

Modern Engineering materials

Coordination Compounds: coordination compounds contain a central metal atom surrounded by non-metal atoms or groups of atoms, called ligands.

Crystal Field Theory (CFT):

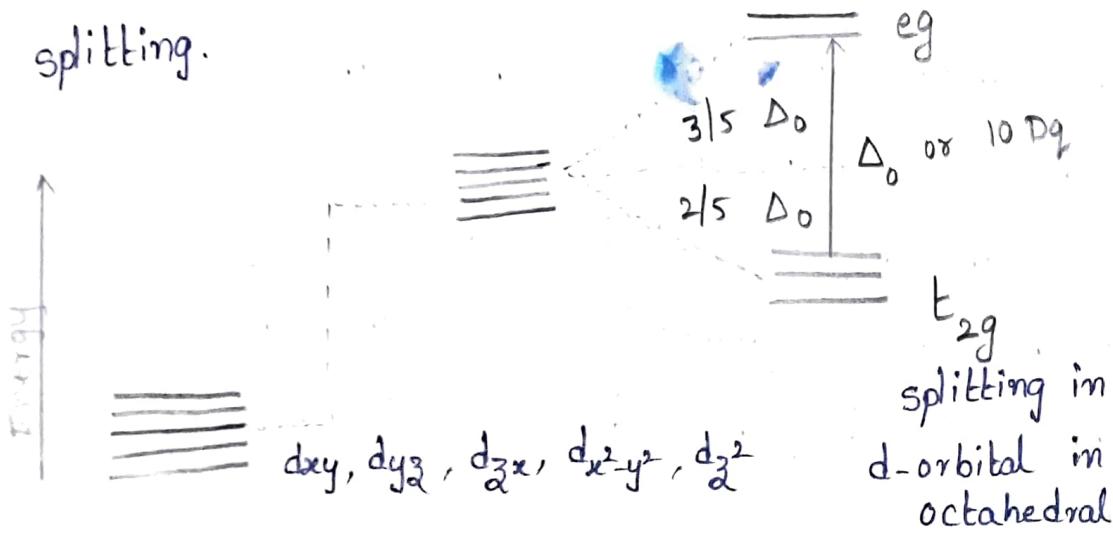
Bethe and vanvleck proposed crystal field theory (CFT) which was later extended by orgel.

- This theory is mainly applicable to transition metals.
- Bonding between the central metal ion and the surrounding ligands are assumed to be ionic i.e bonding between a central metal ion and its ligands simply arises from the purely electrostatic force of attraction.
- An attraction between a positively charged metal ion and negative charge of the ligand.
- The five d-orbitals (d_{xy} , d_{yz} , d_{zx} , $d_{x^2-y^2}$, d_{z^2}) in a metal atom or ion have the same energy (degenerate orbitals).
- If the negative field is due to ligands in a complex it becomes asymmetrical and the degeneracy of the orbitals is changed and results in the splitting of the d-orbitals.

- The pattern of splitting depends upon the nature of the crystal field.

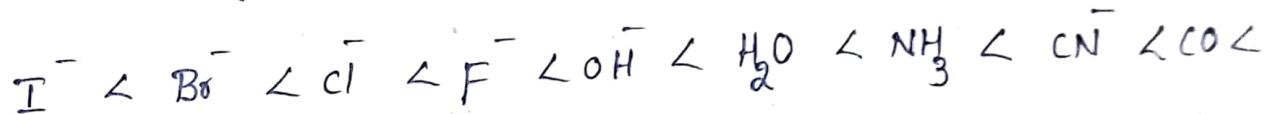
Crystal Field Splitting in Octahedral Geometry:

- In the octahedral complex, six ligands occupy the six corners of an octahedron.
- There will be repulsion between the electrons in metal d-orbitals and the electrons of ligands, not all the d-orbitals (electrons) will be affected equally.
- Thus d-orbitals split into eg orbitals ($d_{x^2-y^2}$, d_{z^2}) and t_{2g} orbitals (d_{xy} , d_{yz} and d_{zx}).
- Hence, under the influence of the approaching ligands the electrons in the orbitals $d_{x^2-y^2}$ and d_{z^2} (eg orbitals) are higher energy compared to d_{xy} , d_{yz} and d_{zx} (t_{2g} orbitals).
- This splitting of the degenerate levels due to the presence of definite geometry is known as crystal field splitting.



The difference between the eg and t_{2g} orbital is Δ_0 or 10 Dq. This is called crystal field stabilization energy (CFSE).

- The eg orbitals are raised by 3/s Δ_0 or 0.6 Δ_0 and t_{2g} orbitals are lowered by 2/s Δ_0 / 0.4 Δ_0 .
- The strong ligands can split the d-orbitals strongly whereas the weak ligands can split weakly.
- Increasing order of splitting capacity.



- The strong ligands (high Δ_0) the electrons to form a pair in the lower t_{2g} and thus the no. of unpaired e_s is reduced. These types of complexes are called Low spin or spin paired complexes.

- The weak ligands (lower Δ_0) the electrons to occupy all the five d-orbitals singly then get paired. These complexes are called high spin complexes or spin-free complexes.

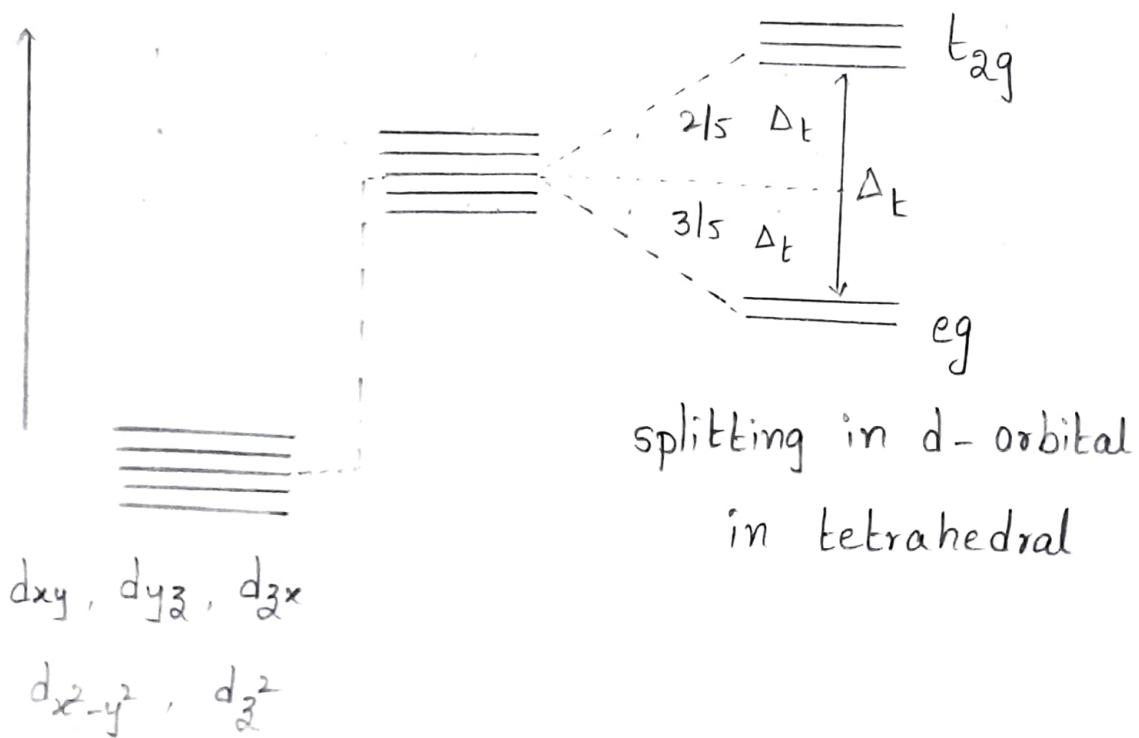
No. of e ⁻ in d	t_{2g}	strong	Ligand	eg	Δ_0		
		d_{xy}	d_{yz}	d_{zx}	$d_{x^2-y^2}$	d_z^2	(CFSE)
d ¹	↑						0.4
d ²	↑		↑				0.8
d ³	↑		↑	↑			1.2
d ⁴	↑↓		↑	↑			1.6
d ⁵	↑↓		↑↓	↑			2.0
d ⁶	↑↓		↑↓	↑↓			2.4
d ⁷	↑↓		↑↓	↑↓	↑		1.8
d ⁸	↑↓		↑↓	↑↓	↑		1.2
d ⁹	↑↓		↑↓	↑↓	↑		0.6
d ¹⁰	↑↓		↑↓	↑↓	↑↓		0

No. of e ⁻ in d'	t_{2g}	weak	ligand	eg	Δ_0	
					(CFSE)	
d ¹	↑					0.4
d ²	↑		↑			0.8
d ³	↑		↑	↑		1.2
d ⁴	↑		↑	↑		0.6
d ⁵	↑		↑	↑	↑	0
d ⁶	↑↓		↑	↑	↑	0.4
d ⁷	↑↓		↑	↑	↑	0.8
d ⁸	↑↓		↑↓	↑	↑	1.2
d ⁹	↑↓		↑↓	↑↓	↑	0.6
d ¹⁰	↑↓		↑↓	↑↓	↑↓	0

Crystal field splitting in Tetrahedral Geometry :

In a tetrahedral complex, the splitting is the reverse of octahedral splitting.

- The directional of approach of the four ligands does not coincide exactly with either the eg or t_{2g} orbitals.
- Now the approach of ligands raises the energy for both eg and t_{2g} sets of orbitals.
- However the energy of t_{2g} sets of orbitals is raised maximum since they are closest to the ligands. Therefore, crystal splitting is opposite to that of octahedral complexes.



The tetrahedral splitting (Δ_t) is always much smaller than the octahedral splitting (Δ_o)

- the orbital splitting energies are not large, so electrons are not paired firstly thus these are also called as high spin complexes.

No. of e^- in 'd'	Strong / weak ligand			Δ_t (CFSE)		
	eg		t_{2g}			
d ¹	↑				0.6	
d ²	↑	↑			1.2	
d ³	↑	↑	↑		0.8	
d ⁴	↑	↑	↑	↑	0.4	
d ⁵	↑	↑	↑	↑	↑	0
d ⁶	↑↑	↑	↑	↑	↑	0.6
d ⁷	↑↑	↑↑	↑	↑	↑	1.2
d ⁸	↑↑	↑↑	↑↑	↑	↑	0.8
d ⁹	↑↑	↑↑	↑↑	↑↑	↑	0.4
d ¹⁰	↑↑	↑↑	↑↑	↑↑	↑↑	0

Properties of coordination compounds :

Oxidation state : A number assigned to an element in chemical combination which represents the number of electrons lost or gained by an atom of that element in the compound.

Co-ordination number :

		Sc	+1	+2	+3			
	-2	-1	Ti	+1	+2	+3	+4	
-3		-1	V	+1	+2	+3	+4	+5
-4	-2	-1	Cr	+1	+2	+3	+4	+5 +6
-3	-2	-1	Mn	+1	+2	+3	+4	+5 +6 +7
-4	-2	-1	Fe	+1	+2	+3	+4	+5 +6 +7
-3		-1	Co	+1	+2	+3	+4	+5
	-2	-1	Ni	+1	+2	+3	+4	
	-2		Cu	+1	+2	+3		
	-2		Zn	+1	+2			

- In 4d series Ruthenium (Ru) also exhibit +8 oxidation states also.
- In 5d series Tridium (Ir) also exhibit +9 oxidation states also.

Co-ordination number:

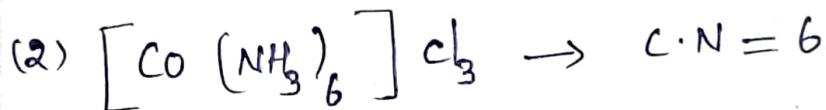
The coordination number of an atom in a given molecule or a crystal refers to the total number of atoms, ion or molecules bonded to the central metal atom.



$$4(+1) + Ni + 6(-1) = 0$$

$$4 + Ni - 6 = 0$$

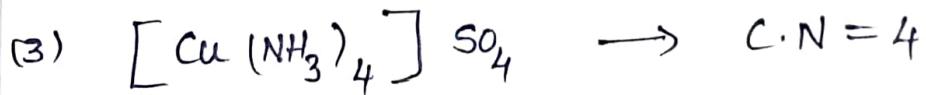
$$\boxed{Ni = +2}$$



$$x + 6(0) + 3(-1) = 0$$

$$x + 0 - 3 = 0$$

$$x = +3 \quad \boxed{Co = +3}$$

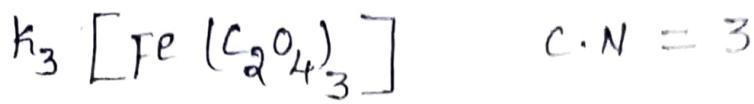


$$cu + 4(0) + 1(-2) = 0$$

$$cu + 0 + (-2) = 0$$

$$\boxed{cu = +2}$$

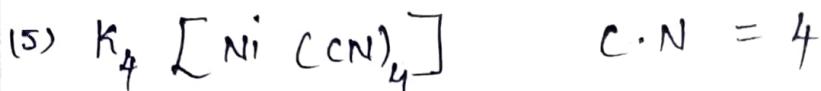
(4)



$$3(+1) + Fe + 3(-2) = 0$$

$$3 + Fe - 6 = 0$$

$$\boxed{Fe=+3}$$



$$4(+1) + Ni + 4(-1) = 0$$

$$4 + Ni - 4 = 0$$

$$\boxed{Ni = 0}$$

colour :

- crystal field theory can explain the colour of the transition metal complexes.
- A substance appears coloured because it absorbs light at specific wavelengths in the visible part of the electromagnetic spectrum and transmits the rest of the wave lengths.
- When the energy of the photon is equal to the difference between the energy of eg and t_{2g} levels an electron is promoted from a lower to higher level.

- In the absence of ligand crystal field splitting does not occur and hence the substance is colourless.

Ex : anhydrous CuSO_4 is colourless.

$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ is blue in colour.

- $[\text{Ti}(\text{H}_2\text{O})_6]^{3+}$ Ti^{3+} has one d-electron in t_{2g} level. If the light corresponding to the energy of the yellow-green region is absorbed by the complex it would excite the electron from t_{2g} level to e_g level, therefore the complex appears violet in colour.

Ex:

$[\text{Co}(\text{H}_2\text{O})_6]^{3+}$ - 600 nm is observed - Green
(Red) (complementary colour)

$[\text{Co}(\text{NH}_3)_6]^{3+}$ - 475 nm is observed - yellow
(Blue)

Magnetic nature :

The transition metal complexes containing one or more unpaired electrons possess a definite value of magnetic moment or magnetic nature. It is denoted by μ (μ_u)

$$\mu = \sqrt{n(n+2)} \text{ BM}$$

The substance having magnetic moments are attracted by magnetic fields. such substances are called paramagnetic substances.

- the substances having no unpaired electrons show zero magnetic moments and are called diamagnetic substances.

Ex: $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ has four unpaired electrons and is paramagnetic nature.

$[\text{Fe}(\text{CN})_6]^{4-}$ has no unpaired electrons and is Diamagnetic nature.

NO. of unpaired electrons	magnetic moment (BM)
1	1.73
2	2.83
3	3.87
4	4.90
5	5.92

conductors, Insulators and Semiconductors :

(i) Good conductors :

These allow the maximum portion of the applied electric field to flow through them. The electrical conductivity of good conductors is of the order of $10^8 \text{ ohm}^{-1} \text{ cm}^{-1}$. Metals are good conductors of electricity.

(ii) Insulators :

They do not practically allow the electric current to flow through them, the electrical conductivity is of the order of $10^{-22} \text{ ohm}^{-1} \text{ cm}^{-1}$. most of the organic and inorganic solids (except Graphite) are poor conductors of electricity.

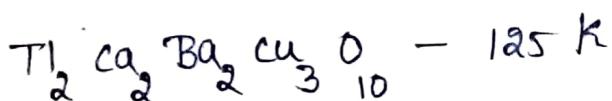
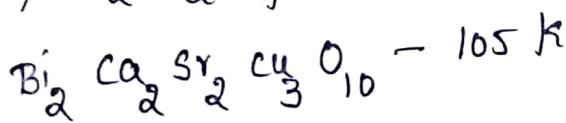
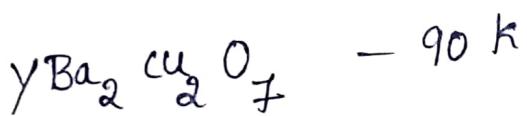
(iii) Semi-conductors :

At room temperature, Semi-conductors allow a portion of electric current to flow through them. The electrical conductivity of a semi-conductor at normal temperature lies between that of a good conductor and an insulator, it is in range of 10^{-9} to $10^2 \text{ ohm}^{-1} \text{ cm}^{-1}$.

Super-conductivity :

The electrical resistance of metals depends upon temperature. Electrical resistance decreases with decrease in temperature and becomes almost zero near the absolute temperature. Materials in this state are said to possess super-conductivity.

- Super-conductivity may be defined as a phenomenon in which metals, alloys and chemical compound become perfect conductors with zero resistivity at temperatures approaching absolute zero.
- Super-conductors are diamagnetic.
- The temperature at which a substance starts behaving as super-conductor is called transition temperature which lies between 2 and 5 K in most of the metals.
- The highest temperature at which super-conductivity has been observed in 23 K for alloys of niobium (Nb_3Ge).
- since 1987, many complex metal oxides have been found to possess super conductivity at fairly high temperatures.



Band Theory in solids (crystals) :

- Band theory explains solids only. In solid crystals a large number of spherical atoms are arranged in a regular close-packed pattern in the form of crystals.
- When the atoms are brought together in solids, the atomic orbitals of the valence shells interact forming molecular orbitals.
- The overlap of a large number of atomic orbitals in a solid leads to a large number of molecular orbitals that are closely spaced in energy and so form an almost continuous band of energy levels.
- The electronic configuration of magnesium is $1s^2 2s^2 2p^6 3s^2$. The $3s$ band in magnesium is completely filled by 'n' electrons of 'n' magnesium atoms. The filled $3s$ band overlaps empty $3p$ band, therefore some electrons in the $3s$ band can move into the $3p$ band and hence magnesium is an excellent conductor.

→ Depending upon the composition of the solid, the bands are of two types.

(a) Overlapping band : The higher band overlap on the lower band to some extent.

Ex : Be

(b) Non-overlapping band : The higher and lower bands separate and do not overlap.

Ex : Li, Na, Cu etc.

- The band of energy levels occupied by the valence electrons is called valency band. It may be filled partially or completely with electrons.

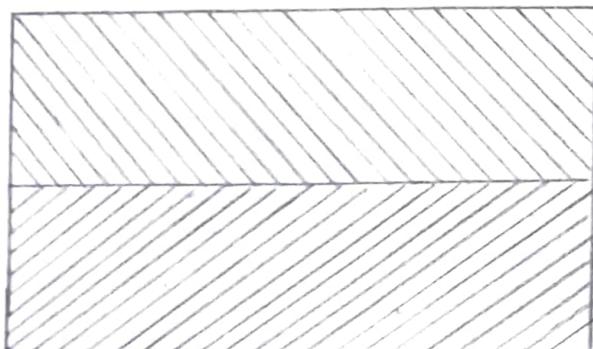
- The band, that is either partly or completely vacant is called conduction band. It is always above the valence band.

- The gap between the valence band and the conduction band is called the forbidden gap. No electron can exist in the forbidden gap. The width of the forbidden gap is called the energy gap (E_g)

Band diagrams:

(a) conductors:

- If a solid is a conductor, it has either partially filled or completely filled valence band overlapping with conduction band.
- When a potential is applied across the solid, some of the electrons raise to the conduction band and hence it acts as a conductor.
- The forbidden gap is not present in good conductors.
- The electrical conductivity of a metal decreases with rise in temperature because increased thermal vibrations of the metal atoms cause scattering of the electrons, thereby obstructing their free flow.

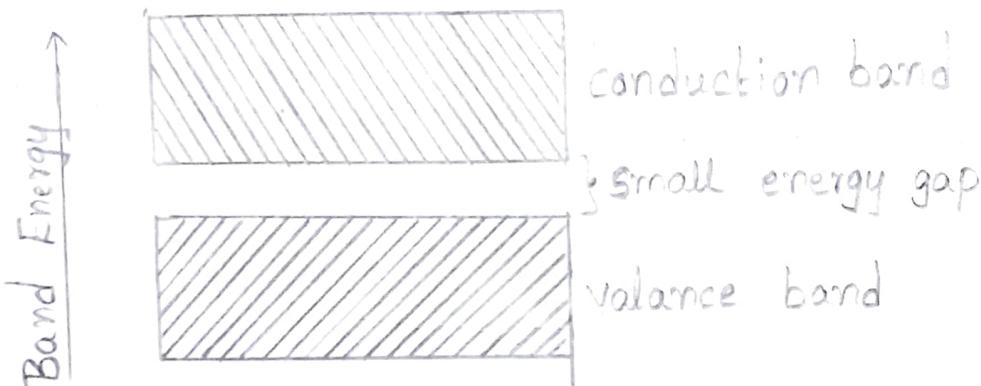


conduction band
overlap
valence band

(b) Semi-conductors:

- If a solid is a semi conductor, it has an almost filled valence band, an empty conduction band and a very narrow energy gap.

- As the temperature increases, the width of the forbidden gap decreases, hence some of the electrons jump into the conduction band.
- so the electrical conductivity of a semiconductor increases with rise in temperature.



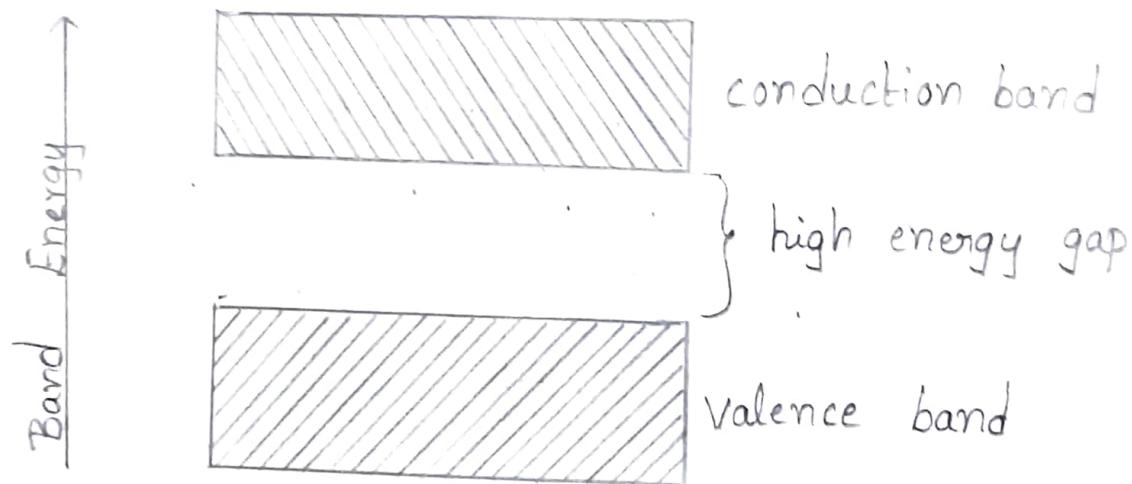
Electrons can also be displaceable from the bands in semiconductors with the help of light energy and this is called photo voltaic effect. This is used in solar cells to convert sunlight into electricity.

(c) Insulators:

- the solid materials which have a full valence band, completely empty conduction band and large energy gap between these two bands are called insulators.
- Higher the energy gap, better is the insulation of the material.

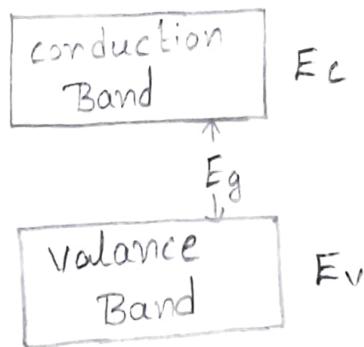
Ex: Diamond (6ev) , glass (10 ev) etc.

- At room temperature , there is no chance for electrons in the valence band to jump into the conduction band.
- Those substances show the best insulating properties at room temperature . However , at higher temperature , some of the valence band electrons jump into the conduction band , hence the insulators exhibit conductivity with increase in temperature.



Role of Doping on Band structures :

- The process of incorporating the desired type of impurities in a crystal lattice is called "doping".
- whose conducting properties have been improved by adding small amounts of impurity called doping agents or dopants.
- The addition of doping agent reduce the energy gap (E_g), there by allowing more electrons to flow from the valence band to the empty conduction band.
- The valence band of semi conductor is full and the conduction band is empty at 0 K.



- one part of the doping agent is added to 10^6 parts of the parent element (Si, Ge etc)
- If the semiconductor has impurity (dopant) atoms, energy states can exist in between the conduction band (E_c) and valence band (E_v). If an atom contains one more valence electron then the semi -

conductor atom will be occupied in the lattice only but not used in bonding.

- Based on the nature of the doping agent, doping are two types.

(1) Intrinsic Semiconductors

(2) Extrinsic Semiconductors

(1) Intrinsic Semiconductors: At 0 K, pure silicon or germanium acts as insulators because electrons fixed in covalent bonds are not available for conduction.

- At higher temperatures some of the covalent bonds are broken and the electrons so released become free to move in the crystal and thus conduct electric current. This type of conduction is known as intrinsic conduction.

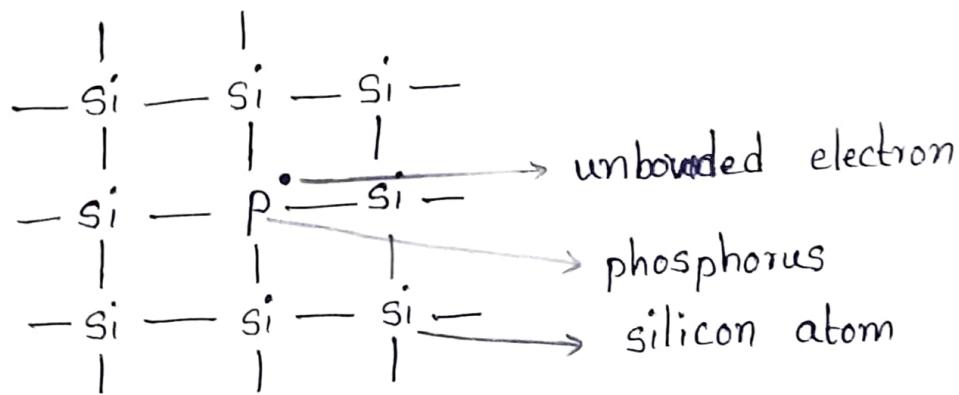
(2) Extrinsic Semiconductors:

- silicon and germanium (group 14 elements) in pure state have very low electrical conductivity.

- The electrical conductivity of these elements is greatly enhanced by the addition of even traces of an element belonging to group 13 (III) or group 15 (V) to the crystals of group 14 (IV) elements.

(i) n-type extrinsic semi conductors :

- It consists of an excess negatively charged electrons obtained by adding an extremely small amount of a pentavalent impurity like p, As and Sb (V group elements) to pure semiconductor (Si or Ge) crystal lattice.
- The doping agent (P or As) forms poor covalent bonds with the surrounding four atoms of semiconductor and the fifth excess electron remains loosely bound to the donor atom itself.
- These loosely bound electrons can easily enter into conduction band from the valence band when an electric field is applied. Therefore, the resulting conduction is called n-type semiconductor.

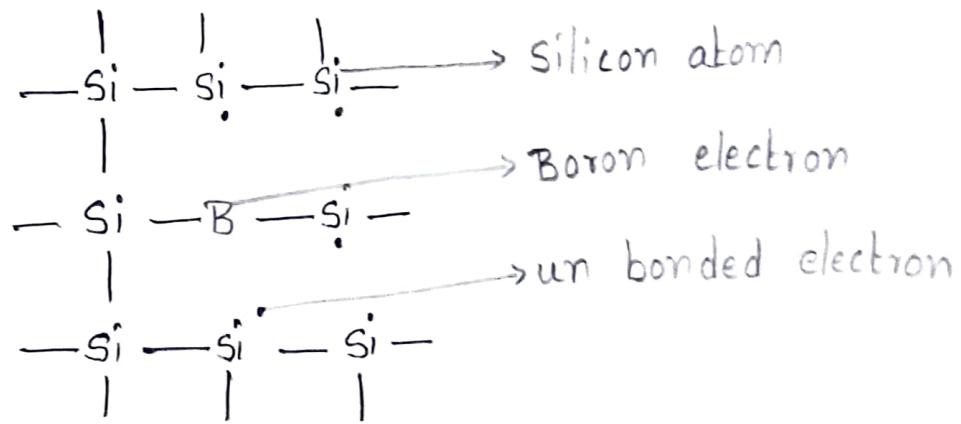


(ii) p-type extrinsic semi conductors :

- These are obtained by adding an extremely small quantity of trivalent impurity such as B, Al (III group elements) to the pure intrinsic semi-

conductor (Si or Ge) crystal lattice.

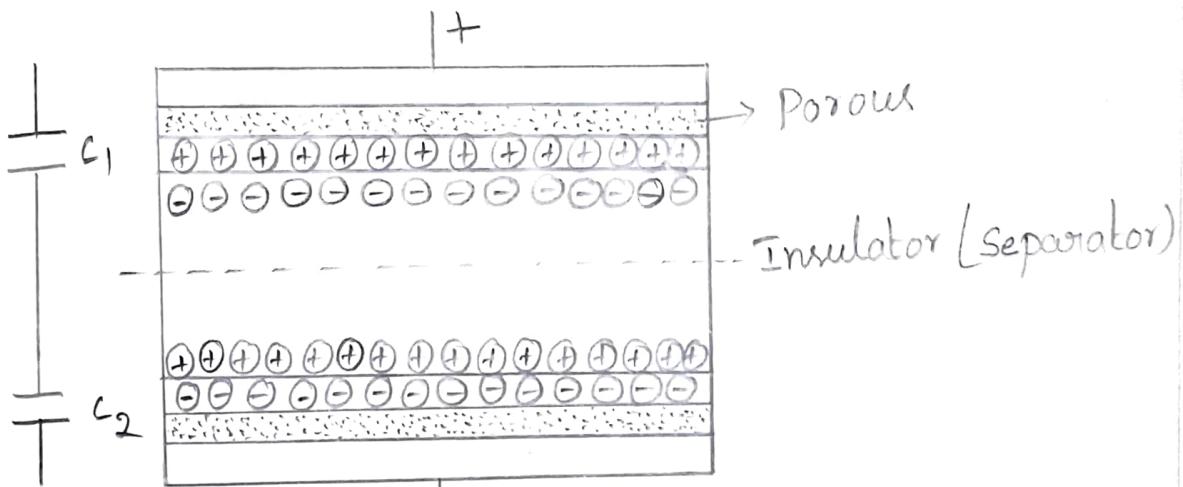
- The three valence electrons present in the trivalent doping agent (B or Al) form three covalent bonds with the surrounding three of the four atoms, thereby one bond of the one of the four surrounding semi-conductor atom is left incomplete. This gives rise to a positive hole.
- This extra electron can move freely through the crystal lattice to increase the conductivity of silicon.
- The lack of an electron between the boron and silicon atoms creates a small positive charge in that area and is often called a positive hole.
- Positive hole is less mobile than free electrons, so the conductivity of a p-type semiconductor is less than that of an n-type semiconductor.



Super Capacitors :

- Super capacitors are electronic device which are used to store extremely large amount of electrical charge. They are also known as ultra capacitors.
- A super capacitor is a specially designed capacitor which has a very large capacitance. Super capacitors combine the properties of capacitors and batteries into one device.

construction :



- The capacitor having two plates one is +ve plate (electrode) and one is -ve plate (electrode) is placed in above and below the capacitor.
- The two plates are coated with porous material, the +ve charge are stored in -ve plate and -ve charge are stored in +ve plate.

- The capacitance of the capacitor is directly proportional to the area of the plate and inversely proportional to distance between the plates.

$$\text{capacitance } (C) = \frac{A}{d}$$

A = Area of the plate

d = distance between the plates.

$$C_{\text{Total}} = \frac{C_1 \times C_2}{C_1 + C_2}$$

- Generally Super capacitors are three types.

(1) Electrostatic double Layer capacitors (EDLC)

(2) pseudo capacitors

(3) Hybrid capacitors

EDLC :

- In this type of capacitors the electrodes are coated with carbon derivatives like charcoal.
- charge is stored electrostatically.
- In this double layered capacitors storage of electrical energy is achieved by charge separation in double layer..
- In capacitor the two electrodes are separated by a insulator (separator) it is made by mica, paper or ceramic material.

pseudo capacitors :

- In pseudo capacitors the electrodes (plates) are coated with metal oxides that possess large electro-chemical pseudo capacitance.
- storage of electrical energy is an electro chemical process and is achieved through redox reaction, intercalation on electrode surface by ions that are specifically absorbed.
- charge is stored electro chemically, so it is a battery.

Hybrid capacitors :

- the electrodes are asymmetric where one of the electrode exhibit electrostatic property while the other exhibits electro chemical property.
- In this the charge is stored in electro statically in one plate and electro chemically on other plate.
- Because both pseudo capacitance and double layered capacitance make inseparable contribution to the full capacitance.
- the concept of super battery and super capacitor have been proposed.

Energy density : The amount of energy stored in a given system (capacitor) per unit mass / liter.

units - Wh/kg (or) Wh/lit

power density : The amount of energy to do work for per unit mass / liter.

units - kW/kg (or) kW/lit

Advantages :

- very high efficiency
- super capacitors offers high energy density and high power density.
- charging rate is high and they offer higher performance reliability.
- Super capacitors have a longer life than a battery (around 10 to 15 years).
- The super capacitors can withstand ~~only~~ any temperature between -30 to 65°C whereas a battery can withstand -10 to 40°C .
- the super capacitor is very light in weight.
- super capacitors can be installed in a small area as they have very small size.

Applications :

- Capacitors are mainly used Energy storage in KERS (Kinetic Energy Recovery System).
- the automotive industry is making use of this approach by using electrical generators that change kinetic energy into electrical energy. this electrical energy is stored in super capacitors and is later used to supply power required for acceleration.
- MP₃ players, photo graphic flash, static memories are a few such application.
- super capacitors can provide back up or emergency shutdown power to low - power equipment such as RAM, SRAM.

Nano chemistry :

Nano science which is the science of the tiny, has gained lot of interest during the last decades. It is a broad field connected to both chemistry, physics, medicine, material science as well as to applied technologies. Nano materials can be metals, ceramics, polymeric materials or composite materials.

- The term nano comes from a Greek word meaning dwarf or extremely small.
- Nano scale materials are too small to be seen with the naked eye and even with conventional lab microscopes.

$$1 \text{ nm} = 10^{-9} \text{ m}$$

Nano materials : Nano materials are usually considered to be materials with at least one external dimension less than 100 nanometers.

Classification :

Based on the dimensionality, nanomaterials are classified as

- (1) zero dimensional (0D)
- (2) one dimensional (1D)
- (3) Two dimensional (2D)
- (4) Three dimensional (3D)

(a) Zero - Dimensional Nanomaterials :

Materials having all the dimensions within the nano-scale (no dimensions). The most common examples of zero-dimensional nanomaterials are nano particles.

(b) One - Dimensional Nanomaterials :

Materials having one of their dimensions outside the nanoscale (two dimensions are in the nanoscale). This leads to needle like - shaped nanomaterials.

Ex: Nano tubes, nanorods and nano wires.

(c) Two - Dimensional Nanomaterials :

Materials having two of their dimensions outside the nanoscale (only one dimension is the nano scale).

- 2D nanomaterials exhibit plate - like shapes.

Ex: Nano films; nanolayers and nano coatings.

(d) Three - Dimensional Nanomaterials :

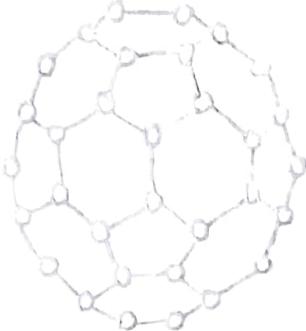
Materials having all their three dimensions outside the nanoscale.

Ex :- Nano flowers, Nano crystals.

Fullerenes :

- The discovery of C_{60} has a long and very interesting history.
- It is a new form of carbon.
- the structure of fullerene was soccer ball.
- they named C_{60} as Buckminster fullerene because of similarity of the structure to be geodesic structure widely created by R. Buckminster Fuller.
- Because of this work W. Kroto, Richard, E. Smalley and Robert were awarded the nobel prize in chemistry in 1996.
- The fullerenes are even number of sp^2 hybrid carbon atoms over the surface of a closed hollow cage.
- Fullerenes consisting of a five membered and six membered rings.
- The structure of C_{60} like a soccer ball with 12 pentagonal and 20 hexagonal carbon rings.
- The bond length in a pentagonal is 1.45 \AA and hexagonal is 1.40 \AA
- At room temp the solubility of C_{60} is 2.8 mg/ml in Toluene.

Fullerenes



- fullerenes are ready to reduce and hence it acts as good oxidising agent.
- It is unstable at higher temp.
- C_{60} is a very poor conductor of electricity but when react with reducing agent (alkali) the resulting compound has high electrical conductivity and even become super conducting.

Preparation of fullerenes :

- fullerenes can be prepared in simple processes.
- Graphite rods are vapourised in an inert atmosphere (Helium) by passing a high electrical current through them.
- this produces a light condensed fullerenes which contain variety of different fullerenes.
- The fullerenes can be extracted through toluene.
- separation and purification can be achieved by column chromatography.

Applications :

Because of wide range of magnetic and conducting properties , fullerenes has the following applications.

- (1) micro - electric devices
- (2) micro - electronic devices
- (3) super conductors
- (4) Non - Linear optical devices
- (5) soft ferro magnetic materials
- (6) adsorbent for gases
- (7) Lubricants
- (8) cosmetics (Anti - accident property)

Carbon Nano Tubes (CNT)

- carbon nano tubes also called Bucky tubes which is allotrope of carbon with a cylindrical nano structure.
- It was discovered by S. Iijima in 1991.
- Nano tubes are the members of the fullerene structural family.
- Their name is derived from their size since the diameter of a nano tube is in the order of a few nano meters ($\sim 1/50,000^{\text{th}}$ of the width of a human hair).

- nano tubes are two types.
 - (1) single walled nano tubes (SWNT's)
 - (2) Multi-walled Nano tubes (MWNT's)
- The chemical bonding of a nano tubes is based on sp^2 hybridisation similar to those of graphite.
- This bonding structure which is stronger than sp^3 bonds found in diamonds provide the molecules with their unique strength.

Properties :

- (1) Strength :
 - CNT are the strongest and stiffest materials in terms of tensile strength and elastic module.
 - A multi-walled carbon nano tube was tested and found tensile strength 63 giga pascals (Gpa).
- (2) Hardness :
 - The diamond is considered as hardest material.
 - SWNT's are very strong with 24 Gpa at room temp.
 - The hardness of this material was measured with a nano indenter as 62 - 152 Gpa.
 - The hardness of reference diamond and Boron nitride sample was 150 and 62 Gpa respectively.

- the bulk modulus of compressed SWNT's was 462 - 54.6 Gpa surprising the value of 420 Gpa for diamond.

(3) Thermal conductivity :

- Experimental results show that SWNT has at room temp thermal conductivity along its axis of about $3500 \text{ W m}^{-1} \text{ K}^{-1}$.
- compare this to copper metal well known for its good thermal conductivity which transmits 385 W/mk
- But SWNT has a room temperature thermal conductivity across its axis of about 1052 W/mk which is comparable thermal conductivity of soil.

(4) Temperature stability :

- CNT's are stable up to 2800°C in vacuum and 750°C in air of temp stability.

(5) Toxicity :

- Determining the toxicity of CNT's has been one of the most pressing question in nano technology.
- Based on the available data show that under some conditions nano-tubes can cross membrane barriers, which causes inflammatory reactions.

- A study by Alexandra Parker from University of Cambridge shows that CNT's can enter into human cells and accumulate in the cytoplasm causing cell death.

Applications :

- Breast cancer tumor destruction.
- Wind mill blades preparation
- Filtration
- CNT act as nano cylinders - absorb H_2 gas.
- Optical industry
- Air craft stress reduction
- Catalyst in some reactions.
- used in drug delivery systems
- Good conductivity.

Graphene

- Graphene is discovered in 2003 an allotrope of carbon , single layer of graphite.
- Graphene is allotrope of carbon.
- Graphene is a Honey comb like structure
- It is a 2D carbon nano material.

- In Graphene all carbon atoms are sp^2 hybridized.
- Graphene is a sheet or paper like structure.
- The thickness of graphene sheet is 0.345 nm.
- Graphene is not only thinnest material but also strongest material.
- It is a great conductor of electricity.
- It is optically transparent, yet so dense that it is impermeable to gases, not even helium can pass through it.



- An inert material and does not readily react with other atoms.
- flexible material and stretchable up to 20%.
- Graphene have highest surface area, 200 times stronger than steel.
- High tensile strength, light weight (just 0.77 mg/m²)

available in variety of forms, it can be wrapped into balls, rolled into tubes.

- High electrical current density (million times that of copper)
- It's stiffness, strength and toughness are one of the reasons that make graphene as individual material.

Applications

- Graphene is useful for solar cells, Super capacitors, graphene batteries and catalysis for fuel cells.
- Energy storage and solar cells.
- photovoltaic devices.