Unit 3- Advanced Engineering Materials

A] Polymers:

* Introduction:-

- Polymers are the long-chain molecules composed of repeating structural units.

Natural Polymers - Starch, Cellulose from plants, proteins, rubber, silk, wool etc.

Synthetic polymers - polyethylene, polystyrene, polyvinyl chloride, polypropylene, polyacrylonitrile, polyesters etc.

- Synthetic polymers are used as alternative materials to metals, wood, glass, insulators etc. due to their special properties like - Low density, High chemical resistance, Elastic nature, Good plasticity, Soft & Flexible, Ability to absorb shock, sound and vibrations etc.

* Definitions:-

1) Polymer:

A polymer can be defined as, a large molecule built by repeating small, simple chemical units called as monomer.

e.g. Polyethylene

$$-\!\!\left(CH_2 - CH_2 - CH_2 - CH_2 - CH_2 - CH_2 \right)\!\!-_n$$

2) Monomer:

Monomer is defined as a low molecular weight compound with at least two or more than two reactive sites to form a high molecular weight compound by polymerization. or

The simple chemical substance of low molecular weight, which can be converted into a polymer.

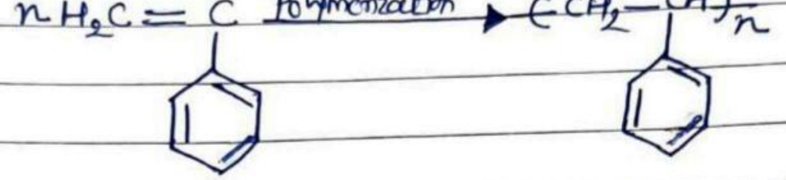
e.g. $n\, CH_2 = CH_2 \longrightarrow -\!\!\left(CH_2 - CH_2 - CH_2 - CH_2 - CH_2 - CH_2 \right)\!\!-_n$

Ethylene (Monomer) — Polyethylene (Polymer)

3) **Polymerization:**

Polymerization is a process of formation of polymer molecules by joining of large number of monomer molecules.
or The process of converting the simple molecules (Monomer) into a high molecular weight compound (Polymer) is called as polymerization.

e.g.



Styrene Polystyrene

(Where, n = no. of monomers in the polymeric chain)

* Functionality of Monomers:-

- **Definition:**

Functionality of monomer can be defined as the number of reactive sites or bonding sites or functional groups present in the molecule of monomer.

- **Types:**

1) Bifunctional monomers-

If the no. of reactive sites in the monomer are two, it is called as bifunctional monomers.
These types of monomers gives linear polymers

e.g.

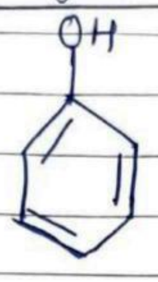
$CH_2 = CH_2$ Ethylene	$CH_2 = CH - Cl$ Vinyl chloride	$CH_2 - OH$ $\vert$ $CH_2 - OH$ Ethylene glycol.

2) Trifunctional monomers –

If the number of reactive sites in the monomer are three, it is called as trifunctional monomer.

These gives mostly branched polymers.

e.g.

 Phenol	CH_2-OH $\vert$ $CH-OH$ $\vert$ CH_2-OH Glycerol	$Cl-CH_2-\underbrace{CH-CH_2}_{O}$ Epichlorohydrin

3) Tetrafunctional (Polyfunctional) monomers –

If the number of reactive sites in the monomer are four, it is called as tetrafunctional monomer.

These results in the formation of a three-dimensional network structure by forming a strong crosslinked polymer.

e.g.

$HC\equiv CH$	$CH_2=CH-CH=CH_2$	$H_2N-\overset{O}{\overset{\Vert}{C}}-NH_2$
Acetylene	Butadiene	Urea

* Classification of polymers:

On the basis of thermal behavior, polymers are classified as Thermosoftening polymers (Thermoplasts) and Thermosetting polymers.

1) Thermosoftening or Thermoplastic polymers:-

- The polymers, which can be softened on heating and hardened on cooling are called as thermosoftening polymers.
- These are linear, long-chain polymers.
- e.g. Polyethylene, Polystyrene, Polyvinylchloride (PVC) etc.

2) Thermosetting polymers:-

- The polymers which becomes hard on heating during molding and cannot be soften or reshaped again, once they solidifies, even after heating are called as thermosetting polymers.
- These are hard, cross-linked polymers.
- e.g. Bakelite, Urea-formaldehyde resin, Nylon 6:6 etc.

* Difference between Thermosoftening polymers and Thermosetting polymers:

Thermosoftening Polymers (Thermoplastic)	Thermosetting Polymers
1. They are formed by Addition polymerization.	1. They are formed by Condensation polymerization.
2. They consists of long chain linear polymers with negligible cross links.	2. They have three dimensional cross linked network structure.
3. Bifunctional monomers are used during polymerization	3. Polyfunctional monomers are used during polymerization.
4. They are soft, weak & less brittle	4. They are hard, strong & more brittle.
5. Relatively lower molecular weight of polymer	5. Relatively higher molecular weight of polymer
6. They are soluble in organic solvents.	6. They are insoluble in organic solvents / any solvent.
7. They can be reclaimed from waste.	7. They can not be reclaimed from waste.
8. They are soften on heating	8. They do not soften on heating.
9. Reshaping is possible several times e.g. Polyethylene, PVC etc.	9. Once formed, no reshaping. e.g. Bakelite, Nylon6:6 etc.

* Speciality Polymers:

- The commercial applications of polymers have increased over the years. Wide variety of polymers are used for engineering and medical applications.
- The demand for the polymer with specific properties for specific application has increased which lead to the development of speciality polymer.
- Speciality polymer are developed to meet the needs of specific industries or applications, such as; Aerospace, Biomedical, Electronics, Automotive etc.
- These polymers exhibit specific properties, such as; High thermal stability, High chemical resistance, High Impact strength, High flexibility, Light weight etc.

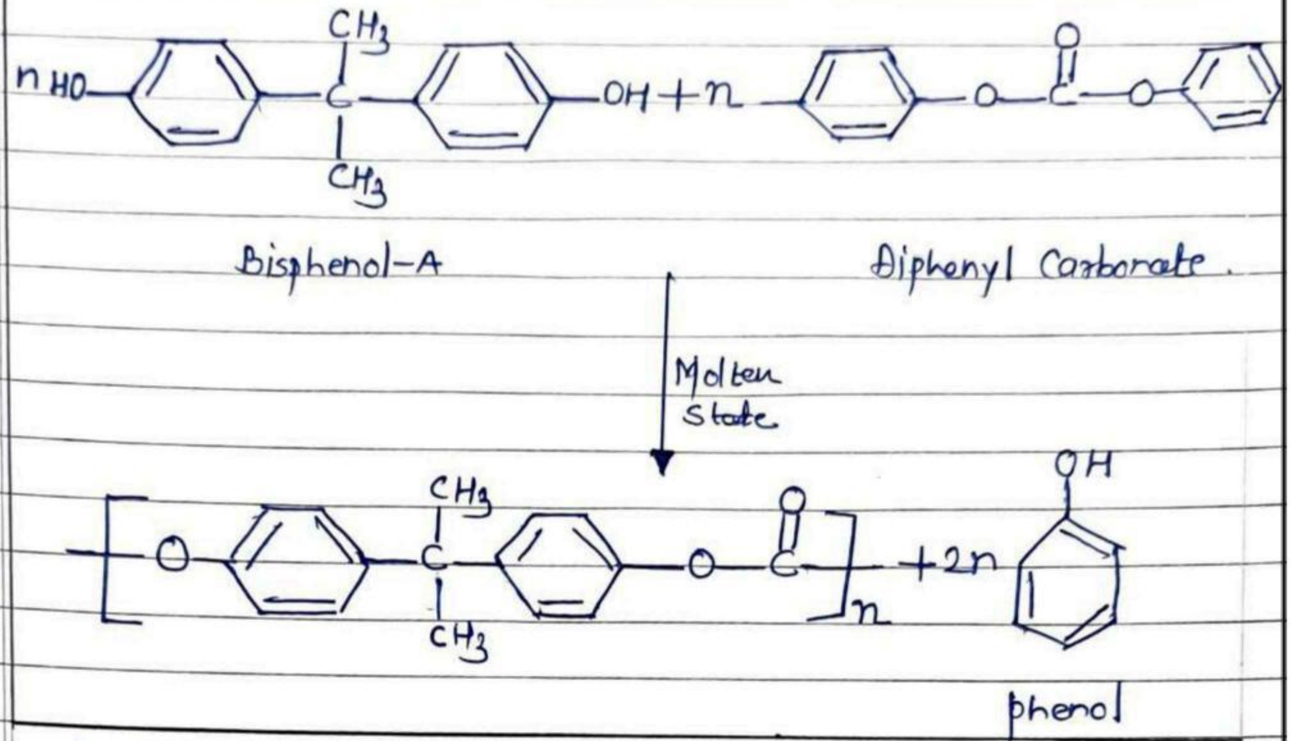
1] Engineering Thermoplastics:-

- Engineering thermoplastics are the group of materials obtained from high polymer resins which provide one or more outstanding properties when compared with the commodity thermoplastics such as polystyrene, polyethylene etc.

- Example :- Polycarbonate.

- Preparation of Polycarbonate :-

It is prepared by using Bisphenol-A and Diphenyl Carbonate Commercially known as Lexan or Merlon.



• **Properties :-**

i) It has very high impact strength and tensile strength over wide range of temperature.

ii) It is highly transparent plastic.

iii) It has good heat resistance.

iv) Light weight.

v) It is an amorphous polymer with excellent mouldability.

vi) Good chemical resistance.

vii) It is resistant to water and many organic compounds.

viii) It has good thermal and oxidative stability in melt.

• **Applications :-**

i) Data storage - Major application of polycarbonate is the production of CDs, DVDs.

ii) Used in safety goggles.

iii) Used in bulletproof windows.

iv) Used in cover of cell phones.
v) Used as Insulator.
vi) It is used in construction materials such as roofing panels and wall cladding.
vii) It is used in aircraft windows and satellite components.
viii) It is used to manufacture car headlight lenses, rearview mirrors and other exterior components.

2] Biodegradable Polymers :-

• Biodegradable polymers are the polymeric materials that can undergo decomposition into harmless gaseous products through the action of microorganisms, enzymes or other biological processes.

• **Biodegradation –**

Biodegradation of a polymer is a process of converting polymer material into harmless simple gaseous products by the action of enzymes present in microorganisms.

• **Factors Responsible for Biodegradation –**

a) Microorganism – Naturally occurring Microorganisms such as bacteria, fungi, algae etc. are responsible for biodegradation of polymers, by breaking C–C bond.

b) Environment –
The suitable environmental conditions for biodegradation needed are Temperature, Moisture, pH, Oxygen, Salt, Pressure, Light etc.

c) Nature of polymer –
For biodegradation, nature of polymer also should be favourable. The presence of hydrolysable / oxidizable linkages, types of functional groups, hydrophobicity & hydrophilicity, molecular weight etc. contribute to the easier biodegradability of polymer.

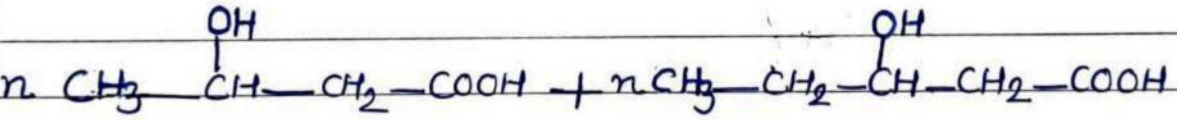
- **Example :- Poly (hydroxybutyrate- hydroxyvalerate)**

- **Preparation :-**

Poly (hydroxybutyrate-hydroxyvalerate) also called as PHBV or Biopol is a copolymer of 3-hydroxybutyric acid and 3-hydroxyvaleric acid.

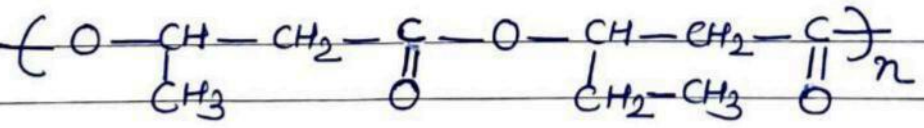
PHBV is produced on polymerization of 3-hydroxybutyric acid and 3-hydroxyvaleric acid monomers. These monomers are produced from glucose

$$\text{Glucose} \xrightarrow[\text{A. eutrophus}]{\text{Fermentation}} \begin{array}{c}\text{3-hydroxybutyric acid} \\ + \\ \text{3-hydroxyvaleric acid}\end{array} \xrightarrow{\text{Polymerization}} \begin{array}{c}\text{Biopol} \\ \text{(PHBV)}\end{array}$$



3-Hydroxybutanoic acid (Hydroxybutyric acid) 3-Hydroxypentanoic acid (Hydroxyvaleric acid)

$$\downarrow -H_2O \text{ polymerization}$$



Poly (Hydroxybutyrate - hydroxyvalerate) (PHBV)

- **Properties:-**

i) It is biodegradable, non-toxic, biocompatible plastic.
ii) PHBV is a thermoplastic polymer.
iii) It has low elongation at break and low impact resistance.
iv) It is flexible and can be easily molded.

- **Applications:-**

i) Used in packing material such as bags, wraps and containers. Used to package food products, such as snack foods, baked goods and dairy products.
ii) Medical applications:- Drug delivery, Internal suture, organ transplant, disposable personal hygiene.
iii) Used in Agriculture for controlled release of fertilizer for the growth of plants.
iv) PHBV is used in cosmetics applications, such as skincare products and haircare products.

3] Conducting Polymers :-

- The polymers that can conduct electricity are known as conducting polymers.
- Conductivity in polymers is observed because of different reasons, which includes high planarity and conjugation present in polymers.
- Scientists Alan J. Heeger, Alan MacDiarmid and Hideki Shirakawa were awarded the Nobel prize in Chemistry in 2020 for the discovery and development of conductive polymers.

* **Structural Requirements of Conducting Polymers:-**

Structural requirements of organic polymers to be conducting are;

i) Polymers should be linear chain

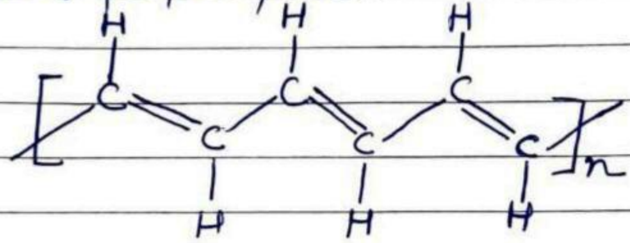
ii) Polymers should have high planarity and high crystallinity in structure.

iii) Polymers should have conjugation in the polymer chain.

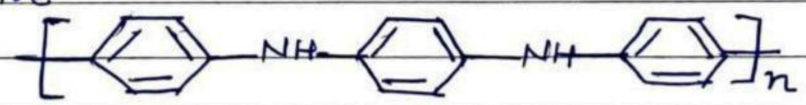
iv) Aromatic conducting polymers should have aromatic rings connected in chain, with continuous resonance.

v) Conducting polymers with heteroatomic system should have lone pair of electrons on heteroatom in conjugation with double bonds.

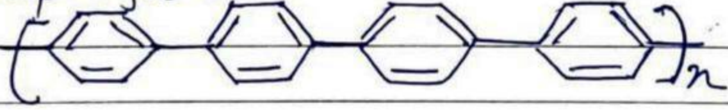
e.g. i) Trans-polyacetylene.



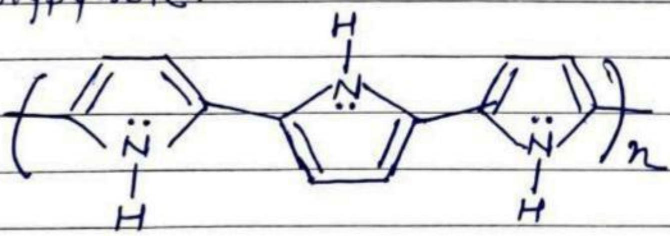
ii) Polyaniline



iii) Polyparaphenylene.



iv) Polypyrrole.



* Types of Conducting Polymers :-

Conducting polymers are categorized into three different types:

1) Intrinsically Conducting Polymers -

- Polymers conduct electricity on their own such conducting polymers are called as intrinsically conducting polymers.

e.g. Trans-polyacetylene, polyparaphenylene, polyaniline etc.

- These types of polymers have a solid backbone which is made up of extensive conjugated system, which is responsible for conductance.

2) Extrinsically Conducting polymers -

- Polymers conduct electricity due to externally added ingredients like metal powder, metal filaments and graphite powder are known as extrinsically conducting polymers.

3) Doped Conducting Polymers -

- Intrinsically conducting polymers possess low conductivity, but their conductivity can be increased by creating charge on the polymer, either by oxidation or reduction, called as doping.
- Doping is of two types - P- doping and N- doping.
- P- doping - The polymers are doped with oxidizing agents (like lewis acids or halogens). In this type of doping, oxidation takes place and positive charge gets developed on polymer chain, increasing conductivity.

The lewis acids used are known as P- dopants.

e.g. I_2, Br_2, $FeCl_3$ etc.

$$(C_2H_2)_n + 2FeCl_3 \xrightarrow{\text{Oxidation}} (C_2H_2)_n^{\oplus} \cdot FeCl_4^{\ominus} + FeCl_2$$

Polyacetylene

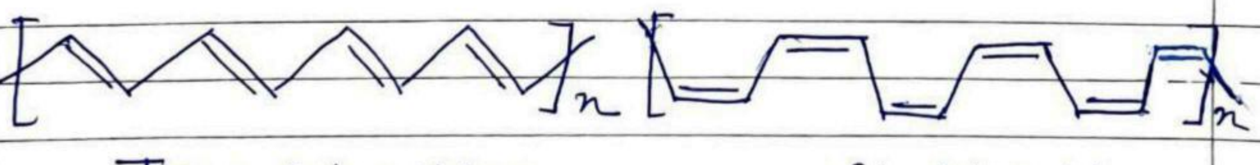
- N-doping – The polymers are doped with reducing agents (like Lewis bases or Alkali metals).
  Reduction takes place and negative charge gets developed on polymer chain, increasing conductivity.
  The Lewis bases used are known as N-dopants.
  eg Li, Na, K etc.

$$\boxed{\underset{\text{Polyacetylene}}{(C_2H_2)_n} + Na \xrightarrow{\text{Reduction}} (C_2H_2)_n^{\ominus} Na^{\oplus}}$$

- Example :- Polyacetylene.
- Polyacetylene is a conjugated polymer formed by alternate double bonds and single bonds in the polymer structure, having repeating unit $(C_2H_2)_n$.
- Polyacetylene exist in two isometric forms : Cis-polyacetylene and Trans-polyacetylene.

- Preparation :-
- Most common method of preparing polyacetylene is by passing acetylene gas over Zeigler-Natta catalyst.
- Polyacetylene structure predominately has cis-conformation, on raising the temp. to about 200°C, stable trans form obtains.

$$n\ \underset{\text{Acetylene}}{H-C\equiv C-H} \xrightarrow[\text{(Zeigler Natta catalyst)}]{TiCl_4 + Al(Et)_3} \underset{\text{Polyacetylene}}{-(HC=CH)_n}.$$



Trans-polyacetylene Cis-polyacetylene.

- **Properties:-**

i) Cis- polyacetylene is flexible whereas, Trans-polyacetylene is brittle.
ii) Both forms shows higher thermal stability.
iii) They are insoluble in common organic solvents.
iv) Light in weight.
v) Stable in air and water.
vi) It shows high electrical conductivity.

- **Applications:-**

i) Used in electronic devices like photodiodes, transistors etc
ii) Used in rechargeable lightweight batteries.
iii) Used in photovoltaic cells.
iv) Used in telecommunication system.
v) Doped polyacetylene shows high electrical conductivity therefore can be used in electrical wiring.
vi) Used in antimicrobial coatings for medical devices and surfaces to prevent the growth of bacteria and other microorganisms.
vii) Used in binding electronic components together.
viii) It is used to produce nanoscale devices such as nanoelectromechanical systems and nanoelectronics.

B] Nanomaterials:

* Introduction:

- Definition-

Nanomaterials are defined as a set of substances where at least one dimension is less than approximately 100 nanometers.

or

A set of substances having very small size in the range of 1 - 100nm are called as nanomaterials.

- Nanomaterials can be metals, ceramic, polymeric or composite materials.
- Some nanomaterials occur naturally but Engineered nanomaterials (EN) are of particular interest. Engineered nanomaterials are designed at the nanoscale level in order to take advantage of their small size and novel properties which are generally not seen in their conventional, bulk, material.

- Properties of Nanomaterials :-

1) High Surface Area to Volume Ration:

The high surface area of nanomaterials in relation to their volume might result in increased reactivity and surface related properties.

2) Quantum Effect:

The nm size of nanomaterials have special confinement effect on the materials, which bring the quantum effect. The energy band structure and charge carrier density can be modified in electrical and optical properties of materials. e.g. LED's, lasers etc.

3) Reduced Imperfections:

Nanomaterials and Nanostructures favours a self-purification process in that the impurities and intrinsic material defects move near the surface on thermal annealing which in turn increases the perfection in materials, affecting the properties of material.

e.g. Thermal stability of any nanomaterial can be enhanced, as a result the mechanical properties of nanomaterials become better than the bulk, materials.

4) Chemical Reactivity:

Nanomaterials have improved chemical reactivity which can be used in catalysis, sensing and enviornmental remediation applications.

• Applications of Nanomaterials :-

1) Electronics:

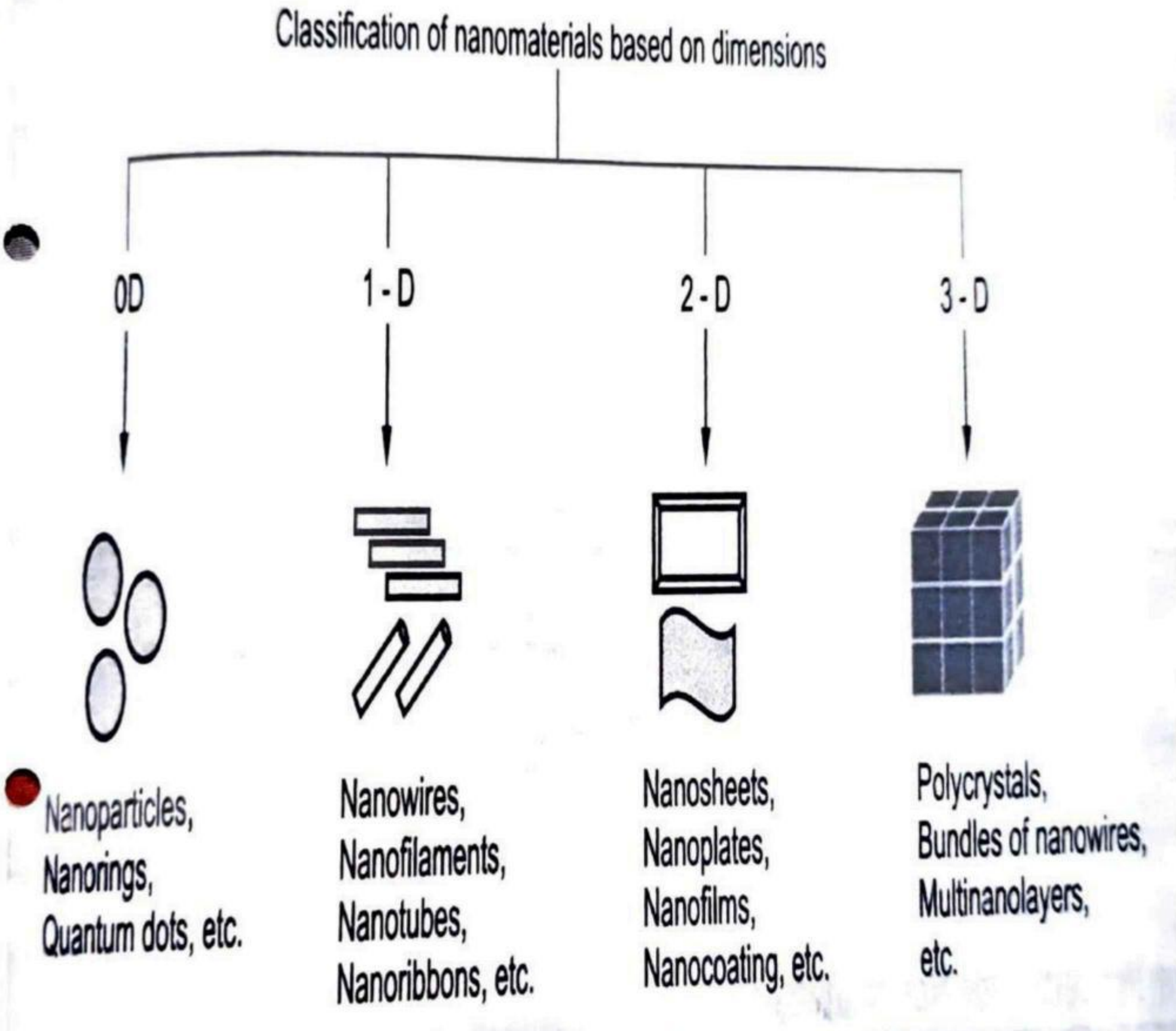
Nanomaterials like graphene and carbon nanotubes are used in electronic components like mobiles, portable computers, wristwatches etc.

2) Energy storage:

Nanomaterials are used in solar cells. It is used to store Hydrogen gas. It enhances the performance of batteries, such as rechargeable batteries used in cellular phones, cordless phones, CD players, Calculators etc.

3) Cosmetics:

Nanomaterials are used in sunscreens as it contains ultraviolet light absorbing zinc oxide and titanium oxide nanoparticles.


Classification of nanomaterials based on dimensions
0D
1 - D
2 - D
3 - D
Nanoparticles,
Nanorings,
Quantum dots, etc.
Nanowires,
Nanofilaments,
Nanotubes,
Nanoribbons, etc.
Nanosheets,
Nanoplates,
Nanofilms,
Nanocoating, etc.
Polycrystals,
Bundles of nanowires,
Multinanolayers,
etc.

Nanobased dyes and colours are quite harmless to skin and can be used in hair creams or gels.

4) Coating:
Coating of nanomaterials offer protection against UV radiations, corrosion and increasing the life of materials.

5) Water purification:
Nanofilters and nanomembranes are used in water purification process.

* Classification of Nanomaterials based on Dimensions:

Classification of Nanomaterials based on Dimensions are as follows;
1) Zero-dimensional nanomaterials
2) One-dimensional nanomaterials.
3) Two-dimensional nanomaterials.
4) Three-dimensional nanomaterials.

1) Zero-dimensional (0D) nanomaterials or Quantum Dots:-

- These nanomaterials have all three dimensions within the nanoscale range i.e. No dimensions are greater than 100 nm.
- Quantum dots, fullerenes, Nanodots are example of 0D NMs.
- They can be crystalline or amorphous, single or polycrystalline, metallic or ceramic.
- 0D QDs are extensively used for LED's, solar cells, lasers etc.

2) One-dimensional (1D) nanomaterials or Quantum Wire:-

- Two of the three dimensions are measured within the nanoscale. One dimension is larger than 100 nm.

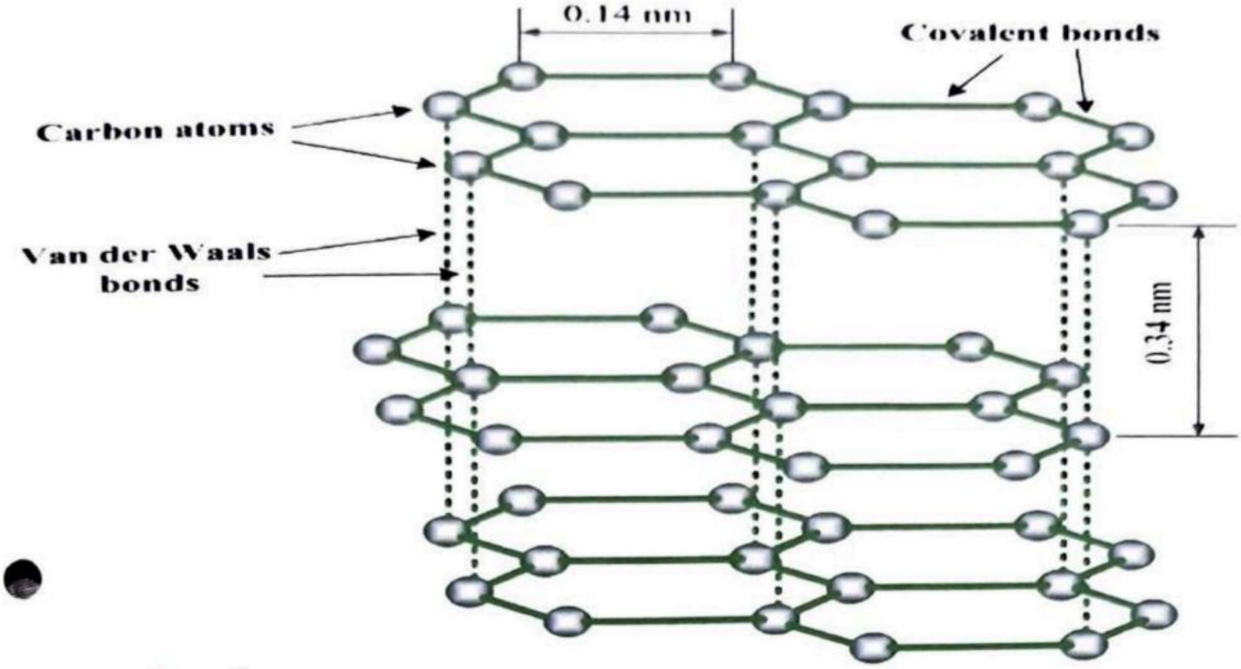
- Examples of 1D NMs are Nanowires, Nanorods, Nanotubes etc.
- They can be crystalline or amorphous, single or polycrystalline, and can be metallic, ceramic or polymeric.
- Used in fuel cell, catalysis etc.

3) Two - dimensional (2D) nanomaterials or Quantum Wells :-

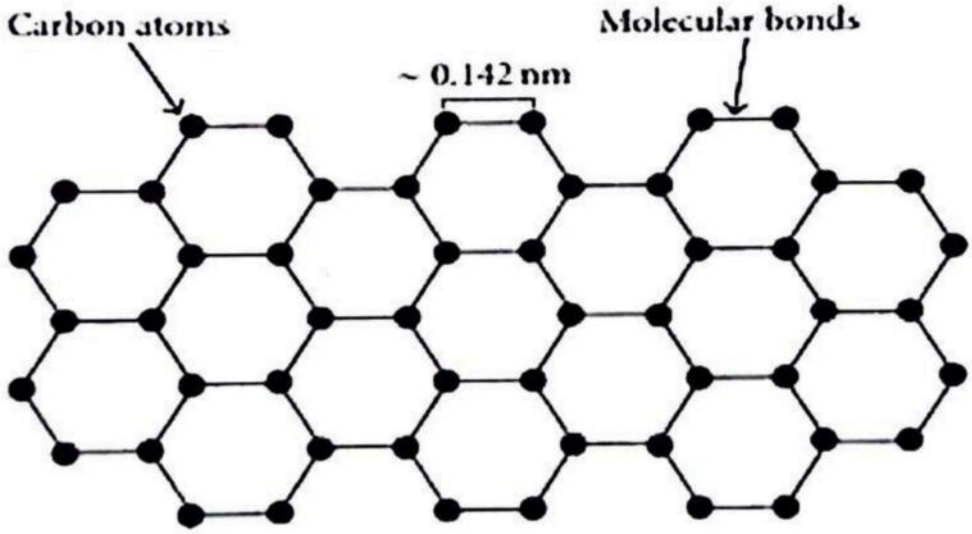
- One of the three dimensions are measured within the nanoscale. Two dimensions are larger than 100 nm.
- Examples - Nanoplates, Nanosheets, Nanofilms etc.
- 2D NMs can be crystalline or amorphous, made up of various chemical compositions.
- Used in energy storage, Electronic sensors etc.

4) Three-dimensional (3D) nanomaterials or Bulk structure :-

- All three dimensions are not measured within the nanoscale. All three dimensions are larger than 100nm.
- Examples - Fullerene (Nanoballs), Bundles of nanowires, bundles of nanotubes, nanocubes etc.
- Used in biosensors, compact electronic devices, air filtration etc.
- All the dimensions are outside the nanoscale range (>100nm), but the bulk material is made up of individual blocks that are in the nanometer scale (1-100nm).
- 3D NMs are bulk NMs, none of the dimensions are confined to nanoscale.



Graphene Molecular Layers in Graphite



Single Graphene Sheet

* Structure, Properties and Applications of Graphene:

- Graphene is a 2D nanomaterial made up of carbon atoms arranged in a hexagonal lattice structure.
- It is a single layer of graphite, with remarkable properties.
- It is called as building block for graphite.
- It is an allotrope of carbon in the form of a two-dimensional, atomic scale, hexagonal lattice.
- It is the basic structural element of other allotropes, including graphite, CNTs and Fullerene.

• Structure of Graphene :-

- Graphene is thinnest two-dimensional carbonaceous nanomaterial.
- It is a two dimensional network of carbon atoms in which carbon atoms are bonded to three other carbon atoms.
- Carbon atoms are arranged in the form of hexagonal rings with the network of single and double bonds.
- All carbon atoms are sp^2 hybridized.
- Bond length between carbon-carbon atoms in graphene is 1.42 A°.
- Sheets of graphene are held together with weak Vander Waal's forces at a distance of 3.4A° in graphite. Due to weak Vander Waal's forces, graphite molecules can slide over each other and because of that, it shows flexibility.

• Properties of Graphene :-

1) Electronic properties -

- Graphene has amazing electronic properties. It has the highest electrical density of all materials and conducts electricity close to the speed of light with virtually no resistance.

- Due to the delocalized electrons in graphene, electrons can travel at extremely high velocity without significant chance of Scattering.

2) Mechanical properties-
- Because of the stable sp^2 bonds, Graphene has high stiffness, strength and toughness, hence used as a reinforcing agent for various composites.
- It is the strongest and hardest material. It is harder than diamond. Its tensile strength is 200 times more than steel.

3) Thermal Conductivity-
- Graphene has high thermal conductivity, 5 times greater than that of graphite.
- Graphene conducts heat in all directions, it is an isotropic conductor.

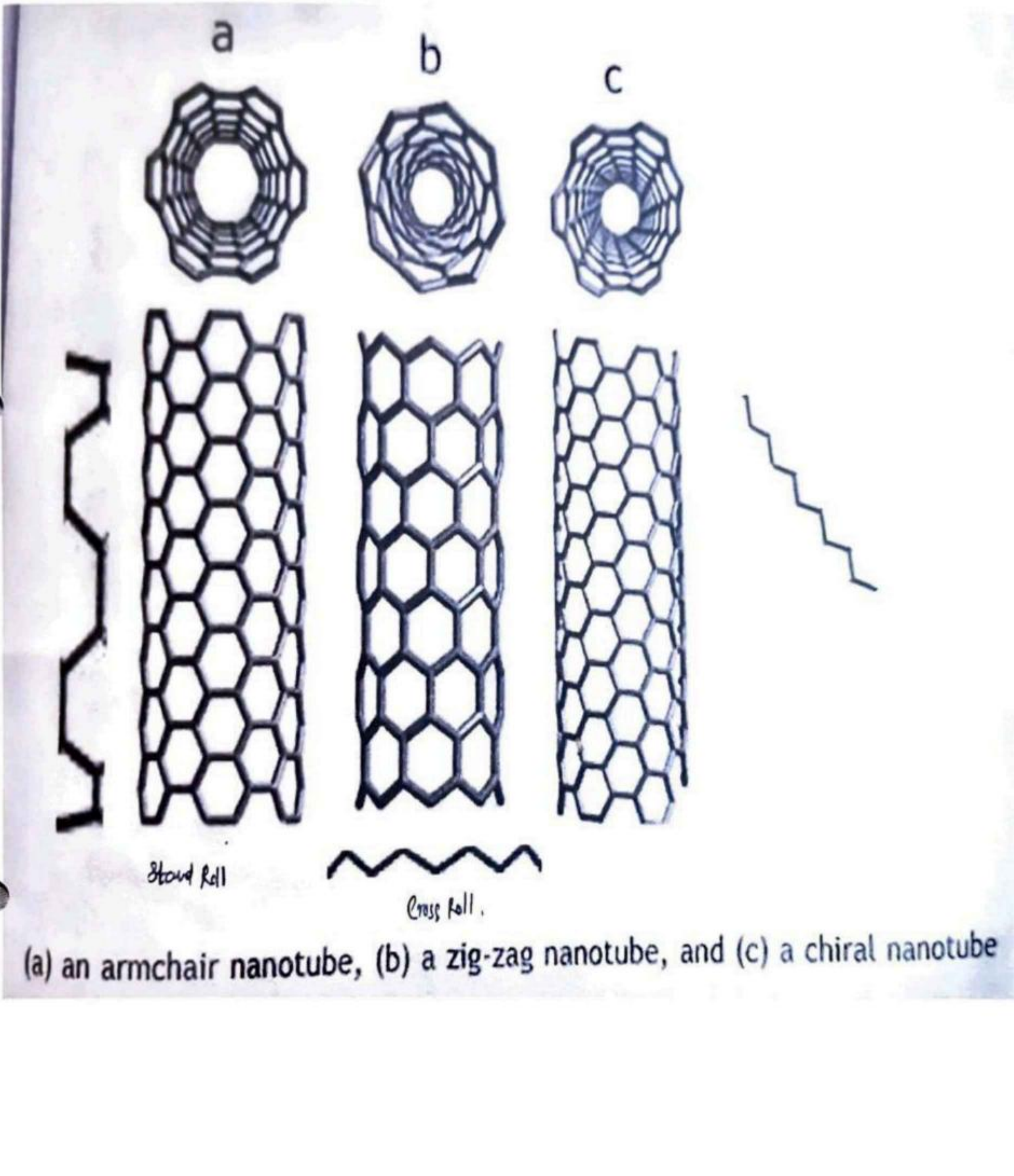
4) Optical properties-
- Graphene shows unique and interesting optical properties. One atom thick layer of Graphene absorbs large amount (2.3%) of white light, making it transparent.

- Applications of Graphene:-

1) Ultrafilteration-
- Graphene can be used as an ultrafilteration medium.
- Single atom thick Graphene filter acts as a barrier between two substances, allowing water to pass through.

2) Energy storage-
Graphene improves both energy capacity and charge rate in rechargeable batteries, as electrode in fuel cells.

3) Gas Storage - Used as adsorbents for storage of H_2 gas.



(a) an armchair nanotube, (b) a zig-zag nanotube, and (c) a chiral nanotube

4) Composite Material -

- In composites, Graphene is typically used as an additive in variety of materials such as polymers, metals, ceramics etc.
- Graphene based composites are used in Aerospace, Automotive and Energy Industries.

* Structure, properties and Applications of Carbon Nanotubes (CNTs):

- Definition-

Carbon nanotubes (CNTs) are cylindrical nanostructures composed of carbon atoms arranged in a hexagonal lattice structure.

- They can be thought of as rolled-up sheets of graphene, with diameters typically in the range of 1-10 nanometers (nm) and lengths ranging from several micrometers to millimeters.

- Structure of Carbon Nanotubes (CNTs):-

Carbon nanotubes are the members of fullerene family and can be imagined as cylinders formed by rolling graphene sheet.

Diameter of CNT is in the order of few nm.

* Types of Carbon Nanotubes -

1. Single Walled Carbon Nanotubes (SWNTs)
2. Multiple Walled Carbon Nanotubes (MWNTs)

1] Single Walled Carbon Nanotubes:

- Formed by rolling or folding of single sheet of graphene.
- The structure of SWNT can be imagined by wrapping a one atom thick layer of graphene into a cylinder.

- Depending on wrapping, the three different designs (types) of SWNTs are Arm Chair, Zigzag and Helical (chiral).

2] Multiple Walled Carbon Nanotubes:

- These consist of two or more number of rolled up concentric layers of graphene.
- Formed by rolling of many sheets of graphene.

- Properties of Carbon Nanotubes (CNTs):-

1) Strength and Elasticity -
- CNTs have higher tensile strength than steel and kevlar. This strength originates from sp^2 bonds between individual carbon atoms.
- CNTs also show elasticity upto certain limit.

2) Chemical Reactivity-
Carbon nanotubes are chemically neutral. So they are chemically stable.

3) Optical properties—
Nanotubes absorb and give off light in the near-infrared spectrum, that can find potential applications in biomedical and nanoelectronic field.

4) Mechanical properties—
- CNTs are stiffer than steel.
- High tensile strength and mechanical stiffness.
- Shows resistance to wear and tear by pressure.

5) Thermal Conductivity—Thermal conductivity of CNT is higher than that of Copper & Diamond.

- Applications of Carbon Nanotubes (CNTs):-

1) As Composites -
CNTs can be used as reinforcement material to build light-weight spacecraft, Tennis rackets, bullet proof jackets etc.

2) As Nanocylinder - To store hydrogen gas.

3) CNTs in Air and Water filteration -
CNT based water and air filteration devices can not only block the smallest particles but also kill most of the bacteria.

4) CNTs in Energy Storage -
- CNTs are preferred materials for electrodes in capacitors and batteries.
- CNTs have been used in supercapacitors producing higher power density.

5) In Batteries -
Lithium can be sandwitched in CNTs.

6) Used as catalyst in organic conversion reactions.

* Quantum Dots (Semiconductor Nanoparticles):

- Definition :-

Quantum dots (QDs) are ultrasmall size semiconductor nanoparticles, whose size ranges from few nanometers to 10 nanometers and exhibit unique optical and electronic properties by their quantum confinement effect.

- Quantum dots were discovered by the Russian physicist Alexey Ekimov in 1981.

- Structure - 0 Dimensional (0D) nanostructure; particle is confined on all 3 spatial dimensions. Due to nano size, it show quantum effects, change energy levels of their electrons.

- Examples - Typically, QDs are composed of the elements of periodic groups II-VI, III-V and IV-VI, materials like CdSe, CdS_2, PbSe, GaAs etc.

- General Features -

i) When illuminated by UV light, some of the electrons recieve enough energy to break free from the atoms.
ii) This capacity allows them to move around the nanoparticle, creating a conductance band in which electrons are free to move through a material and conduct electricity. When these electrons drop back into the outer orbit around the atom, they emit light.
iii) The colour of that light depends on the energy difference between the conductance band and the valence band.
iv) A majority of QDs have the ability to emit light of

specific wavelengths if excited by light or electricity.

- **Types of Quantum Dots:-**

There are three main types of Quantum dots;

1) III - V Semiconductor Quantum Dots -

- They are made up of elements from Group III (Boron, Al, Ga, In) and from Group V (N, P, Arsenic, Antimony) from periodic table.
- Best known example of this type is Gallium - Arsenide (GaAs). It is used as a light source in optical data processing and as an amplification medium in lasers.

2) II - VI Semiconductor Quantum Dots -

- They are made up of elements from Group II i.e. transition metals (Zn, Cd) and Group VI (O, S, Selenium, Tellurim) from periodic table.
- The important examples of this type are Cadmium Selenide (CdSe), Cadmium Telluride (CdTe) and Zinc Oxide (ZnO).
- They show outstanding fluorescence properties and widely used in electronics, photonics, photovoltaics, biomedicine etc.

3) Silicon (Si) QDs -

- They are made up of element silicon, which is the standard material of semiconductor and chip industry.
- Silicon QDs have great potential to be used as a component of optical chip, optical sensors etc.

• Properties of Quantum Dots :-

1) Photoluminescence -

QDs exhibit strong and tunable photoluminescence. They can emit light of different colours (wavelengths) depending on size. This property makes them valuable for applications in displays, lighting etc.

2) Semiconductor Behavior -

QDs are semiconductors that can conduct electricity under certain conditions, showing potential use in electronics and photodetectors.

3) Photostability -

- Compared to fluorescent proteins and conventional chemical dyes, quantum dots are frequently more photostable.
- They do not significantly deteriorate when exposed to light for extended periods of time.

4) Optoelectronic properties -

- QDs have properties in between bulk semiconductors and discrete atoms. They change the properties as a function of both size and shape.
- Large QDs of 5-6 nm diameter emit longer wavelengths, smaller QDs 2-3 nm emit shorter wavelengths.

The colour depends upon exact composition of QDs.

Applications of Quantum Dots:-

1) Solar Cells -

The traditional solar cells are made up of semiconductors which are costly to generate as well as these have 33% upper limit efficiency in conversion of sunlight to electricity. QDs increases this efficiency to approximately 60%

2) Photo Catalysis -

QDs can acts as photo catalysts for chemical conversion of water into hydrogen in presence of light.

3) Alternative to Traditional Dyes -

- QDs are an attractive alternative to traditional organic dyes because of their high quantum yield and photostability. QDs have high quantum yield because they have a high density of energy states near the bandgap.
- A higher quantum yield means a brighter emission. The quantum yield of some QDs is 20 times greater than traditional organic fluorophores.

4) Sensors and Detectors -

Sensors and detectors using quantum dots are used in security, medical diagnostics and environmental monitoring.

5) Optoelectronic devices -

Optoelectronic devices like lasers, photodetectors use quantum dots.

6) QDs are used in communication devices.