

## Syllabus

**Polymers:** Introduction, Synthesis, and applications of Polyurethane. Polymer Composites-Kevlar Fibre,

**Conducting Polymers:** Synthesis & Mechanism of conduction in polyaniline and factors influencing conductivity of organic polymers.

**Biodegradable polymers:** Introduction and their requirements. Synthesis and properties of Polylactic acid.

**Nanomaterials:** Introduction, size-dependent properties (Surface area, Electrical, Optical, and Catalytic properties). Synthesis of nanomaterials: Top-down and bottom-up approaches, Synthesis by Sol-gel, precipitation and chemical vapor deposition, Nanoscale materials: Fullerenes, Carbon nanotubes, and graphene's –properties and applications.

## Lesson Objectives

After completion of this module the students will learn

- Conducting Polymers: Synthesis & Mechanism of conduction in polyaniline and factors influencing conductivity of organic polymers.
- Biodegradable polymer types and requirements, Synthesis and properties of Polylactic acid.
- Size-dependent properties (Surface area, Electrical, Optical, and Catalytic properties).
- Synthesis of nanomaterials by Top-down and bottom-up approaches, Synthesis by Sol-gel, precipitation and chemical vapor deposition.
- Nanoscale materials properties and applications of fullerenes, carbon nanotubes, and graphene's.

## Introduction

Innovation in engineering often means the clever use of a new material—new to a particular application, but not necessarily (although sometimes) new in the sense of recently developed. Materials are important to mankind because of the benefits that can be derived from the manipulation of their properties. Examples include electrical conductivity, dielectric constant, magnetization, optical transmittance, strength and toughness. All of these properties originate from the internal structures of the materials. Structural features of materials include their types of atoms, the local configurations of the atoms, and the arrangements of these configurations into microstructures.

On basis of materials involves relating the desired properties and relative performance of a material in a certain application to the structure of the atoms and phases in that material through characterization. It also involves design, modelling, simulation, processing, and

production methods. Research in the field of materials science involves many peripheral areas.

**The module consists of four materials sections such as polymer, biomaterials and Nanomaterials.**

**Definition of polymers:** A polymer is a large molecule of high molecular weight obtained by the chemical interaction of many small molecules of low molecular weight of one or more type. The process of manufacture of a polymer is called the polymerization.

**Monomers:** Small molecules of low molecular weight, which combine to give a polymer, are called monomers.

**Degree of polymerization:** The number of monomers used in the process is called degree of polymerization.

**Functionality:** The total number of functional groups or bonding sites present in a monomer molecule is called the functionality of the monomer.

**Classification of polymers:**

**Based on their sources they are classified into**

**Natural polymers:** The polymers, which are obtained from natural sources such as plants and animals, are called natural polymers.

Egs. Wood, cellulose, Jute, Cotton, Wool, Silk, Proteins, Natural rubber etc.

**Synthetic polymers:**

The polymers, which are synthesized from simple molecules, are called synthetic polymers.

Egs: Nylon66, PVC, Polystyrene, Teflon, Plexiglass, Polyesters, Polyethylene etc.

**Based on their thermal behaviour they are classified into**

Thermoplastic polymers: egs: PVC, Polyethylene etc.

Thermosetting polymers: egs: Bakelite, Urea-Formaldehyde etc.

**Based on their mechanism of polymerization they are classified into**

Addition polymers: egs: PVC, Polyethylene etc.

Condensation polymers: egs: Nylon66, Polyester etc.

**Based on their properties they are classified into**

**Elastomers** - Natural rubber

**Fibres** - Jute, Wood, Silk etc

**Resins** - Urea- Formaldehyde, Epoxy resins, Phenol- Formaldehyde etc.

**Plastics** - Plexiglass, PVC, Teflon etc.

**Polymerization:** Is the process of conversion of low molecular weight substances into high molecular weight substances with or without the elimination of by products such as HCl, H<sub>2</sub>O, NH<sub>3</sub> etc.

### Types of polymerization:

**Addition (chain) polymerization:** A polymerization reaction in which monomers containing one or more double bonds are linked to each other without the elimination of any by products, usually in the presence of initiators is called addition polymerization.

e.g.: 1. Formation of polythene.



1. Formation of Buna-N



Butadiene

Acrylonitrile

Buna -N

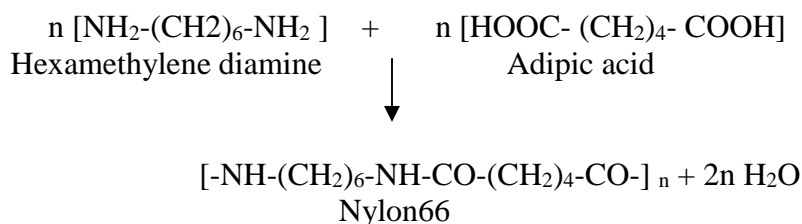
### The main features of addition (chain) polymerization are:

1. Only olefinic compounds can undergo addition polymerization.
2. No elimination of by products.
3. Double bond provides required bonding sites.
4. The addition of monomers takes place rapidly.
5. Linear polymers are produced.
6. The addition polymerization is brought about by free radical, ionic or co-ordination mechanism.
7. The molecular weight of the polymer is an integral multiple of the monomer.
8. The elemental composition of the polymer is same as that of monomer.

### Condensation (step) polymerization:

A polymerization reaction in which bi or poly functional monomers undergo intermolecular condensation with continuous elimination of by products such as H<sub>2</sub>O, HCl, NH<sub>3</sub> etc. is called condensation or step polymerization.

e.g: 1. Formation of Nylon66



2. Formation of polyester



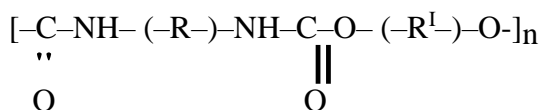


**The main features of condensation polymerization are:**

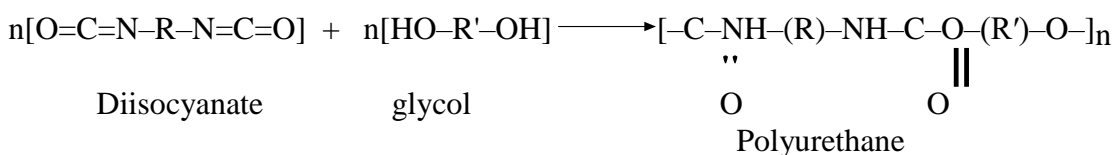
1. The monomers having two or more reactive functional groups can undergo condensation polymerization.
2. There is elimination of by-products.
3. Polymerization proceeds through intermolecular condensation.
4. The polymer chain builds up is slow and stepwise.
5. Polymerization is catalysed by acids or alkali.
6. Linear or cross-linked polymers are produced.
7. The elemental composition of the polymer is different from that of the monomers.

**Polyurethanes:** Perlon-U is obtained by the reaction of 1,4-butane diol with 1,4-hexane diisocyanate.

These are characterized by the presence of urethane linkage ( $-\text{NHCOO}-$ ) in their repeating units. They have linear structure and are represented by the following structure:



It can be synthesized by the polymerization of di-isocyanate with glycol.



OR



**Properties:**

- Polyurethanes are less stable than polyamides (nylons) at elevated temperature (because of the presence of additional oxygen in the chain which increases its flexibility).
- Melting point of polyurethanes is much less than that of the corresponding polyamides.
- They are characterized by excellent resistance to abrasion and solvents.

**Applications:**

- It is used for floor coating for gymnasium and dance floors where high abrasion resistance is required
- Used as surface coatings, films, foams and adhesives.

- They are used for cushions because of improved strength, lower density and easier fabrication.
- It is used in lightweight garments and swim suits because of its stretching property.
- They are used to cast to produce gaskets and seal

### Polymer composites:

Two or more distinct components, which combine to form a new class of material suitable for structural applications are referred to as composite materials. A composite containing polymer matrix is known as polymer composite.

The properties of the composite system are not attainable by the individual components acting alone.

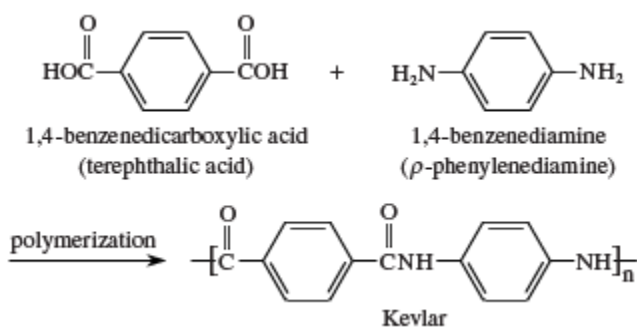
### Properties of polymer composites:

- They are light in weight.
- They have high strength to weight ratio.
- They are much stronger and durable than conventional metals like steel and aluminium.
- They have high fatigue strength.
- They have good corrosion resistance
- They are most suitable for aerospace applications due to their lightweight.

### Kevlar:

Kevlar belongs to a family of aramids. It is a aromatic polyamide with the name poly [para-phenylene terephthamide]

The linkage through para position s of the phenyl rings gives Kevlar a strong ability to stretch and hence its extra strength.



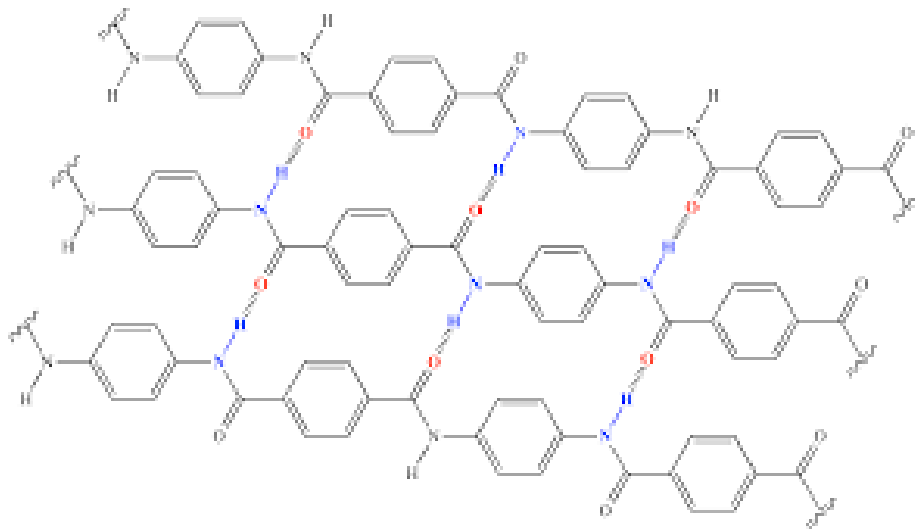


Fig.3.2. Kevlar cloth material (Bullet proof)

### Properties

It has higher tensile strength and modulus than fiberglass.  
Kevlar fibers are used for structures requiring good stiffness,  
High abrasion resistance and lightweight.

### Uses

In lightweight boat hulls,  
Aircraft fuselage panels,  
Pressure vessels,  
High performance racecars,  
Bulletproof vests and puncture resistant bicycle tyres.

## CONDUCTING POLYMERS

**Definition:** “An organic polymer with highly delocalized pi-electron system having electrical conductance is called conducting polymer”.

Ex: Polyacetylene, polypyrrole, polythiophene, polyphenylene, polyaniline, etc.

Conducting polymers are generally obtained by doping an oxidizing or reducing agent into organic polymer consisting of alternating single and double bonds. Normally electrons in a polymer are localized and do not take part in the conductivity, but the doping can delocalize the pi-electrons responsible for conduction as shown in fig.3.3

### Chemical synthesis of polyaniline:

- An aqueous solution of 0.1M  $(\text{NH}_4)_2\text{S}_2\text{O}_8$  is added slowly with stirring to a 1.0M aniline hydrochloride dissolved in 1.0M aqueous solution of HCl.

- After the addition the mixture is stirred continuously for about two hours.
- Polymerization reaction is exothermic so to maintain the temperature 3-4°C, the reaction vessel is placed in an ice bath maintained at -1°C for one hour with constant stirring.
- During polymerization, color changes from light blue to blue green to copper tint to green.
- Polyaniline finally gets precipitated in the green form. This is filtered, washed with distilled water followed by washing with methanol or acetone until the washings are colorless.
- The residue is transferred to a beaker containing 1.0M aq. Solution of HCl and allowed to stand overnight.
- The precipitate is filtered and dried under vacuum at 60-80°C for 8 hours when a green salt, emeraldine is obtained.
- This is stirred with 0.1M NH<sub>4</sub>OH for 6 hours at a pH of 9 filtered, washed with distilled water followed by methanol and finally with diethyl ether.
- The resulting solid is dried at 60-80°C under vacuum.

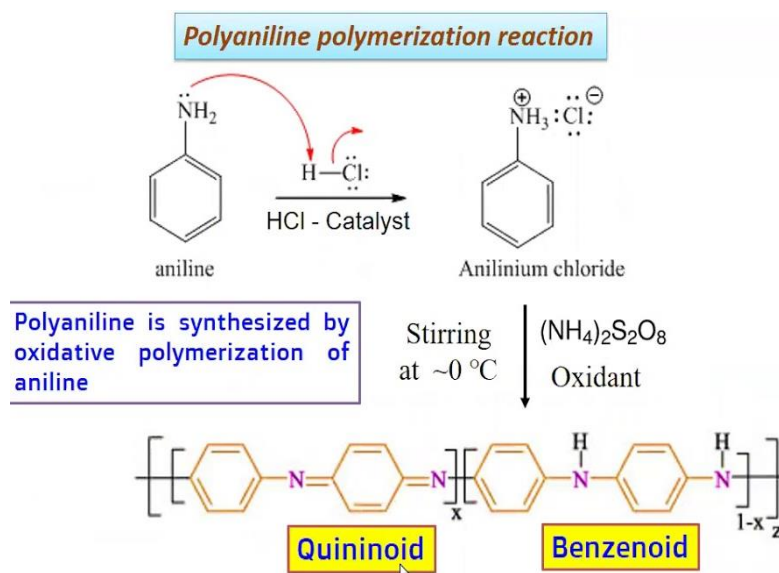


Fig.3.3 Preparation of polyaniline

### Mechanism of conduction in polyaniline

Polyaniline is a semiconductor on its own, but when doped, its conductivity increases. It can be doped by oxidation with halogen (I<sub>2</sub>) called P-doping or by reduction with alkali

metal (Na) called N-doping.

Mechanism of conduction in polyaniline can be explained by taking any one of the doping.

### P-doping mechanism:

In this process Pi-electrons of polymer are partially oxidized using a suitable oxidizing agent like  $I_2$  vapor. This creates positively charged sites on polymer backbone, which are current carriers for conduction.

The removal of an electron (oxidation) from polymer pi-back bone using  $I_2$  as oxidizing agent leads to the formation of delocalized radical ion called "polaron".

A second oxidation of a chain containing polaron followed by radical recombination yields 2 charge carriers on each chain. The positive charge sites on the polymer chain are compensated by anions  $I_3^-$  formed by oxidizing agent during doping.

The delocalized positive charges on the polymer chain are mobile. Thus, these delocalized positive charges are current carriers for the conduction. These charges must move from chain to chain as depicted in fig3.4 & 3.5

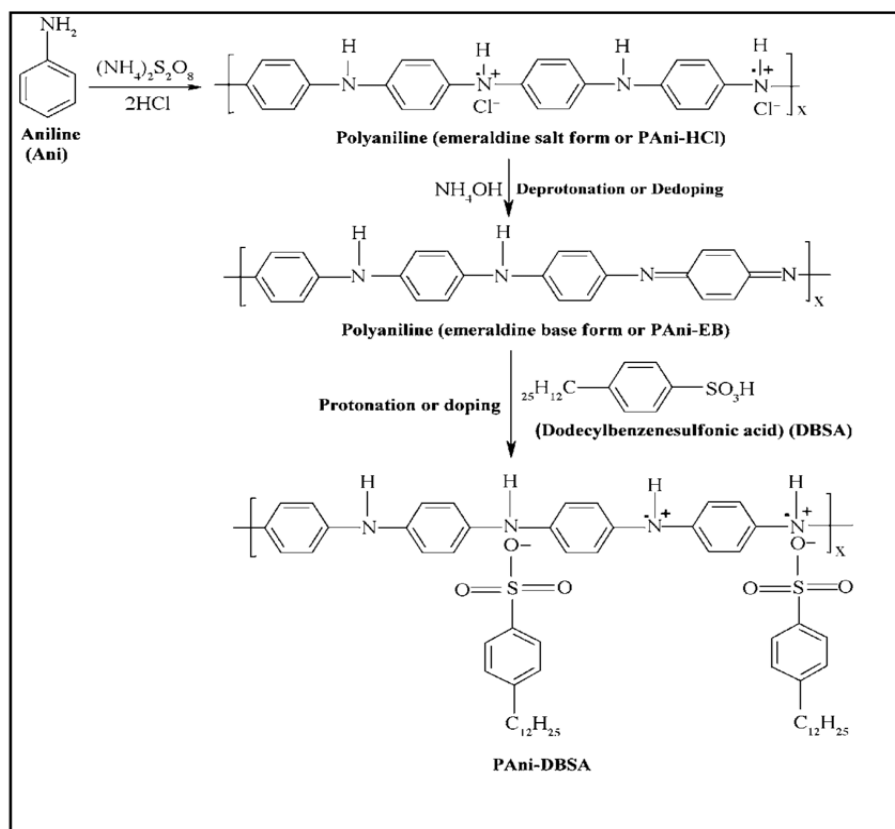


Fig3.4 Doping of PAN



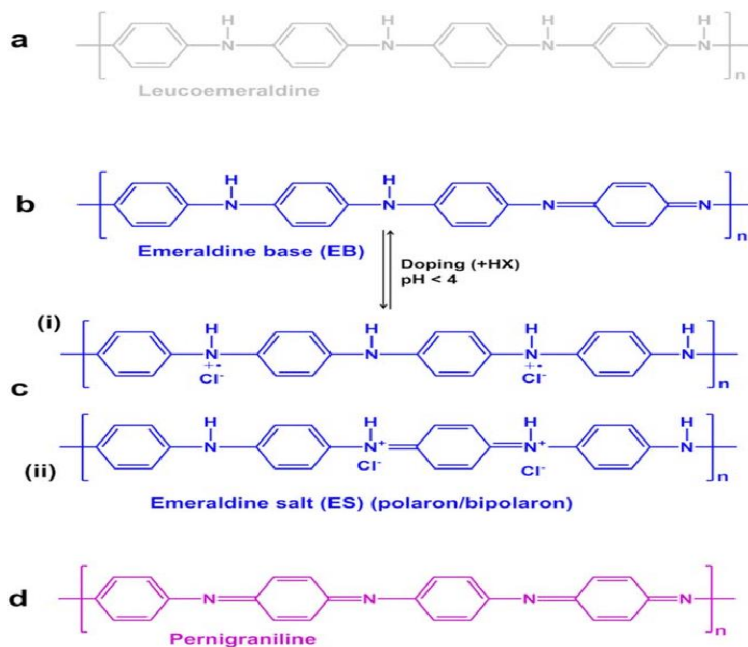


Fig. 3.5 Different form of PAN

### Application

- One of the important applications of conducting aniline is its use as an electrode material for rechargeable batteries.
- Emeraldine base has been used as a resist for lithography
- One of the major applications of conducting polyaniline is its use as a new engineering material to control electromagnetic radiation/dissipation of static charge
- Polyaniline has also attracted considerable attention as an electrochemical transducer for biosensors which are used in clinical technology
- polyaniline shows electrochromic properties which can be used to produce smart windows that absorb sunlight and control solar energy

### Biodegradable polymers

#### Introduction

Tailoring new materials within a perspective of eco-design or sustainable development is a philosophy that is applied to more and more materials. It is the reason why material components such as biodegradable polymers can be considered as 'interesting' – environmentally safe – alternatives. Besides, ecological concerns have resulted in a resumed interest in renewable resources-based products.

PLA belongs to the family of aliphatic polyesters commonly made from  $\alpha$ -hydroxy acids, which also includes, for example, polyglycolic acid (PGA). It is one of the few polymers in which the stereochemical structure can easily be modified by polymerizing a controlled.

The synthesis of PLA is a multistep process which starts from the production of lactic acid and ends with its polymerization. An intermediate step is often the formation of the lactide. Figure 21.2 shows that the synthesis of PLA can follow three main routes. Lactic acid is condensation polymerized to yield a low molecular weight, brittle polymer, which, for the most part, is unusable, unless external coupling agents are employed to increase its chains length. Second route is the azeotropic dehydrative condensation of lactic acid. It can yield high molecular weight PLA without the use of chain extenders or special adjuvants. The third and main process is ring-opening polymerization (ROP) of lactide to obtain high molecular weight PLA, patented by Cargill (US) in 1992. Finally, lactic acid units can be part of a more complex macromolecular architecture as in copolymers as shown in fig3.6

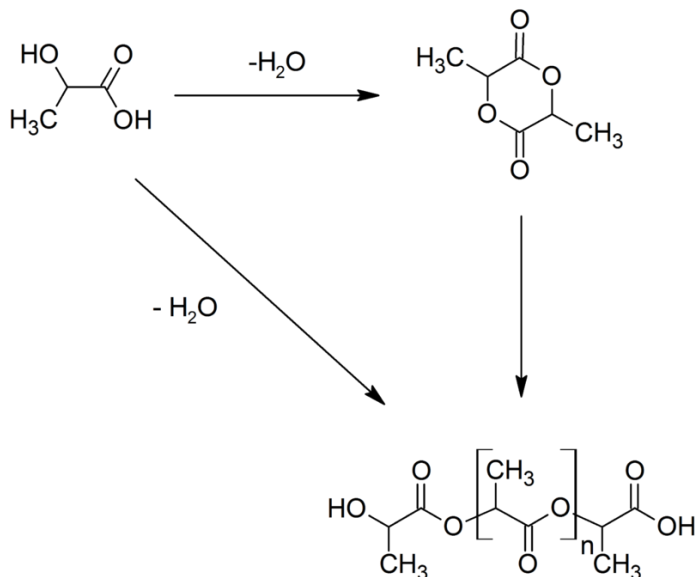


Fig.3.6 Mechanism of Synthesis of PLA

The properties of PLA, as indeed those of other polymers, depend on its molecular characteristics, as well as on the presence of ordered structures, such as crystalline thickness, crystallinity, spherulite size, morphology and degree of chain orientation.

The physical properties of polylactide are related to the enantiomeric purity of the lactic acid stereo-copolymers.

Homo-PLA is a linear macromolecule with a molecular architecture that is determined by its stereochemical composition.

PLA can be produced in a totally amorphous or with up to 40 per cent crystalline.

PLA resins containing more than 93 per cent of l -lactic acid are semi-crystalline, but, when it contains 50–93 per cent of it, it is entirely amorphous.

### Surface energy

Surface energy is critically important to many processes (printing, multilayering, etc.) and it influences the interfacial tension.

**Solubility**

A good solvent for PLA and for most of the corresponding copolymers is chloroform. Other solvents are chlorinated or fluorinated organic compounds, dioxane, dioxolane and furan. Among non-solvents, the most relative compounds are water, alcohols

**Mechanical properties**

The mechanical properties of PLA can vary to a large extent, ranging from soft and elastic materials to stiff and high strength materials, according to different parameters, such as crystallinity, polymer structure and molecular weight, material formulation (plasticizers, blend, composites, etc.) and processing (e.g. orientation).

**Biomedical applications**

PLA has been widely studied for use in medical applications because of its bio resorbability and biocompatible properties in the human body.

The main reported examples on medical or biomedical products are fracture fixation devices like screws, sutures, delivery systems and micro-titration plates

Commercially available PLA packaging can provide better mechanical properties than polystyrene and have properties more or less comparable to those of PET.

Studies show that PLA is an economically feasible material for biodegradable packaging.

## **Nanomaterial**

**Nanoscience**

Study on fundamental relationships between physical properties and material dimensions on the nanometer scale

**Nanotechnology**

A technology of design, production, characterization, and applications of Nanostructured materials (size and shape, also fundamental understanding of physical properties and phenomena).

or

The branch of technology that deals with dimensions and tolerances of less than 100 nanometers, especially the manipulation of individual atoms and molecules.

**The Scale of Nano world****Why is Small Good?**

- **Faster**
- **Lighter**
- **Can get into small spaces**

- Cheaper
- More energy efficient
- Different properties for very small structures

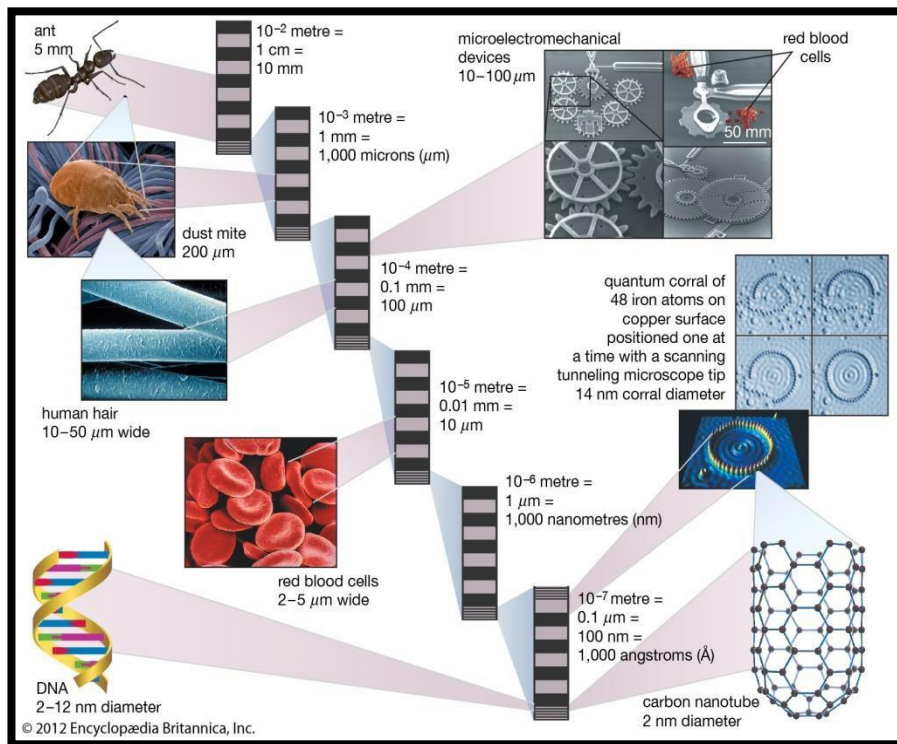


Fig3.6 Representation of Natural and Synthetic nanomaterials.

## Properties of Nanomaterial

### Surface area and catalytic activity

Due to their small dimensions, nanomaterials have an extremely large surface area to volume ratio, which makes a large proportion of the surface or interfacial atoms, resulting in more "surface" dependent material properties. As surface area per mass of a material increases, a greater amount of the material can come into contact with surrounding materials, thus affecting reactivity. One advantage of greater surface area and improved reactivity in nanostructured materials is that they act as better catalysts.

### Optical properties

The reduction of material dimension has a prominent effect on the optical properties of nanomaterial. One is due to increased energy level spacing, quantum size effect and the other is because of surface Plasmon resonance.

Decreasing the size of a nanostructure material increases the energy difference,  $\Delta E$

between allowed electron energy levels (quantum size effect). When an electron drops from a higher energy state to a lower energy state, a quantum  $\lambda = hc / \Delta E$  may be emitted. Larger  $\Delta E$  implies shorter wavelength lead to Blue shift and the color of the nonmaterial different from that of bulk materials.

e.g.: The optical absorption peak of a semiconductor nanoparticles shifts to lower wavelength due to increased band gap.

### Electrical Properties

Electrical conductivity decreases with a reduced dimension due to the increased surface scattering, However, it can be increased due to better ordering in micro-structure. Example

- Nanocrystalline materials are used as very good separator plates in the batteries, because they can hold more charge than the bulk materials.
- Nickel-metal hydride batteries of Nanocrystalline nickel and metal hydride, requires far less frequent charging and last much longer.

### Mechanical properties

Mechanical properties of solids depend on the microstructure. *i.e.* the chemical composition, the arrangement of the atoms (the atomic structure) and the *size* of a *solid* in one, two or three *dimensions*. Nonmaterial have less defects compared to that of bulk materials, which increases the mechanical strength. Nonmaterial are stronger, harder and more wear resistant and corrosion resistant. Malleability and ductility increases when particle size is reduced to nanoscale. e.g. Nanocrystalline carbides are much stronger, harder and wear resistant and are used in/for micro drill.

### Magnetic properties

Magnetic nanoparticles show a variety of unusual magnetic behaviors when compared to the bulk materials.

Example: Ferromagnetic behavior of bulk material disappears when the particle size is reduced and transforms into super-paramagnetic.

Note: Superparamagnetic is a form of magnetism, which appears in small ferromagnetic or ferrimagnetic nanoparticles. Insufficiently small nanoparticles. magnetization can randomly flip direction under the influence of temperature.

### Thermal property

Melting point decreases when a particle size is reduced to nanoscale. Surface atoms require less energy to move because they are in contact with fewer atoms of the substance. Changes in melting point occur because nanoscale materials have as much

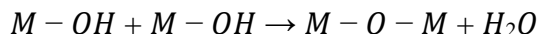
larger surface to volume ratio than bulk materials, drastically altering their thermodynamic and thermal properties. As the metal particle size decreases, the melting temperature also decreases.

### SOL – GEL PROCESSES

Sol gel processes principle is conversion of precursor solution into gel via hydrolysis and condensation reactions as shown in fig.3.7

Sol gel processes allow to synthesis of Nano materials of high purity. This process involves five steps

1. Preparation of sol: sol is prepared by suspended particles in water during suspension hydrolysis reaction takes place.  
$$M - O - R + H_2 O \rightarrow M - OH + R - OH$$
2. Conversion of sol into gel: sol is converted into gel by condensation reaction forming network between oxides. When networking takes place, the viscosity of the solution increases.



3. Aging of gel: during which poly condensation reaction continue until the gel is transformed into solid mass.
4. Removal of solvent: Further the solid mass is isolated from the solvent by thermal evaporation. The product formed is xerogel.
5. Heat treatment: solid mass (xerogel) obtained is dried at nearly to 800C to get fine Nano particle powder.

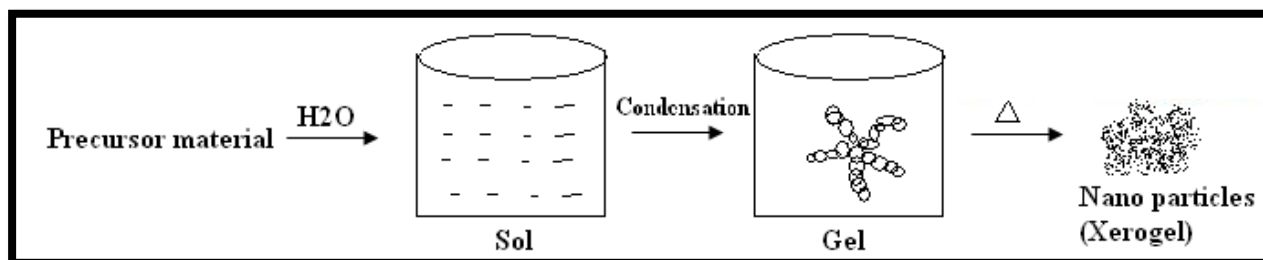


Fig. 3.7 Sol gel method.

Advantages:

- It is very useful for the synthesis of glasses, glass ceramics or ceramic materials at lower temperature.
- Mono sized nano particles are produced by this method.

### PRECIPITATION METHOD

**Principle:** The principle involved in the precipitation of precursor materials at constant pH via condensation.

**Processes:** In this method inorganic metal salt such as chloride, sulphate, nitrate ions etc., are used as precursor. Precursor materials is dissolved in water and undergo hydrolysis where metal ions exist in metal hydrates form. On adding base like NaOH/NH<sub>4</sub>OH, pH of the solution changes and reaches super saturation level leading to condensation of precursor to form metal hydroxide precipitate. The precipitate is washed with water, filtered and finally calcinated at higher temperature to convert metal hydroxide into metal oxide by dehydrogenation takes place.

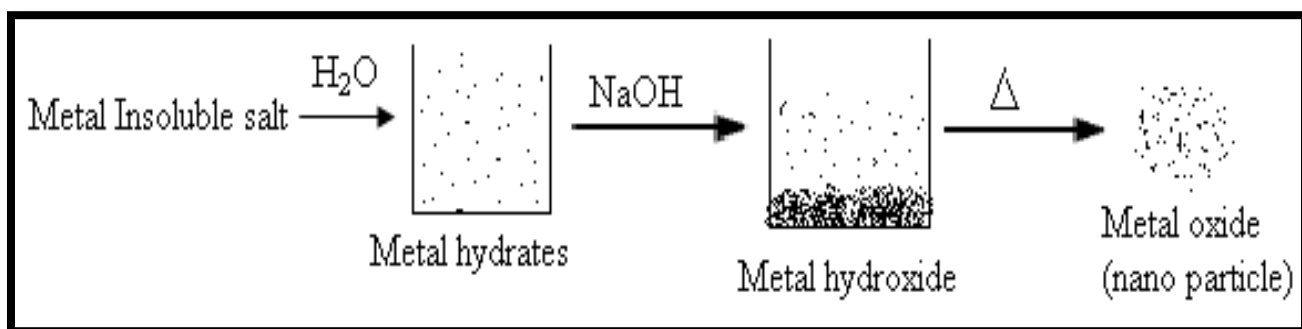
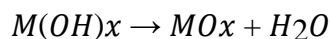
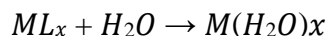


Fig.3.8 Precipitation method

**Advantages:**

- The process is relatively economical.
- The wide range of single and multi-components to oxide Nano powders can be synthesized.

**CHEMICAL VAPOUR CONDENSATION**

**Principle:** the process involved is conversion of precursor (metal organic compound) into vapors in reduced pressure atmosphere.

**Processes:** the precursor (starting material) is vaporized in a bubble and mixed with inert gas like nitrogen to carry vapors into heating furnace. Condensation reaction takes place in heating furnace at a particular temperature required for the reaction to take place. The product formed after the condensation process is in the form of clusters. The clusters are then condensed into Nano particles in a cold finger which are removed by scraping.

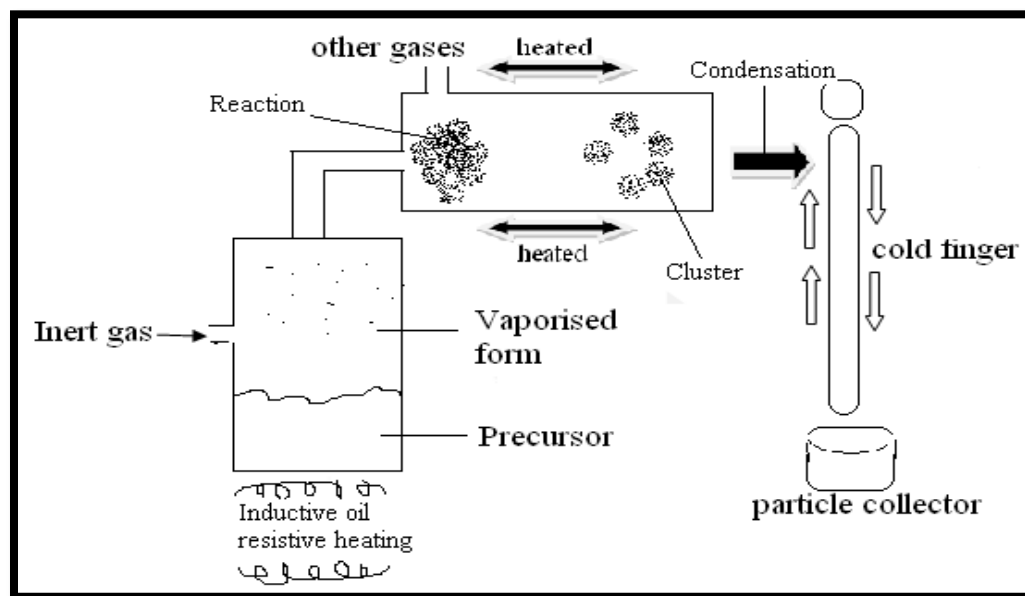


Fig.3.9 Chemical Vapour Deposition (CVD) method

**Advantages:**

- This process is continuous.
- The production capabilities are larger
- Quantities in excess of 20g/hr. have been readily produced with a small-scale laboratory reactor



**Graphene is** a semi-metal with small overlap between the valence and the conduction bands (zero band gap material).

It is an allotrope (form) of carbon consisting of a single layer of carbon atoms arranged in a hexagonal lattice. It is the basic structural element of many other allotropes of carbon, such as graphite, diamond, charcoal, carbon nanotubes and fullerenes.

Graphene is a crystalline allotrope of carbon with 2-dimensional properties. Its carbon atoms are packed densely in a regular atomic-scale chicken wire (hexagonal) pattern.

Each atom has four bonds: one  $\sigma$  bond with each of its three neighbors and one  $\pi$ -bond that is oriented out of plane. The atoms are about 1.42 Å apart.

Graphene's hexagonal lattice can be regarded as two interleaving triangular lattices. This perspective was successfully used to calculate the band structure for a single graphite layer using a tight-binding approximation.

Graphene's stability is due to its tightly packed carbon atoms and a  $sp^2$  orbital hybridization – a combination of orbitals s,  $p_x$  and  $p_y$  that constitute the  $\sigma$ -bond. The final  $p_z$  electron makes up the  $\pi$ -bond. The  $\pi$ -bonds hybridize together to form the  $\pi$ -band and  $\pi^*$ -bands. These bands are responsible for most of Graphene's notable electronic properties, via the half-filled band that permits free-moving electrons as shown in fig 3.10 and 3.11

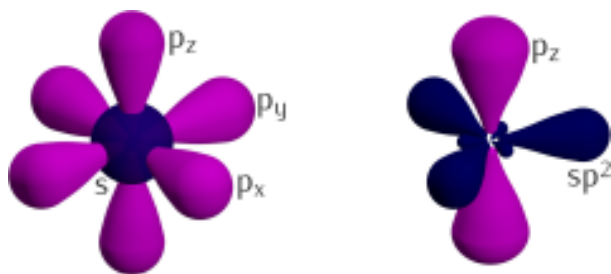


Fig 3.10 Orbital Shapes and overlapping

Carbon orbitals 2s, 2 $p_x$ , 2 $p_y$  form the hybrid orbital  $sp^2$  with three major lobes at 120°. The remaining orbital,  $p_z$ , is sticking out of the graphene's plane

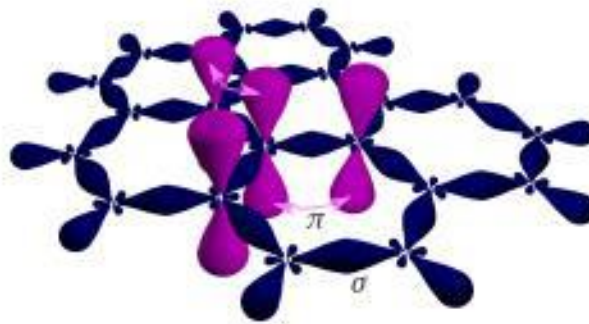


Fig 3.11 Overlapping of orbitals

Sigma and pi bonds in graphene. Sigma bonds result from an overlap of  $sp^2$  hybrid orbitals, whereas pi bonds emerge from tunneling between the protruding  $p_z$  orbitals

## FULLERENES

- Fullerenes are class of molecules made of only carbon atoms having closed cage like structure.
- Many number of fullerene molecules with different carbon atoms like C<sub>60</sub>, C<sub>70</sub>, C<sub>74</sub>, C<sub>76</sub> etc., have been prepared but C<sub>60</sub> is more stable as shown in fig.3.12
- The C<sub>60</sub> molecule had spherical shape resembling a soccer ball (football). It is also commonly called as Bucky ball.
- The C<sub>60</sub> molecule consist of 12 pentagons and 20 hexagons and each pentagon is surrounded by five hexagons and each hexagon is surrounded by three hexagons and three pentagons placed next to each other alternately fold in the form of ball.
- Each carbon atom on the cage surface is bonded to three carbon neighbors therefore is sp<sup>2</sup> hybridized. The chemical formula for fullerene is C<sub>20+2n</sub>.
- In fullerenes, 12 pentagonal rings are necessary and sufficient to form the cage closure.
- It is quite stable, breaking the balls requires temperature of about 1000 °C. Fullerene has high tensile strength and high packing density.

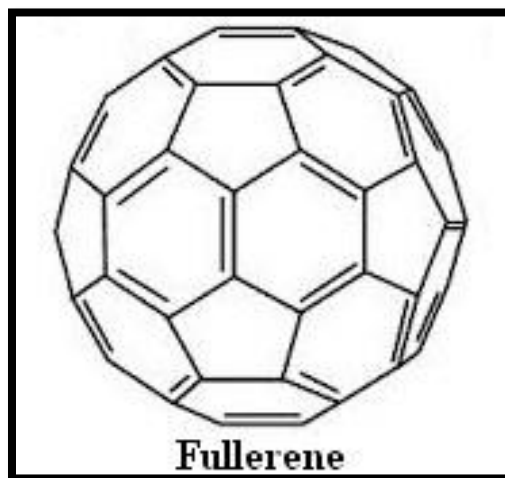


Fig.3.12 Structure of fullerene

Properties:

Property	Application
<ul style="list-style-type: none"> <li>High-speed electron mobility</li> </ul>	Transistors, lasers, photo detectors
<ul style="list-style-type: none"> <li>Large specific surface area</li> <li>Conductance</li> </ul>	Sensors
<ul style="list-style-type: none"> <li>Linear band structure (Dirac spectrum for mass less fermions)</li> </ul>	Field effect transistors
<ul style="list-style-type: none"> <li>High electrical conductivity</li> <li>High-speed electron mobility</li> <li>High optical transmittance</li> </ul>	Transparent conductive film
<ul style="list-style-type: none"> <li>High theoretical surface area</li> <li>Electron transfer along 2d surface</li> </ul>	Clean energy devices
<ul style="list-style-type: none"> <li>Anomalous quantum hall effect</li> </ul>	Ballistic transistors
<ul style="list-style-type: none"> <li>Irrelevant spin-orbit coupling</li> </ul>	Spin-Valve Devices
<ul style="list-style-type: none"> <li>High conductivity</li> </ul>	Conductive materials, electrical batteries, super capacitors
<ul style="list-style-type: none"> <li>Easy absorption of gases</li> </ul>	Contamination control
<ul style="list-style-type: none"> <li>Transparency (&gt;99%)</li> <li>High electronic conductivity</li> </ul>	Displays, touch screens
<ul style="list-style-type: none"> <li>Impermeability</li> </ul>	Coatings
<ul style="list-style-type: none"> <li>High mechanical stress (hardness)</li> </ul>	Construction

## CARBON NANO TUBES

- Carbon nanotubes are allotropes of carbon with a cylindrical nanostructure having diameter measuring on the nanometer scale.
- Nanotubes are members of the fullerene's structural family.
- The diameter of nanotubes is in the range of 1 – 50nm. It is one dimensional material like Nano wires.
- Their name is derived from long, hollow structure with the walls formed by one atom thick sheets of carbon called Graphene.
- These are formed from graphite sheet and the graphite layer appears like a rolled up continuous unbroken hexagonal mesh and carbon molecules at the apexes of the hexagons.
- These tubes were originally called as Bucky tubes now called as carbon nanotubes. Each shell is made of  $sp^2$  trivalent carbon atoms like chicken wire.

The layers in nanotubes are not chemically bonded to each other but held together by weak Van der Waals forces.

The tube is closed at each end, Nanotubes are one of the most commonly building blocks of Nano technology. With high tensile strength, thermal conductivity better than purest diamonds with the ability of carry high currents.

Single walled nanotubes (SWCNT): these are formed by rolling up of single graphite layer. Diameter of single walled nanotubes is 1.4nm and length up to few micrometers as shown in fig 3.12

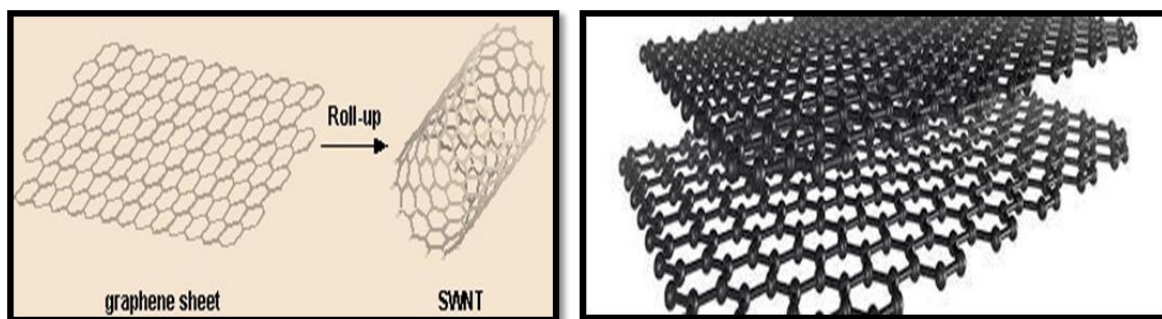


Fig.3.12 SWCNT and Sheets

Multi walled nanotubes (MWCNT): it consists of two or more concentric Graphene cylinders with Van der Waals force between adjacent tubes. Diameter is from 30 to 50nm and length up to few micrometers as shown in fig 3.13

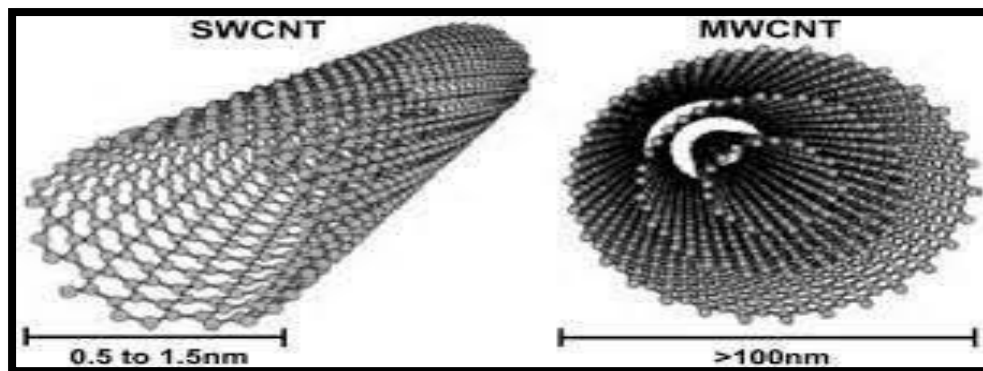


Fig. 3.13 SWCNT conversion to MWCNT

**Properties:**

- CNTs have High Electrical Conductivity
- CNTs have Very High Tensile Strength
- CNTs are Highly Flexible- can be bent considerably without damage
- CNTs are Very Elastic ~18% elongation to failure
- CNTs have High Thermal Conductivity

**Applications:**

Carbon Nanotubes Technology can be used for a wide range of new and existing applications:

- Conductive plastics
- Structural composite materials
- Flat-panel displays
- Gas storage
- Micro- and Nano-electronics
- Radar-absorbing coating
- Batteries with improved lifetime
- Biosensors for harmful gases