupied.

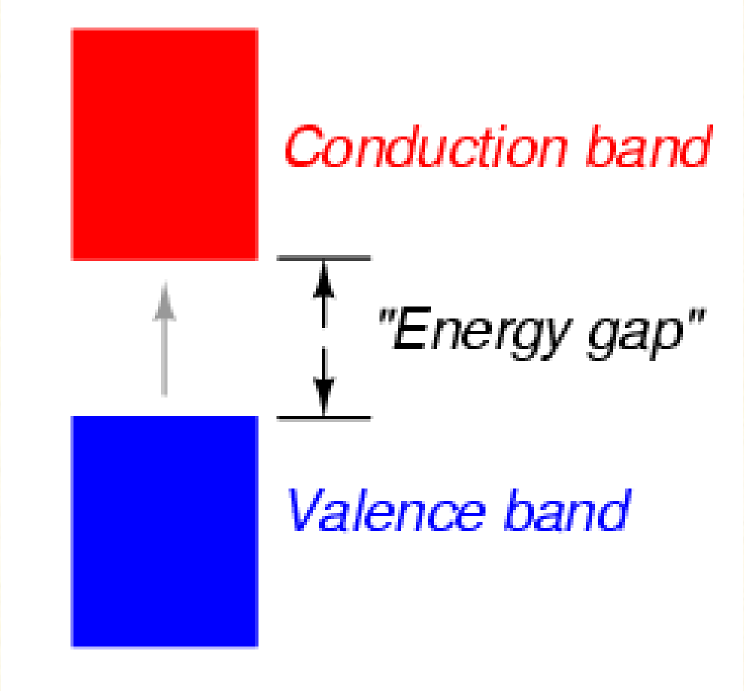
In conductors, the valence band is empty.

Also in conductors, the energy gap is nonexistent or relatively small.

Semiconductor

Insulators



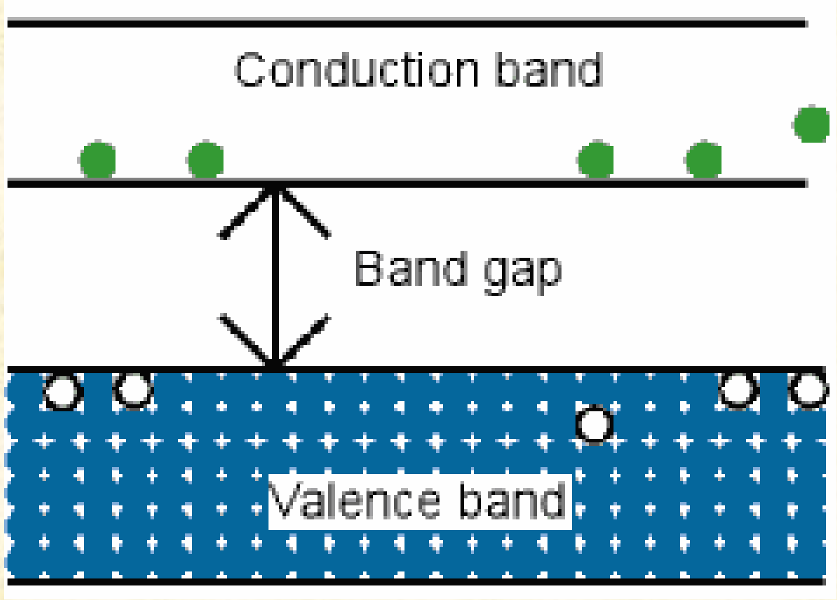


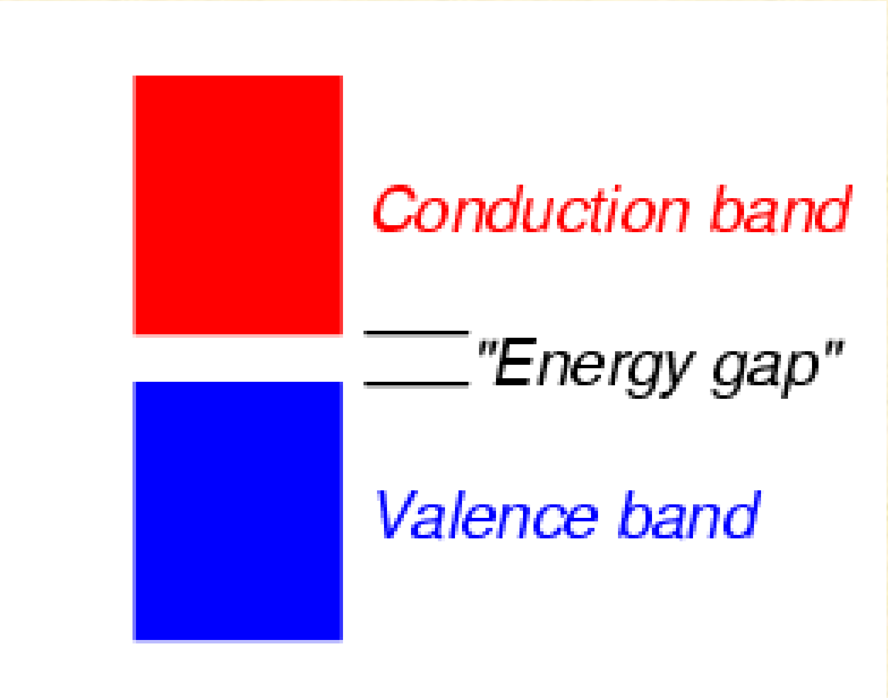
In insulators, the valence band is full.

Also in insulators, the energy gap is relatively large.

Semiconductor

Semiconductors



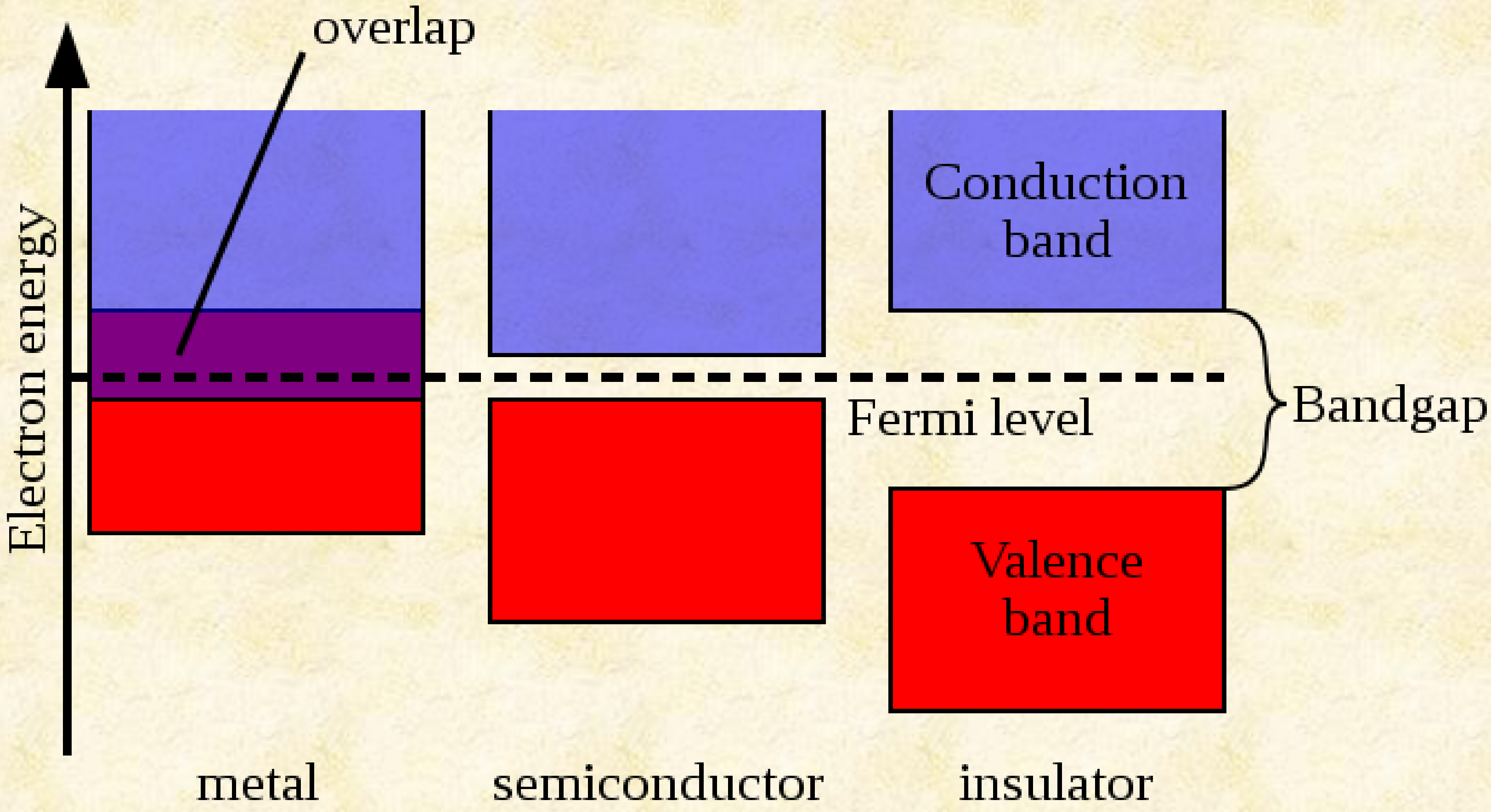


In semiconductors, the valence band is full but the energy gap is intermediate.

Only a small leap is required for an electron to enter the Conduction Band.

Semiconductor

Band Diagrams

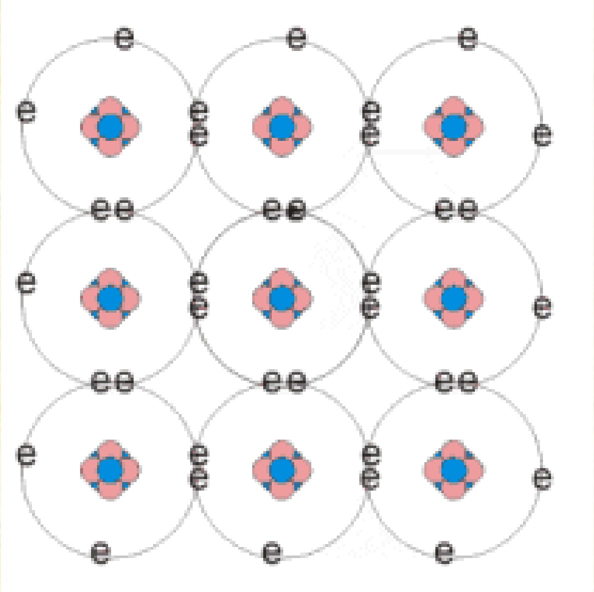


Semiconductor

- e.g. silicon or germanium
- at very low temperatures these have the properties of insulators
- as the material warms up some electrons break free and can move about, and it takes on the properties of a conductor - albeit a poor one
- however, semiconductors have several properties that make them distinct from conductors and insulators

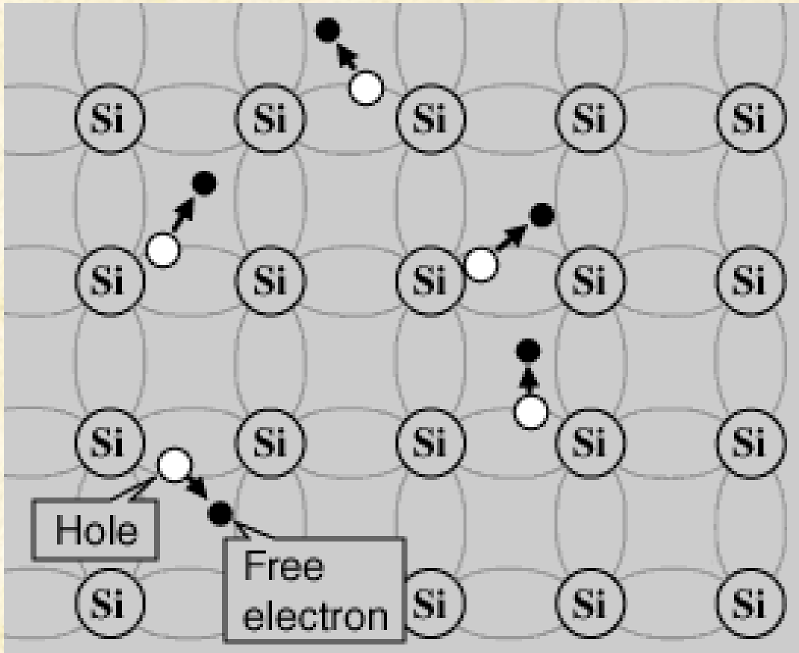
Semiconductor

Intrinsic Silicon



A silicon crystal is different from an insulator.

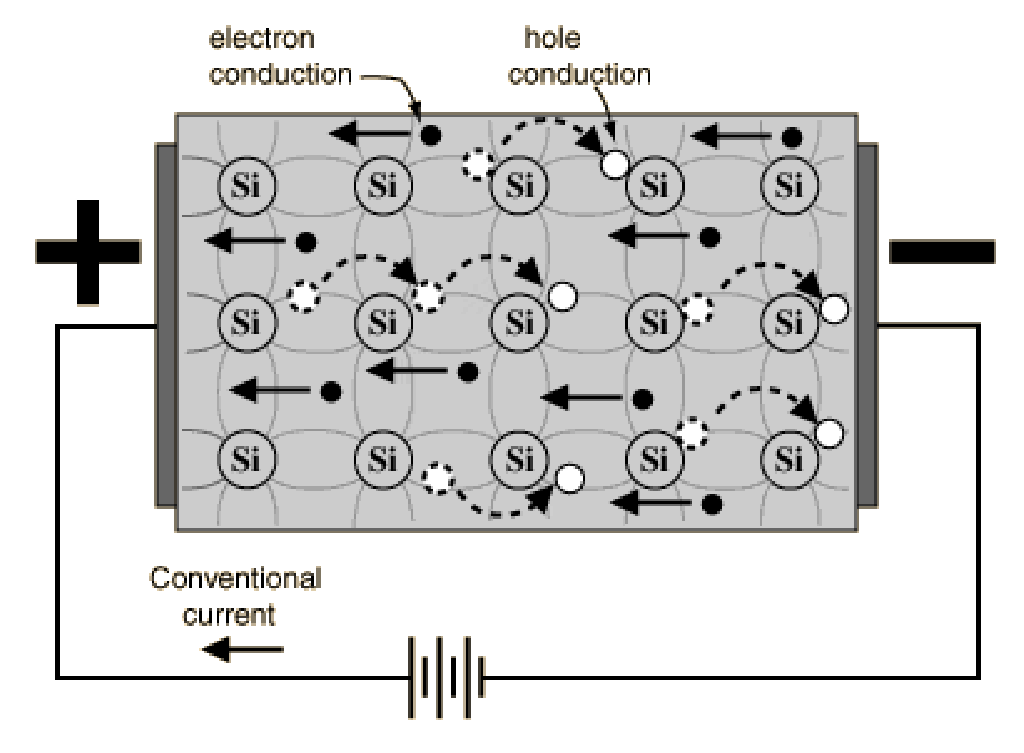
At any temperature above absolute zero temperature, there is a finite probability that an electron in the lattice will be knocked loose from its position.



The electron in the lattice knocked loose from its position leaves behind an electron deficiency called a "hole".

Semiconductor

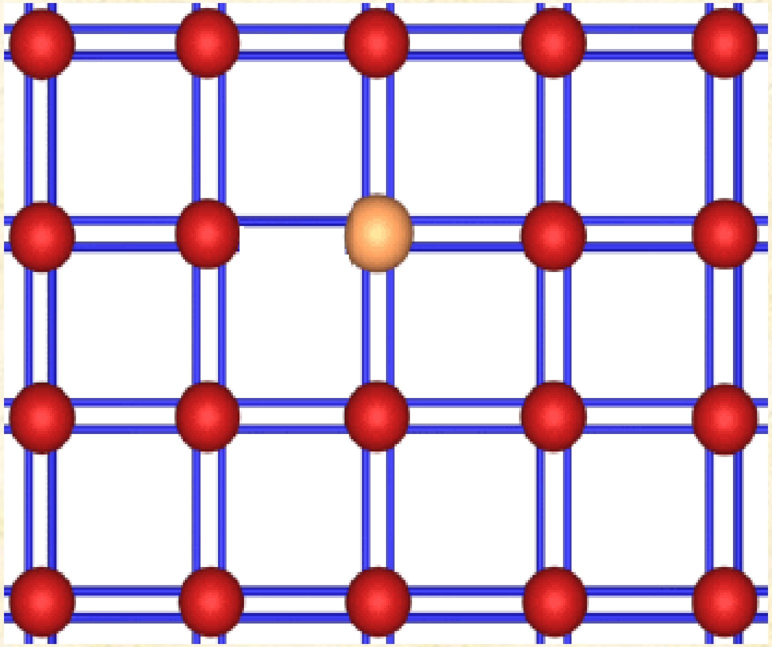
Current Flow



If a voltage is applied, then both the electron and the hole can contribute to a small current flow.

Semiconductor

Doping



The conductivity of the intrinsic semiconductor can be increased by adding small amount of impurities. The process of adding impurities to the intrinsic (pure) semiconductor is called **doping**. The doped semiconductor is then called extrinsic (impure) semi conductor

Semiconductor

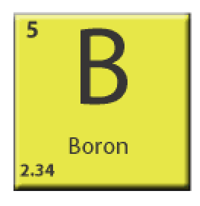
Extrinsic Semi Conductor:

- The conductivity of the intrinsic semiconductor can be increased by adding small amount of impurities. The process of adding impurities to the intrinsic (pure) semiconductor is called **doping**. The doped semiconductor is then called extrinsic (impure) semi conductor.

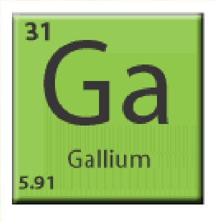
- Depending on the dopant (impurity) used, extrinsic semi conductor can be divided in to two classes.

- N-type Semi conductor.
- P-type Semi conductor.

P-Type Doping

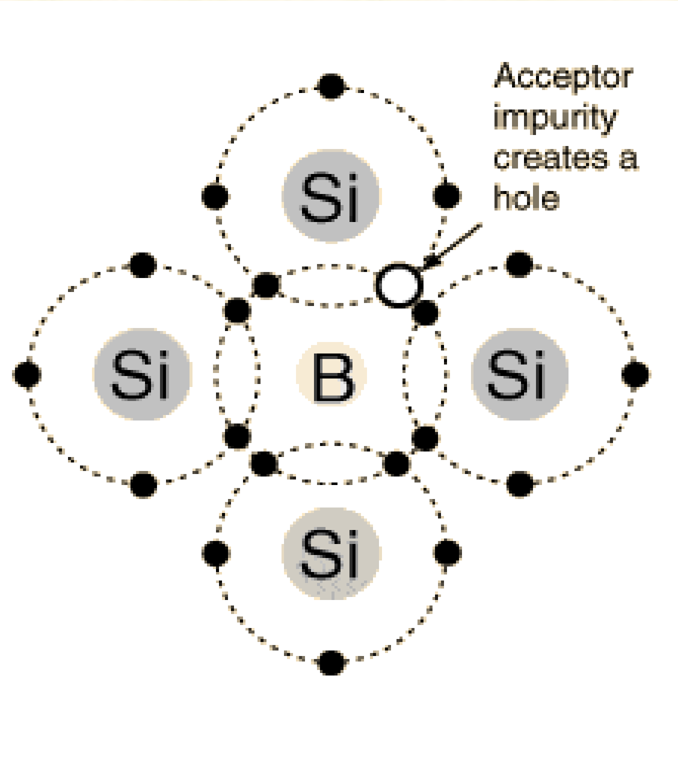


In P-type doping, boron or gallium is the dopant.

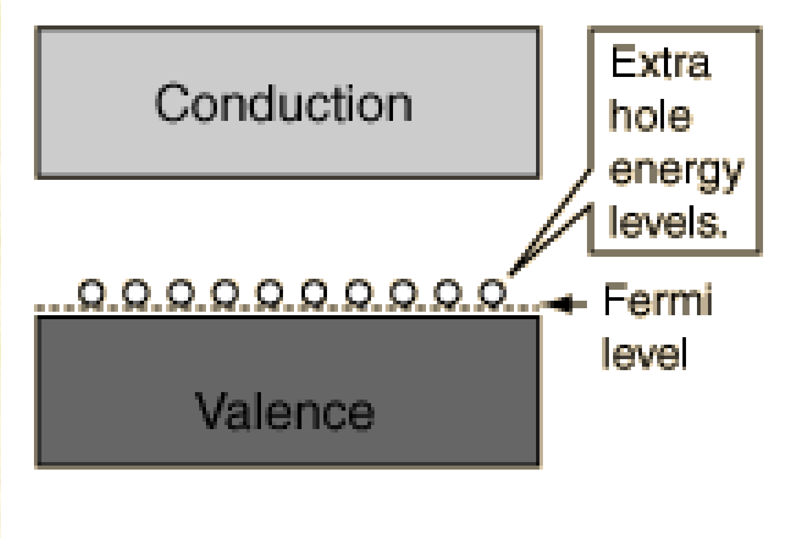


Boron and gallium each have only three outer electrons.

When mixed into the silicon lattice, they form "holes" in the lattice where a silicon electron has nothing to bond to.



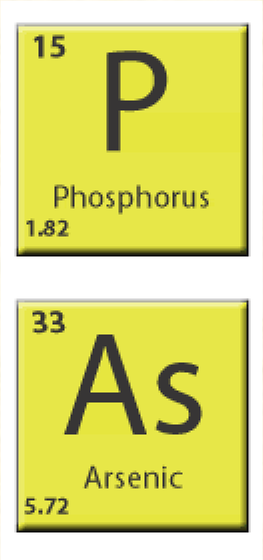
P-Type Doping



The absence of an electron creates the effect of a positive charge, hence the name P-type.

Holes can conduct current. A hole happily accepts an electron from a neighbor, moving the hole over a space. P-type silicon is a good conductor.

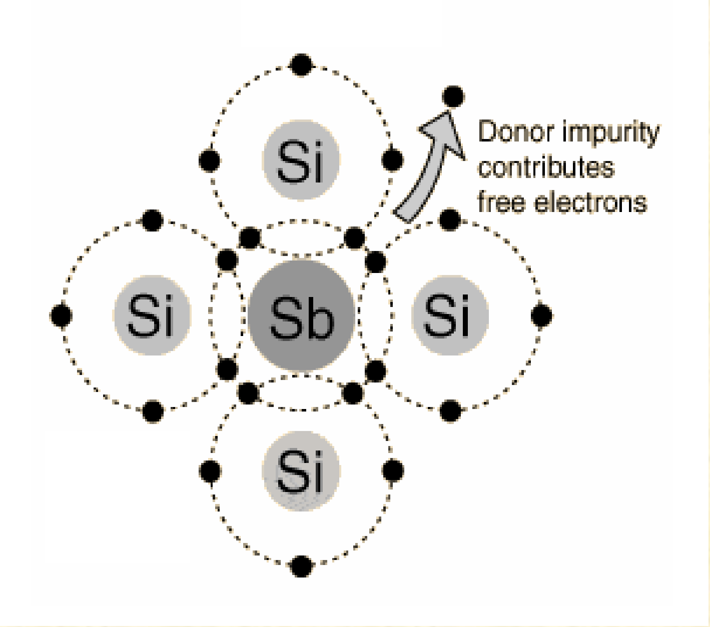
N-Type Doping



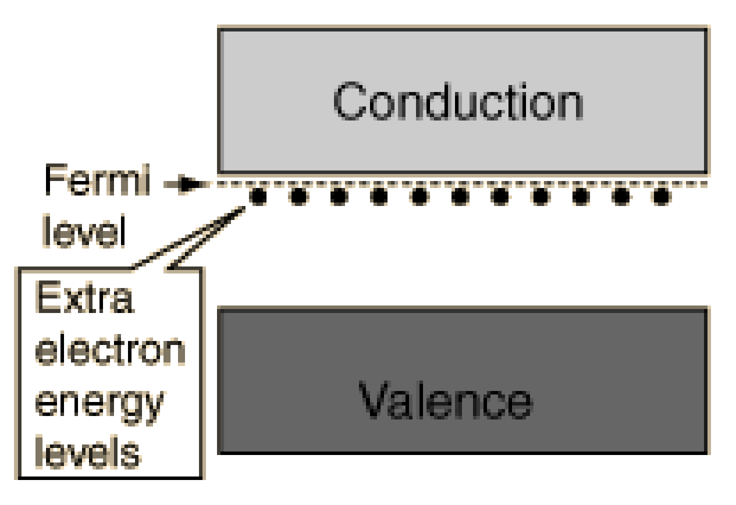
In N-type doping, phosphorus or arsenic is added to the silicon in small quantities.

Phosphorus and arsenic each have five outer electrons, so they're out of place when they get into the silicon lattice.

The fifth electron has nothing to bond to, so it's free to move around.



N-Type Doping



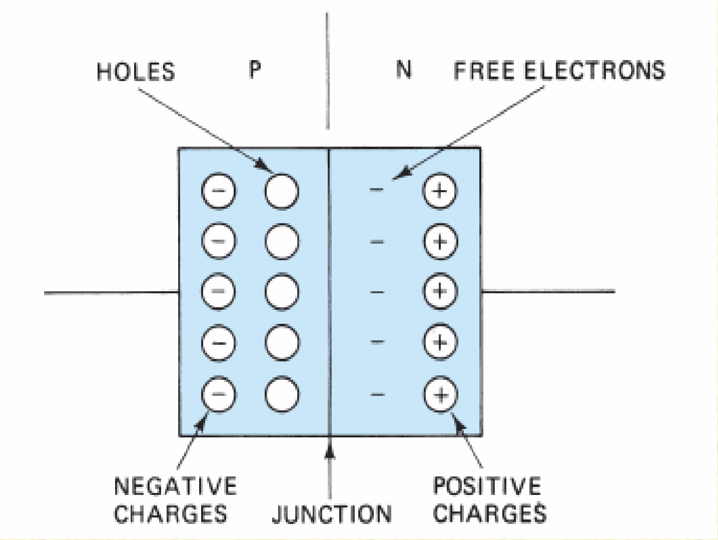
It takes only a very small quantity of the impurity to create enough free electrons to allow an electric current to flow through the silicon. N-type silicon is a good conductor.

Electrons have a negative charge, hence the name N-type.

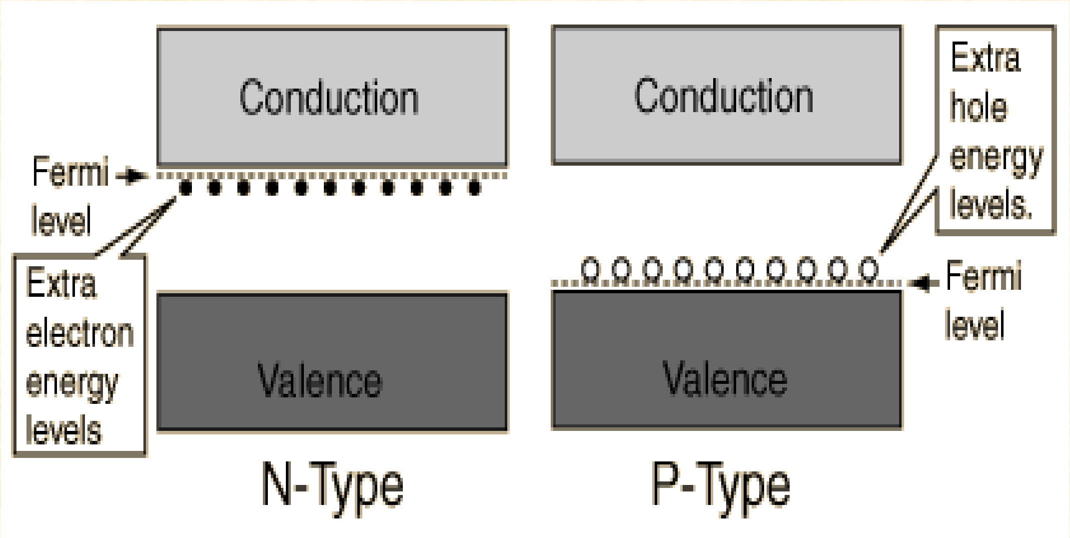
HOW HOLES MOVE

- Current flow is expressed as the movement of electrons from one atom to another.
- In semiconductor and electronic terms, the movement of electrons fills the holes of the P-type material.
- Therefore, as the holes are filled with electrons, the unfilled holes move opposite to the flow of the electrons.
- This concept of holes movement is called the **hole theory** of current flow.

The holes move in the direction opposite that of electron flow.

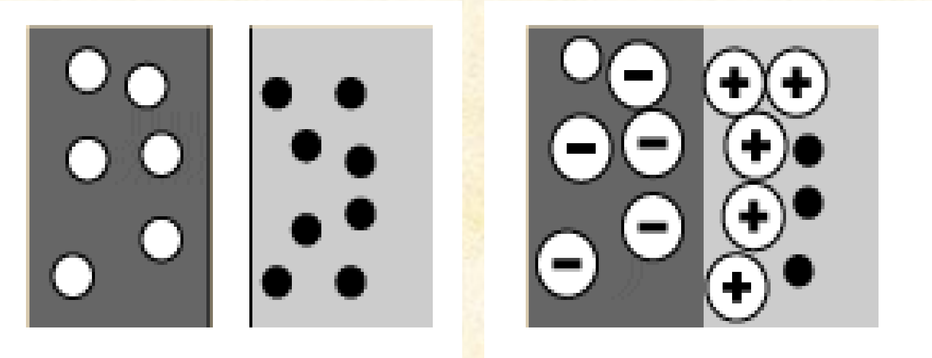


P-N Junction

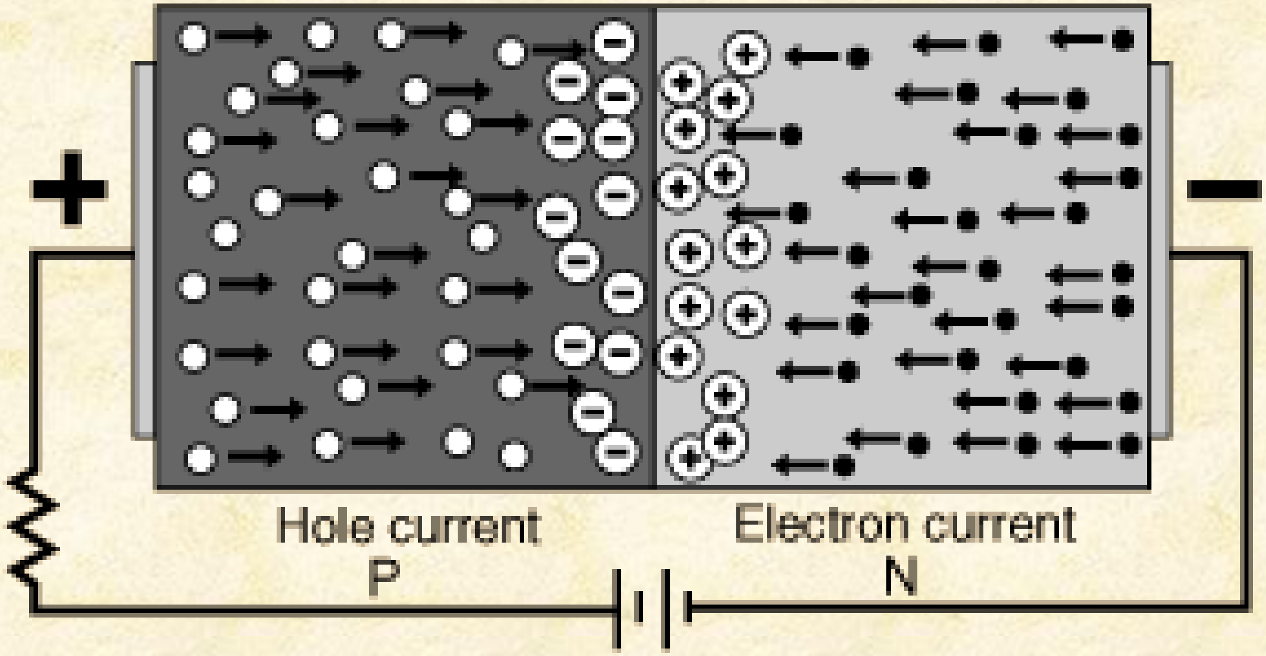


In the n-type region there are extra electrons and in the p-type region, there are holes from the acceptor impurities .

In the p-type region there are holes from the acceptor impurities and in the n-type region there are extra electrons.

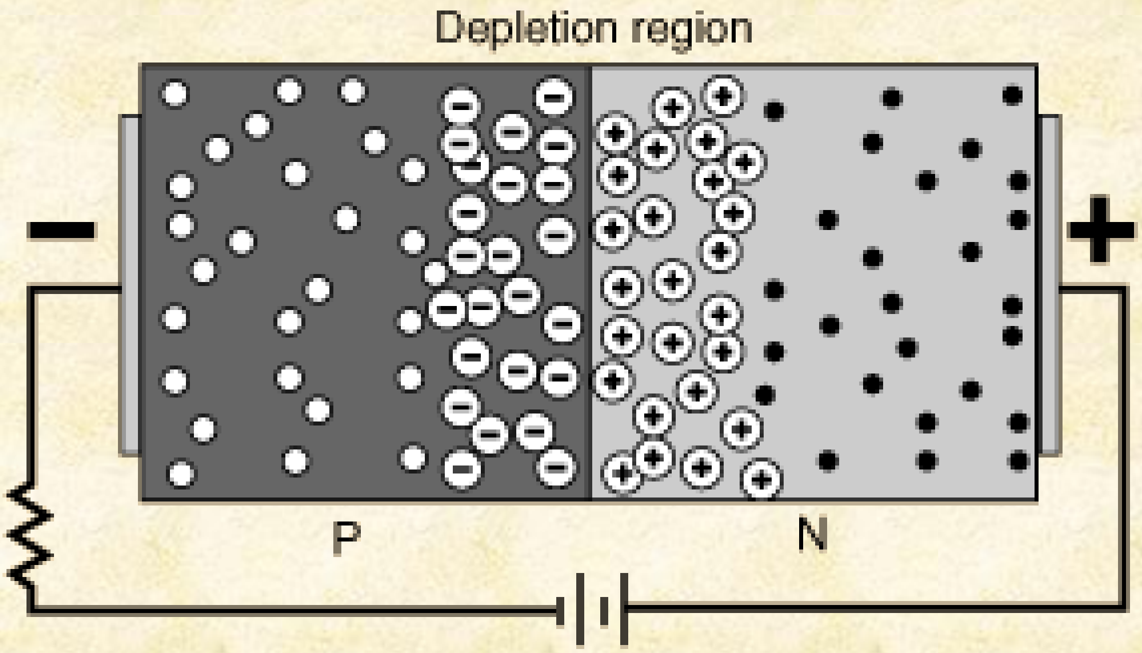


Forward Biasing



Forward biasing the p-n junction drives holes to the junction from the p-type material and electrons to the junction from the n-type material.

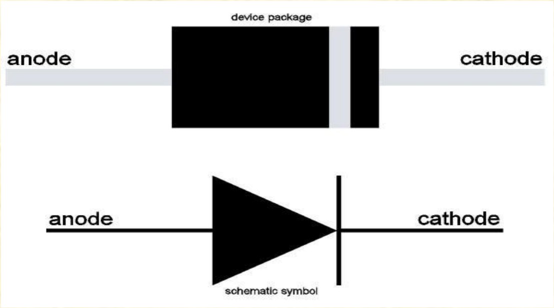
Reverse Biasing



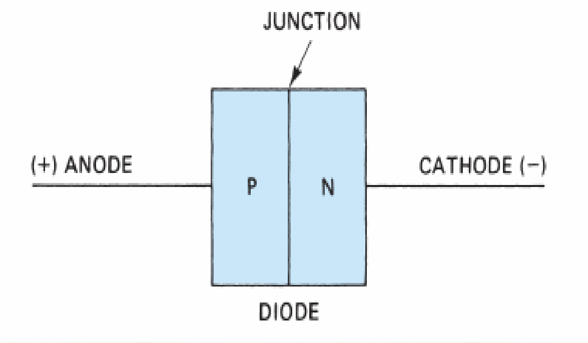
The application of a reverse voltage to the p-n junction will cause a transient current to flow as both electrons and holes are pulled away from the junction.

DIODES

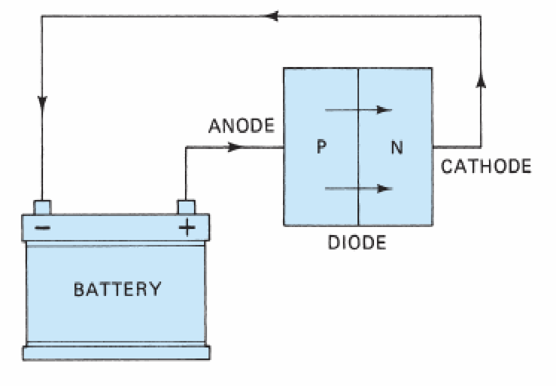
- A diode is an electronic component that
  - has two terminals,
  - limits current to one direction, and
  - has nonlinear (non-Ohmic) behavior.
- Diodes are p-n junctions that “turn on” at a specific voltage.
- Diodes have an anode (p-side) and a cathode (n-side).
- Positive current normally flows from the anode to the cathode.
- Diodes are useful for protecting circuitry from harmful voltage or current.
- Diodes are a basic building block of the charge-collecting element in many detectors.



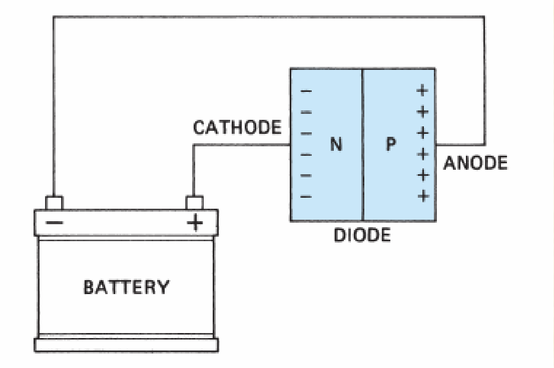
DIODES



A diode is a component with P- and N-type material together. The negative electrode is called the cathode and the positive electrode is called the anode.



Diode connected to a battery with correct polarity (+ to + and - to -). Current flows through the diode. This condition is called forward bias.



Diode connected with reversed polarity. No current flows across the junction between the P-type and N-type material. This connection is called reverse bias.

Type of DIODES

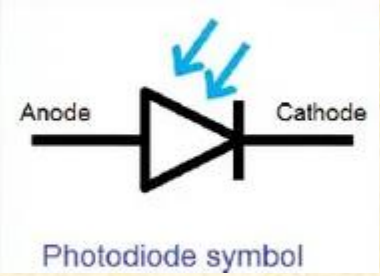
PHOTODIODES

A photo diode or a photo detector is an optoelectronic device that absorbs optical energy and converts into electrical energy. Which usually is shown as a photocurrent. Photodiodes are specially designed to operate in reverse bias condition. These diodes have a slow response time when the surface area of the photodiode increases.

The main features of these diodes include the following.

The linearity of the diode is good with respect to incident light

Noise is low.



The response is wide spectral

Rugged mechanically

Light weight and compact

Long life

Working of Photodiode

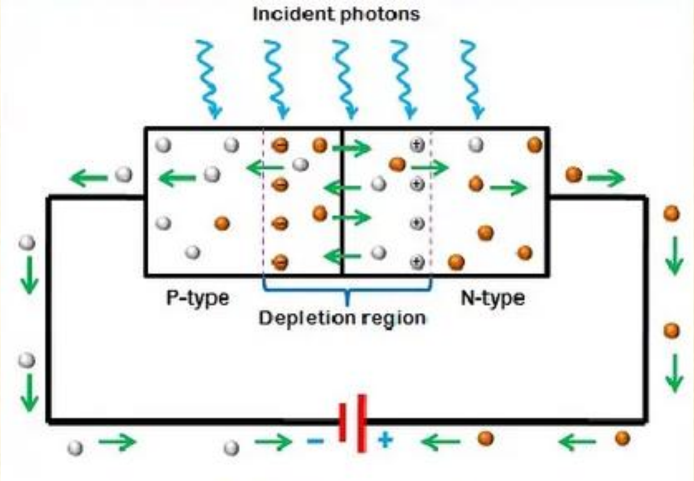
In reverse bias condition, the minority carriers generated are recombined before they reach the junction. Therefore no current will flow through the junction.

So an external energy should be applied at the depletion region to increase the population of the minority carriers and thus increase in the current flow.

To overcome this problem a special diode called photodiode is used. Photons or light is used as external energy to generate more number of minority carriers.

when a photon of ample energy strikes the diode, it makes a couple of an electron-hole. This mechanism is also called as the inner photoelectric effect.

Therefore holes move towards the anode and electrons move towards the cathode, and a photo current will be generated

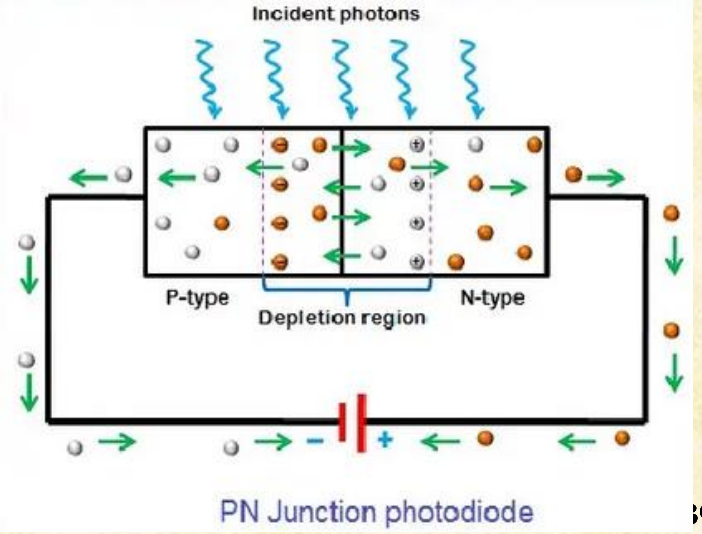


PN Junction photodiode

Working of Photodiode

When no light is applied to the reverse bias photodiode, it carries a small reverse current due to external voltage. This small electric current under the absence of light is called dark current. It is denoted by Iλ

The total current through the photodiode is the sum of the dark current and the photocurrent. The dark current must be reduced to increase the sensitivity of the device.

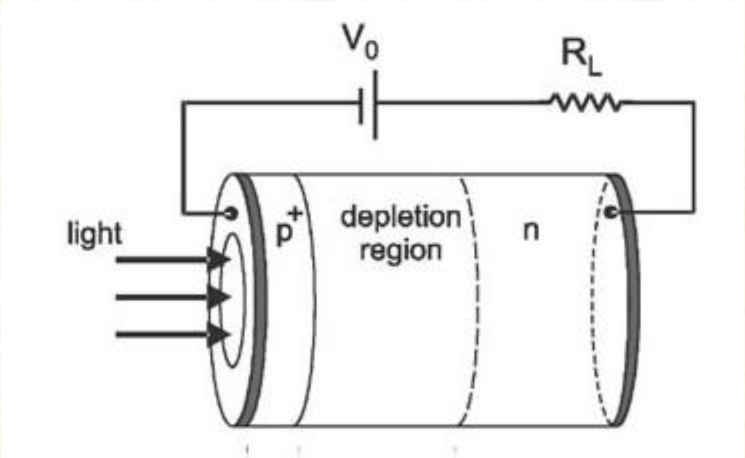


Type of DIODES

Photodiode

PN Photodiode

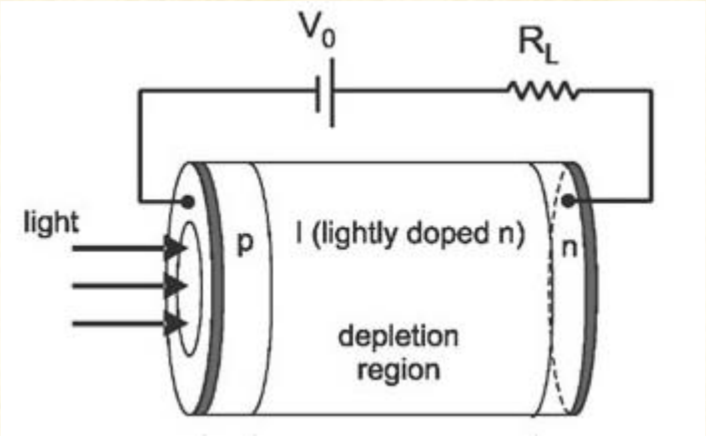
The PN photodiode was the first form of photodiode to be developed. Its performance is not as advanced as some of the other types and therefore its use is less now

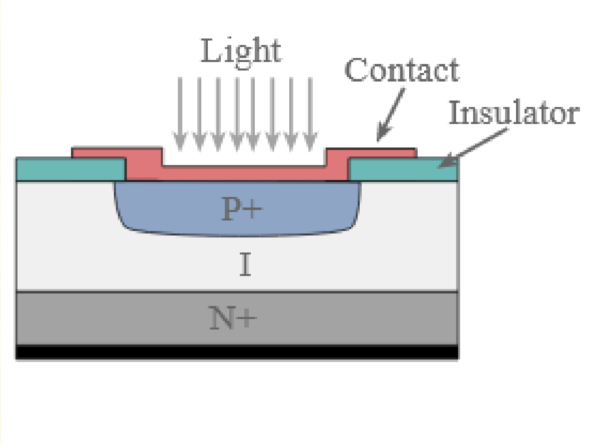


Type of DIODES

PIN Photodiode

The PIN photodiode is one of the most widely used forms of photodiode today. The PIN photodiode collects the light photons more efficiently than the more standard PN photodiode because of the wide intrinsic area between the P and N regions allow for more light to be collected, and in addition to this it also offers a lower capacitance.



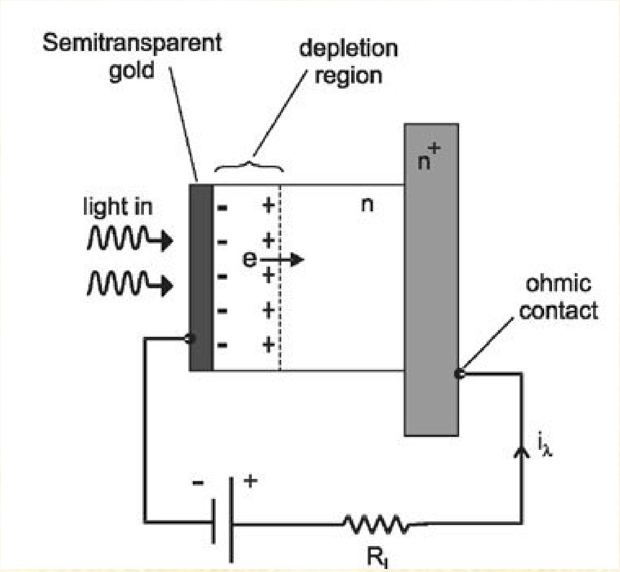


Typical PIN photodiode structure

Type of DIODES

Schottky photodiode

The Schottky photodiode tis based upon the Schottky diode. The small diode junction means that there is very little junction capacitance and this means that it can operate at high speeds. As a result, this form of photo diode is often used in high bandwidth optical communication systems, e.g. fibre optic links.



Type of DIODES

Avalanche Photodiode

The avalanche photodiode possesses a similar structure to that of the PN or PIN photodiode. An avalanche diode structure similar to that of a Schottky photodiode may also be used but the use of this version is much less common. The main difference of the avalanche photodiode to other forms of photodiode is that it operates under a high reverse bias condition. This enables avalanche multiplication of the holes and electrons created by the photon / light impact.

advantages

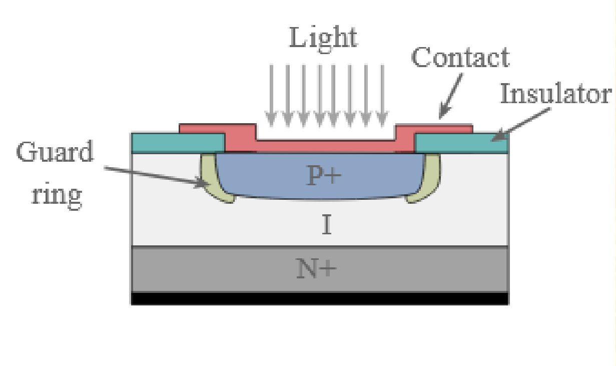
High level of sensitivity as a result of avalanche gain

disadvantages:

Much higher operating voltage may be required.

Avalanche photodiode produces a much higher level of noise than a PN photodiode

Avalanche process means that the output is not linear



Avalanche PIN photodiode structure

Applications of Photodiode

the applications of photodiodes involve charge-coupled devices, photoconductors, and photomultiplier tubes.

These diodes are used in consumer electronics devices likesmoke detectors, compact disc players, televisions and remote controls in VCRs.

It uses in consumer devices like clock radios, camera light meters, and street lights

Photodiodes are frequently used for exact measurement of the intensity of light in science & industry.

Photodiodes are also widely used innumerous medical applications like instruments to analyze samples, detectors for computed tomography and also used in blood gas monitors.

It is frequently used for lighting regulation and in optical communications.

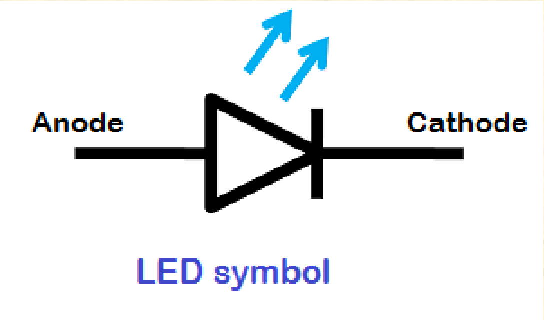
Type of DIODES

Light Emitting Diode

The light emitting diode is P-N junction diode, which consists of two leads and semiconductor light source.

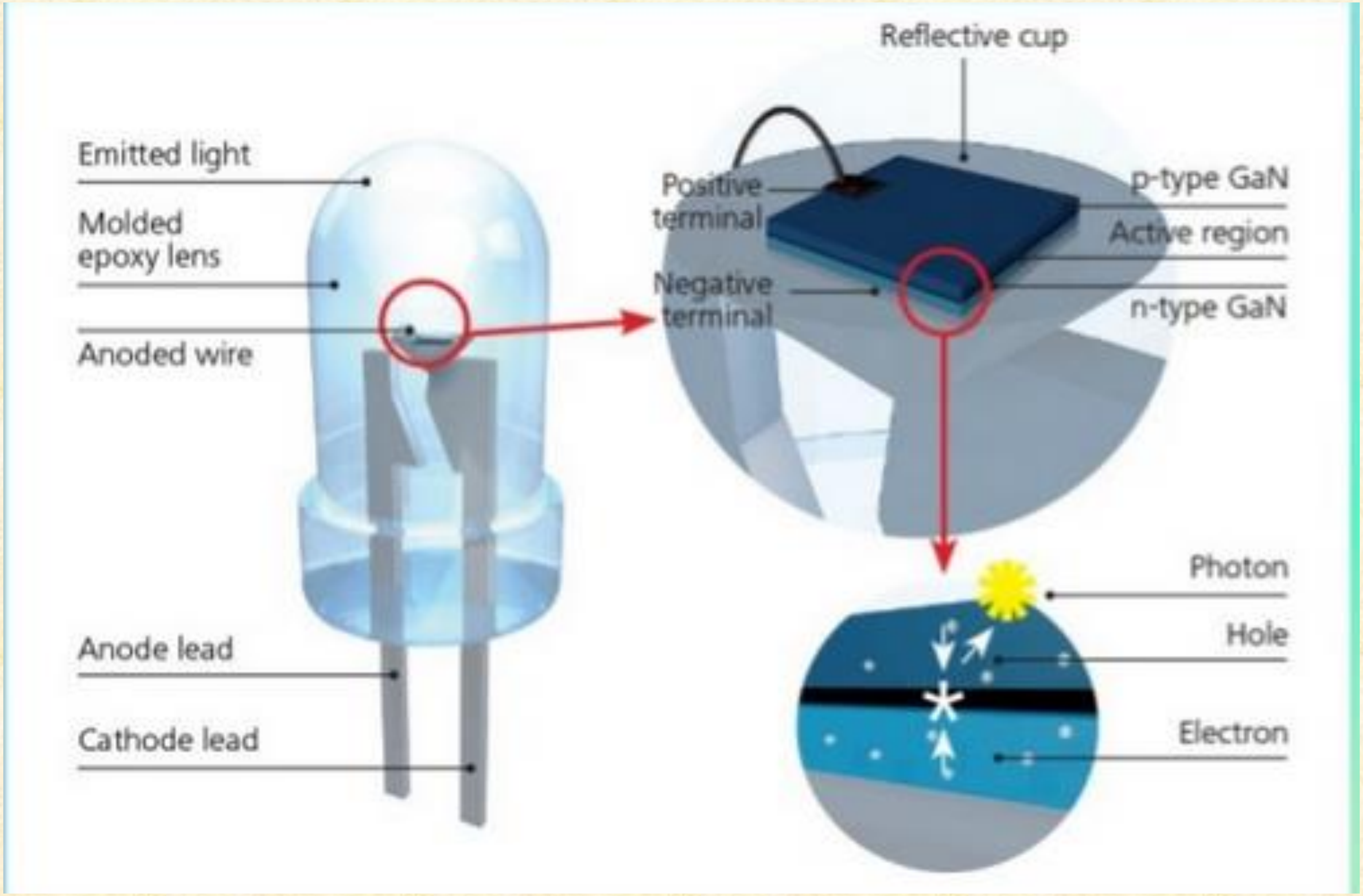
When it is activated by applying the suitable voltages across its leads then it emits the light energy in the form of photons and the color of this light was determined by the band gap of semiconductor material.

This light energy is produced by the recombination of electrons and electron holes with in this device and this process is called electroluminescence process. This process was stated in twentieth century from solid state material when it is heated at room temperature then it emits the light energy.

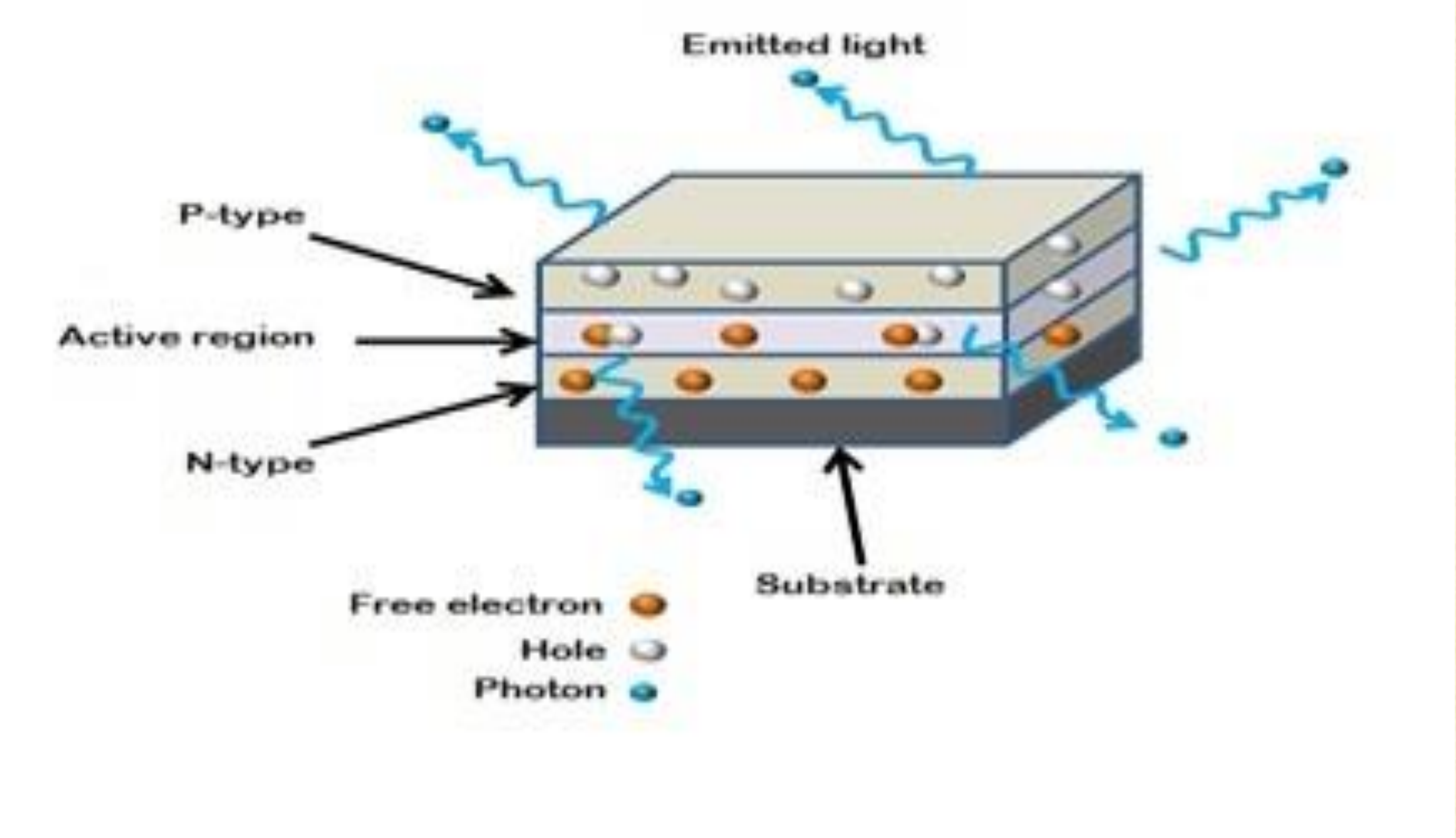


At the beginning the infrared light emitting diode was developed and its light intensity was low but it is still frequently used in variety of consumer electronics circuits such as remote controls.

Construction of Light Emitting Diode



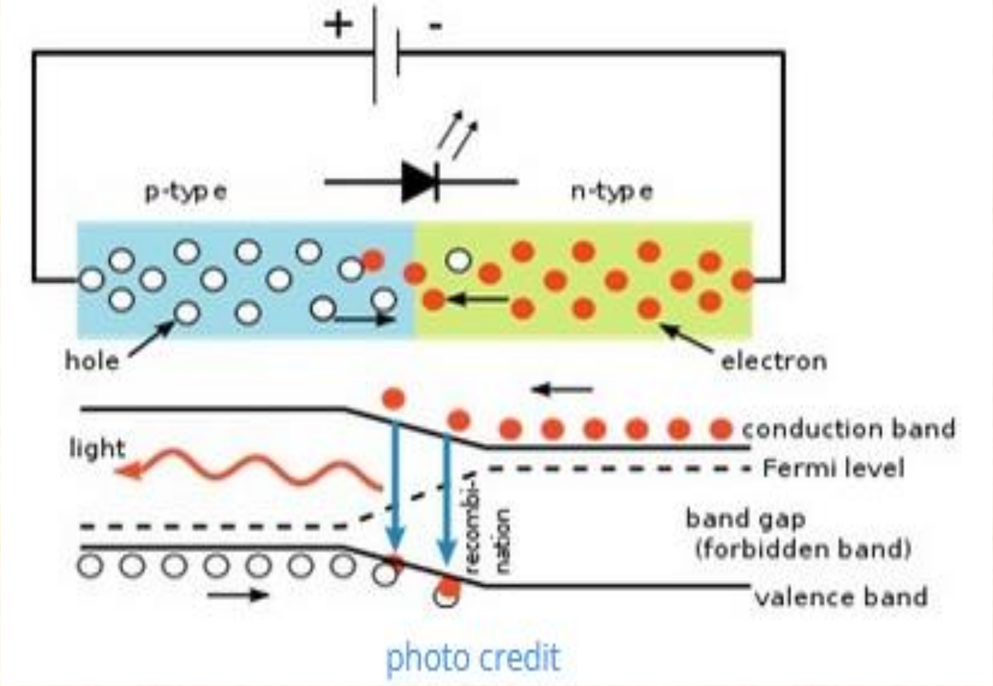
Electrical Basics

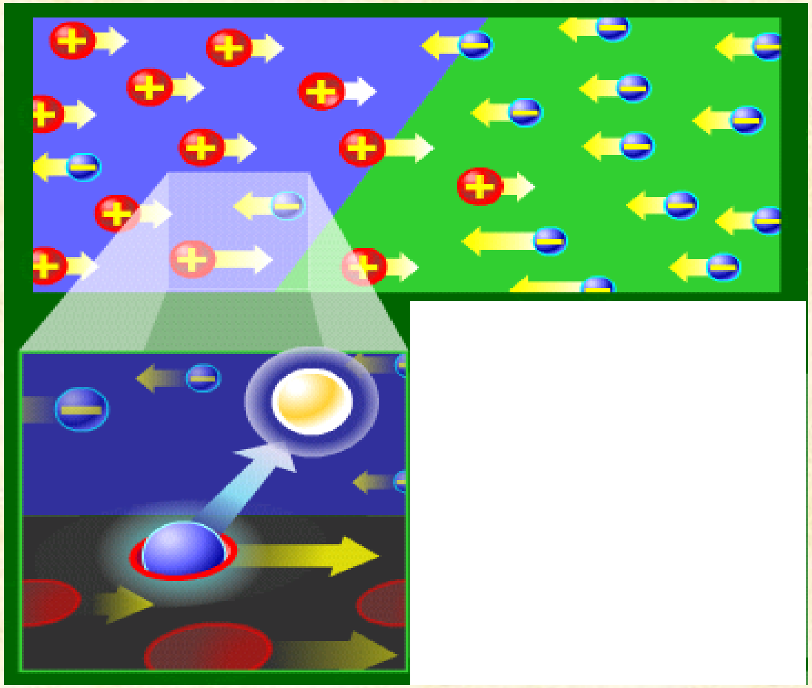


These three semiconductor material layers are made three regions which are called a P-type region which is top one, active region which is middle one and N-type region which is bottom one.

Working Principle Light Emitting Diode

In the light LED ,the anode is connected to positive terminal of dc supply and cathode is connected to the negative terminal





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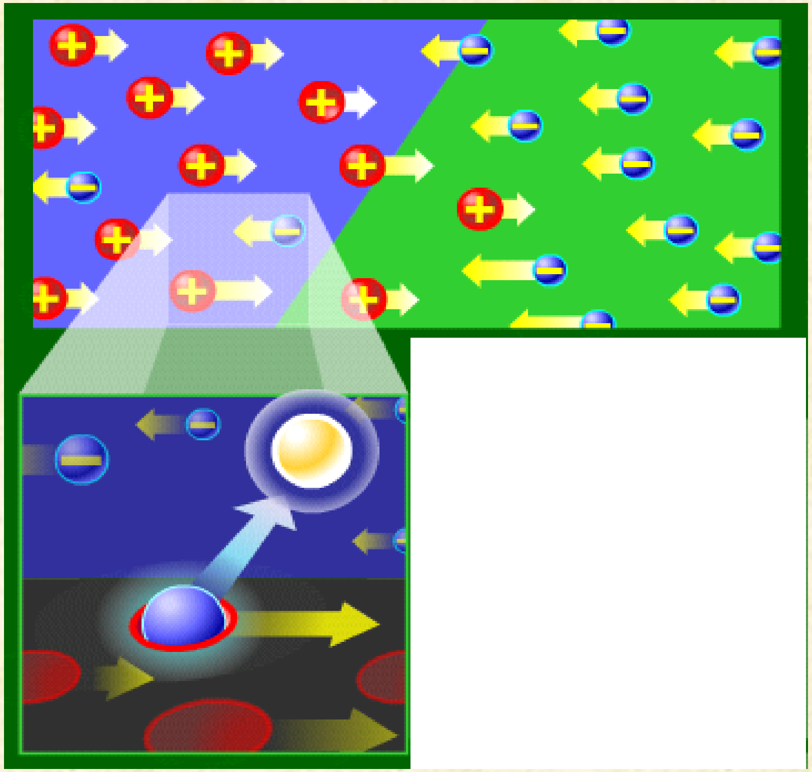
Working Principle Light Emitting Diode



When current flows across a diode

Negative electrons move one way and positive holes move the other way

The wholes exist at a lower energy level than the free electrons

Therefore when a free electrons falls it losses energy

This energy is emitted in a form of a photon, which causes light

The color of the light is determined by the fall of the electron and hence energy level of the photon

Types of Light Emitting Diode

The LEDs are divided into three major types, accordingly to its material.

Traditional Inorganic LEDs:

This type of LED is the traditional form of diode that has been available since the 1960s. It is manufactured from inorganic materials. Some of the more widely used are compound semiconductors such as Aluminium gallium arsenide, Gallium arsenide phosphide, and many more – the colour of the light is often dependent upon the materials used.

These are available in market with different shapes and colures such as surface mounted LED, Single colure LED, Multi-colure LED and Flashing LED.

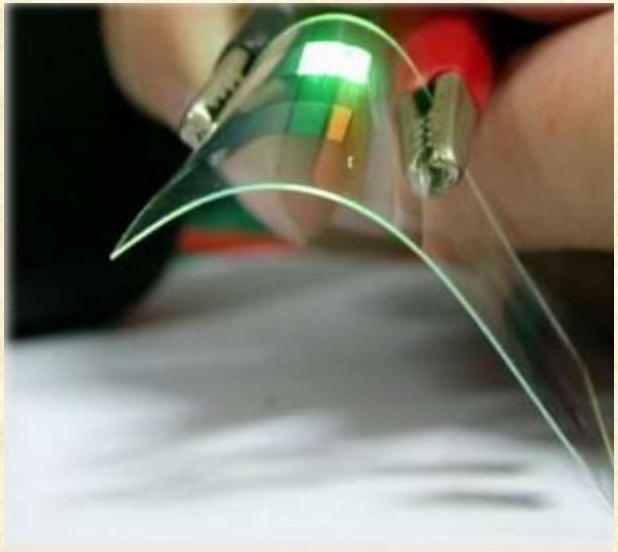
Types of Light Emitting Diode

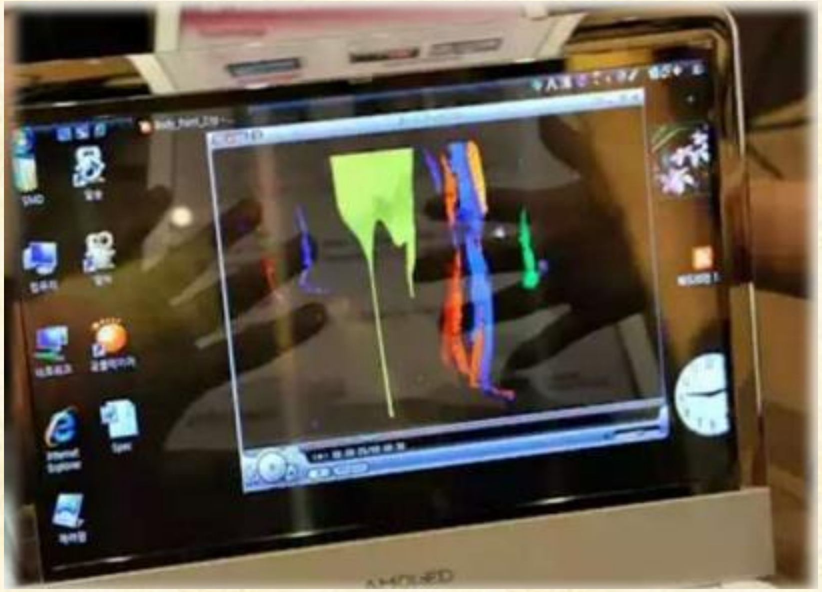
Organic LEDs:

This type of LED is made with organic material therefore these are called organic LEDs.

These are produced a light form defined PN junction, therefore their light is shows in the form of point of light. The organic LEDs are manufactured in sheets therefore these are providing a diffuse area of light means these can be used for wide area of surface.

The OLED mostly used display technology computer monitors, television , mobile phone Screen etc





Types of Light Emitting Diode

High Brightness LEDs:

The high brightness LEDs (HBLEDs) are the type of organic LEDs and these are widely used for lightening purpose. Essentially, this type of LEDs is same as organic LEDs but only different is that these are having high brightness in output light. For generating high brightness, these LEDs are required to be able a high current and high power dissipation therefore these LEDs are mounted on heat sink for removing the unwanted heat.

Types of Light Emitting Diode

Multi Color LED

Bi-colour LEDs : is constructed by having two LEDs in parallel with each other in the same package, but they are wired with one external connection of the package going to the cathode of one diode, and the anode of the other. The other lead is again connected to the anode of the first diode and the cathode of the second. In this way when a voltage is applied one way round, one LED will light, and when it is applied the other way round, the other one will light.

Tri-colour LEDs: This type of LED has three leads enabling any combination of LEDs to be light, i.e. the first LED, the second, or both. The most popular form of tri-colour LED uses a red and green diode. This means that when one diode is on, then either red or green is produced. If both are light, then the colours combine to form yellow.

Applications of Light Emitting Diode

These are used in security alarm system such as burglar alarm system.

There are used in electronic calculators for showing the digital data.

These are used in mobile phones for taking the pictures.

These are used in traffic signals for controlling the traffic crowds in cites.

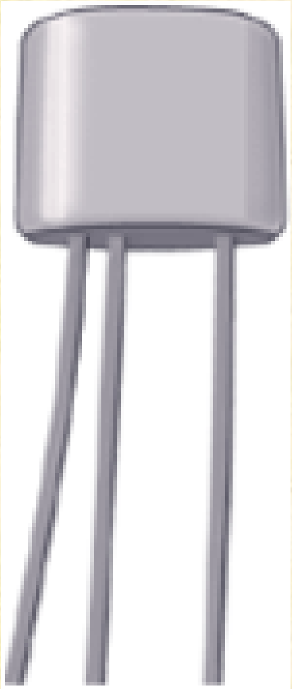
These are used for lighting purpose such as in homes lights, factory lights and street lights etc. Instead of incandescent lamps for saving the energy.

These are used in digital computers for displaying the computer data.

Transistor

Definition of a Transistor

- A **transistor** is a semiconductor device that can perform the following electrical functions.
  - Act as an electrical switch in a circuit.
  - Act as an amplifier of current in a circuit.
  - Regulate the current in a circuit.

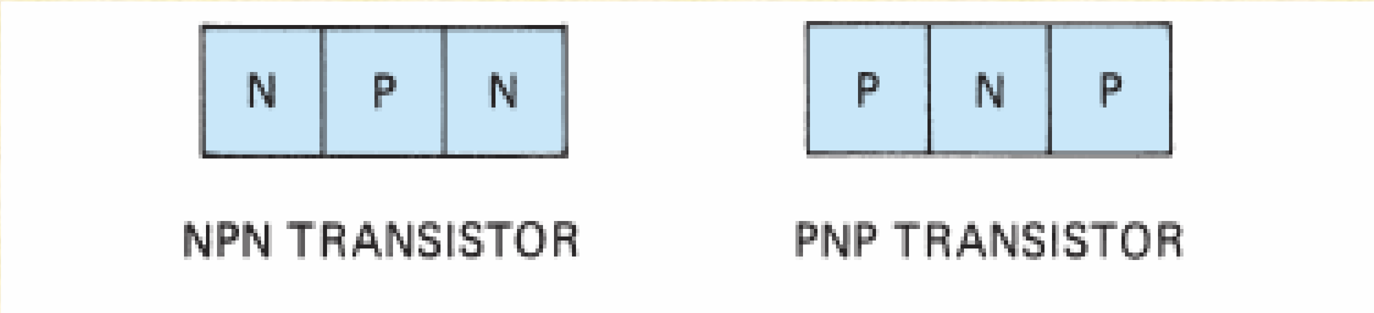


Transistor consists of three terminal active device which transforms current flow from low resistance path to high resistance path.
This transfer of current through resistance path, given the name to the device ‘transfer resistor’ as transistor.

Transistor

Construction of a Transistor

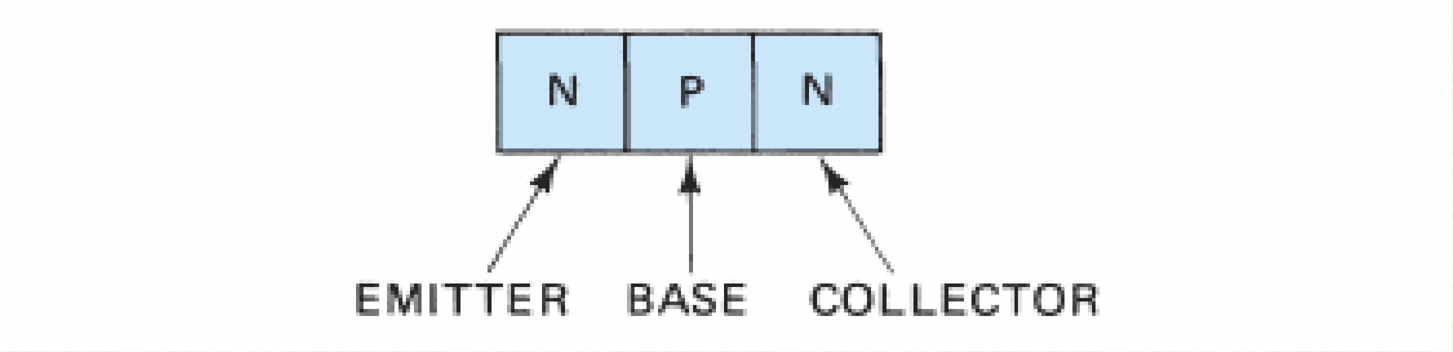
Bipolar transistors use P- and N-type materials to form the three parts of a transistor. The P- and N-type materials can be arranged either as a PNP transistor or an NPN transistor. The difference is in how the transistor is turned on or off. Positive voltage to the base turns on an NPN transistor whereas a lower or negative voltage is necessary to turn on a PNP transistor.



Transistor

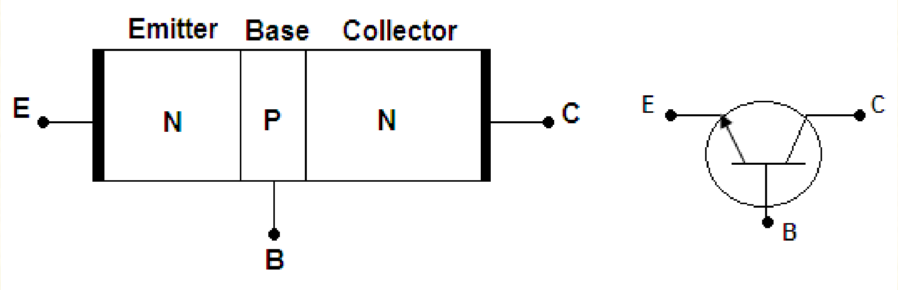
The three parts of a transistor are the emitter (E), the base (B), and the collector (C).

- The center section of a transistor is called the base; it controls current flow through the transistor
- Collector (C): the source of the current
- Emitter (E): the destination of the current



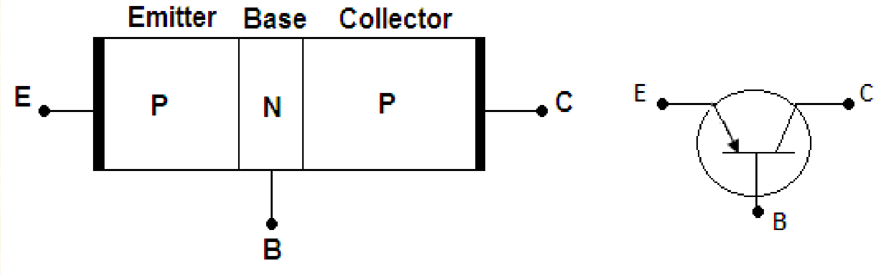
Transistor

If a P-type material is sandwiched between two N-type materials ,the resulting structure is called NPN transistor.



Fig(a): NPN Transistor

If N-type material is sandwiched between the two P-type materials , the resulting structure is called PNP transistor.



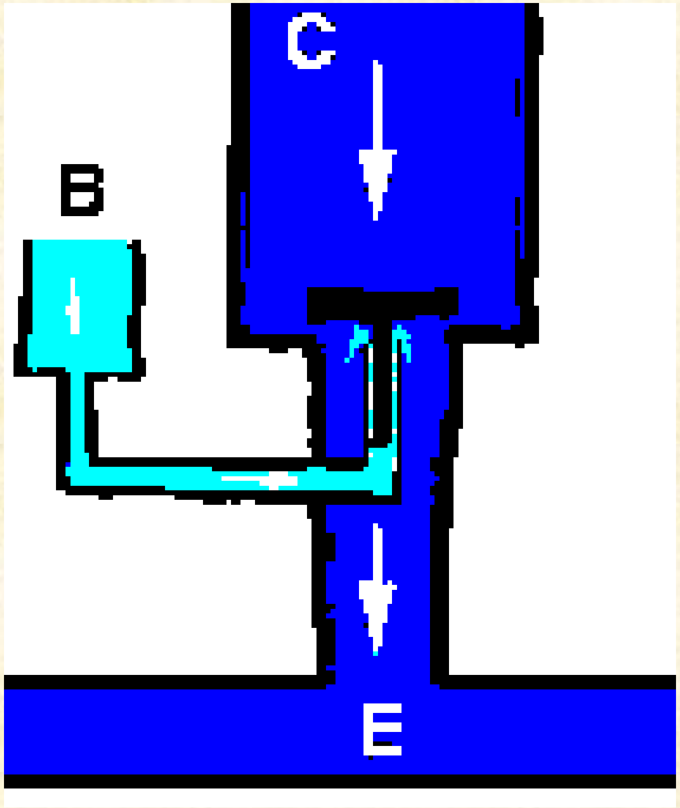
Fig(b): PNP Transistor

In both cases, the first layer where the emission or injection of the carriers starts is called emitter. The second layer through which carriers passes is called the base and the third layer which collects the injected carriers is called collector.

Transistor

HOW A TRANSISTOR WORKS

Water Flow Model



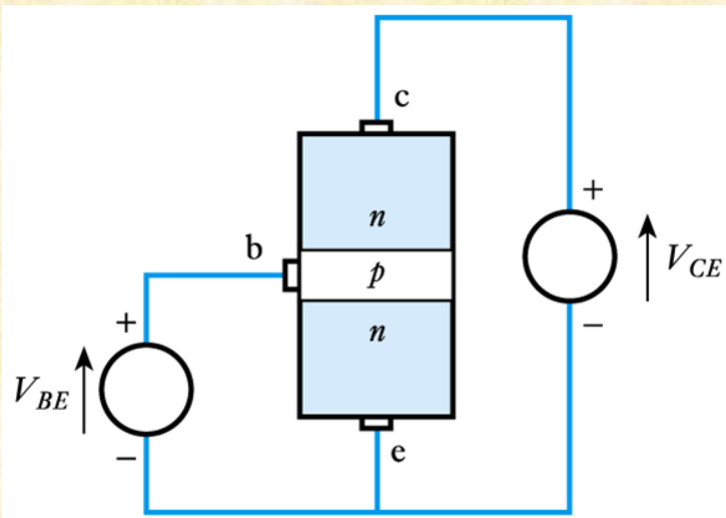
Water flow in B raises the plunger so that water can flow from C to E.

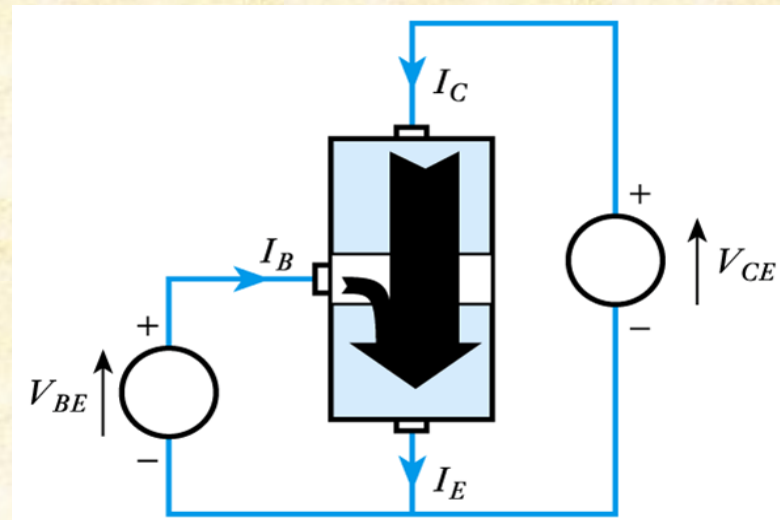
Small flow turns on and off bigger flow.

Put signal on B, transfer signal C to E.

Transistor

HOW A TRANSISTOR WORKS





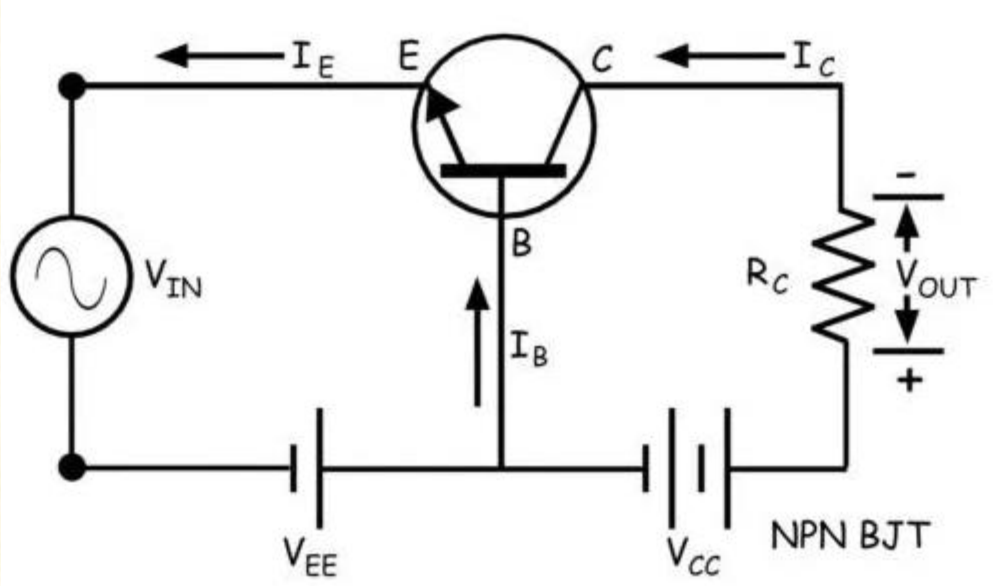
Basic transistor operation. A small current flowing through the base and emitter of the transistor turns on the transistor and permits a higher-amperage current to flow from the collector and the emitter.

Transistor

Methods of the transistor connecting

Common base

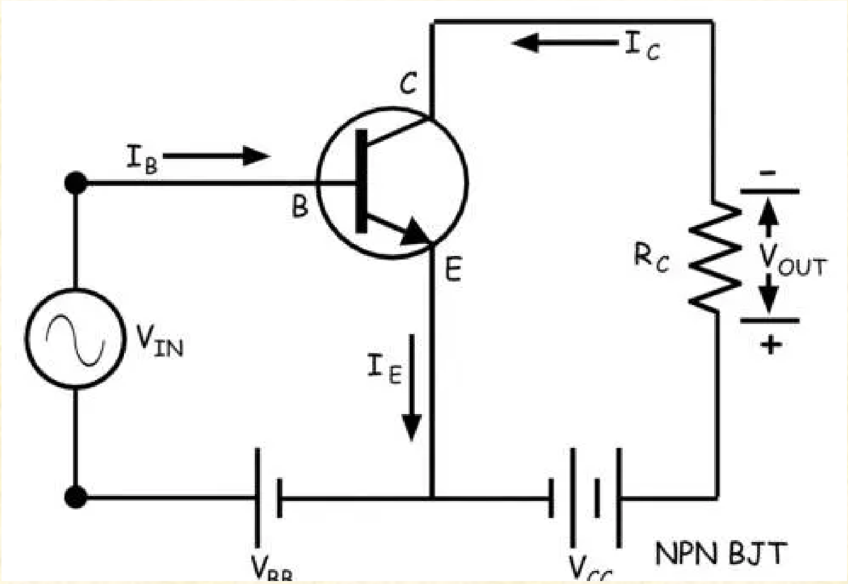
In this configuration, the emitter terminal of the transistor serves as the input, the collector the output, and the base is common and connected to ground.



Transistor

Common emitter

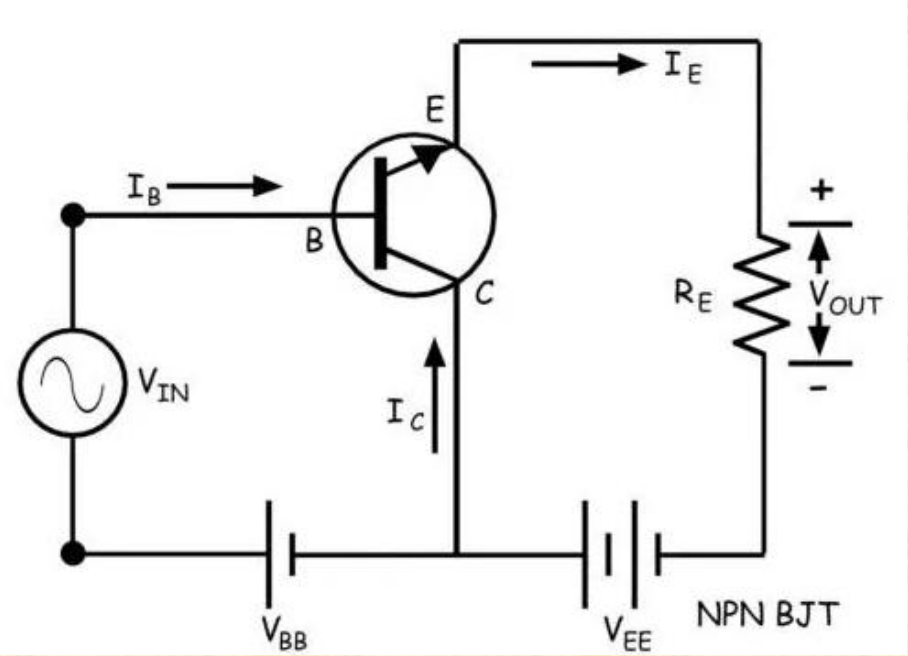
Common Emitter Transistor is the most commonly used transistor connection. Here the emitter terminal is common for both input and output circuit. The circuit connected between base and emitter is the input circuit and the circuit connected between collector and emitter is the output circuit.



Transistor

Common collector

In common collector configuration the input circuit is between base and collector terminal and the output circuit is between emitter and collector terminal.



Transistor

transistor amplifier

A transistor can amplify a signal if the signal is strong enough to trigger the base of a transistor on and off.

The resulting on–off current flow through the transistor can be connected to a higher-powered electrical circuit