

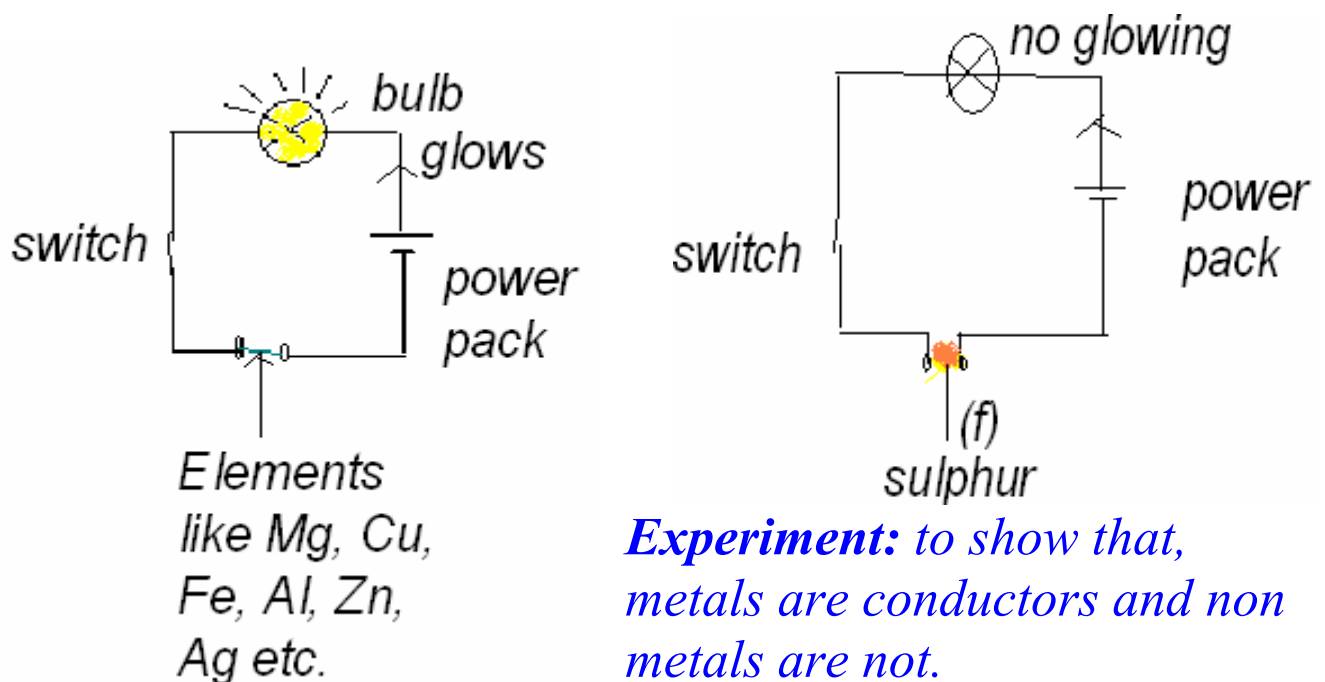
# SOLID STATE DEVICES

(Electronic components)

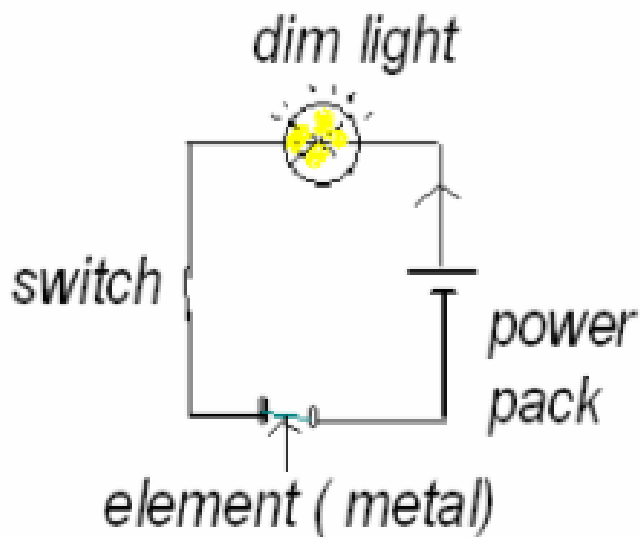
## Electrical conductivity

[1] “Electrical conductivity is a measure of a material's ability to conduct an electric current”

Metals are good conductors of electricity, and glass, vacuums, rubber are poor conductors (or insulators). Also the elements on the left of the periodic table (metals) conduct electricity and those on the right (non metals) do not allow current to flow through. Investigate as follows.



**Experiment:** to show that, metals are conductors and non metals are not.



Metallic elements change their conducting behaviour when the circuit (*with metals connected as before*) is left for some time. Metal gets heated and the bulb gets dim.

In between metals and insulators, is another category of elements called semiconductors or metalloids (e.g Si & Ge) found in group IV A of the periodic table.

## About Gr IVA elements:

Conductivity of Group IVA elements in the 1940s initiated “electronics”.

part of periodic table

Gr IB	Gr II B	Gr III A	Gr IV A	Gr V A	Gr VI A	Gr VII A	Gr VIII
							He 2
		B 5	C 6	N 7	O 8	F 9	Ne 10
		Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54
Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86

Silicon (Si) has 14 [2, 8, 4] electrons. There are 10 core electrons and 4 valence electrons.

Germanium (Ge) has 32 [2, 8, 18, 4] electrons, and has 4 valence electrons to participate in chemical reactions.

A section of the periodic table showing some metals, **semimetals** and non-metals is given below:

		IIIA	IVA	VA	VIA		
		5 B	6 C	7 N	8 O		
		13 Al	14 Si	15 P	16 S		
IB	IIB	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se
		47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te

*Why are there differences between metals, semimetals & non-metals?*

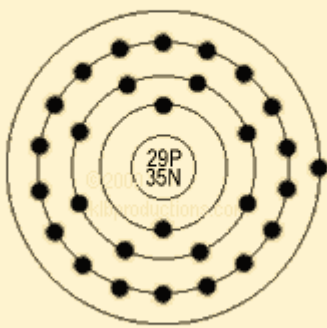
*Metals have free electrons to conduct electricity whereas a non-metal like sulphur accepts electrons instead & Semimetals share electrons.*

*Is that all? No! To learn more, we'll go into the details of what is called the "Band structure of matter".*

# “BAND STRUCTURE OF MATTER”

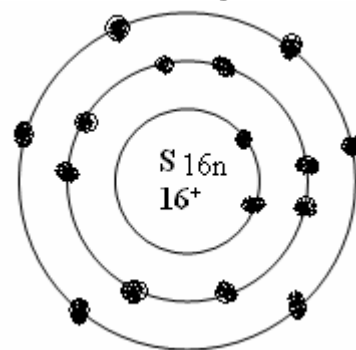
Consider the copper atom ( $\text{Cu}^{29}$ ), ( $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^9$ ), rearranged as  $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$  - a popular **conductor**, where the highest energy band containing electrons (**valency band**) is partially filled, (only one electron) ( $4s^1$ ).

- **Electron Configuration:**  
 $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$
- **Electrons per Energy Level:** 2,8,18,1  
**Shell Model**



- **Ionic Radius:**  $0.73 \text{ \AA}$
- **Filling Orbital:**  $3d^{10}$

In an **insulator** however, the highest energy band containing electrons is



completely filled.e.g plastic, rubber etc. where

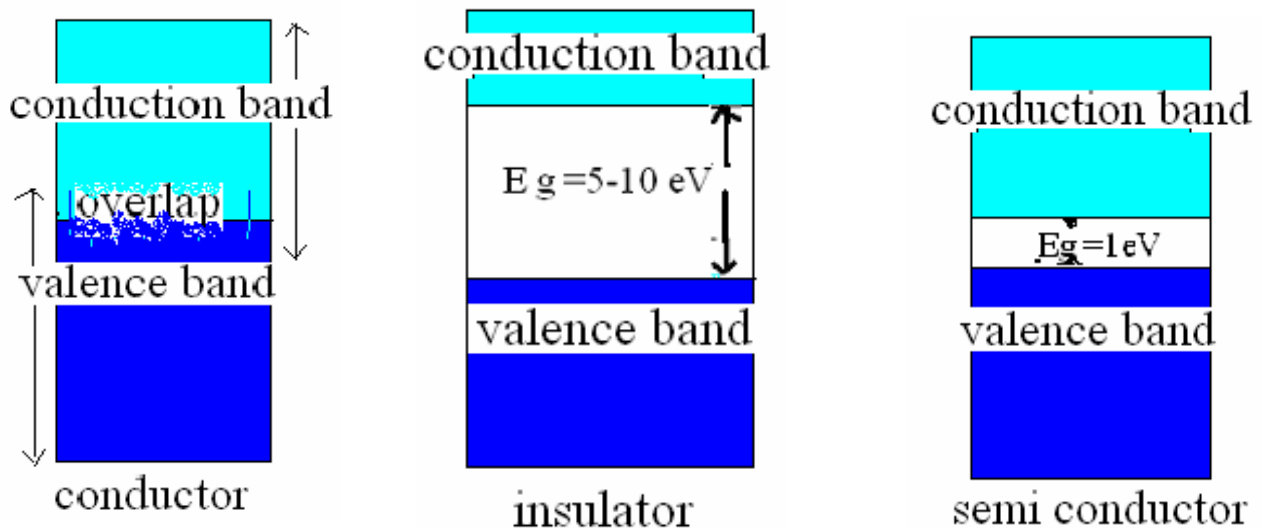
[2]

macro molecules are found. Sulphur (S 16) [2,8,6] also doesn't liberate free electrons, like metals.

[3] The next energy band called the '**conduction band**' is separated from the valency band by a '**band gap**' or energy gap, Eg of **5-10 eV**. It's also called the '**forbidden energy gap**'. At room temperature, no electron can acquire the 5 eV needed to reach the conduction band. Hence the insulators are non conductors.

In semiconductors, the energy gap  $E_g$  is around  $1 \text{ eV}$  only – between the conductors and insulators.

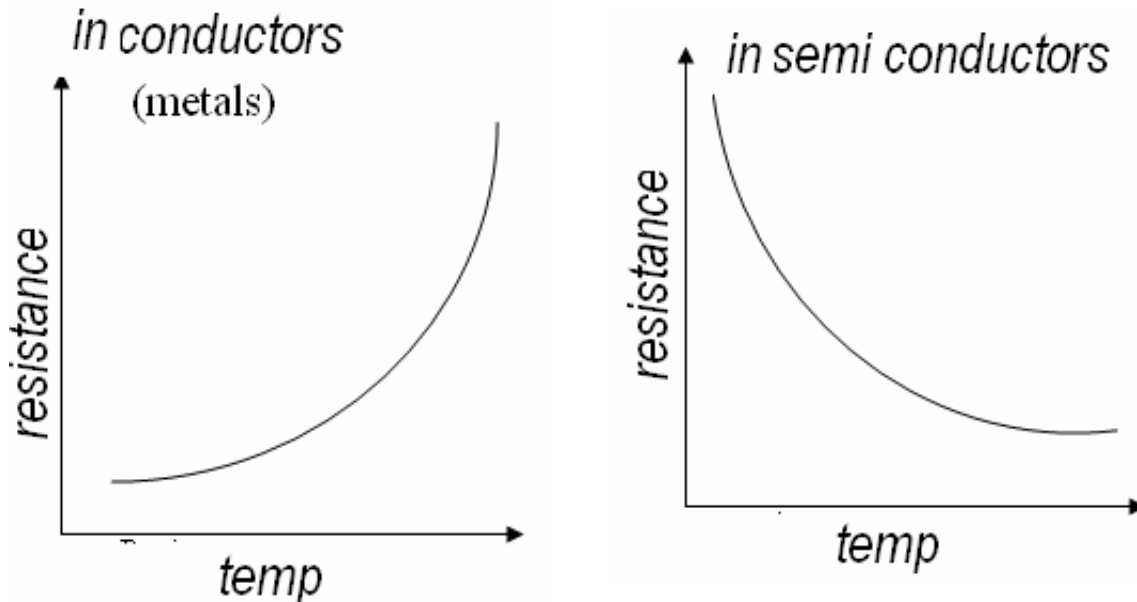
**The energy band model** can be used to explain the difference between conductors, insulators and semiconductors:



- In metals, the valence band is partly filled. When an electric field is supplied, additional energy makes it occupy the higher level in the valence band.
- In metals, **the conduction band and valence band overlap**. Hence more valence electrons are available for conducting current.
- They have lower resistance. e.g Ag, Cu

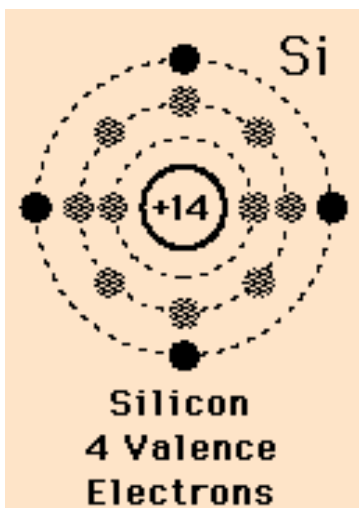
- However when the metals are heated, the resistance increases and the **flow of electricity will reduce**.

[4]



## THE BEHAVIOUR EXCLUSIVE TO SEMICONDUCTORS:

[5]



Silicon ( $\text{Si}_{14}$ ), has an electronic configuration of  $1s^2 2s^2 2p^6 3s^2 3p^2$ . It has an 'energy gap' of around **1 eV**. A few electrons can acquire energy to reach the conduction band and a very small current may flow when a voltage is applied to a semiconductor.

[6]

Near absolute zero ( $-273^{\circ}\text{C}$  or  $0\text{K}$ ), all molecular movement stops, and there are no free carriers. Hence the semiconductor element acts as an insulator at  $0\text{K}$ .

At higher temperature, more electrons will jump to the conduction band, thus contributing to higher conductivity, thus creating what are called “holes” in the valence band.

In physics, a hole is an electric charge carrier with a positive charge, equal in magnitude but opposite in polarity to the charge on the electron.

Conduction by holes and electrons is called intrinsic conduction where the number of electrons and the number of holes are equal.  $n = p$ .

<i>Movement</i>
<i>Electron</i> ←
<i>Holes</i> →

*View the illustrations (by the author) for an analogy, based on Kids at the playground equipment*



For more information on diodes: visit [http://www.allaboutcircuits.com/vol\\_3/chpt\\_3/1.html](http://www.allaboutcircuits.com/vol_3/chpt_3/1.html) and [http://www.massmind.org/images/www/hobby\\_elec/e\\_diode.htm](http://www.massmind.org/images/www/hobby_elec/e_diode.htm)

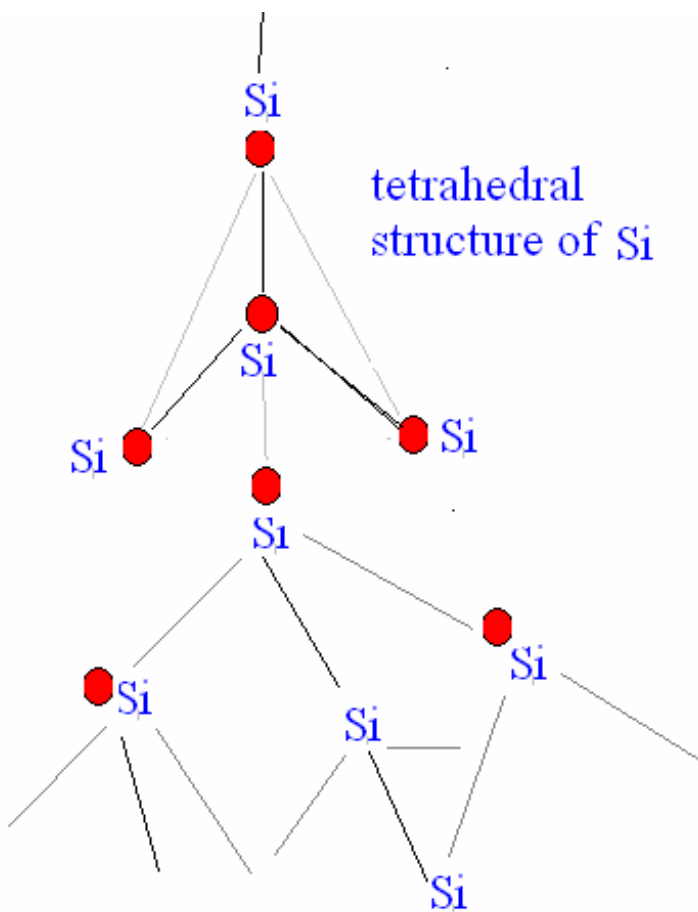
[7]

The two semi-conductor elements used in solid state devices:

## Germanium

A single crystal of Ge obtained from 'Germanium melt' is used in electronic devices. Germanium was discovered in 1940s.

## Silicon



Silica  $\text{SiO}_2$  (common sand) is reduced to Si. A single crystal of Si is obtained from the purified melt of Si. Si was discovered in the 1950s. Since the 1960s, Si has become the preferred semiconductor material for solid state devices.

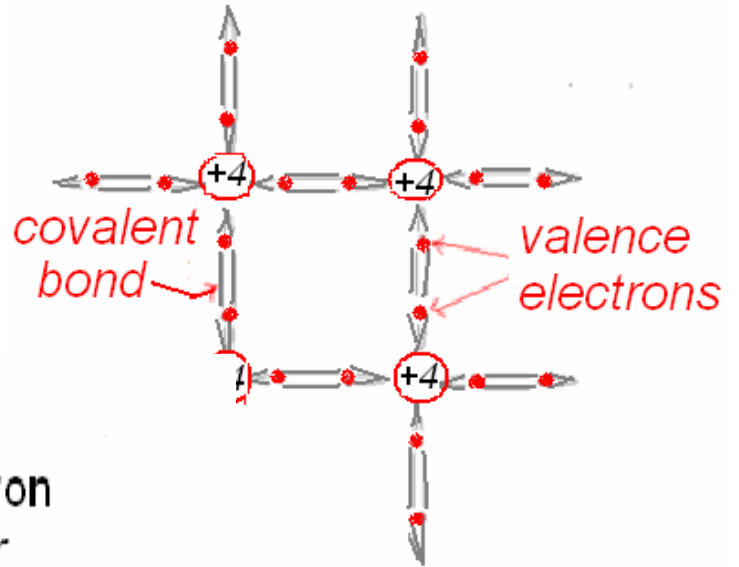
Si and Ge have a **tetrahedral structure** -

like the Gr IV Carbon (C) atoms in diamond. Every atom of Si is bonded to four other Si atoms.

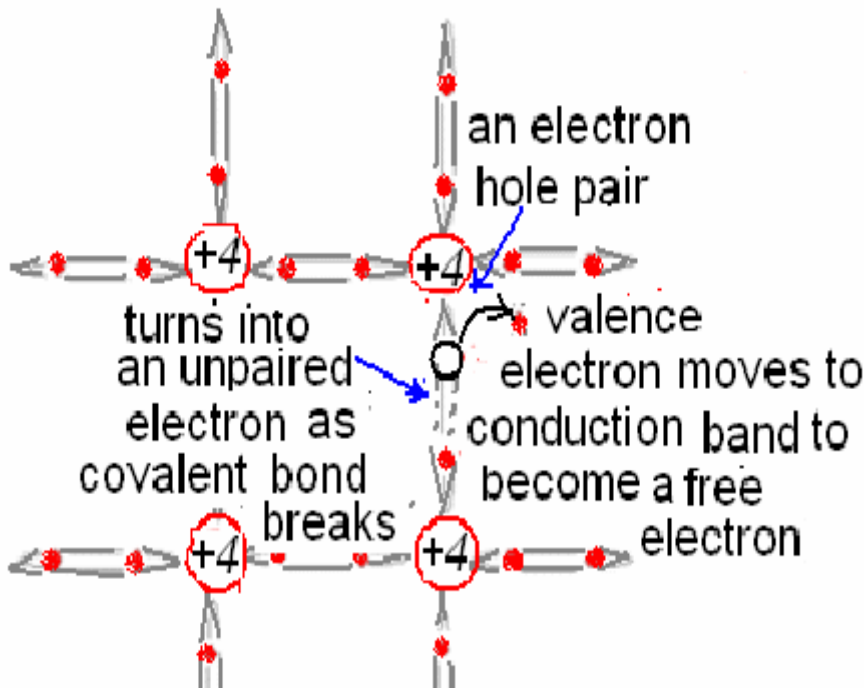
Similarly, each Ge atom is bonded to four other Ge atoms.

# Two dimensional representation of the bonding:

At low temperature

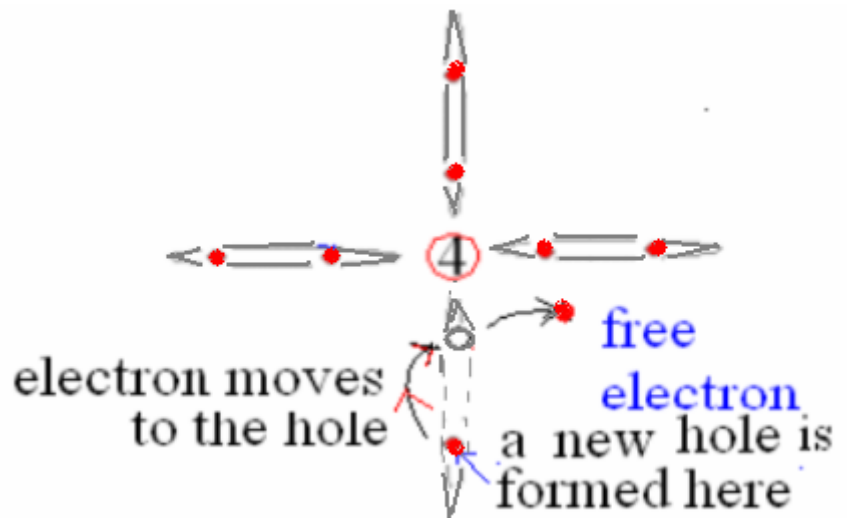


When heated



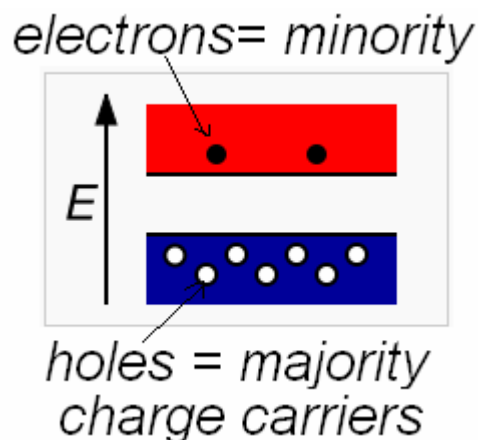
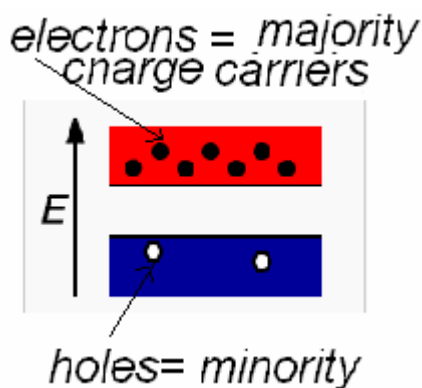
In Si and Ge, such electron pairs are the carriers of current.

In the lattice structure also, the 'hole' moves opposite to the movement of electron



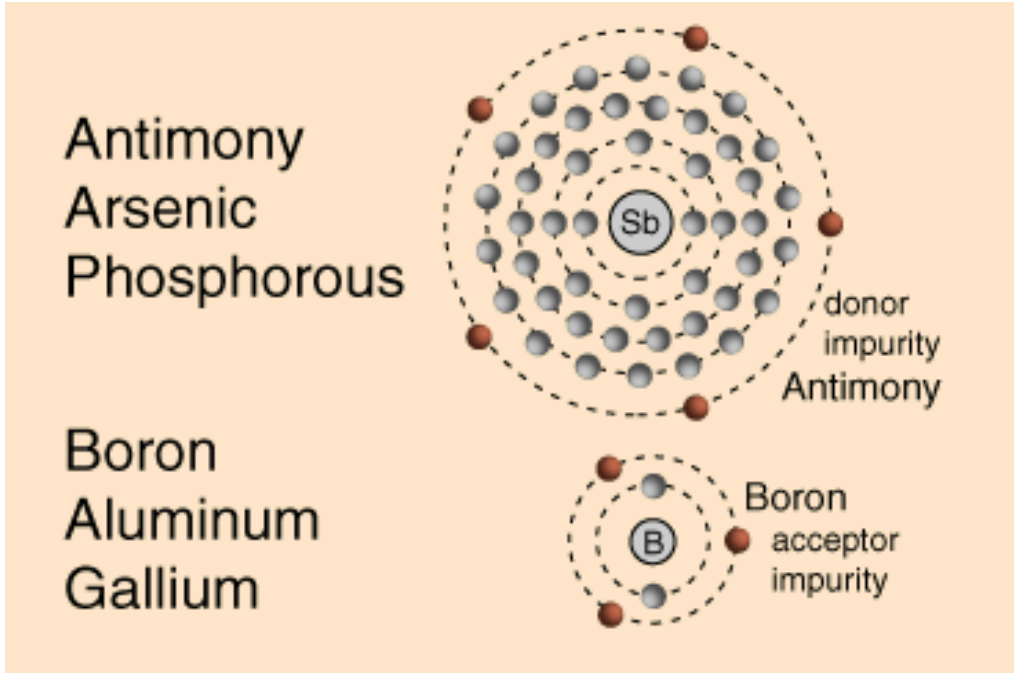
# THE DOPING OF SEMICONDUCTORS

- The conductivity of semiconductors can be increased by introducing impurities by a process known as **doping**.
- Each impurity atom adds one **electron** or one "**hole**" that may flow freely.
- Once doped, it will conduct electricity nearly as well as metals.
- Conduction in doped conductors is **extrinsic** [8]
- In **n-type** electrons > holes
- In **p-type** holes > electrons



- **n** means negative charge of electrons
- **p** means positive charge of holes

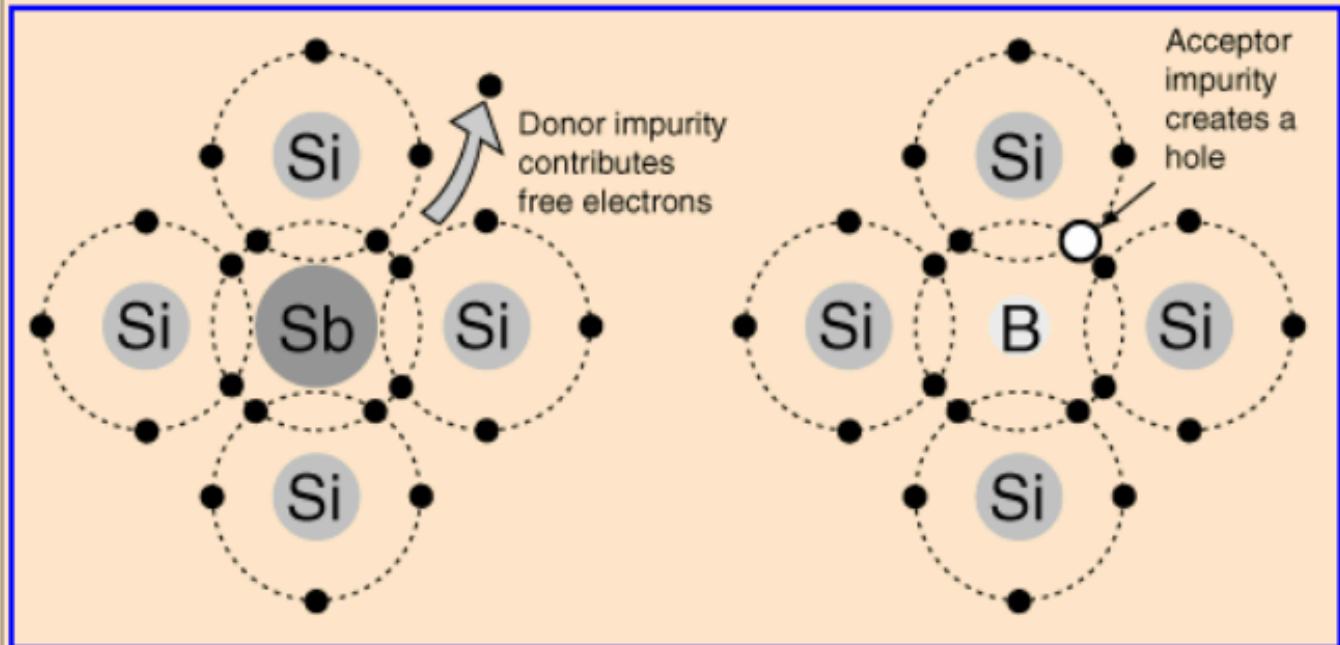
# [9] Impurities



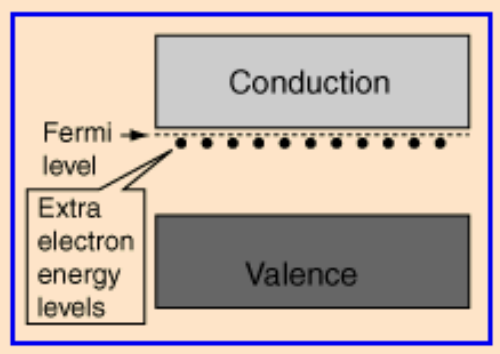
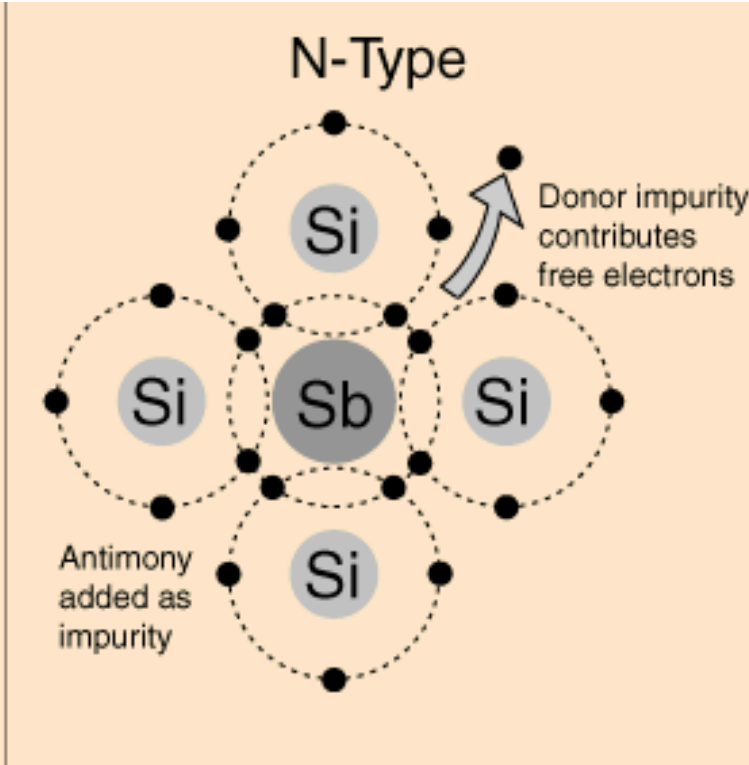
Pentavalent  
impurities

Trivalent  
impurities

## N- and P- Type Semiconductors

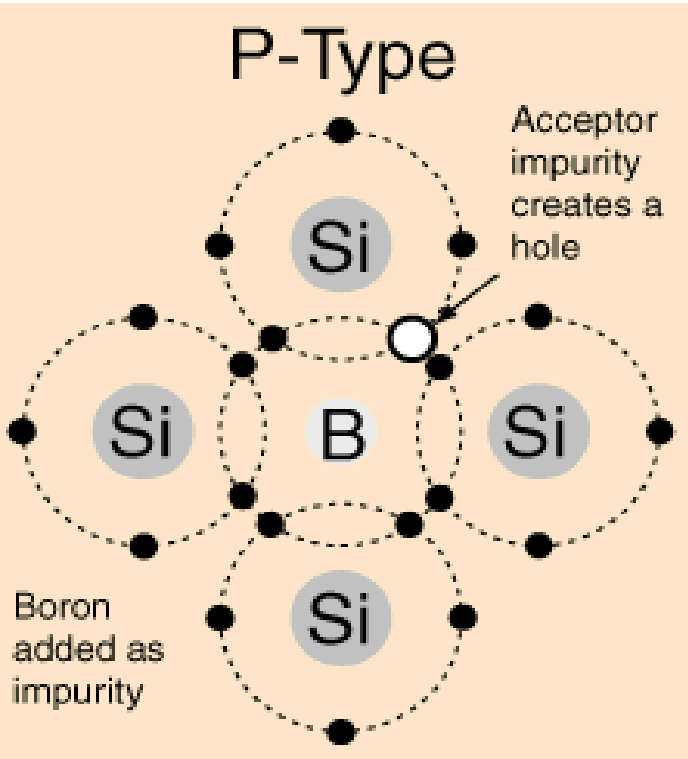


# N-Type Semiconductor

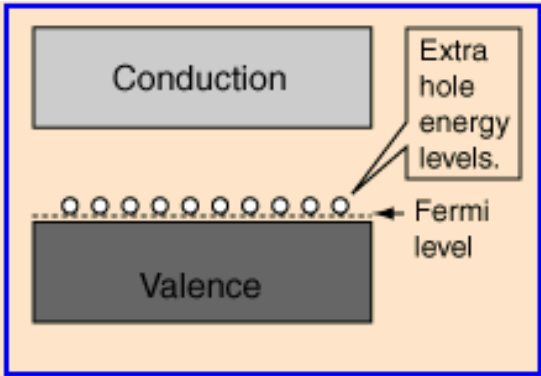


Pentavalent impurities contribute free electrons to increase conductivity

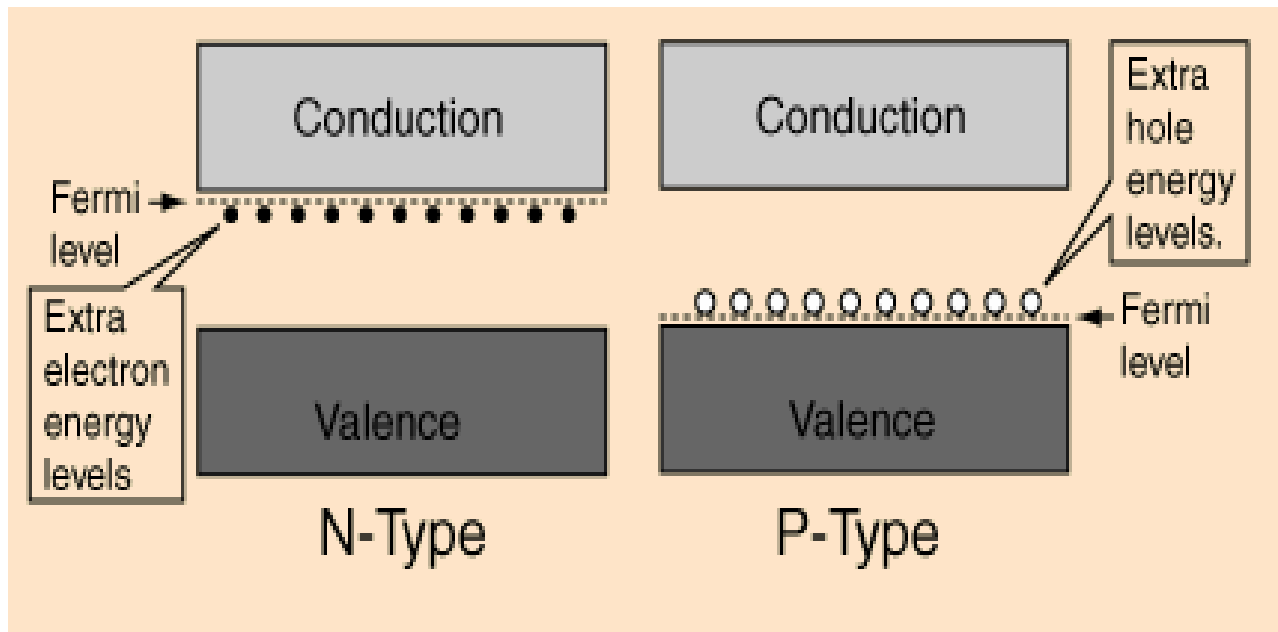
# P-Type Semiconductor



Trivalent impurities create "holes".



## Bands for Doped Semiconductors



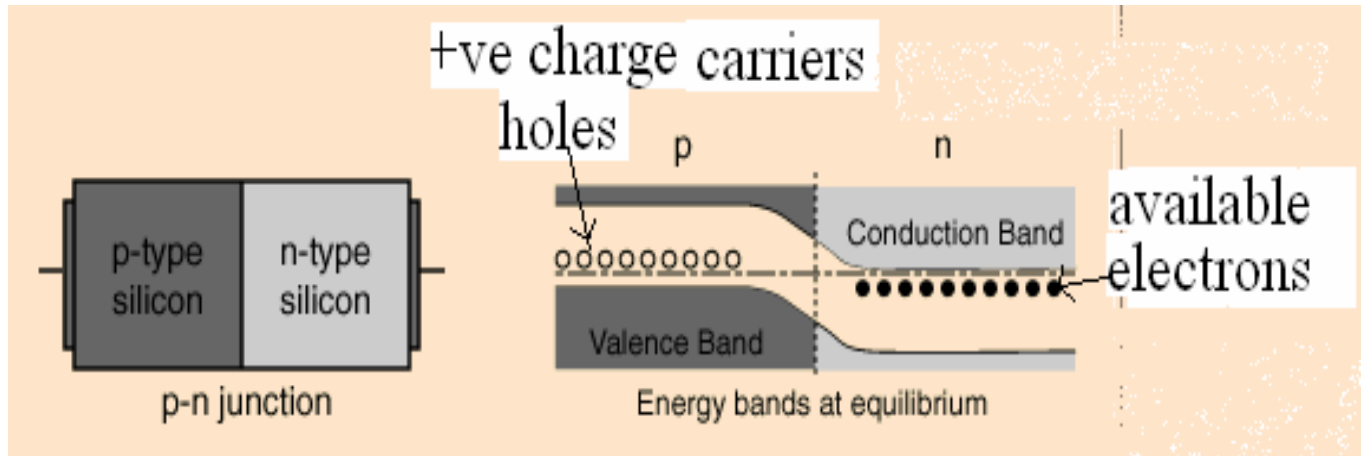
Extra levels added by impurities.

In n-type materials, there are ‘electron energy levels’ near the top of the band gap which can be easily excited into the conduction band.

In p-type materials, extra holes in the band gap allow the excitation of valence band electrons, leaving mobile holes in the valence band.

[10]

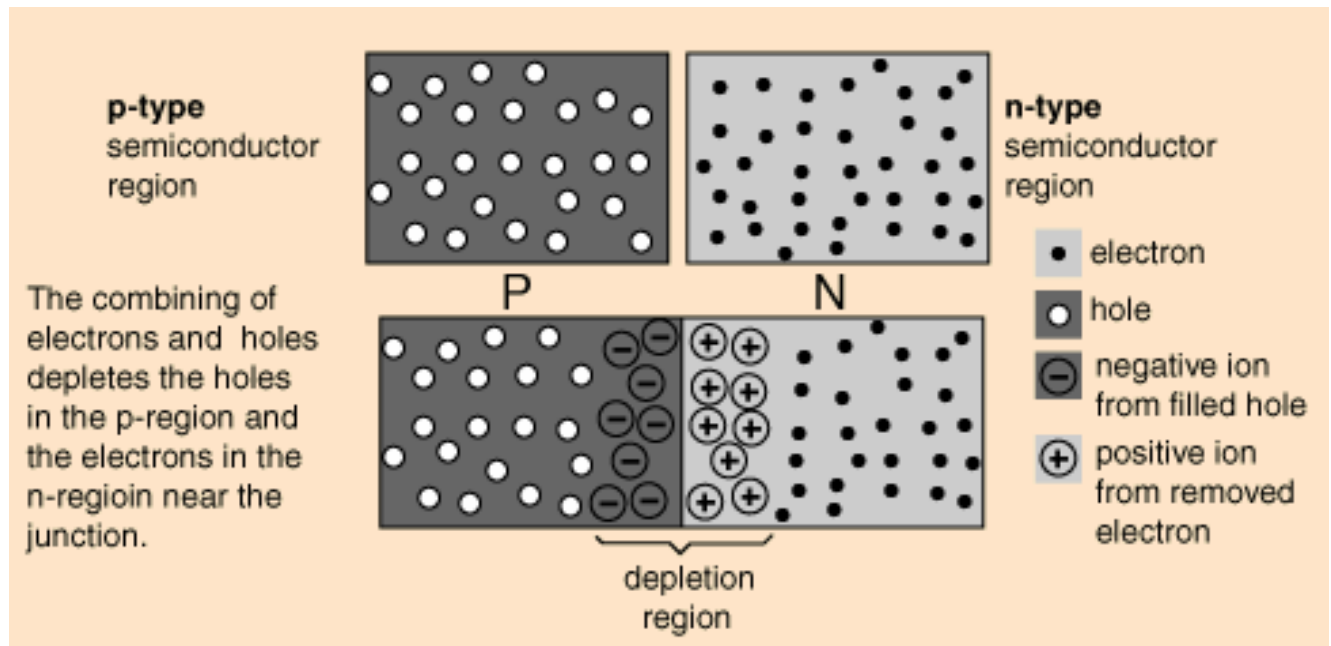
## P-N junctions



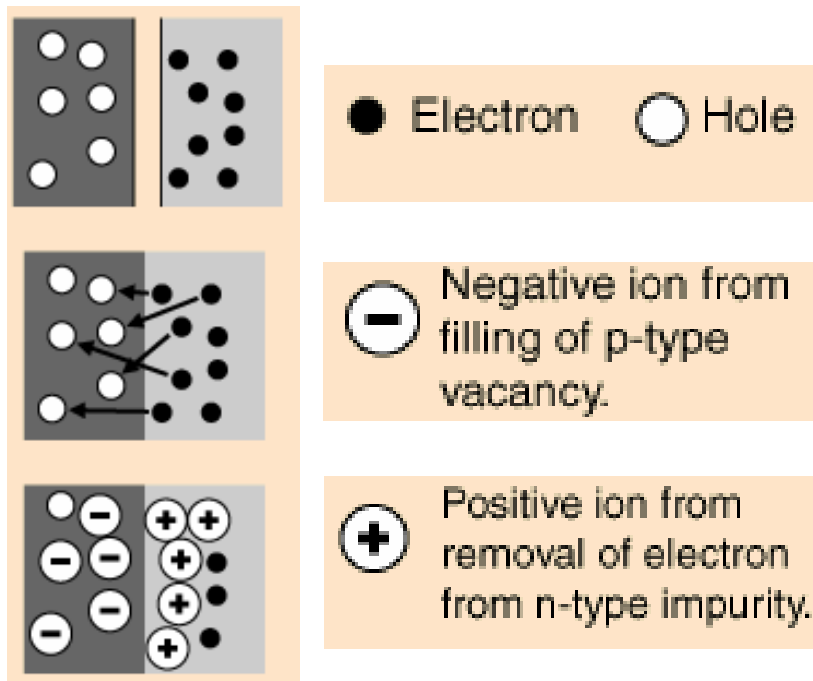
**Equilibrium condition** of the P-N junction.

- When p-type and n-type semiconductors contact each other, the junction behaves differently from either type of material alone.
- Current will flow readily in one direction (forward biased) but not in the other (reverse biased), creating the basic **diode**.
- Near the junction, **electrons** diffuse to combine with **holes**, creating a "**depletion region**".

# DEPLETION REGION



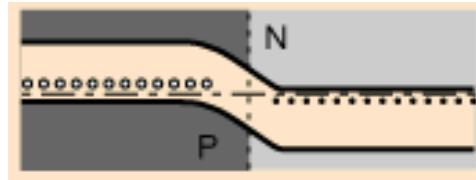
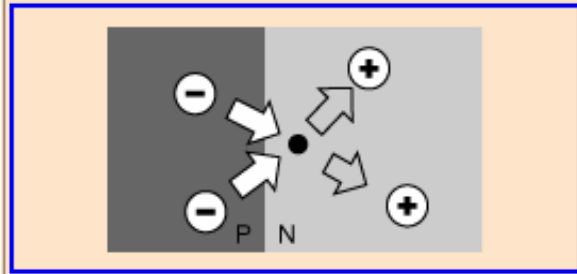
## Depletion region details:



## Bias effect on electrons in depletion zone

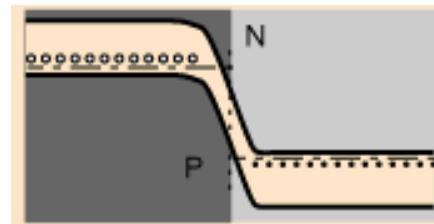
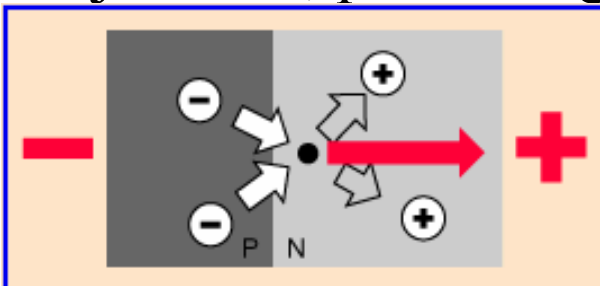
### At equilibrium

There is no migration of electrons from n to p as they are repelled by -ve ions in the p region.



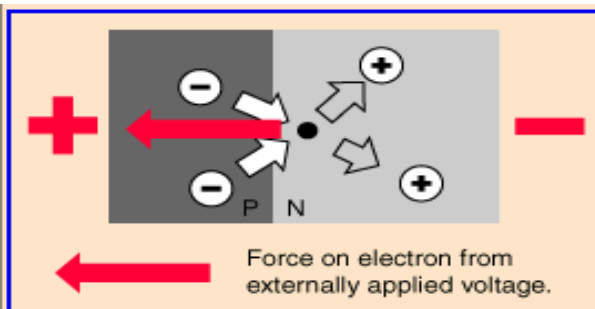
### Reverse bias

A reverse voltage drives the electrons away from the junction, preventing conduction.

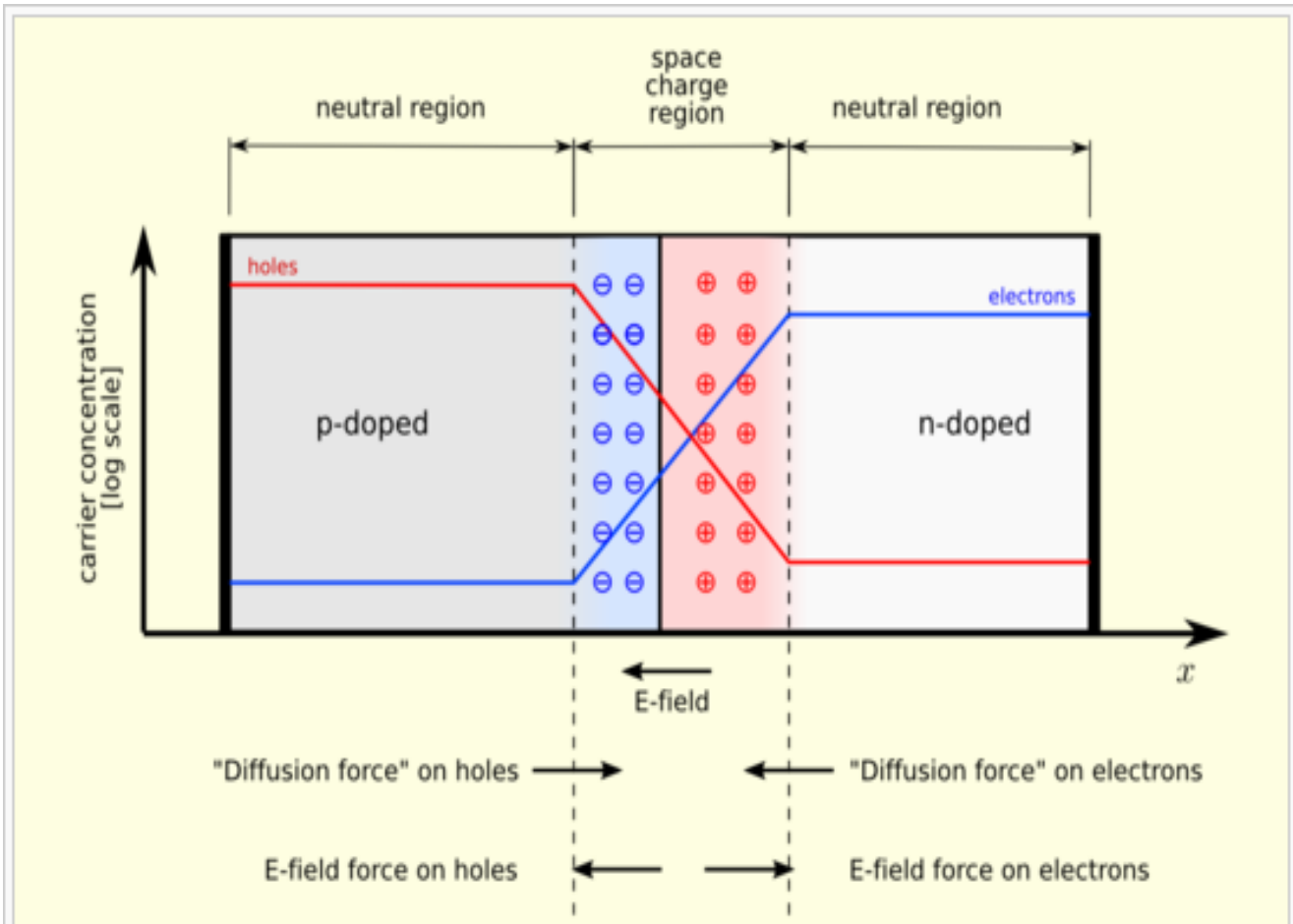


### Forward bias

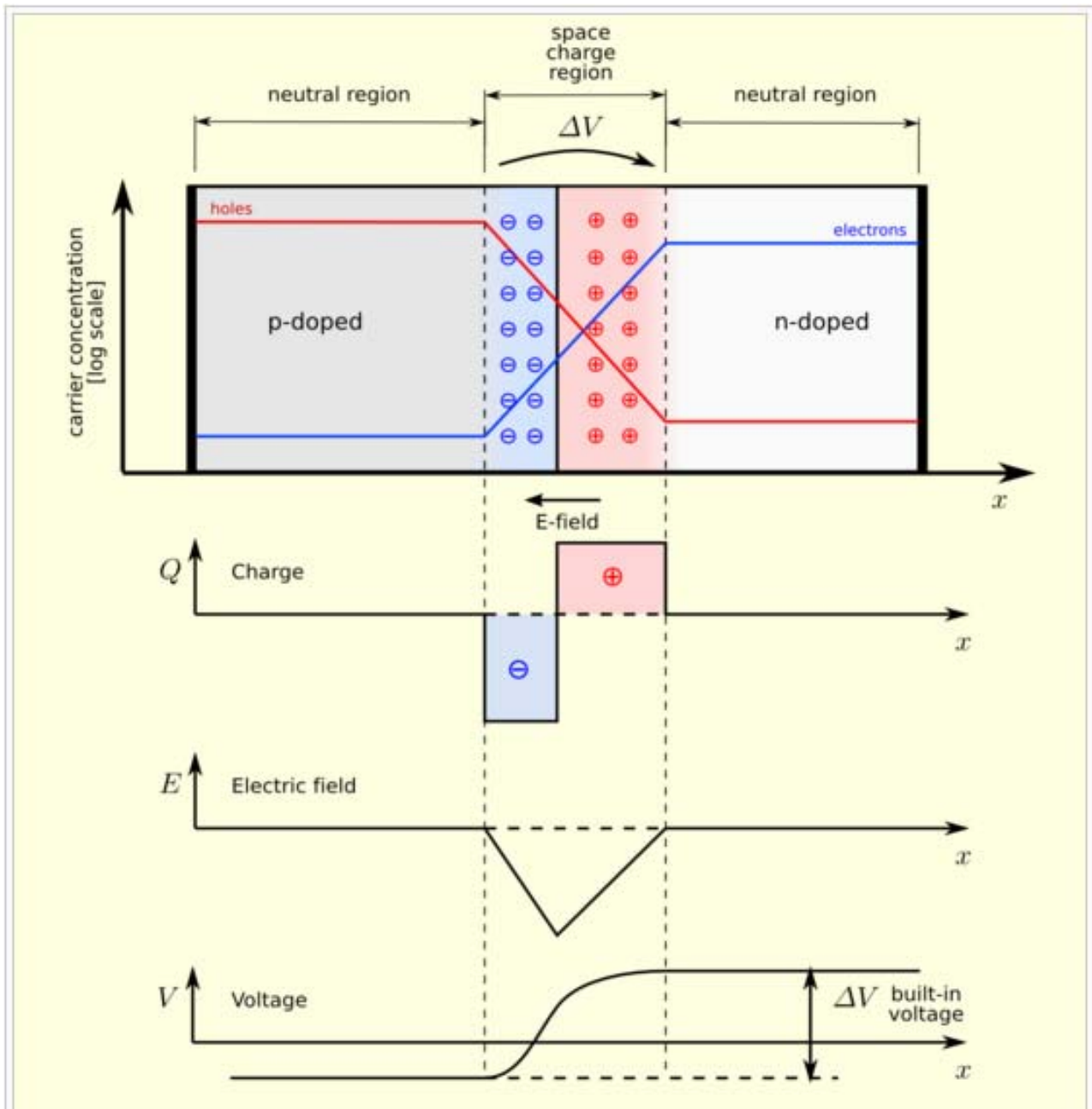
Electrons will flow with very small resistance in the forward direction.



# [11] Operation of the P-N junction



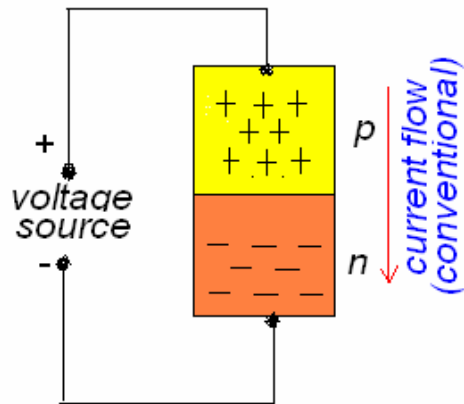
**Figure A.** A p-n junction in thermal equilibrium with zero bias voltage applied. Electrons and holes concentration are reported respectively with blue and red lines. Gray regions are charge neutral. Light red zone is positively charged. Light blue zone is negatively charged. The electric field is shown on the bottom, the electrostatic force on electrons and holes and the direction in which the diffusion tends to move electrons and holes.



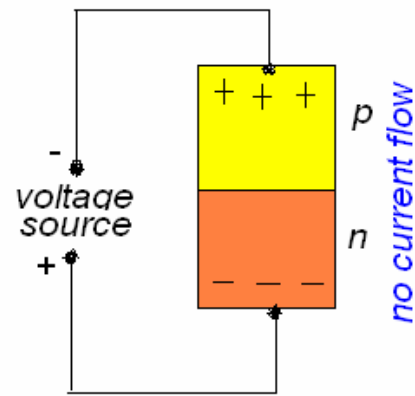
**Figure B.** A PN junction in thermal equilibrium with zero bias voltage applied. Under the junction, plots for the charge density, the electric field and the voltage are reported.

[12]

## Operation of diodes (schematic diagram)



Voltage in forward bias



in reverse bias

[13]

## USES of p-n junctions:

### Light emitting diodes (LED)

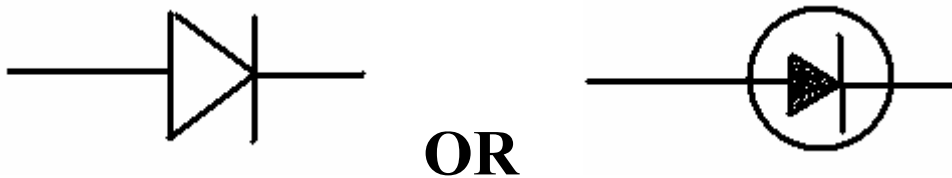
When a P-N junction is **forward biased**, a current begins to flow. Electrons cross from the 'n' region to the 'p' region and combine with the 'holes' and 'photons', emitting an energy equivalent to the band gap, eg: as in LED displays on VCRs and CD players.

## Solar cells and photodiodes

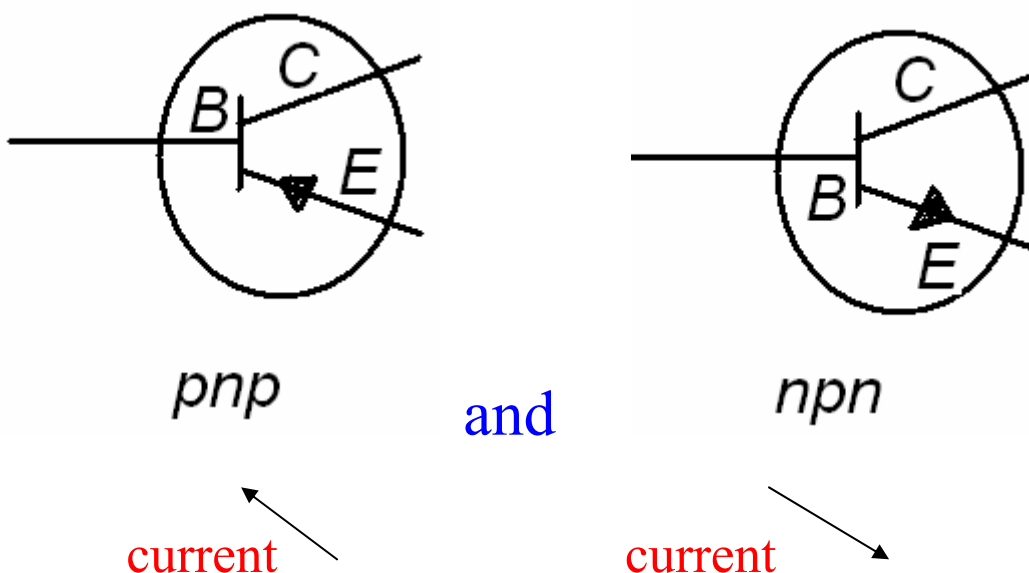
These are P-N junctions used in the reverse way. Photons are absorbed and it becomes a source of emf and power.

A **diode** is a **nonlinear device** because its current is not proportional to its voltage. In a resistor, it is a straight line.

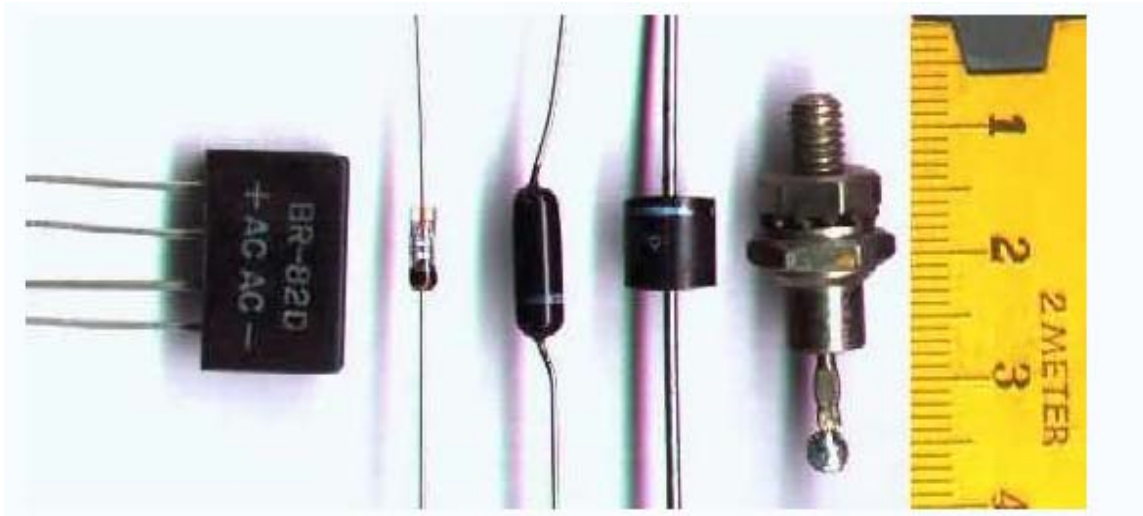
**Diodes** are symbolised as:



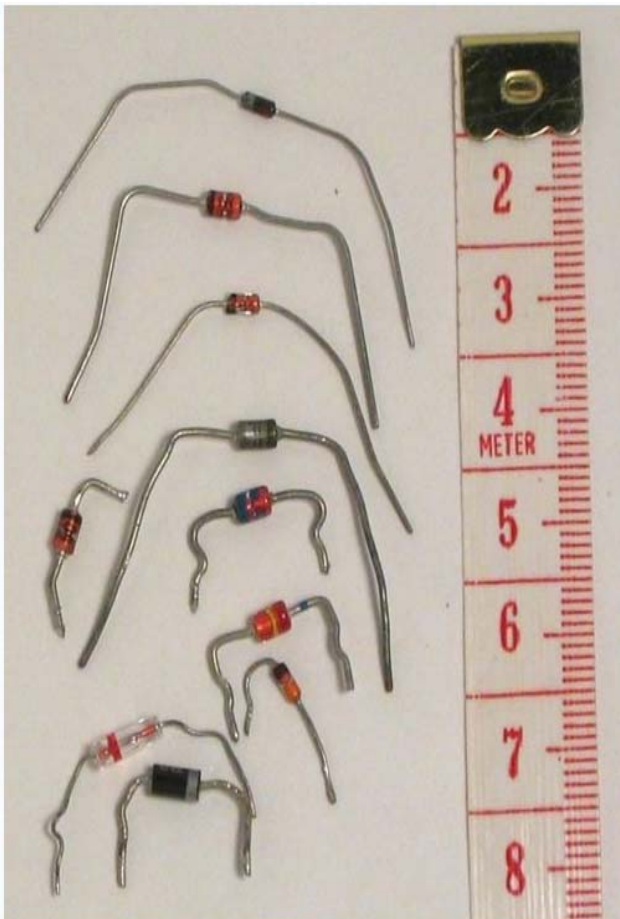
**Transistors** are also non linear devices, symbolised as:



[14] Types of diodes (scale in cm)



Several types of diodes



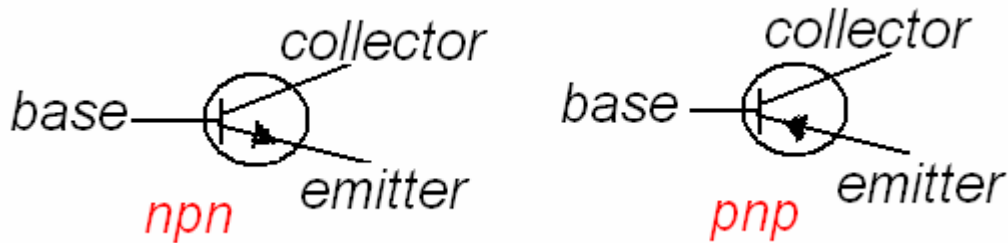
Semiconductor crystal



## Transistors:

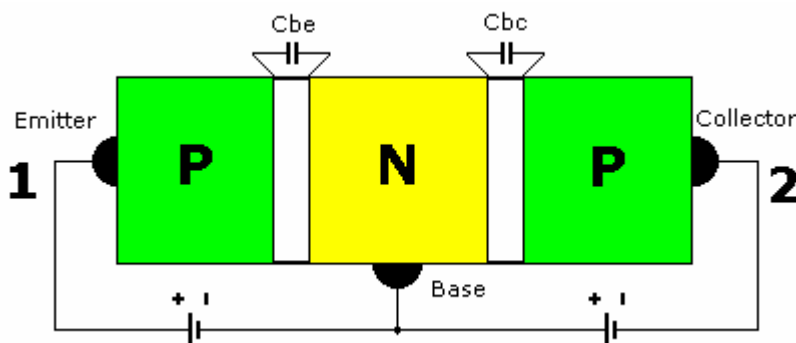
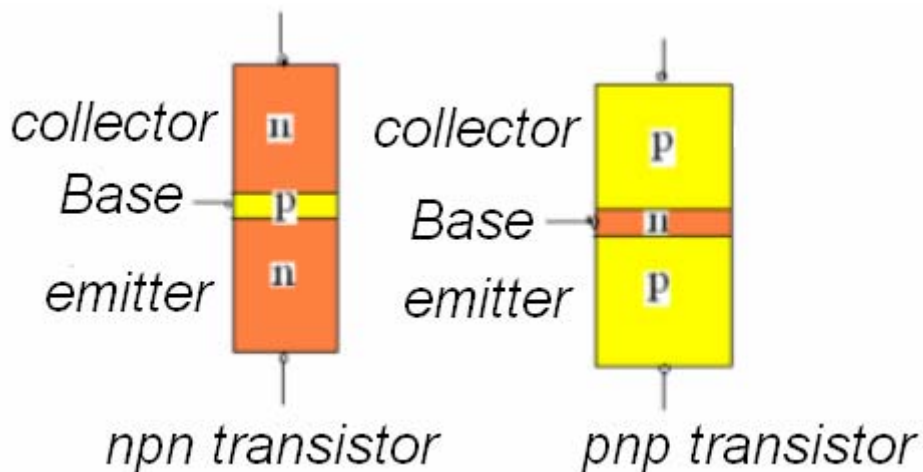
Transistors consist of three semiconductors: The collector, base and emitter.

Symbols for npn and pnp transistors are:



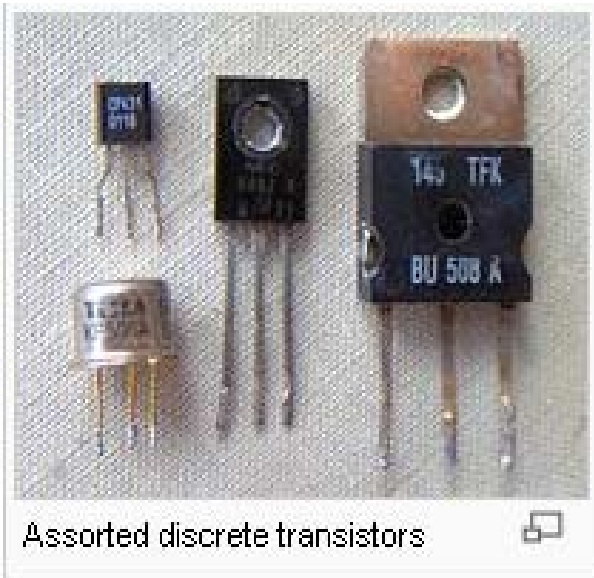
[15]

Schematic diagrams:

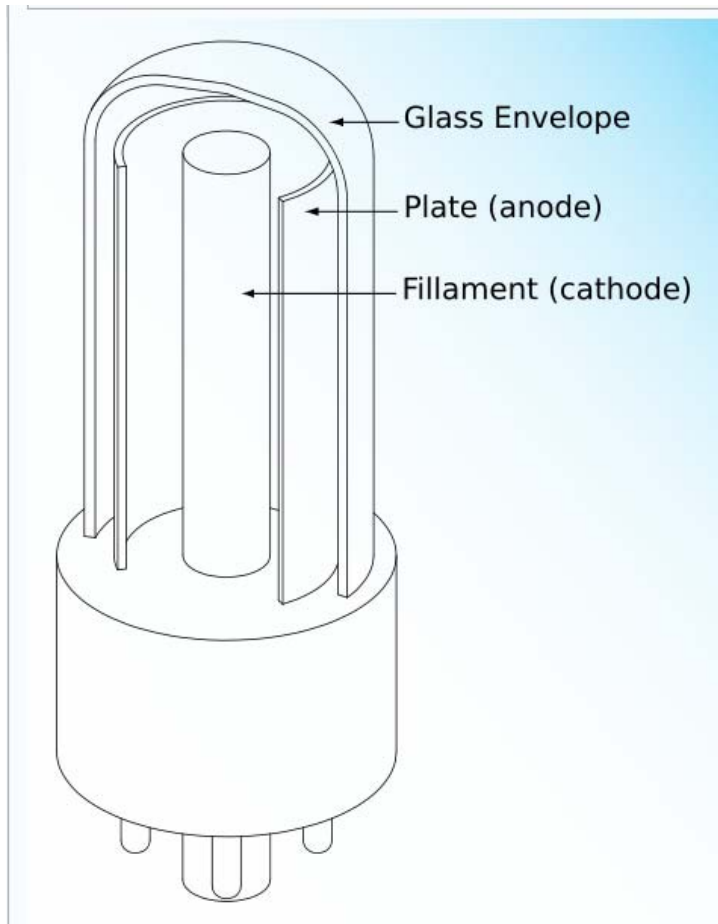


Sandwich construction of a PNP transistor

[16]



- A transistor is a semiconductor- device, commonly used as an amplifier or an electrically controlled switch.
- Used in a wide variety of digital and analogue [17] functions.



## Why solid state devices superseded thermionic devices?

- the thermionic valves are much bigger
- They consume more electrical energy,
- they cannot operate fast
- they need a start

up time

[18]

A vacuum tube diode

## References :

Giancoli D C, PHYSICS International, sixth edition 2006, page #

[3]	.....	p826
[12]	.....	p830
[13]	.....	p828
[15]	.....	p830

Warren N G, Excel HSC physics, 2006 page#

[4]	.....	p124
[6]	.....	p117
[7]	.....	p117

[1] [http://en.wikipedia.org/wiki/Electrical\\_conductivity](http://en.wikipedia.org/wiki/Electrical_conductivity)

[2] <http://environmentalchemistry.com/yogi/periodic/Cu.html#Overview>

[5] <http://hyperphysics.phy-astr.gsu.edu/hbase/solids/sili.html#c3>

[8] [http://en.wikipedia.org/wiki/Extrinsic\\_semiconductor#the\\_two\\_types\\_of\\_extrinsic\\_semiconductor](http://en.wikipedia.org/wiki/Extrinsic_semiconductor#the_two_types_of_extrinsic_semiconductor)

[9] <http://hyperphysics.phy-astr.gsu.edu/hbase/solids/dope.html#c1>

[10] <http://hyperphysics.phy-astr.gsu.edu/hbase/solids/pnjun.html>

[11] [http://en.wikipedia.org/wiki/P-n\\_junction](http://en.wikipedia.org/wiki/P-n_junction)

[14] <http://en.wikipedia.org/wiki/Diode>

[16] <http://www.electronics-tutorials.com/basics/transistors.htm>

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[18] [http://en.wikipedia.org/wiki/Vacuum\\_tube](http://en.wikipedia.org/wiki/Vacuum_tube)

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