CO-4: Polymers & Plastics

K L University
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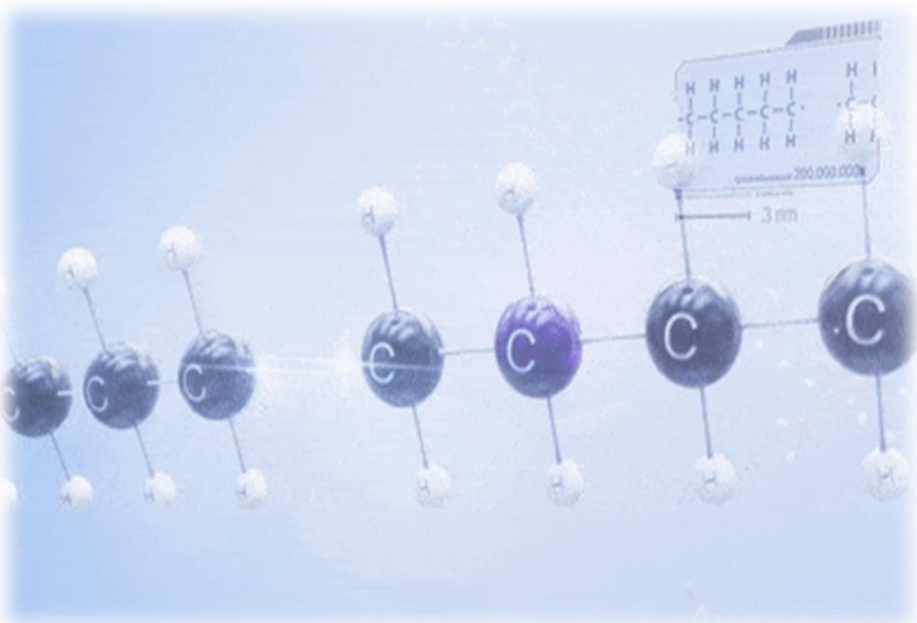


Department of Chemistry
Koneru Lakshmaiah Education Foundation (**KLEF**)

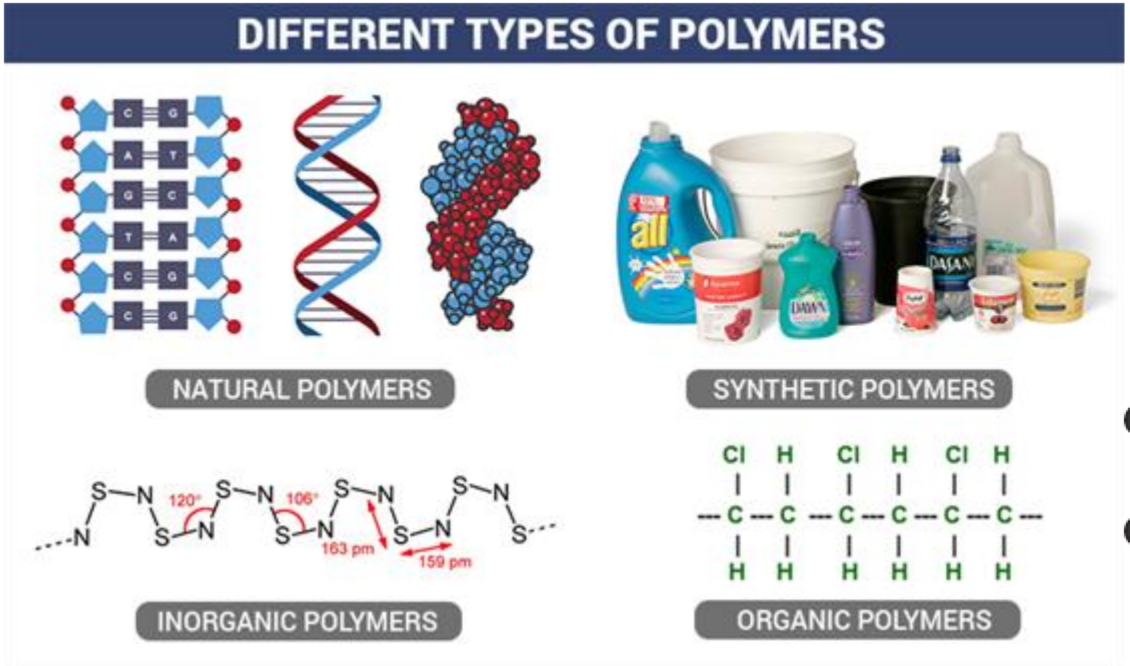
What are Polymers?

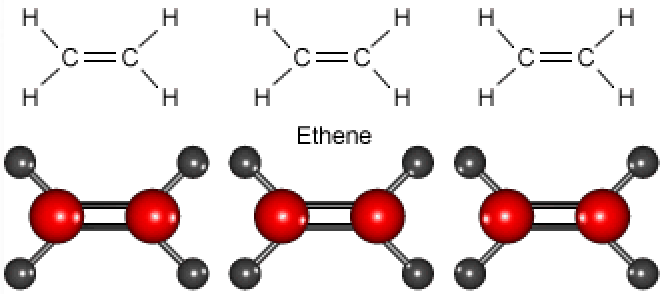
The term polymer refers to chemical compounds consisting of large molecules/macromolecules which are **constructed** from **repeating subunits** that are linked by numerous intertwined links.

There are two types of polymers.

Natural Polymers: Wool, cotton, DNA, proteins.

Synthetic polymers : Teflon, Polyethylene, Nylon, polyester.

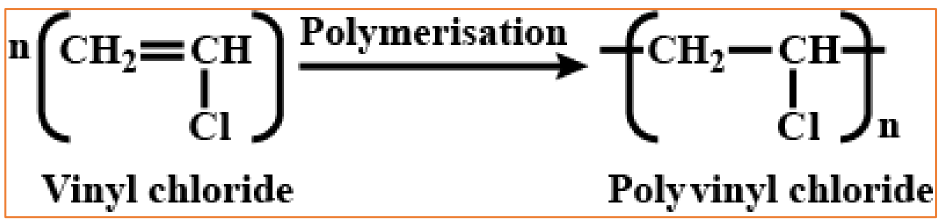


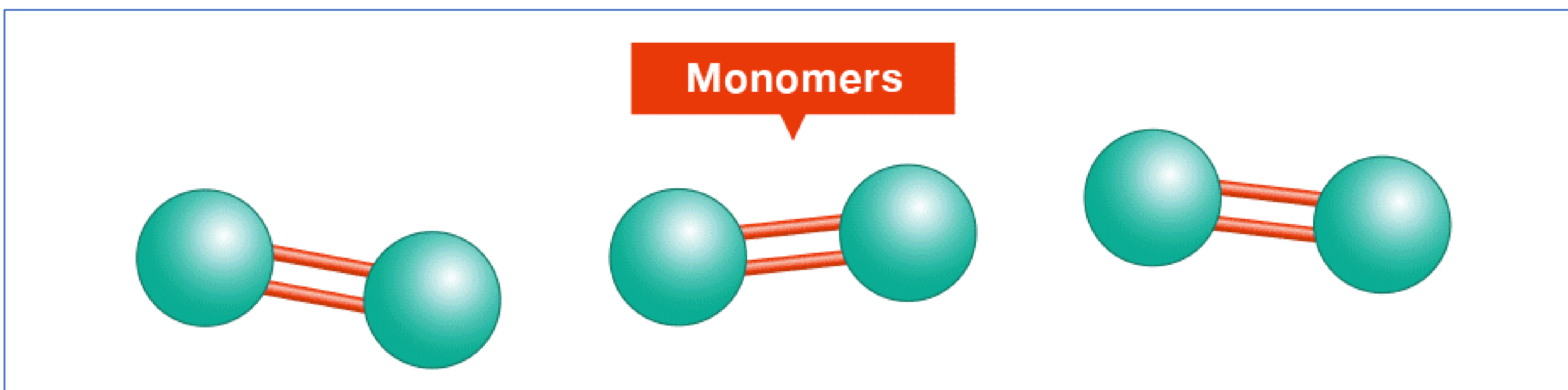


What are Monomers?

Monomers: The individual small and simple molecules from which the polymer is formed. They are joined together by chemical bonds.

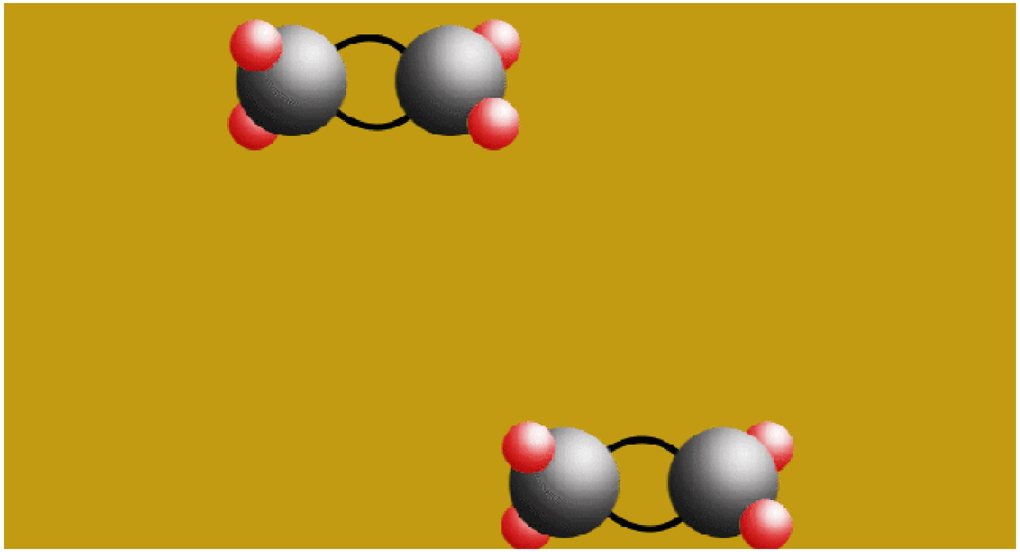
Examples: Vinyl chloride, ethylene, propylene etc.





Polymerization

Polymerization is a process of reacting monomer molecules together in a **chemical reaction** to form polymer chains or three-dimensional networks.



Degree of polymerization (DP)

$$5\ CH_2 = CH_2 \longrightarrow -CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-$$

Degree of polymerization is 5

Classification based on DP

Oligo polymers: they have a low degree of polymerization, with mol. wt. ranging from 500-5000.

High polymers: they have a high degree of polymerization, with mol. wt. ranging from 10,000-20,000.

Basics of polymers

Polymers: Complex and giant molecules, made from joining many small and simple molecules by primary valency linkage.

Monomers: The individual small and simple molecules from which the polymer is formed.

Polymerization: The process by which monomer molecules are linked to form a big polymer molecule

Functionality: The no. of bonding sites or active sites in a monomer.

Degree of polymerization: Number of monomeric units forming the polymer chain.

Tacticity: spatial arrangement of pendant groups of successive stereocenters (asymmetric carbon) in the main chain.

Classification of polymer

Polymers can be classified into various types depending on their category.

Based on origin:

Natural & synthetic polymers.

Based on constituent groups:

Organic & inorganic polymers.

Based on applications:

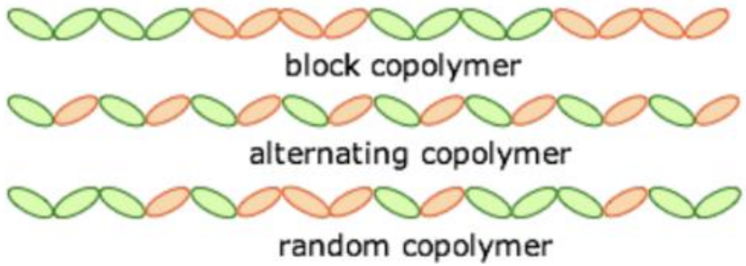
Plastics, elastomers, fibres, liquids, & resins.

Based on mechanism of formation:

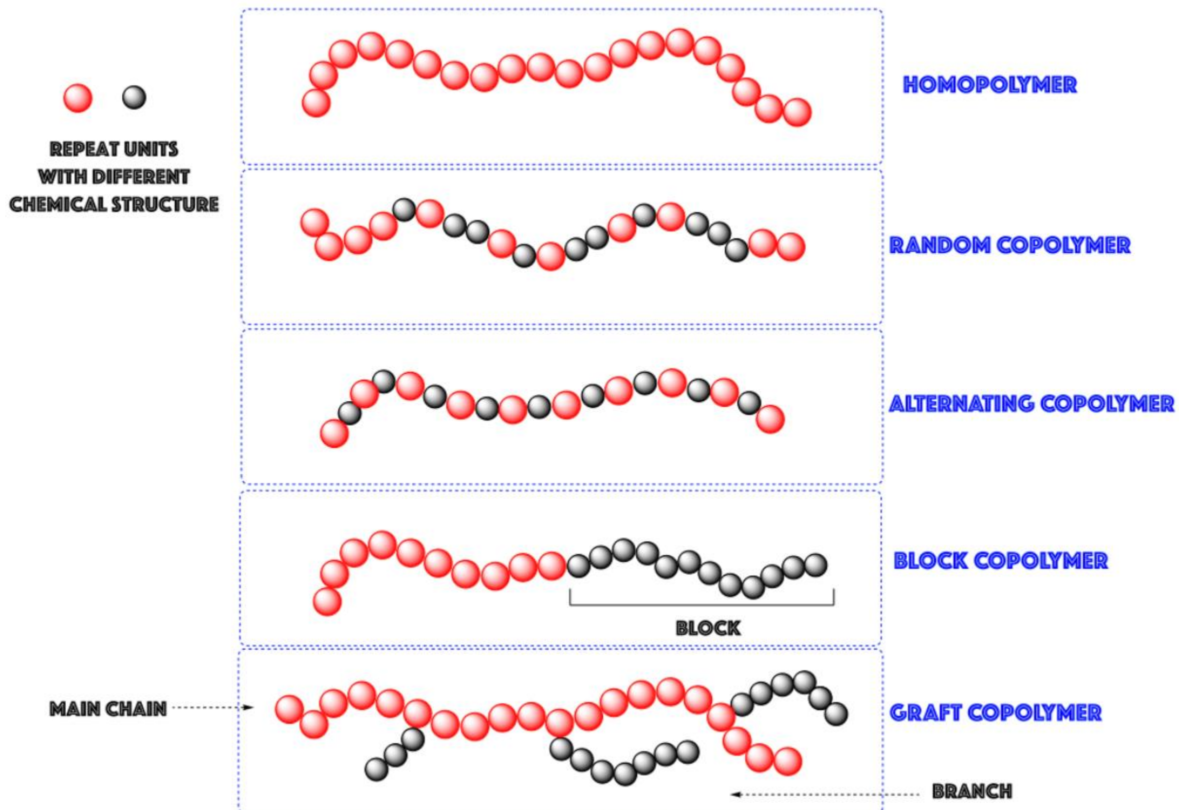
Addition polymers/condensation/chain-growth/step-growth polymers.

Types of polymers-based on monomer units

Examples: polyethylene, polystyrene, polyacrylamide, etc



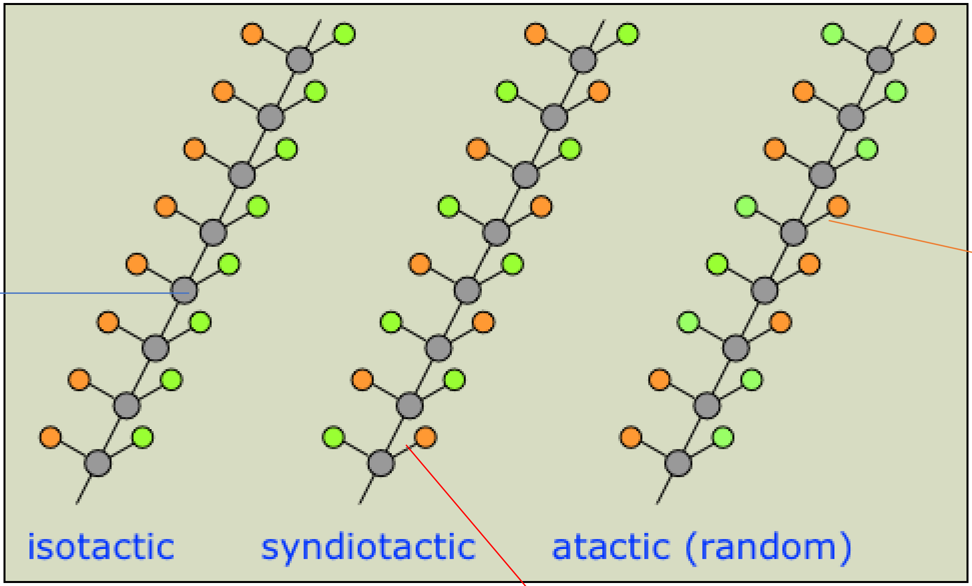
Ex.; poly(vinyl chloride-co-vinyl acetate).



Tacticity

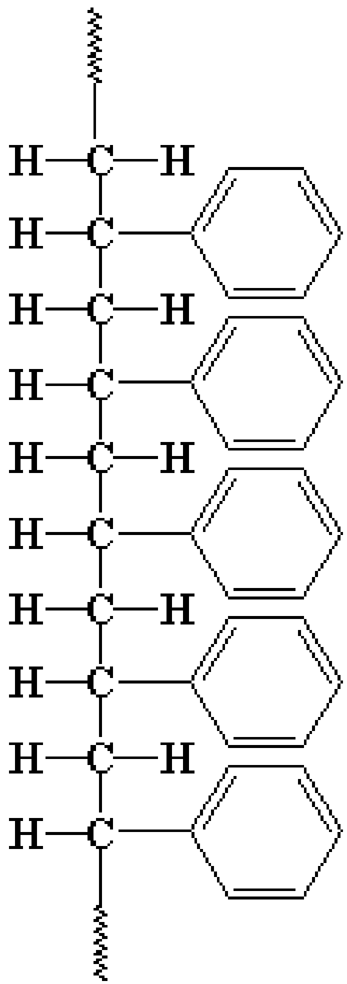
- Tacticity refers to the orientation or arrangement of functional groups in a polymer with respect to the main chain.

FG arranged on the same side of a polymer chain

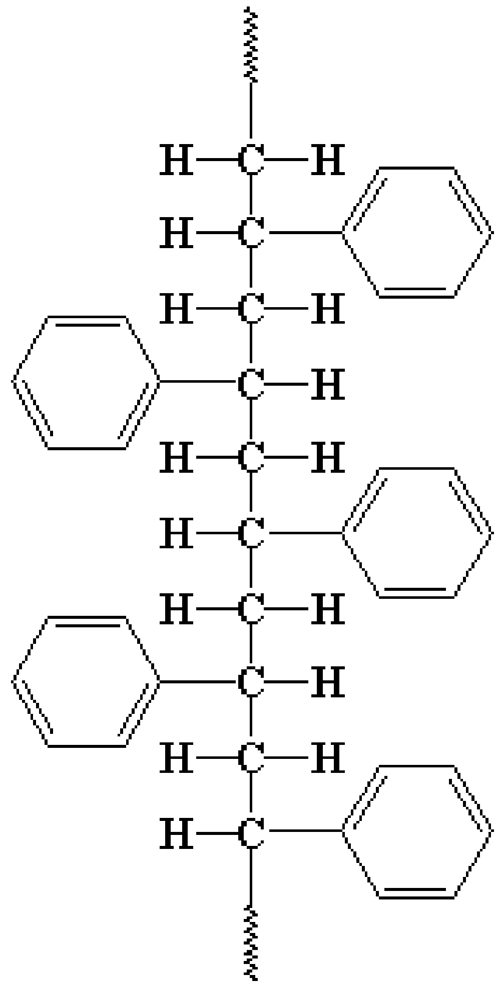


FG arranged on the randomly of a polymer chain

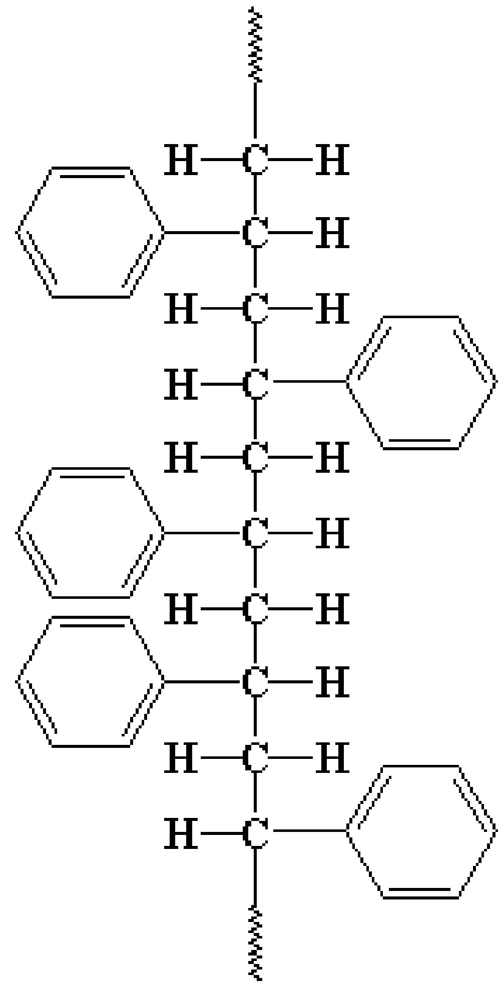
FG arranged in alternative manner of a polymer chain



Isotactic



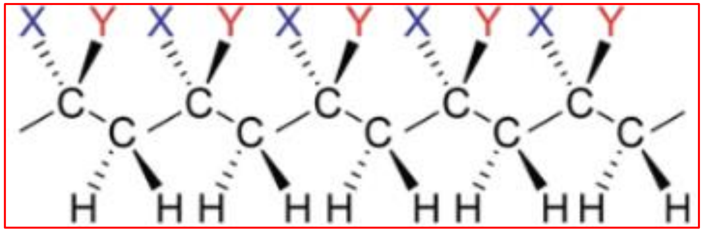
Syndiotactic



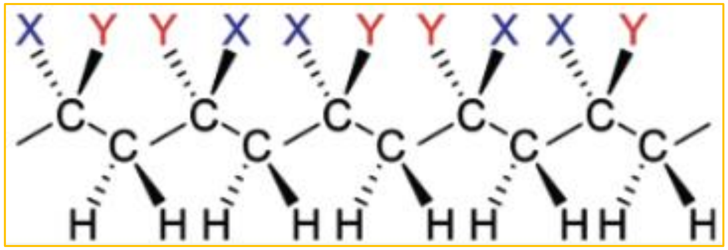
Atactic

Types of polymers-based on tacticity

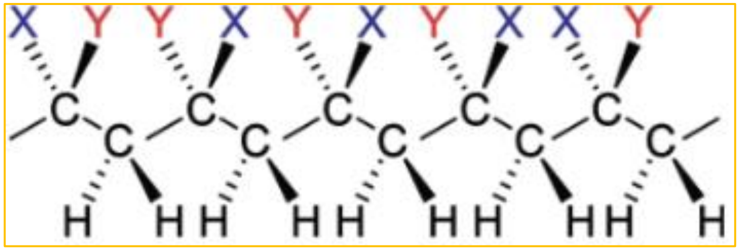
Isotactic polymer: all functional groups are on the same side of the polymer chain.



Alternating/Syndiotactic polymer: all functional groups are arranged alternatively on either side of the polymer chain in a regular fashion.



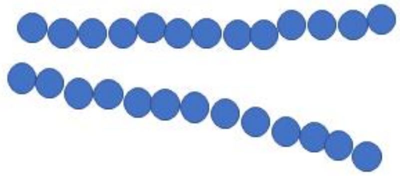
Random or Atactic polymer: all functional groups are arranged randomly on both sides of the polymer chain.



Types of polymers-based on applications

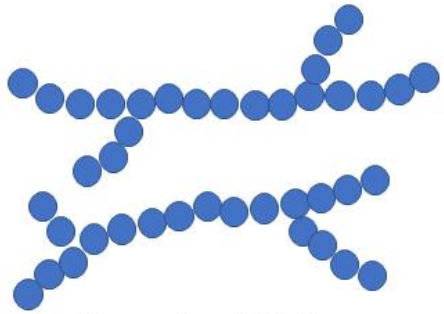
- A polymer that can be reshaped into **hard and tough utility articles** by applying heat, pressure or both is said to be a **plastic.** Ex: Polystyrene, Poly(vinyl chloride), Poly(methyl methacrylate), polyester etc.
- A polymer that shows **good strength and elongation** upon chemical treatment is called an **elastomer**. Ex: Polyisoprene, polyisobutylene, etc.
- A polymer that can be drawn into a **long filament-like material**, whose length is at least 100 times its diameter is called a **fibre**. Ex: Nylon, terylene, polyester, polyacrylonitrile, etc.
- A polymer used as **adhesives, potting compounds, sealants** etc., in a liquid form is called as **liquid resin.** Ex: Epoxy adhesives, poly sulfides, sealants, etc.

Classification of polymers-based on chain configurations



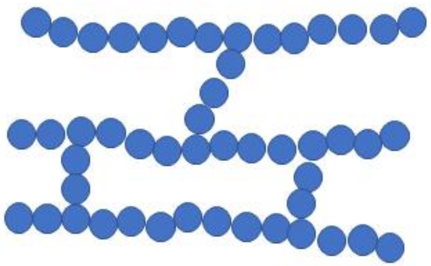
Linear Polymers

E.g., High density polyethylene, PVC.



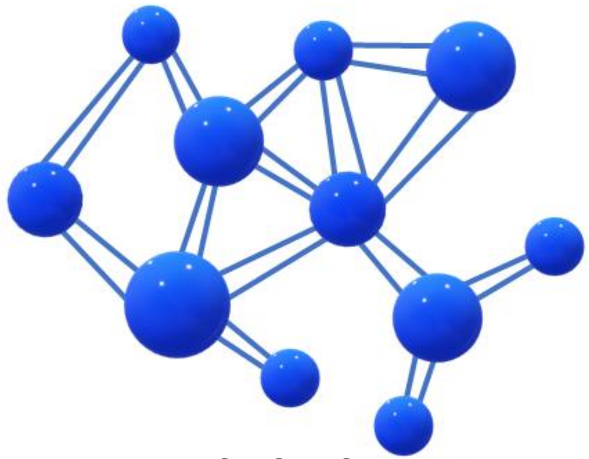
Branched Polymers

E.g., Low density polyethylene.



Crosslinked Polymers

E.g., a rubber band is a collection of flexible polymer chains cross-linked with sulfur, it is a single molecule, vulcanized rubber, urea-formaldehyde resins.

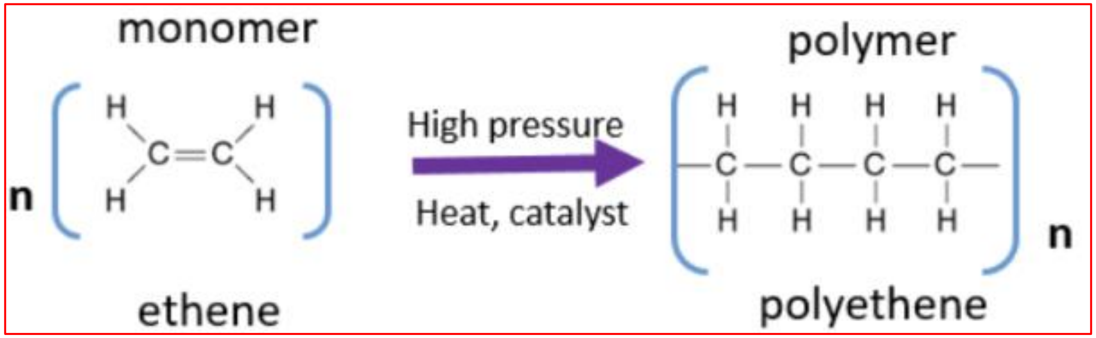


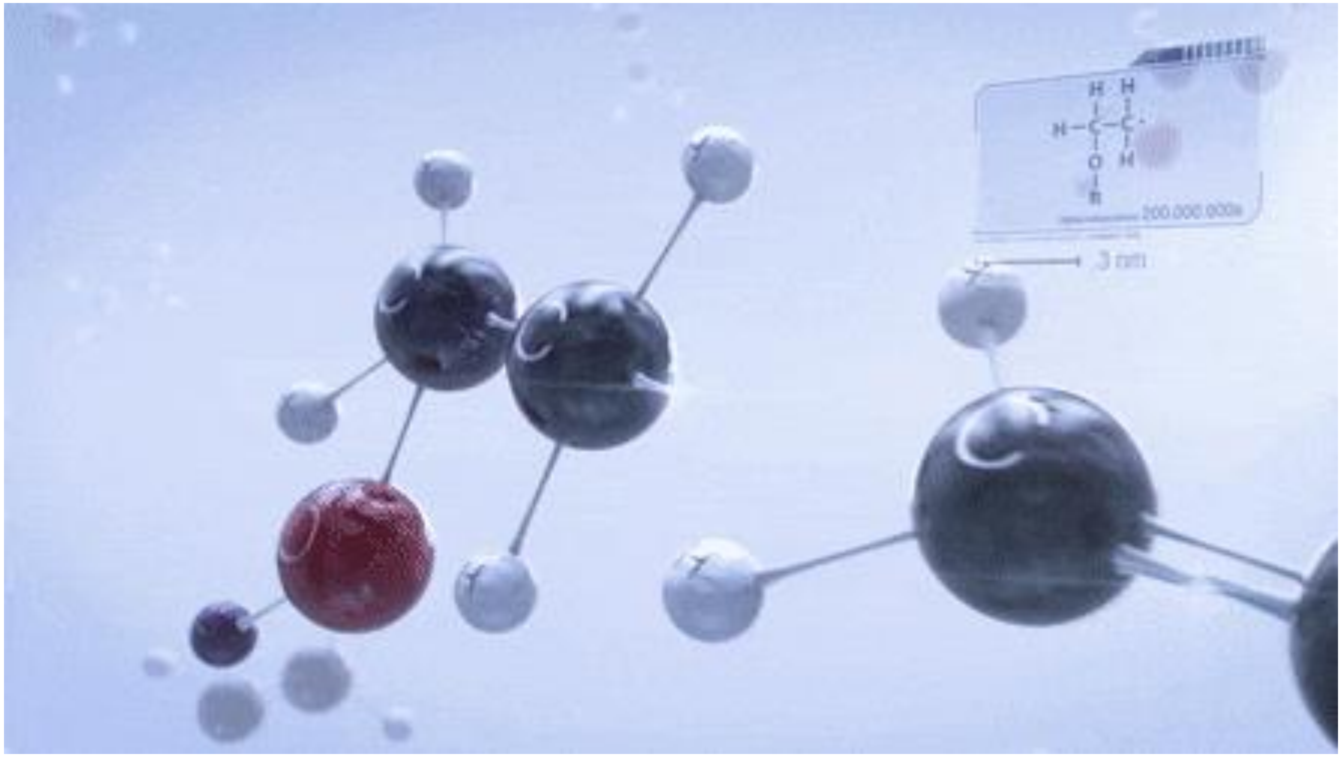
Networked Polymers

E.g., Bakelite, melamine etc.,

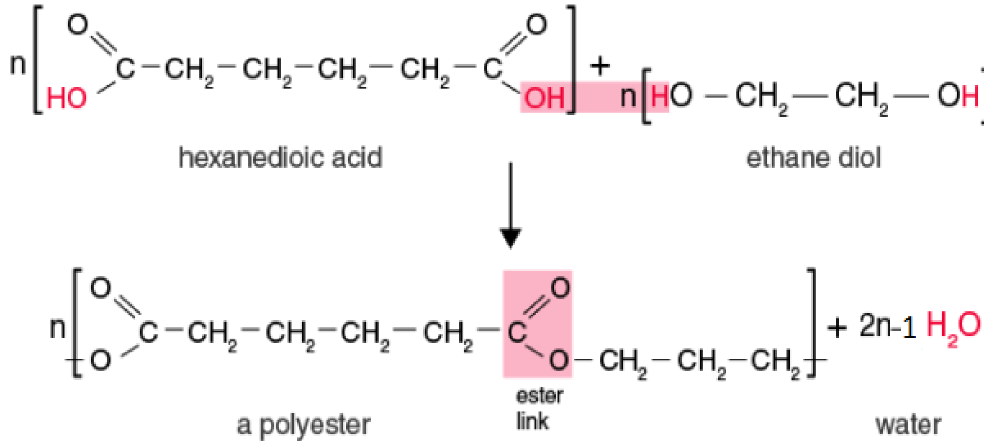
Classification of polymers-based on the method of synthesis

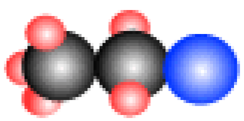
Addition Polymers

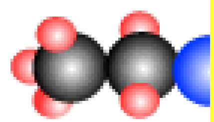


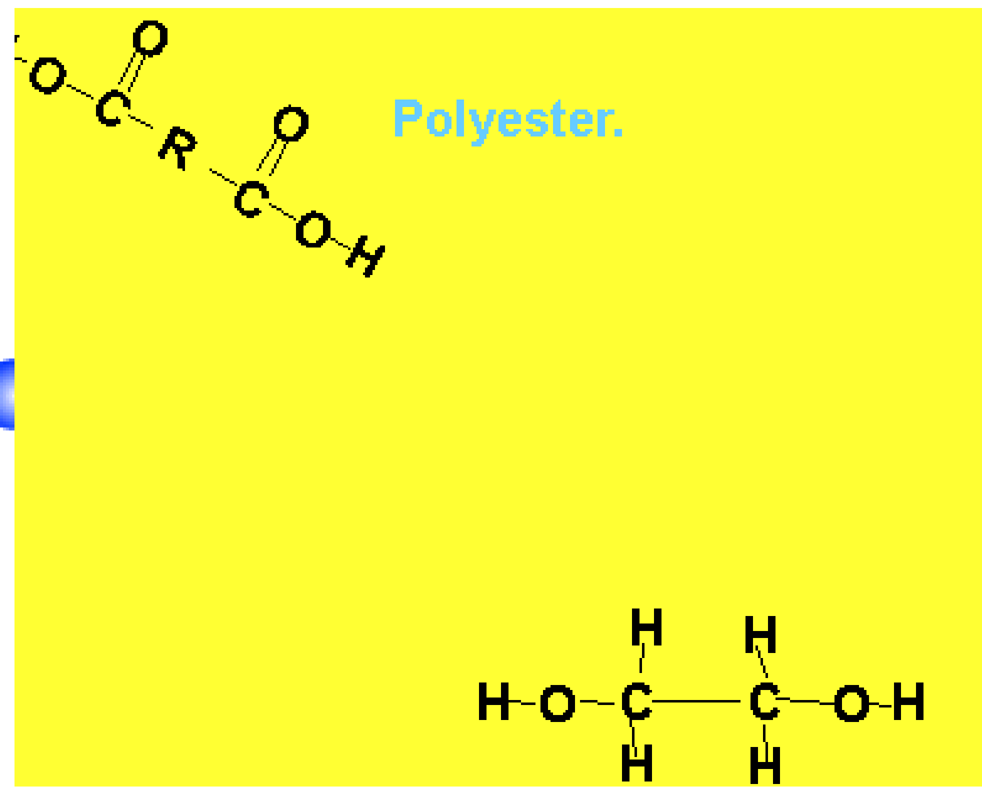


Condensation Polymers

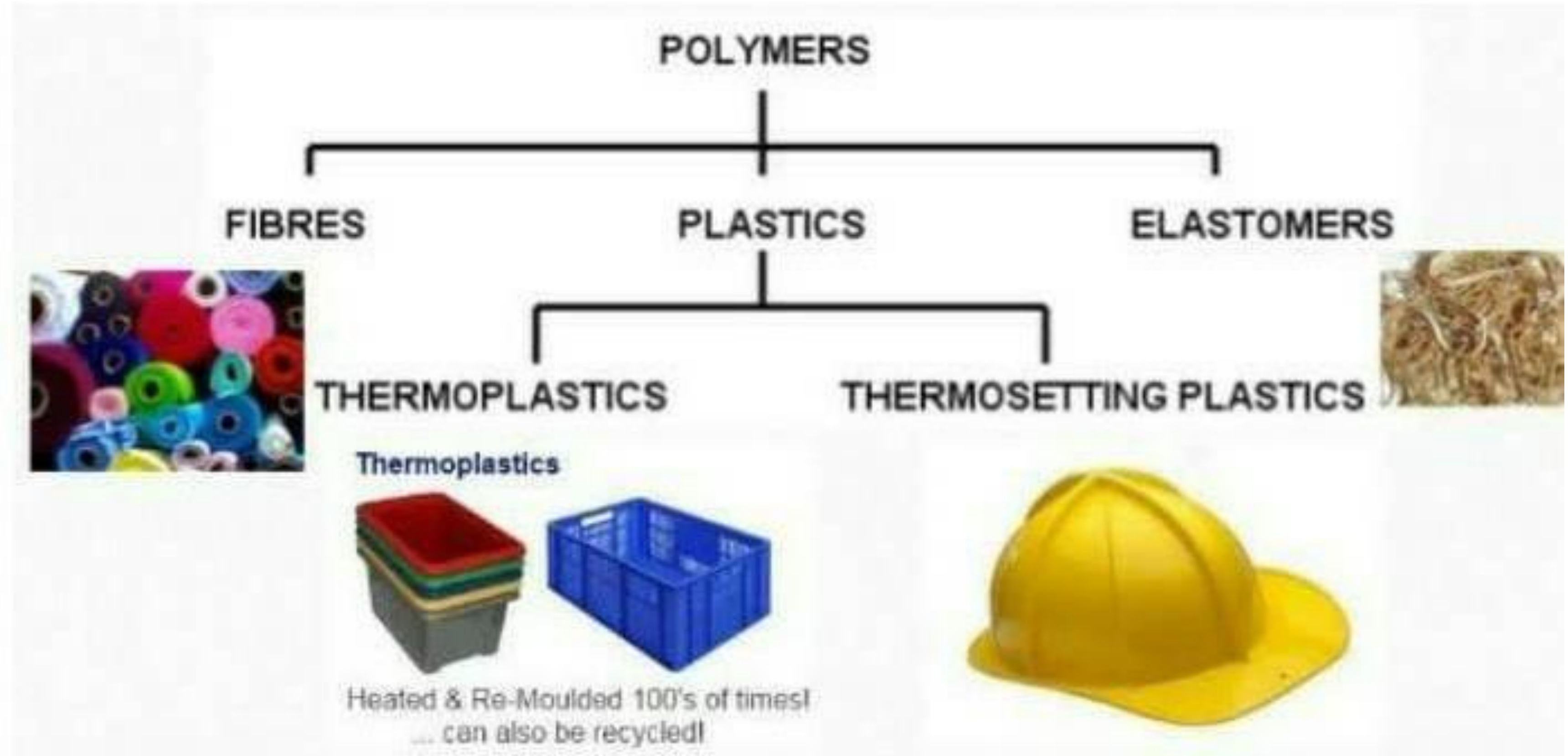








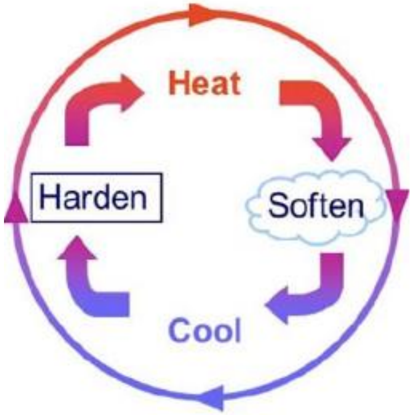
Classification of polymers-based on molecular forces



Classification of polymers-based on molecular forces

Thermoplastic polymers

- Linear polymers with long chains that soften on heating and harden on cooling reversibly.
- These are solid at room temperatures and viscous liquids when heated. So, they are shaped by extrusion, molding or pressing.
- They can be recycled and reused several times by heating and cooling.
- These plastics will return to its original shape, unless damaged due to overheating or overstretching; this property is called plastic memory. E.g., polystyrene, polyethylene, PVC, PTFE.
- Applications: Milk jugs, soft drink bottles, etc.

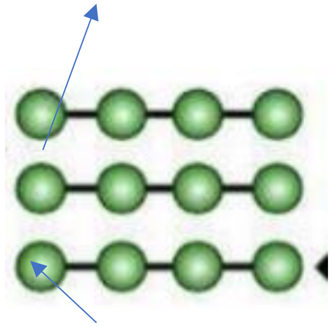


Classification of polymers-based on molecular forces

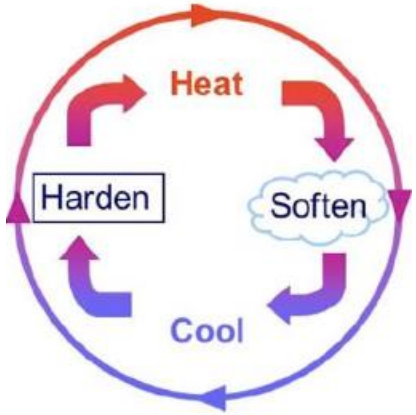
Thermoplastic polymers

- They are synthesized by addition polymerization
- They are straight chain or slightly branched polymers, held together by weak van der Waal's forces of attraction.
- Molecules of thermoplastics are linear, or long chains with very few entanglements.
- So, when heat is applied, molecules move apart and disentangle, causing them to soften, making them malleable to reshaping.
- On cooling, the molecules regain their original positions, making the plastic stiff and hard again. This process of heating and cooling can be repeated several times.
- They are generally soluble in organic solvents.

No links b/w polymers chains helps movement



Monomers

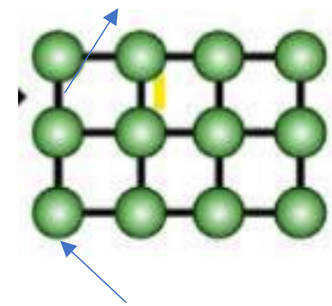


Classification of polymers-based on molecular forces

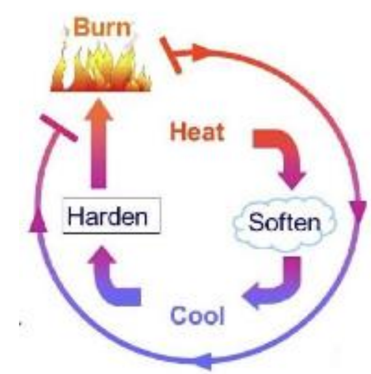
Thermosetting polymers

- Thermosetting polymer or resins, also called thermoset, is a polymer that is irreversibly hardened by curing from a soft solid or viscous liquid prepolymer or resin
- Various polymer chains are cross-linked three dimensionally using strong covalent bonds or cross links.
- They are prepared by condensation polymerization.
- They resist heat softening and solvent attack.
- Once set after curing, they cannot be softened and recycled. E.g., polyester resins like fiber glass; polyurethanes: mattresses, coatings, adhesives; vulcanized rubber; bakelite: phenol-formaldehyde resin.

Links b/w polymers chains stops movement b/w them



Monomers

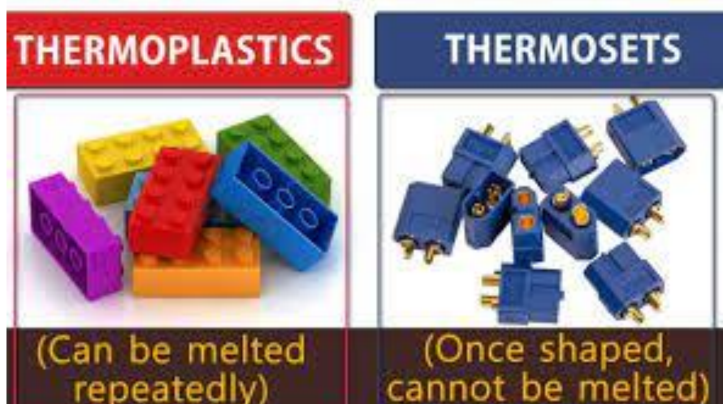


Classification of polymers-based on molecular forces

Thermoplastic polymers	Thermosetting polymers
Linear, long chain polymers, held together by weak **van der Waal's forces**	Long chain polymers that are interlinked three dimensionally by strong **covalent bonds**
They are formed by **addition polymerization**	They are formed by **condensation polymerization**
They are different types of thermoplastics, some rigid, and others extremely flexible, though they are **malleable and flexible at high temperatures**	They are rigid and non-flexible at high temperatures, and are usually **brittle and strong**
Soften upon heating, and harden on cooling reversibly due to the weak interlinking forces	Upon heating and cooling, they harden irreversibly, they set permanently.
Repeated heating and cooling does not affect their structure, and the changes are purely physical	Prolonged heating causes charring of polymers
Soluble in organic solvents	**Insoluble** in organic solvents
E.g., Polyethylene, polyvinyl chloride	E.g., Polyester resin, bakelite

Classification of polymers-based on molecular forces

Thermoplastics	Thermosetting polymers
1. Soften on heating	1. Do not soften on heating
2. Long chain linear	2. 3-D structure
3. By addition polymerisation	3. By condensation polymerisation
4. Can be reshaped and reused	4. Can not be reshaped
5. Soft weak and less brittle	5. Hard and strong
6. Soluble in org. solvents	6. Insoluble in org. solvents.
7. Reclaimed for wastes	7. Can not be reclaimed

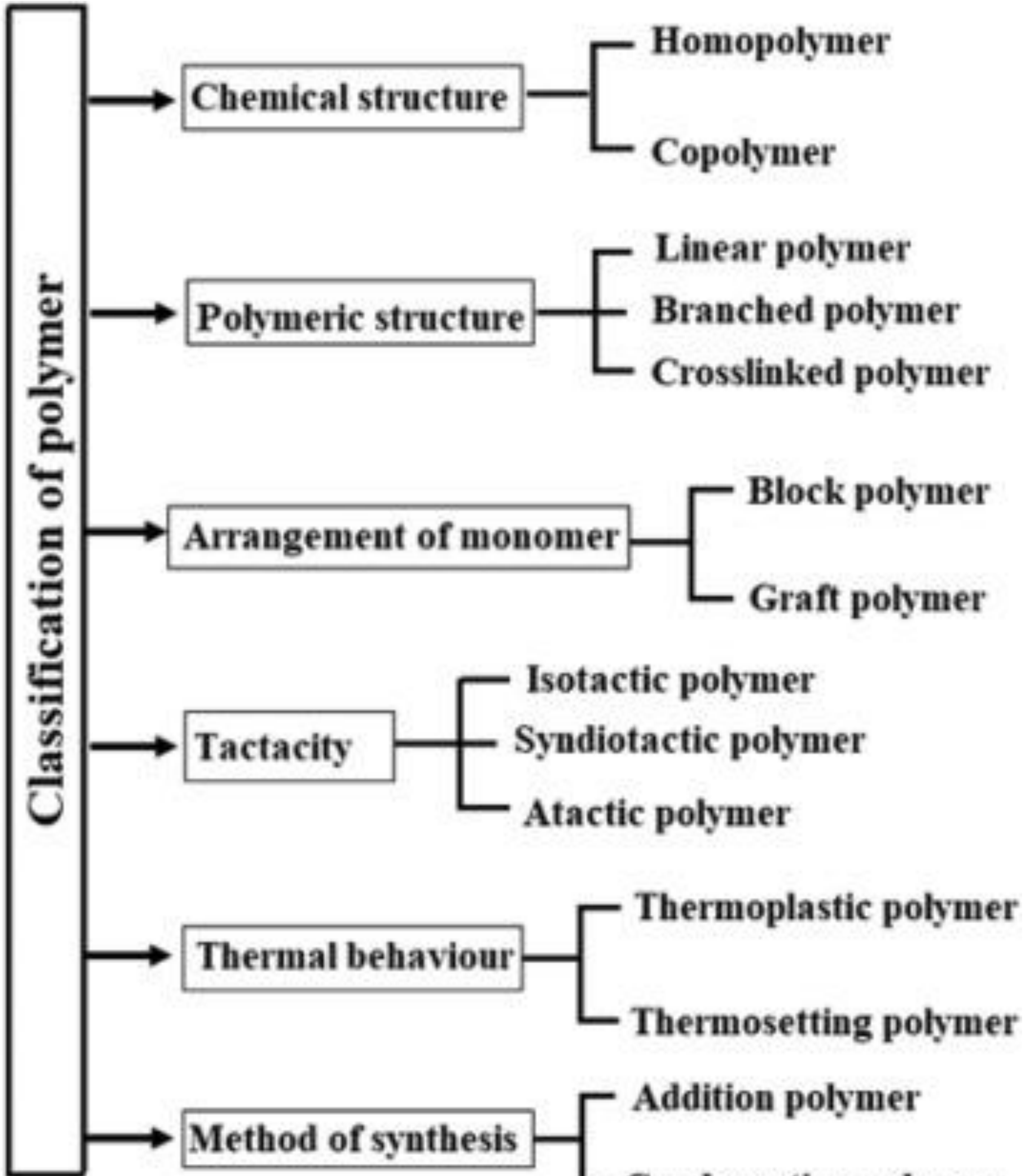


Classification of polymers-based on molecular forces

Elastomers

- Elastomer is a polymer with **viscoelasticity** (i.e., both viscosity and elasticity) and weak intermolecular forces and low Young's modulus.
- Elastomers can be stretched to **at least thrice its length** but returns to its original shape and dimensions when the stretching force is released.
- They exist in the form of a coil in the normal state, and hence can be stretched like a spring.
- The elasticity is caused by lengthening and shortening of their polymeric chain springs. E.g., rubber, latex


Classification of polymer
Chemical structure
Homopolymer
Copolymer
Polymeric structure
Linear polymer
Branched polymer
Crosslinked polymer
Arrangement of monomer
Block polymer
Graft polymer
Tacticity
Isotactic polymer
Syndiotactic polymer
Atactic polymer
Thermal behaviour
Thermoplastic polymer
Thermosetting polymer
Method of synthesis
Addition polymer
Condensation polymer

Addition Polymerization- Mechanism

1. Chain initiation:-

a) Formation of free radicals from the initiator.

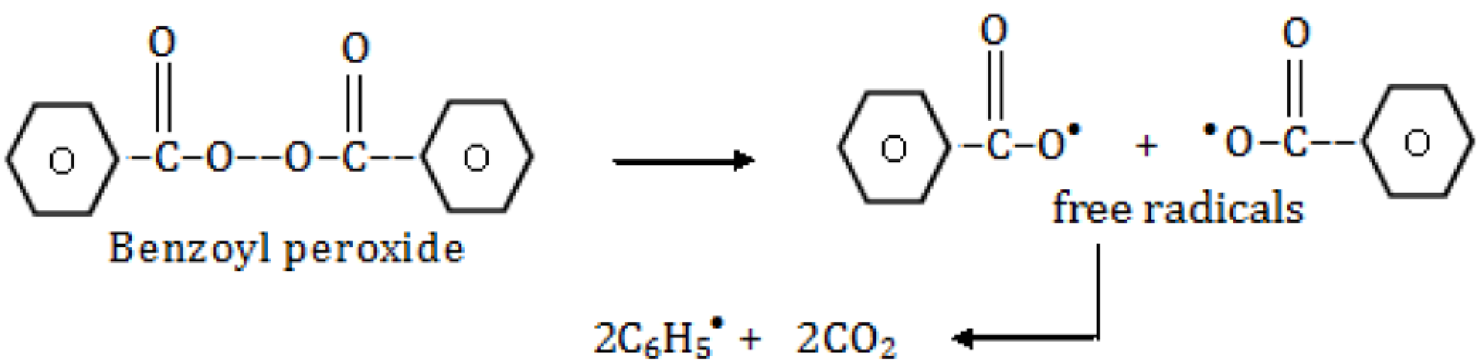
$$\text{Initiator} \longrightarrow 2\,R^{\bullet}\ \text{free radicals}$$

b) Addition of free radicals to monomer to form a free radical intermediate.

$$R^{\bullet} + \underset{\displaystyle X}{CH_2{=}\overset{}{CH}} \longrightarrow \underset{\displaystyle X}{R{-}CH_2{-}CH^{\bullet}}$$

X = substituent group

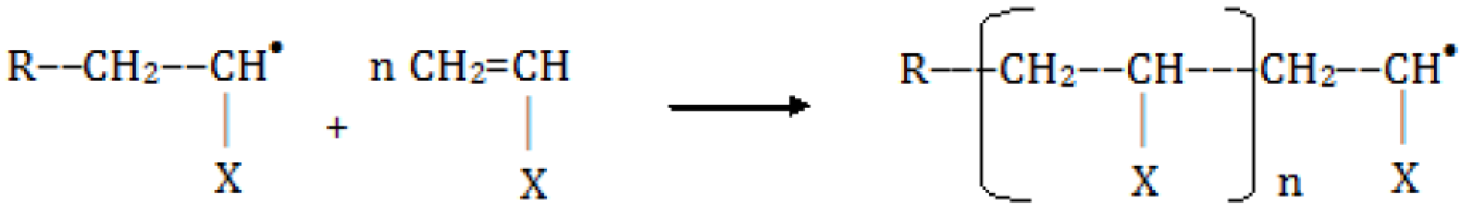
Free radical Intermediate



Addition Polymerization- Mechanism

2. Chain propagation:-

Here addition of monomer molecules to the intermediate takes place one by one leads to the formation of macro-radicals.

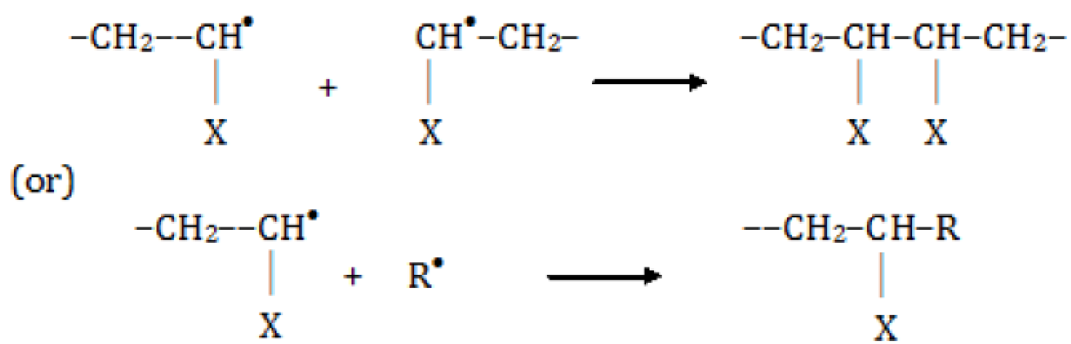


Macro radical

3. Chain termination:-

The growing polymer chain is terminated by many ways.

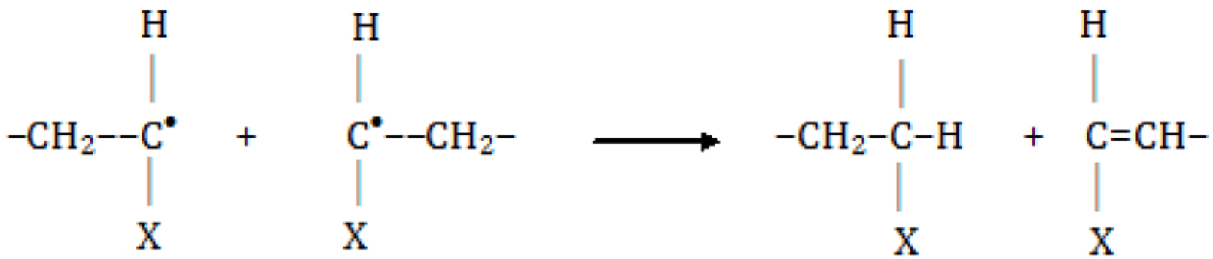
a) Recombination:-
Combination of two free radicals leads to termination.

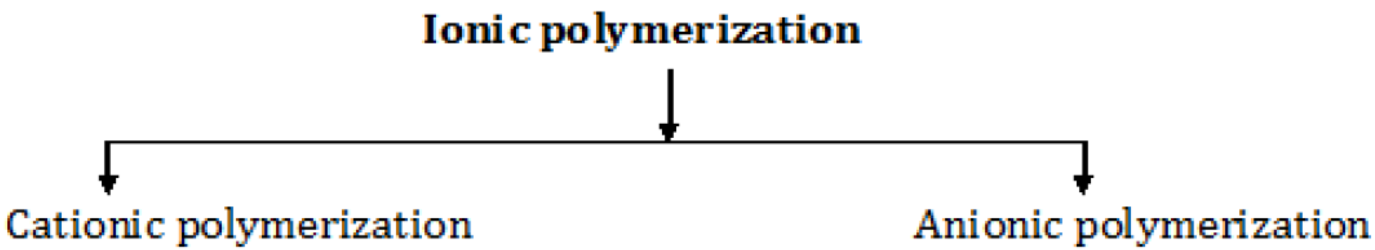


Addition Polymerization- Mechanism

b) Disproportionation:-

Transfer of ‘H’ atom from one radical to another leads to formation of two macro molecules, one of them with a double bond.





Cationic polymerization:-
Monomers with electron releasing groups (-OCH_3, -OC_2H_5 & -C_6H_5 etc) undergo cationic polymerization in the presence of Lewis acids like $AlCl_3$, BF_3, $SnCl_4$ etc. Cationic polymerization takes place with higher rates even at low temperature.

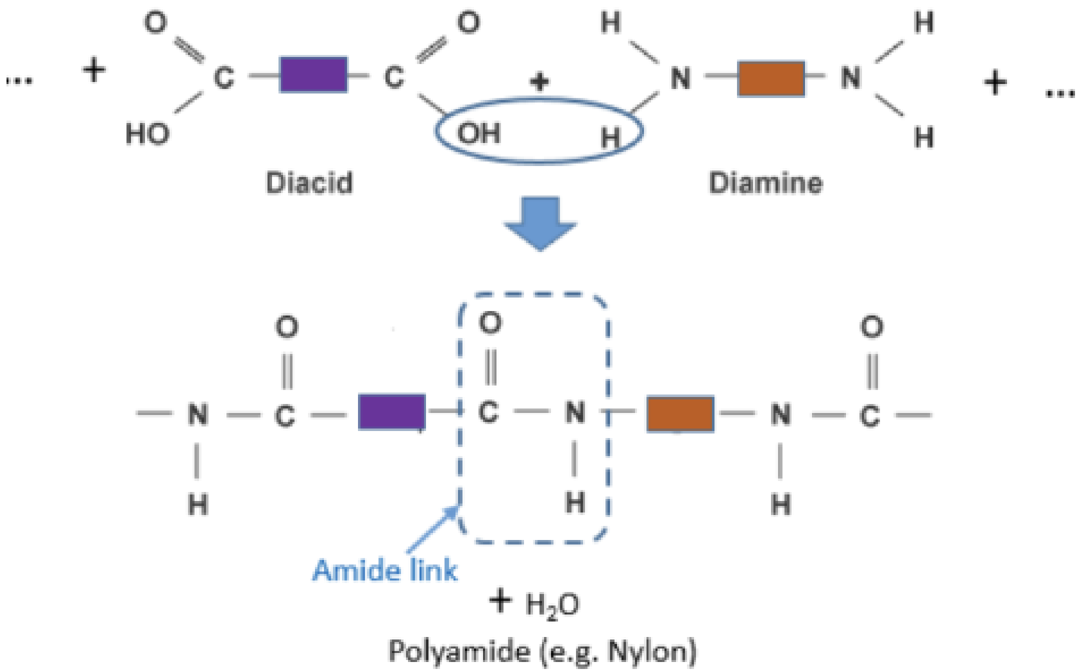
Anionic polymerization:-
Monomers with electron withdrawing groups (-CN, CH_3COO- and C_6H_5 etc) undergo anionic polymerization in presence of sodium or potassium amide.

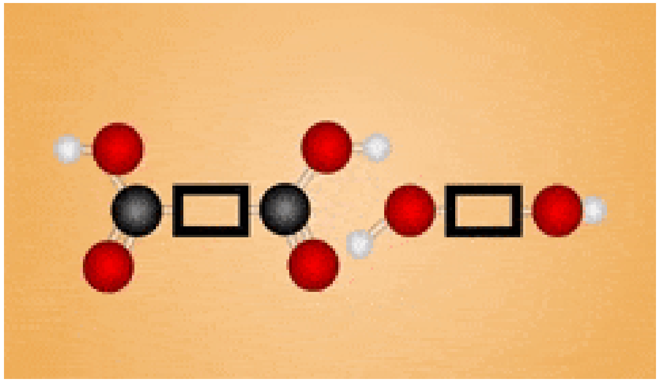
Classification of polymers-based on the method of synthesis

Condensation or step-growth polymerization

Polymerization occurs stepwise by reaction between reactive functional groups, followed by **elimination of small molecules** such as water, ammonia, HCl, etc.

Diacid + Diamine → Polyamide

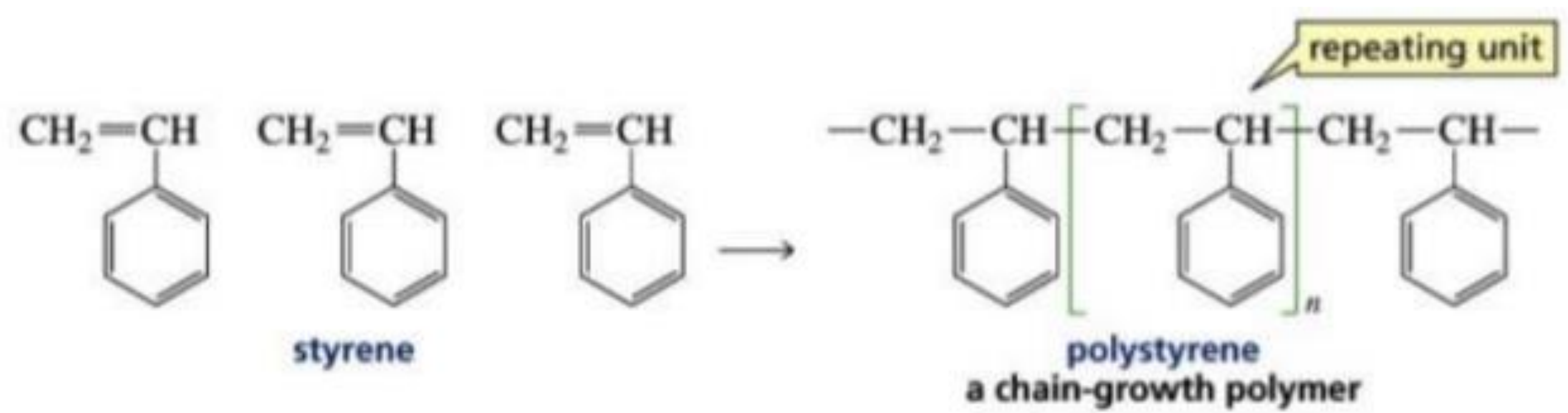


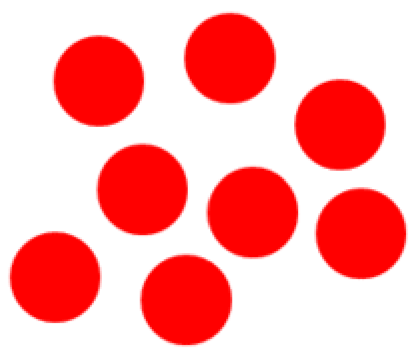


Classification of polymers-based on the method of synthesis

Chain growth polymers

Successive addition of monomeric units to the growing chain.

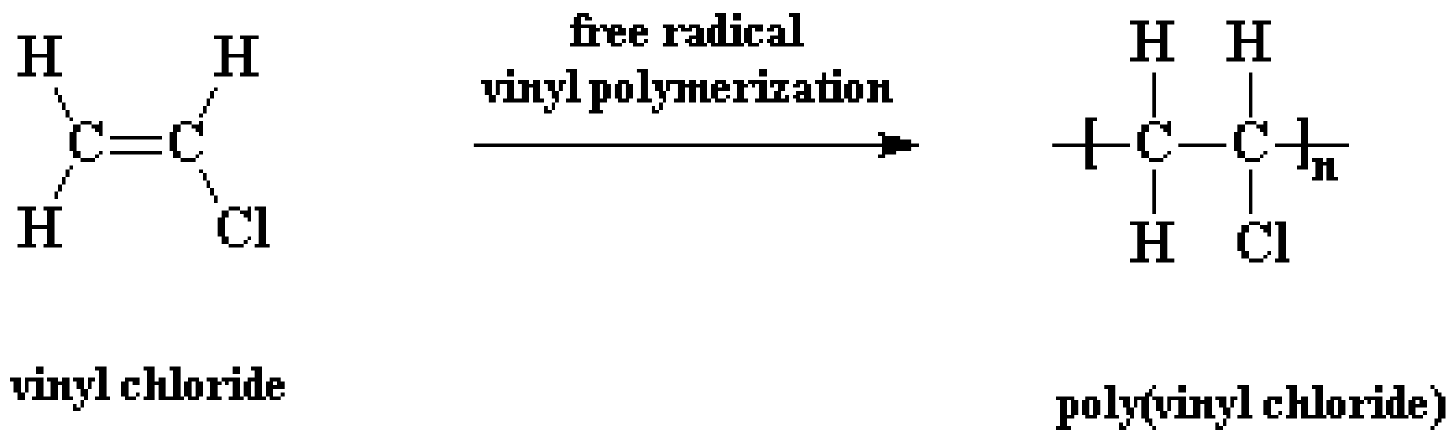




Individual polymers

Preparation of Poly vinyl chloride

Polyvinyl chloride is prepared by heating a water emulsion of vinyl chloride in presence of benzyl peroxide or hydrogen peroxide in autoclave under pressure.



Properties

Polyvinyl chloride is

- Colourless
- Odourless
- Non-inflammable
- Chemically inert
- Soluble in hot ethyl chloride

Uses

Used for the preparation of

- Safety helmets

- Light fittings
- Tyres, cycles

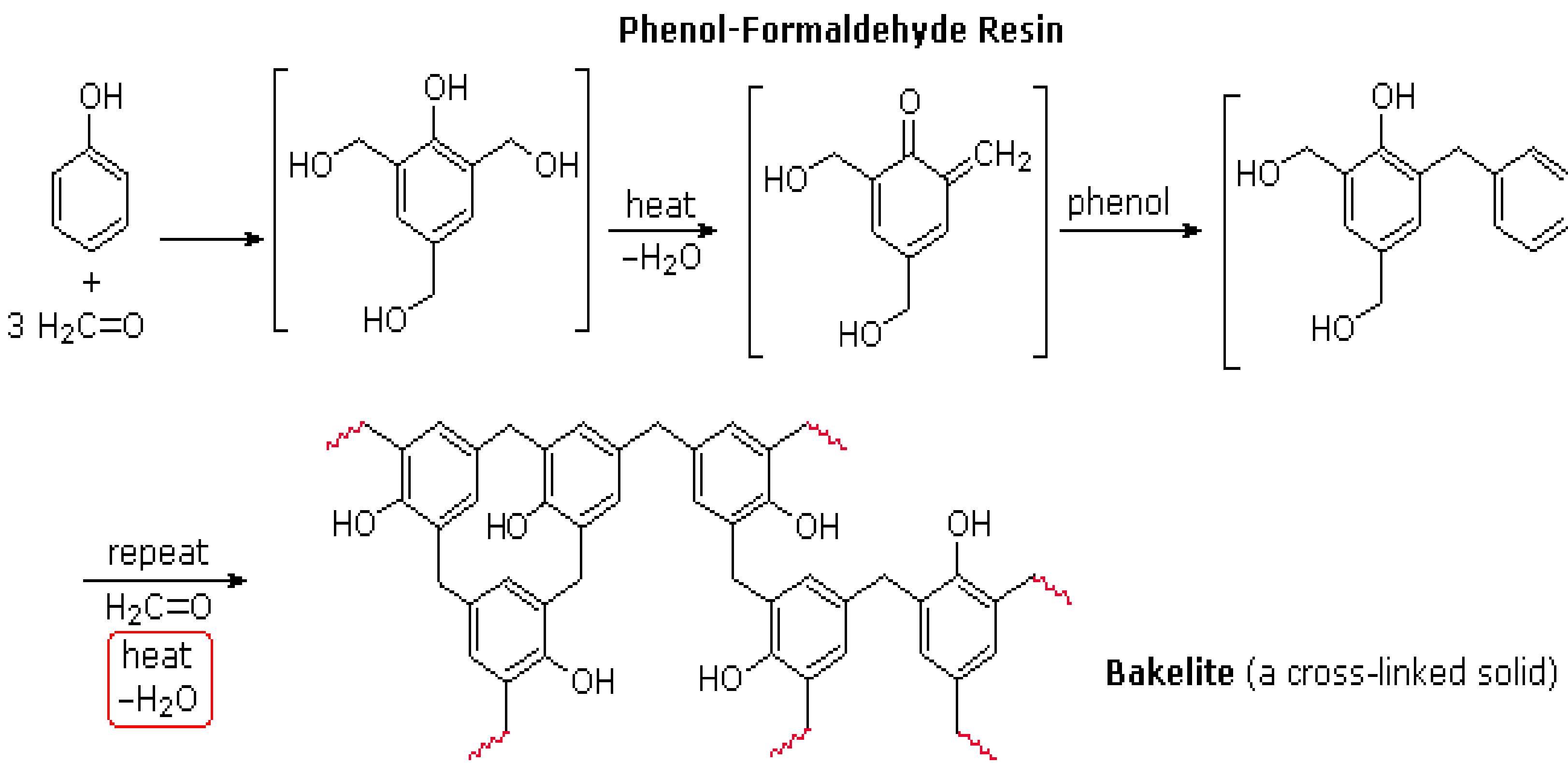
- Refrigerator components

- Sheets, which are employed for tank linin gs

Phenol formaldehyde resins :Bakelite Preparation

These are formed by the poly condensation between phenol and formaldehyde.

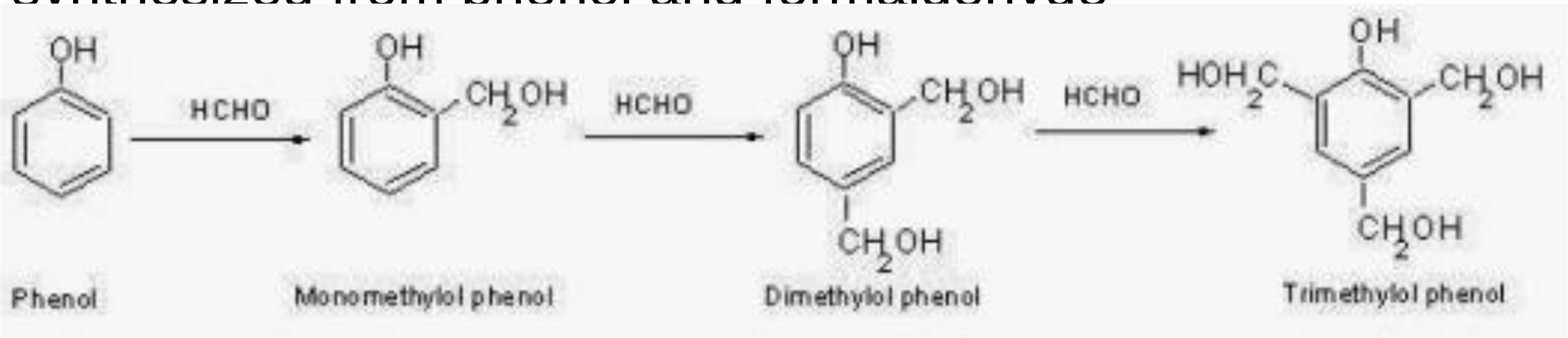
The reaction is catalysed by acid or base



Steps in synthesis of Bakelite

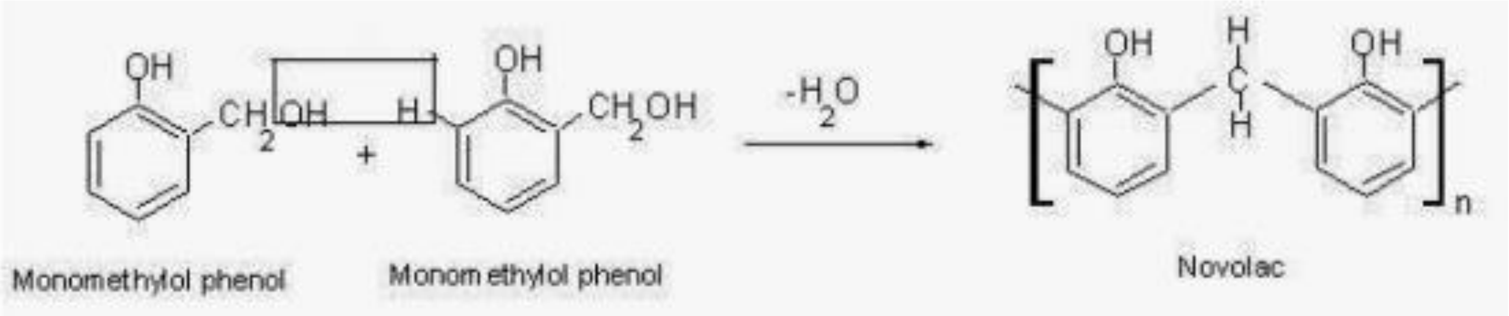
I. Methylolation

- In this step, mono, di and tri methylol phenols are synthesized from phenol and formaldehyde



II: Formation of novolac resins

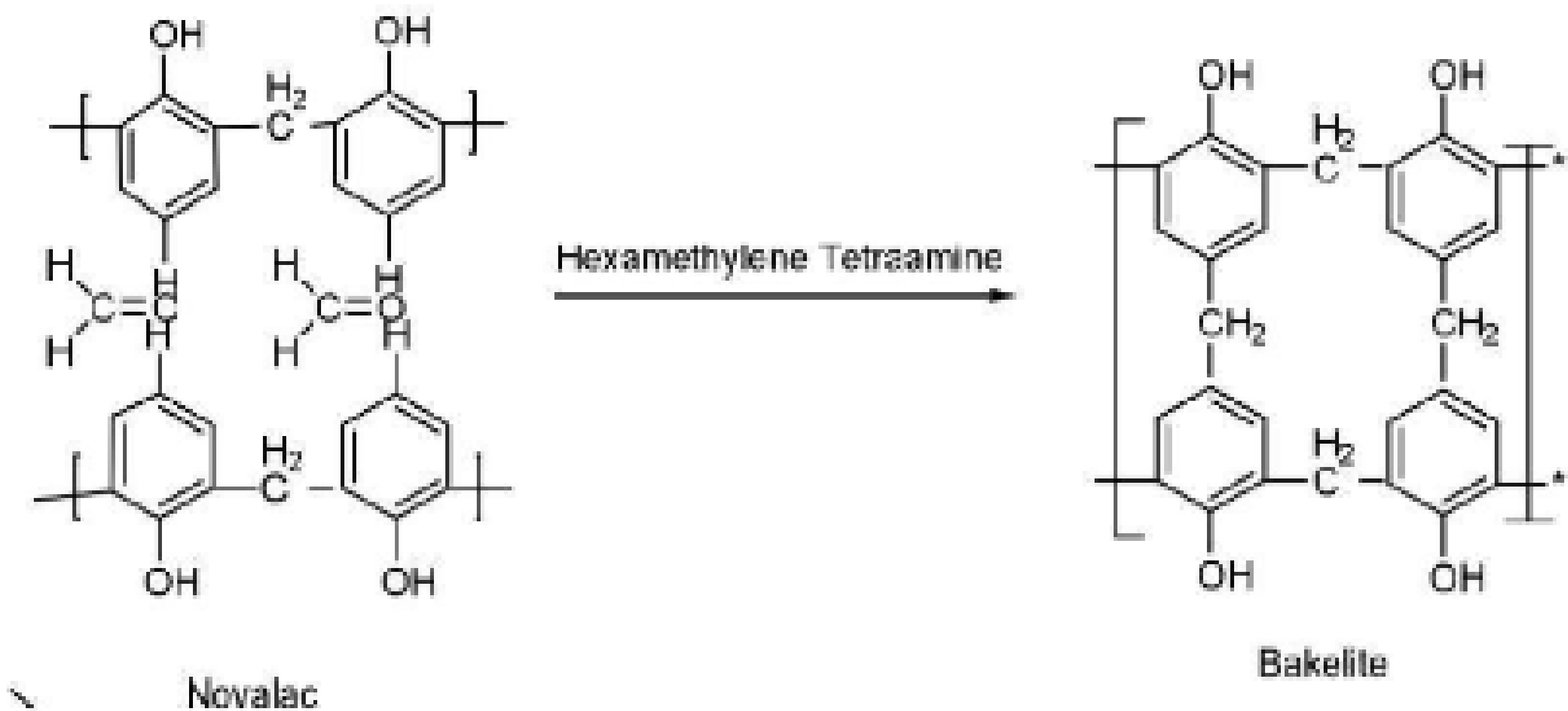
- Monomethylol phenols condense together to form novolac resins as shown below



Steps in synthesis of Bakelite

III: Formation of bakelite

- Novolac is heated further in the presence of HCHO producer, i.e., hexamethylene tetraamine (curing agent) at high temperature and pressure to form cross-linked polymers, bakelite.



Properties of Bakelite

These are

- Rigid
- Hard , resistant to heat
- With stand to high temperature
- Good insulator

Uses of bakelite

Used for the preparation of

- Electrical insulator parts like

- Switches

- Plugs

- Handles

Moulded articles like

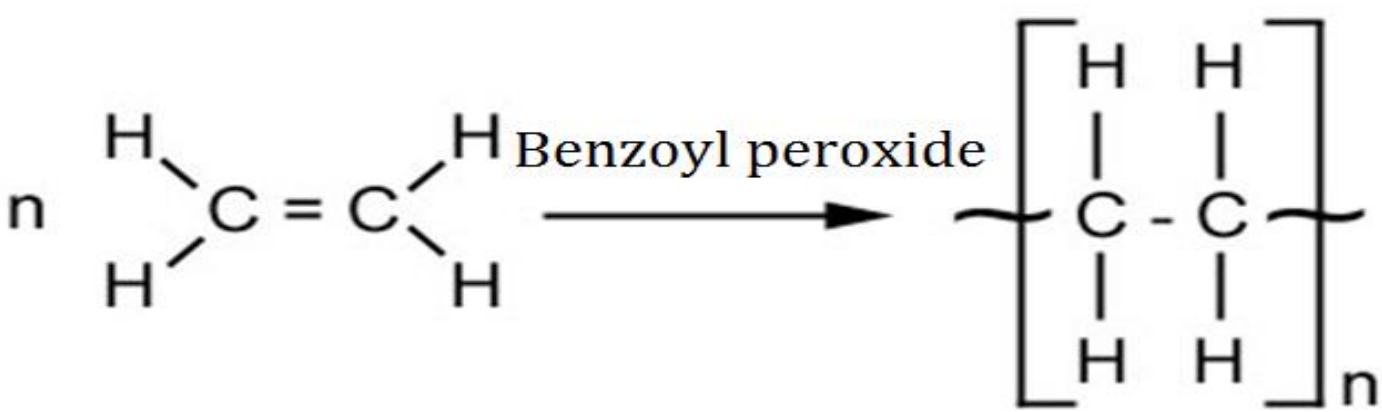
- Telephone parts

- Cabinets for T.V

- Cabinets for radio

Polyethylene
Preparation of LDPE

LDPE is prepared by heating ethylene at 100^0C-300^0C under high pressure 1500-3000 atm in presence of benzoyl peroxide(initiator) and benzene(solvent).



Ethylene

Polyethylene

Properties

- Density range from 918-935 kg/m3
- Very tough
- Flexible

Uses

- Domestic ware

❖Squeeze bottles

❖Tubing

❖Cold water tanks

Preparation of HDPE

HDPE is prepared by heating ethylene at 300^0C under 1 atm pressure in presence of aluminum based oxide(catalyst) and paraffin (diluting agent).

Properties

- Density range from 935-965 kg/m3
- Stronger
- Stiffer

Uses

- Dustbins

- Bottle crates

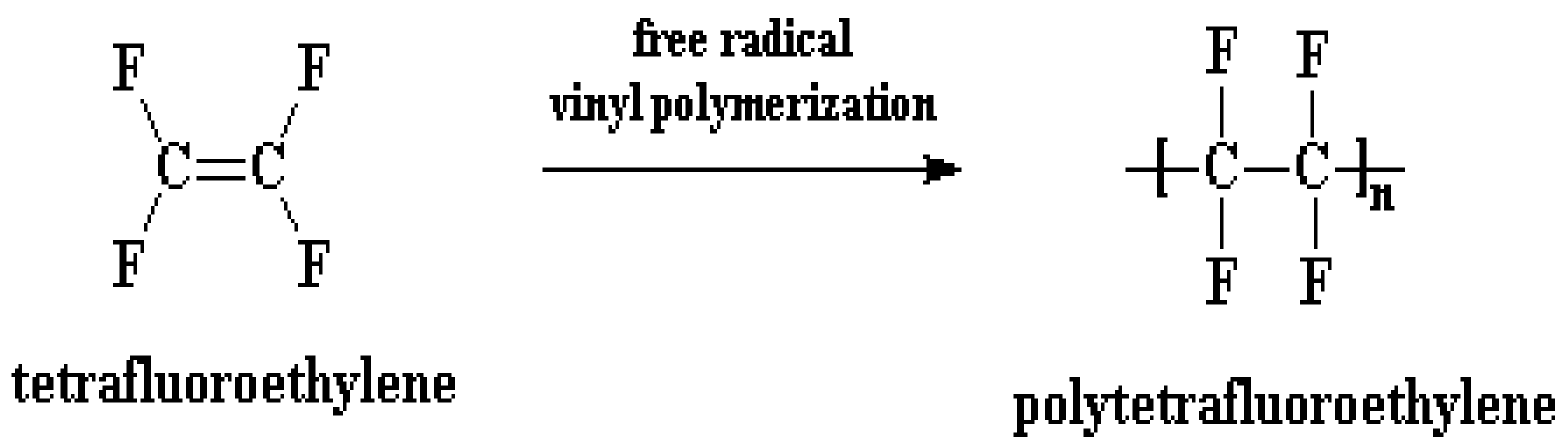
- Pipes

- Fluid containers

Teflon (poly tetra flouro ethylene ,PTFE) or Fluon

Preparation

Poly tetra flouro ethylene is prepared by polymerisation of a water emulsion of tetra flouro ethylene in presence of benzoyl peroxide under pressure.



Properties

1. Due to presence of highly electro negative fluorine atom, very strong attractive forces between different chains.
2. Due to strong attractive forces

Teflon is extreme tough

High softening point (>350^0)

High chemical resistance towards all chemicals

Except hot alkali metal and hot fluorine

Uses:

Used as

- Insulating material for motors, cables

- Coatings

- Impregnating glass
- Asbestos fibre

- Clothes

- Wires

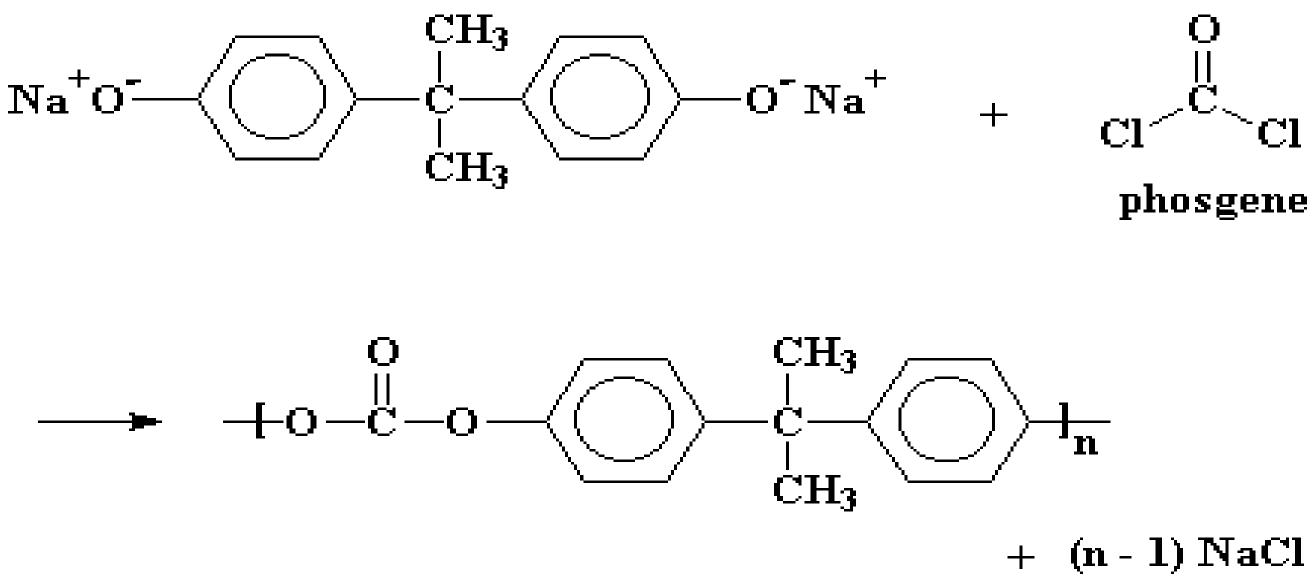
- Fittings

Poly Carbonates

Polymers of containing –o-co-o- functionality

Preparation

By the treatment of bisphenol-A with phosgene in presence of sodium hydroxide.



Properties

Polycarbonates

- Good electrical insulators
- Heat and flame resistance
- Easily soluble in organic solvents and alkali solvents
- Undergo large plastic deformation without cracking
- Highly transparent to visible light
- Low scratch resistance

Uses

Used in

Preparation of Compact disc, DVD'S

Construction industry

Automotive components

- Manufacture of lenses like sunglasses, eyeglasses

- Aircraft components

Conducting Polymers

- A conducting polymer is an organic based polymer that can act as a semiconductor or a conductor.
- The most widely studied organic polymers are

  - Polyacetylene
  - Polyaniline (PANI)
  - Polypyrroles
  - Polythiophenes
  - Polyphenylene vinylenes

Conducting Polymers

- Conducting polymers (CPs) are extensively conjugated molecules: they have alternating single and double bonds. In these molecules, electrons can move from one end of the polymer to the other through the extended p-orbital system.
- Hence CPs are known to be either semiconductors or conductors giving themunique optical and electrical properties.
- Most polymers are poor conductors due to non-availability of large number offree electrons in the conduction process.
- However, conducting polymers possess electrical conductivity like metalconductors

Different types

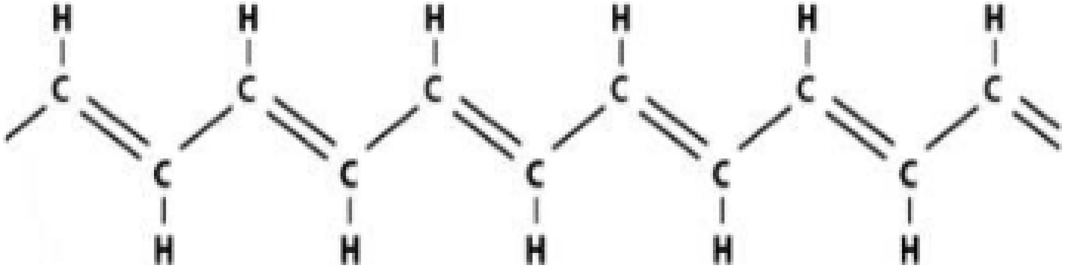
- Intrinsically conducting polymers (ICP)
- Doped conducting polymers
- Extrinsically conducting polymers (ECP

Conducting Polymers

- Density of charge carriers
- Their mobility
- The direction
- Presence of doping materials
- Temperature

Intrinsically Conducting Polymers (ICPs)

- Alternating single and double bonds is called conjugated double bonds.
- In conjugation, the bonds between the carbon atoms are alternately single and double. Every bond contains a localized “sigma” (σ) bond which forms a strong chemical bond.
- In addition, every double bond also contains a less strongly localized “pi” (π) bond which is weaker.
- Conjugation of sigma and pi-electrons over the entire backbone, forms valence bands and conduction bands. Eg: Poly-acetylene polymers like poly-p-phenylene, polyaniline, polypyrrole.



Doped Conducting Polymers

- It is obtained by exposing a polymer to a charge transfer agent in either gas phase or in solution.
- ICPs possess low conductivity (10-10/Ohm.cm), low ionization potential and high electron affinity.
- So, they can be easily oxidized or reduced.

Doping

The conductivity of ICP can be increased by **creating positive charges (oxidation)** or by **negative charges (reduction)** on the polymer backbone. This technique is called DOPING .
The polymer structure is disturbed - either by removing electrons from (oxidation) or inserting them into (reduction) the material.

Types of materials

- Oxidation with halogen (or p-doping).
- Reduction with alkali metal (called n-doping)

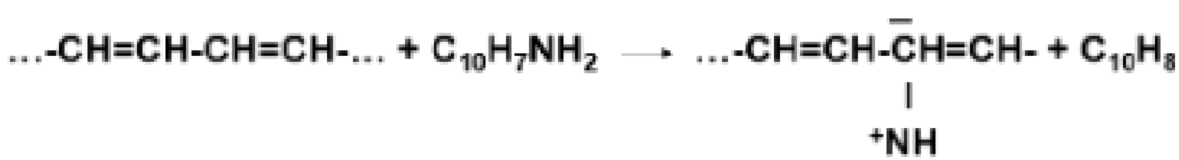
Intrinsically Conducting Polymers (ICPs)

- It involves treating an intrinsically conducting polymer with a Lewis acid which leads to oxidation process and positive charges on the polymer backbone
- Some of the p-dopants are I_2,Br_2,AsF_5,PF_5 etc.

$$\underset{\text{Polyacetylene}}{2(C_2H_2)_n} + 3I_2 \longrightarrow \underset{\text{Lewis acid}}{2[(C_2H_2)_n^{+} I_3^{-}]}$$

N-doping

- It involves treating an ICP with a Lewis base which leads to reduction and negative charges on the polymer backbone.
- Some of the n-dopants are Li, Na, Ca, FeCl3, naphthylamine etc.



Extrinsically Conducting Polymers (ICPs)

- These are those polymers whose conductivity is due to the presence of externally added ingredients in them.

(1) Conductive element filled polymer:

- It is a resin/polymer filled with carbon black, metallic fibers, metal oxides etc.
- Polymer acts as a binder to those elements.
- These have good bulk conductivity and are low in cost, light weight, strong and durable.
- They can be in different forms, shapes and sizes.

(2) Blended element filled polymer:

It is product obtained by blending a conventional polymer with a conducting polymer either by physical or by chemical change.
Such polymers can be processed and possess better physical, chemical and mechanical strength.

Applications of conducting polymers

- As sensors into clothing
- Conducting polymer textiles as a camouflage for defense machinery. Since the textiles have no sharp edges, they absorb more than 50%of the incident microwave radiation.
- In LEDs
- In controlled drug release applications etc.

Applications of conducting polymers

Group 1

Electrostatic materials
Conducting adhesives
Artificial nerves
Antistatic clothing
Piezoceramics
Active electronics:

Group 2

Molecular electronics
Electrical displays
Chemical & thermal sensors
Rechargeable batteries
Drug release systems
Optical computers
Ion exchange membranes
Electromechanical actuators

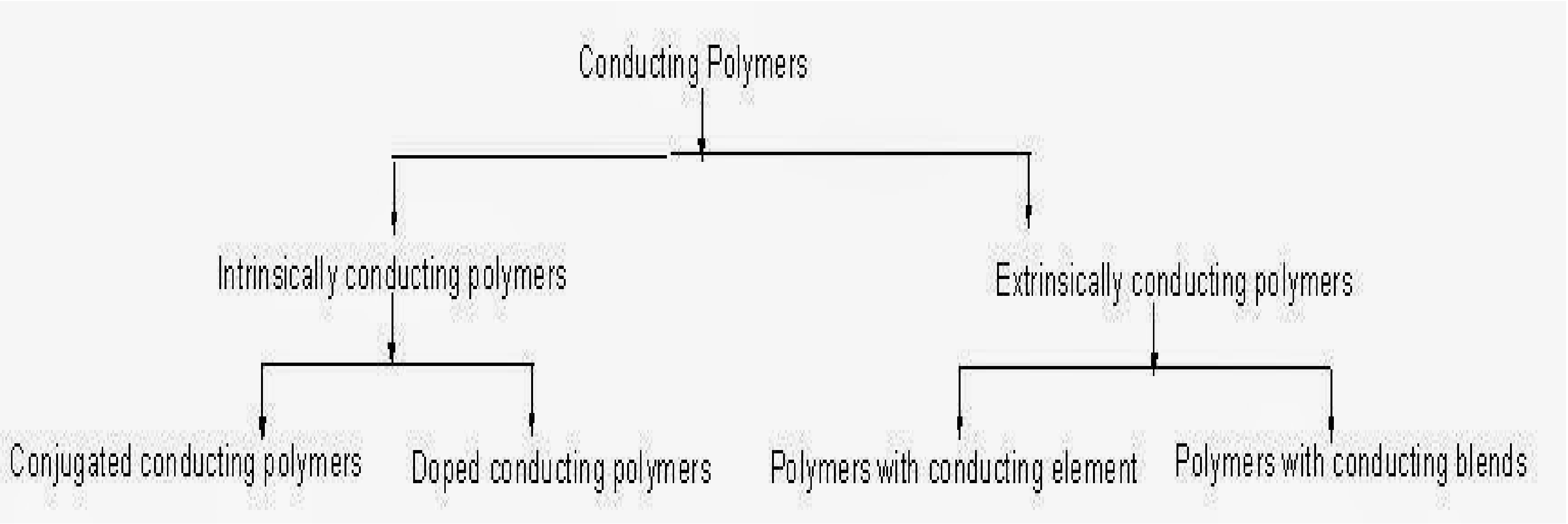
The first group utilizes their conductivity as its main property. The second group utilizes their electroactivity.

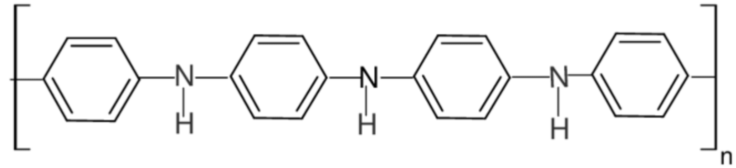
Conducting Polymers

•Polymers that can conduct electricity are called conducting polymers.

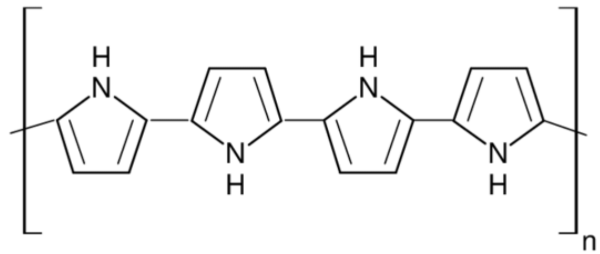
Ex: Poly acetylene, poly aniline, poly pyrrole, poly thiophene, poly quinolene etc.

On the basis of their conduction properties conducting polymers are classified into two types

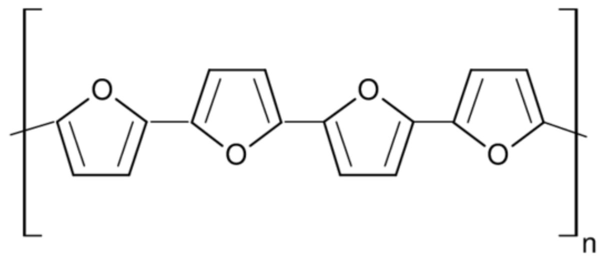




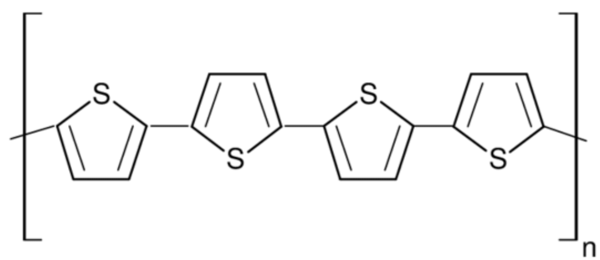
Polyaniline



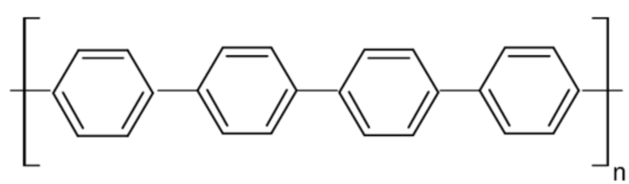
Polypyrrole



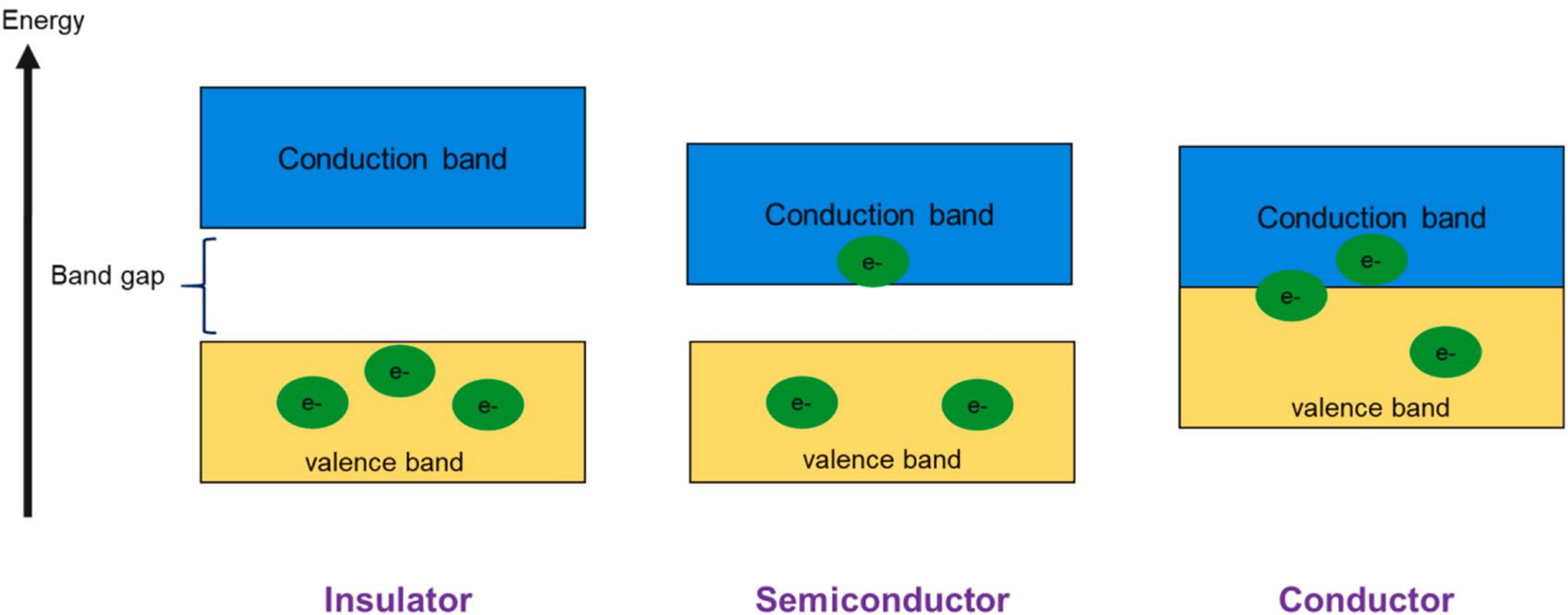
Polyfuran

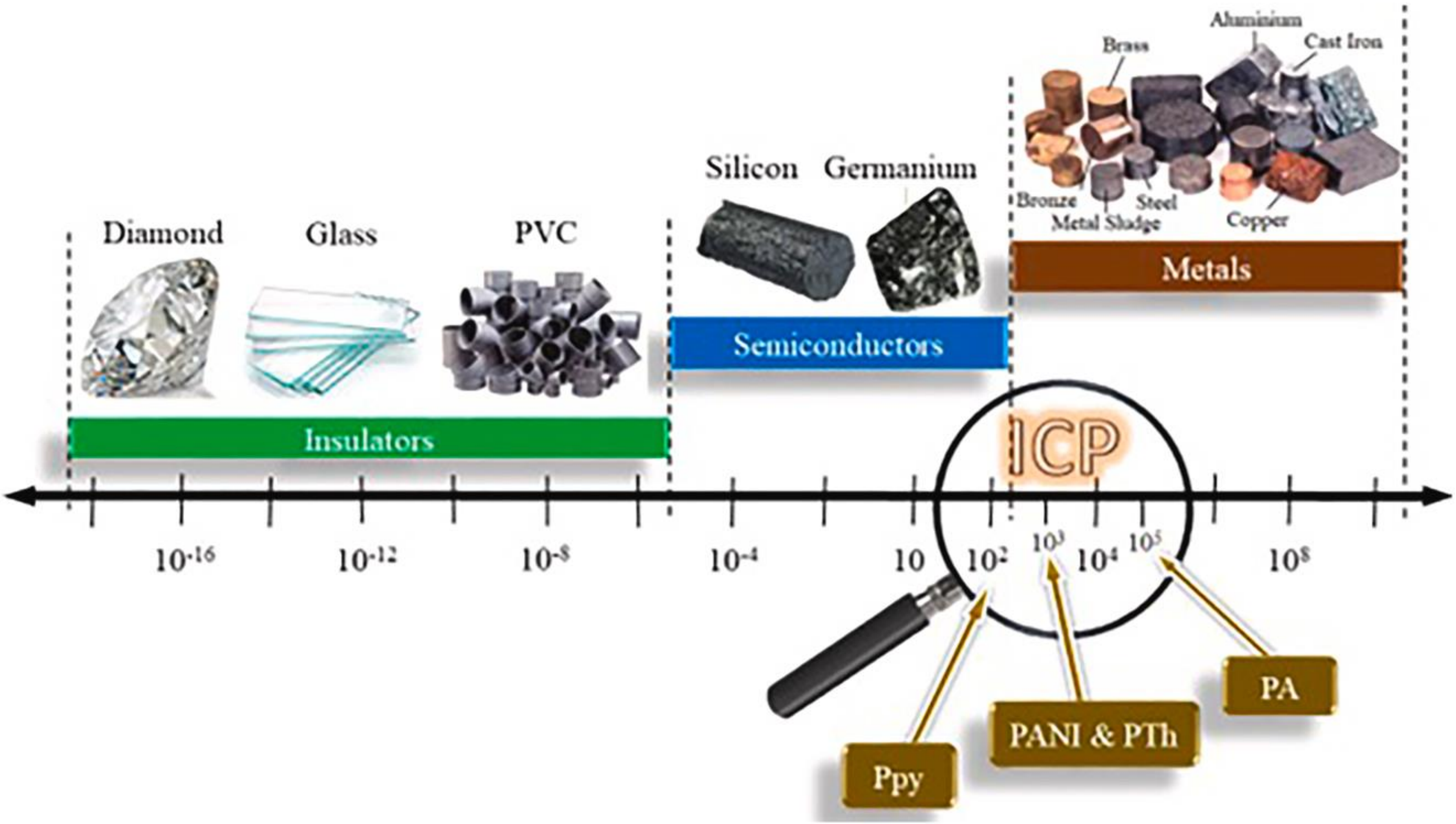


Polythiophen



Polyphenyle


Energy
Band gap
Conduction band
e-
e-
e-
valence band
Conduction band
e-
e-
e-
valence band
Conduction band
e-
e-
e-
valence band
Insulator
Semiconductor
Conductor



Diamond
Glass
PVC
Silicon
Germanium
Brass
Aluminium
Cast Iron
Bronze
Steel
Metal Sludge
Copper
Metals
Semiconductors
Insulators
ICP
10^{-16}
10^{-12}
10^{-8}
10^{-4}
10
10^{2}
10^{3}
10^{4}
10^{5}
10^{8}
Ppy
PANI & PTh
PA

Conducting Polymers

Intrinsically Conducting Polymers

Conjugation

•These polymers contain conjugated or delocalized π - e^- pairs in the back bone responsible for conduction.

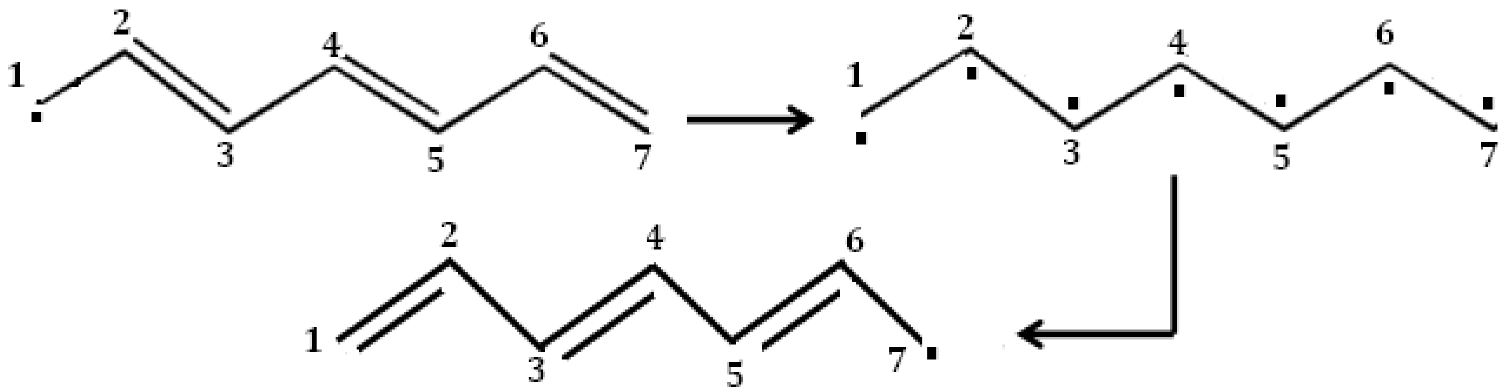
•The orbital's of conjugated π - e^- form valency band as well as conduction band and they are extended over the entire polymer molecule.

•When current is passed electrons enter conduction band due to shifting of π - e^-.

•Ex; Conduction of poly acetylene due to conjugation.

•When current is passed into poly acetylene, the electron enters the unhybridised P-orbital of carbon atom and moves through the C – C bonds.

Conducting Polymers



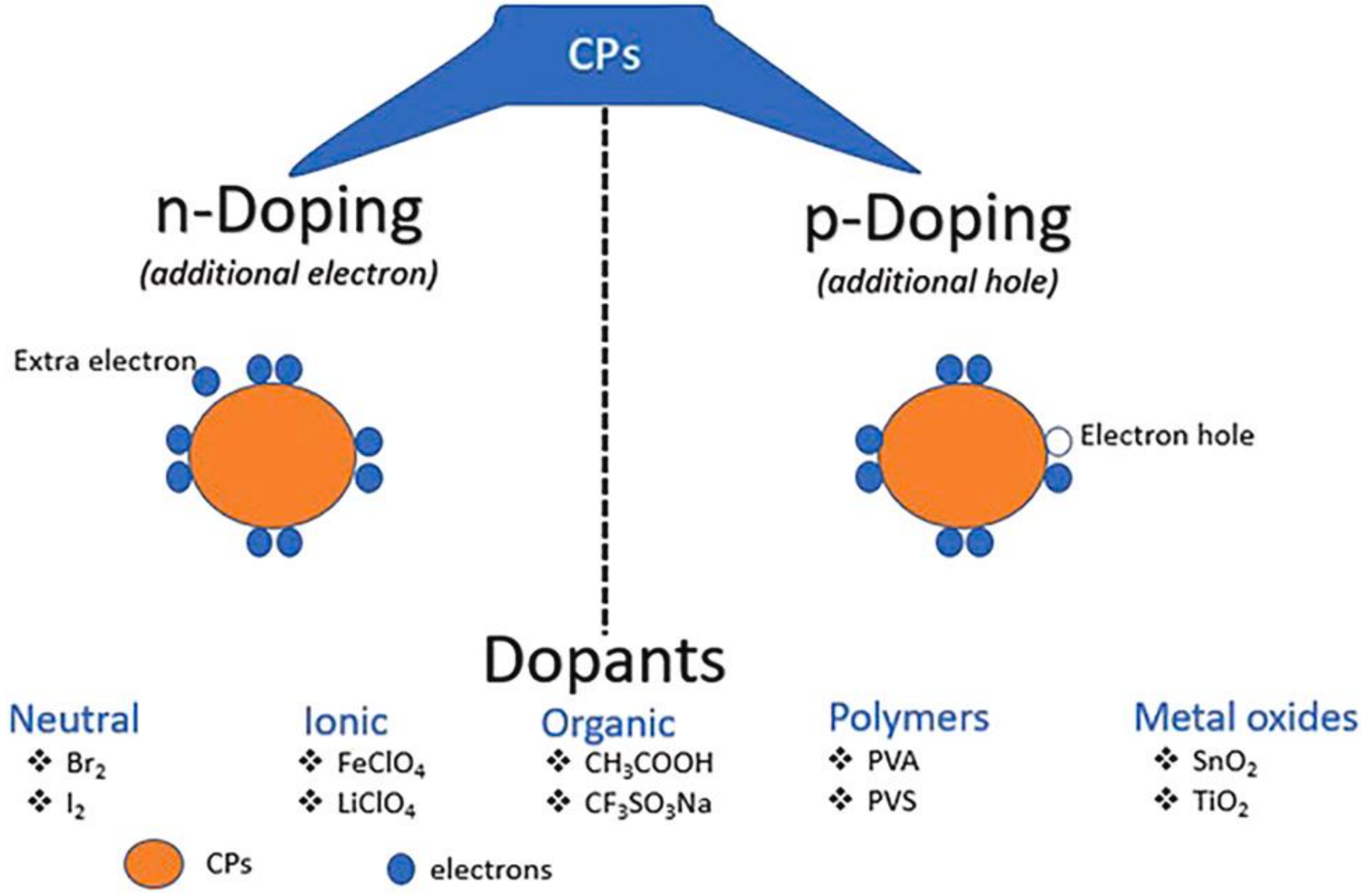
<u>Doped conducting polymers</u>

•Polymers can conduct due to doping and by using doping agents or dopants.

•Doping of conducting polymers can be two different types.

♠p-Doping (or) Oxidative Doping

♠n-Doping (or) Reductive Doping



CPs
n-Doping
(additional electron)
p-Doping
(additional hole)
Extra electron
Electron hole
Dopants
Neutral
❖ Br_2
❖ I_2
Ionic
❖ $FeClO_4$
❖ $LiClO_4$
Organic
❖ CH_3COOH
❖ CF_3SO_3Na
Polymers
❖ PVA
❖ PVS
Metal oxides
❖ SnO_2
❖ TiO_2
CPs
electrons

Conducting Polymers

P-Doping (or) Oxidative Doping:

•In this method the polymer is treated with an oxidizing agent like Lewis acid which acts as a dopant.

•Examples of dopants used: $FeCl_3$, I_2 etc.

$$\underset{\text{Poly acetylene}}{(CH)_x} + \underset{\text{Lewis acid}}{A} \longrightarrow \underset{\text{P-doped poly acetylene}}{(CH)_x^{+} A^{-}}$$

Mechanism of P-Doping:

•During this process, oxidation of polymer takes place due to dopant and forms a cation called Polaron.

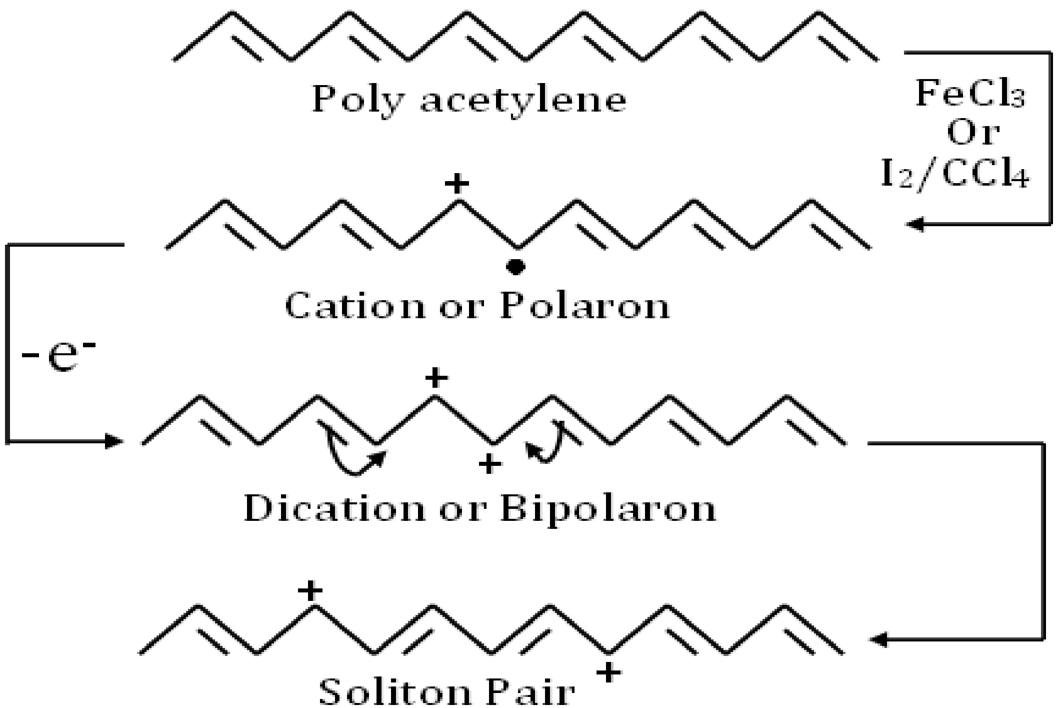
•On further oxidation of polymer results in the formation of a dication or bipolaron.

Conducting Polymers

•The charges get separated by forming a soliton pair.

•The cation occupies the band gap between valency band and conduction band, thereby creating a conducting path.

• So electrons move through this path.



Conducting Polymers

n-Doping (or) Reductive Doping:

- In this method, the polymer is treated with a reducing agent like a Lewis base which acts as a dopant.
- Ex; Sodium Naphthalide $Na^{+}(C_{10}H_{8})^{-}$

$$\underset{\text{Poly acetylene}}{(CH)_x} + \underset{\text{Lewis base}}{B} \longrightarrow \underset{\text{n-doped poly acetylene}}{(CH)_x^{-}B^{+}}$$

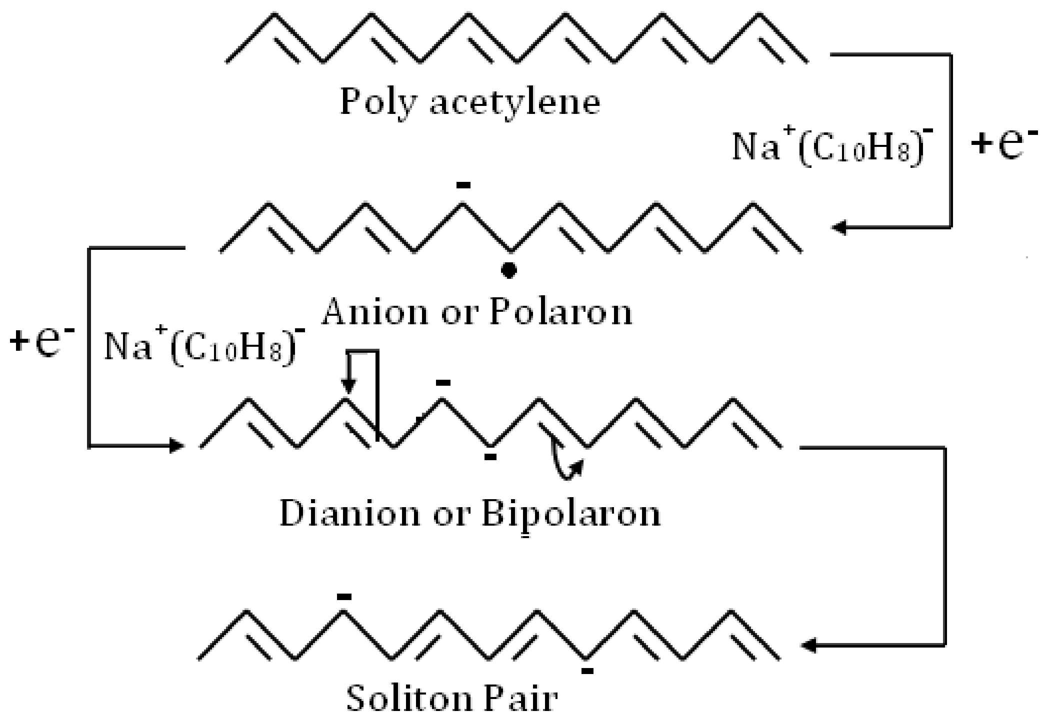
$$(CH)_x + Na^{+}(C_{10}H_8)^{-} \longrightarrow Na^{+}(CH)_x^{-} + C_{10}H_8$$

Mechanism of n-Doping:

- During this process, reduction of polymer takes place due to dopant and forms an anion called Polaron.
- On further reduction of polymer results in the formation of a dianion or bipolaron.

Conducting Polymers

- The charges get separated to form a soliton pair.
- The anions occupy the band gap between valency band and conduction band thereby creating a conducting path.
- So that electrons move through this path.



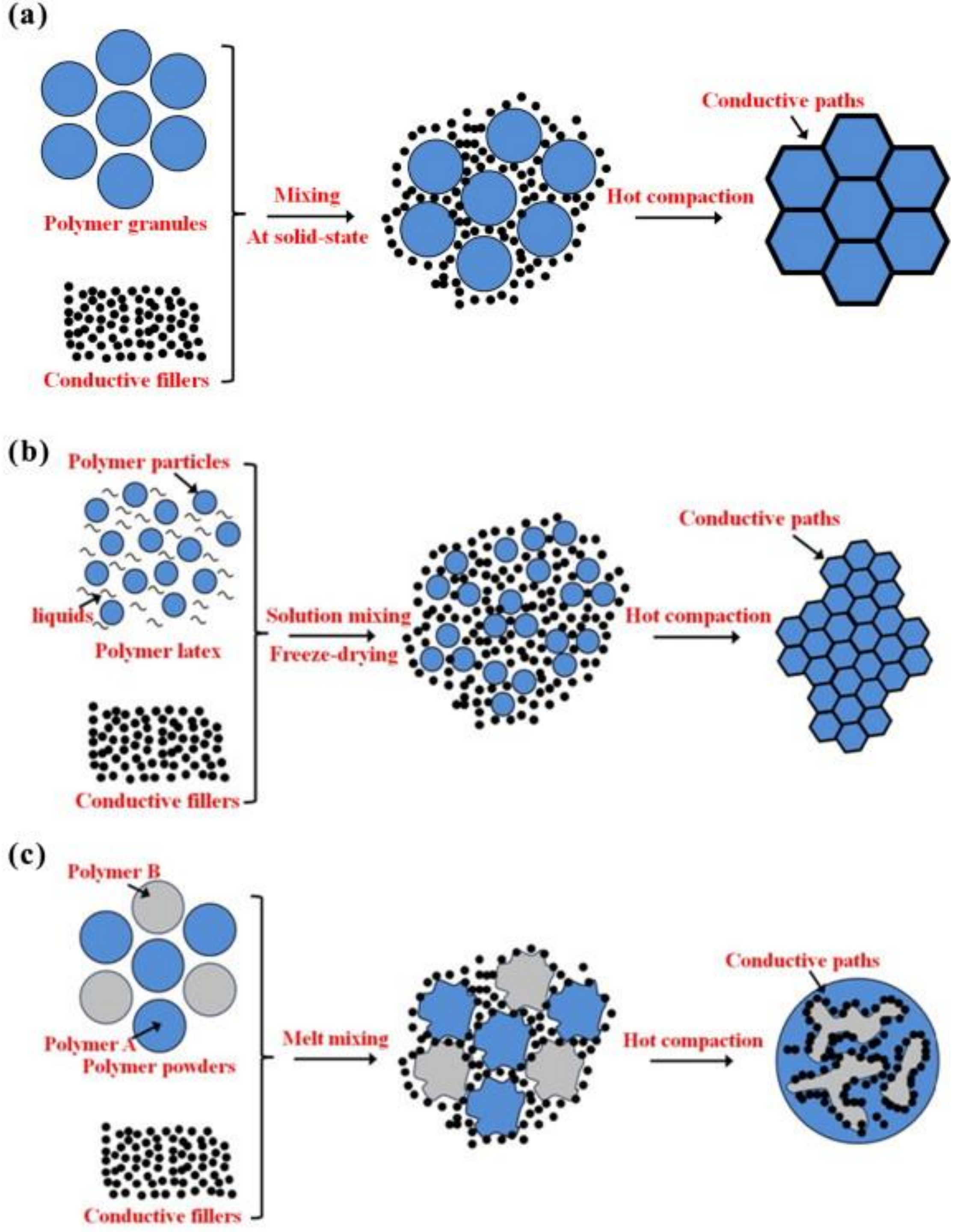
Conducting Polymers

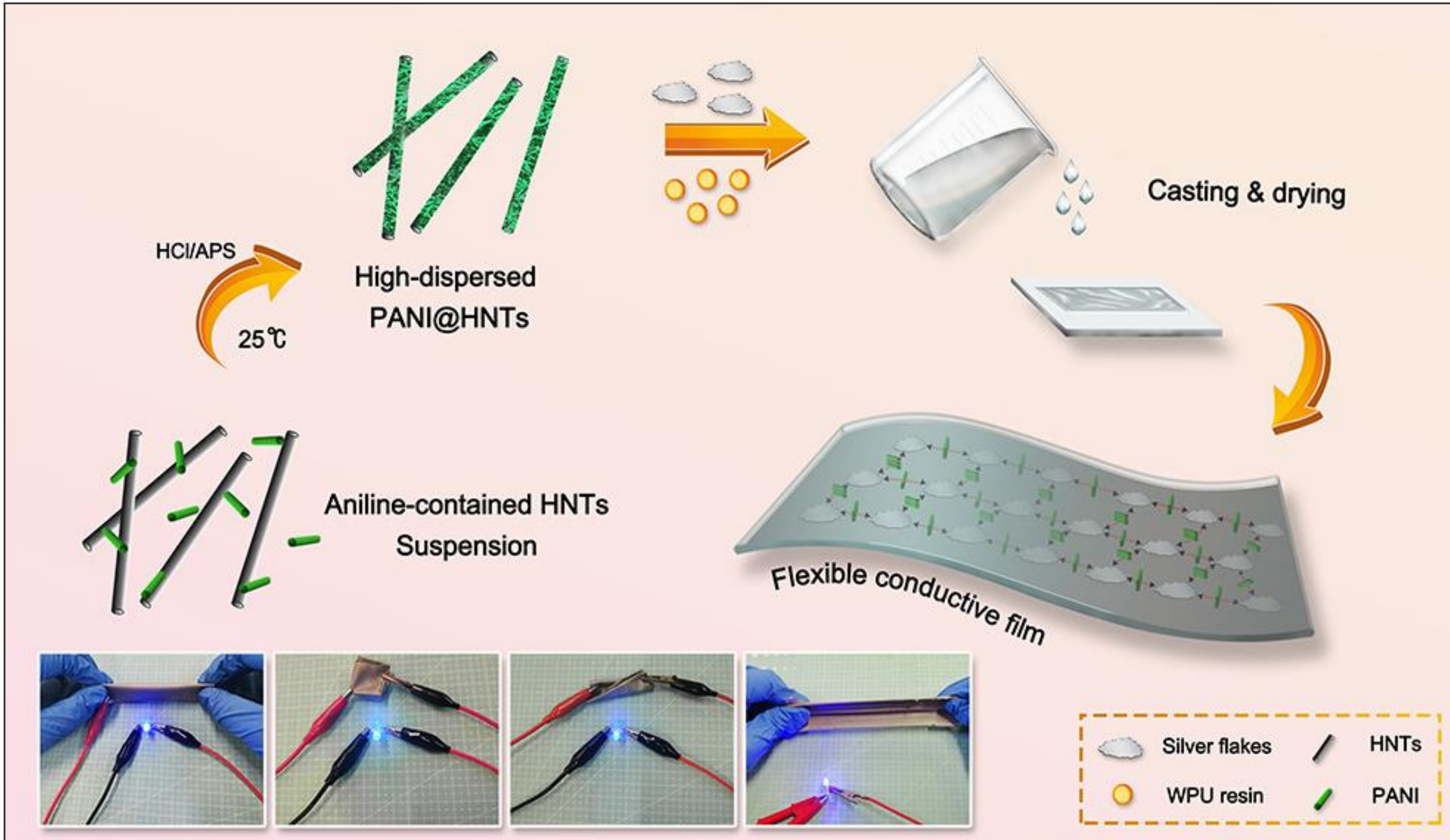
Extrinsically Conducting Polymers

- Some of the polymers conduct electricity due to externally added ingredients to them.
- They are of two types.
    - Polymers with conductive elements filled
    - Blended conducting polymers

Polymers with conductive elements filled

- In these polymers, the polymer acts as a ‘binder’ and holds the conducting element added so that the polymer becomes a conductor.
- Examples of conductive elements are carbon black, metallic fibers, metallic oxides etc.
- Minimum concentration of conductive element to be added so that the polymer becomes a conductor is called percolation threshold.
- The conductive elements added to create a conducting path in the polymer.


(a)
Polymer granules
Conductive fillers
Mixing
At solid-state
Hot compaction
Conductive paths
(b)
Polymer particles
liquids
Polymer latex
Conductive fillers
Solution mixing
Freeze-drying
Hot compaction
Conductive paths
(c)
Polymer B
Polymer A
Polymer powders
Conductive fillers
Melt mixing
Hot compaction
Conductive paths



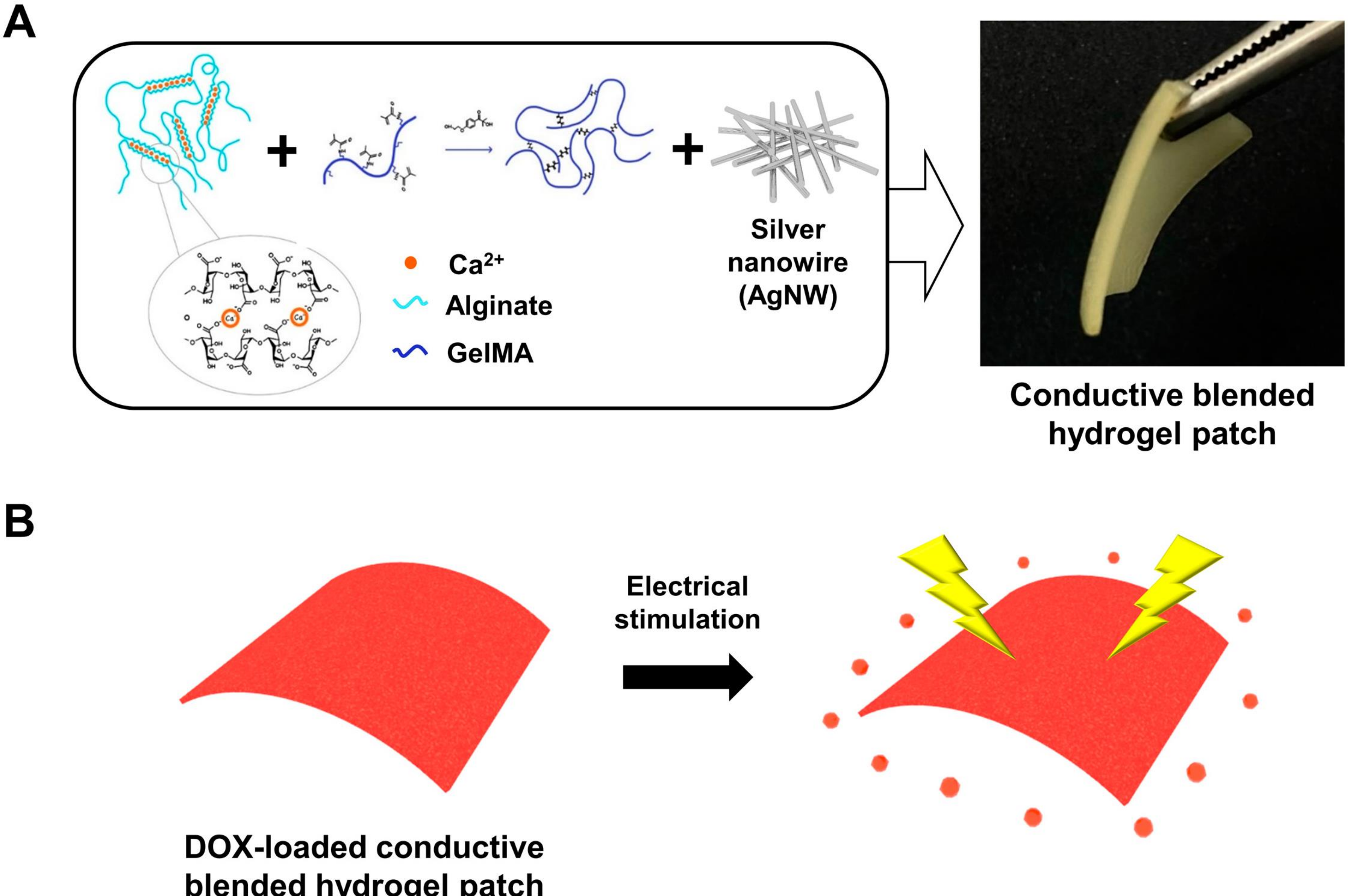
HCl/APS
25℃
High-dispersed
PANI@HNTs
Casting & drying
Aniline-contained HNTs
Suspension
Flexible conductive film
Silver flakes
HNTs
WPU resin
PANI

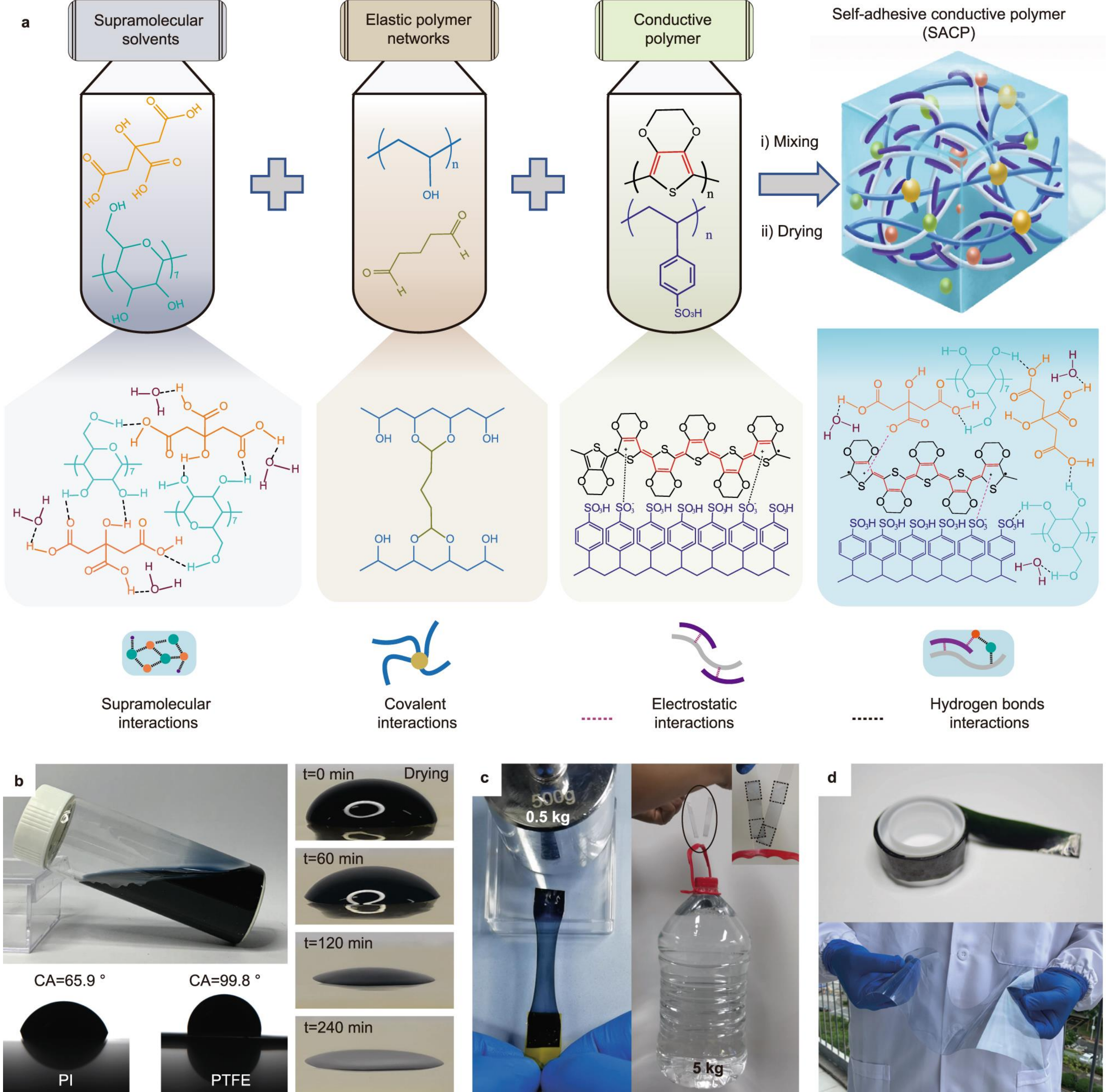
Conducting Polymers

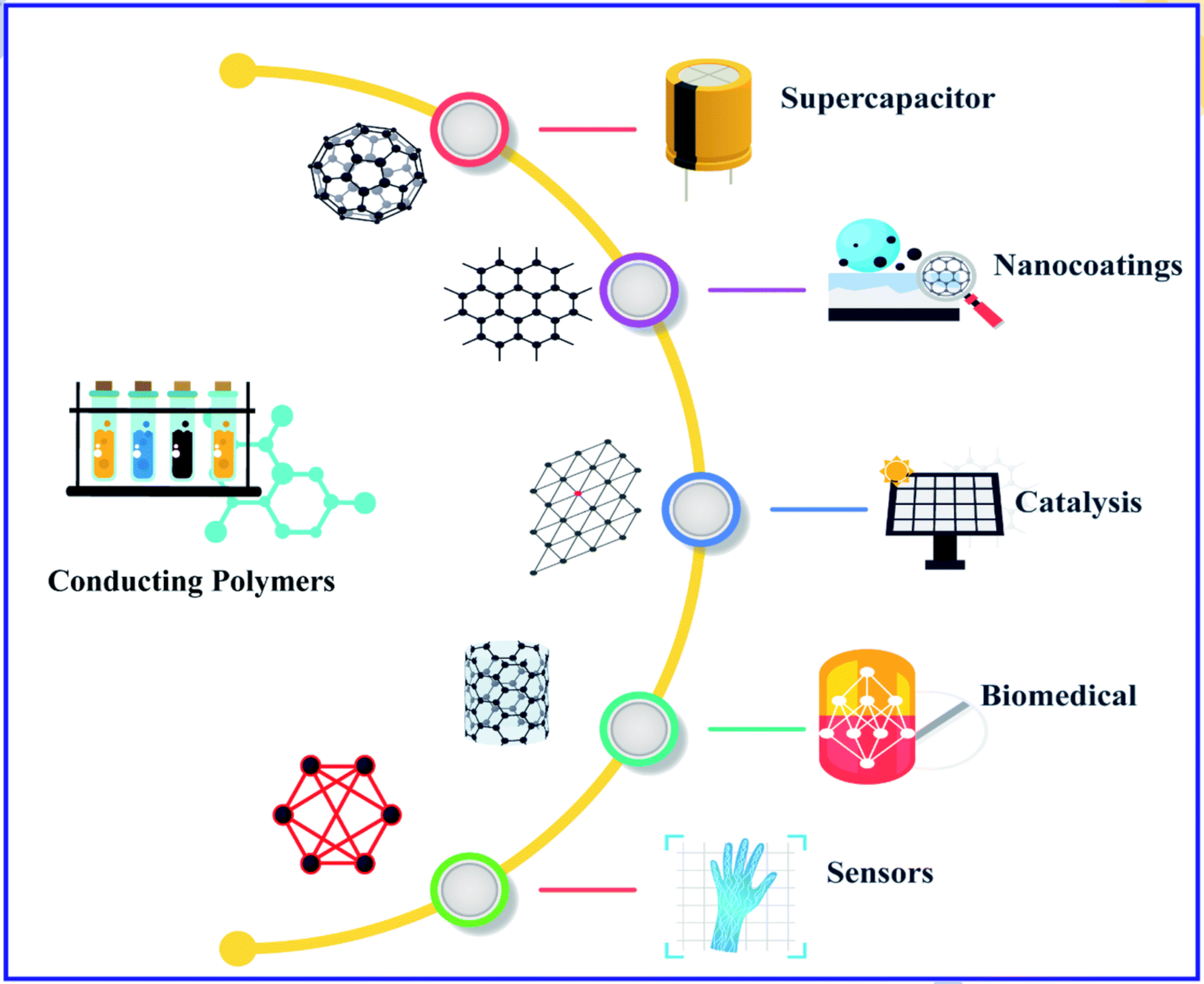
Blended conducting polymers

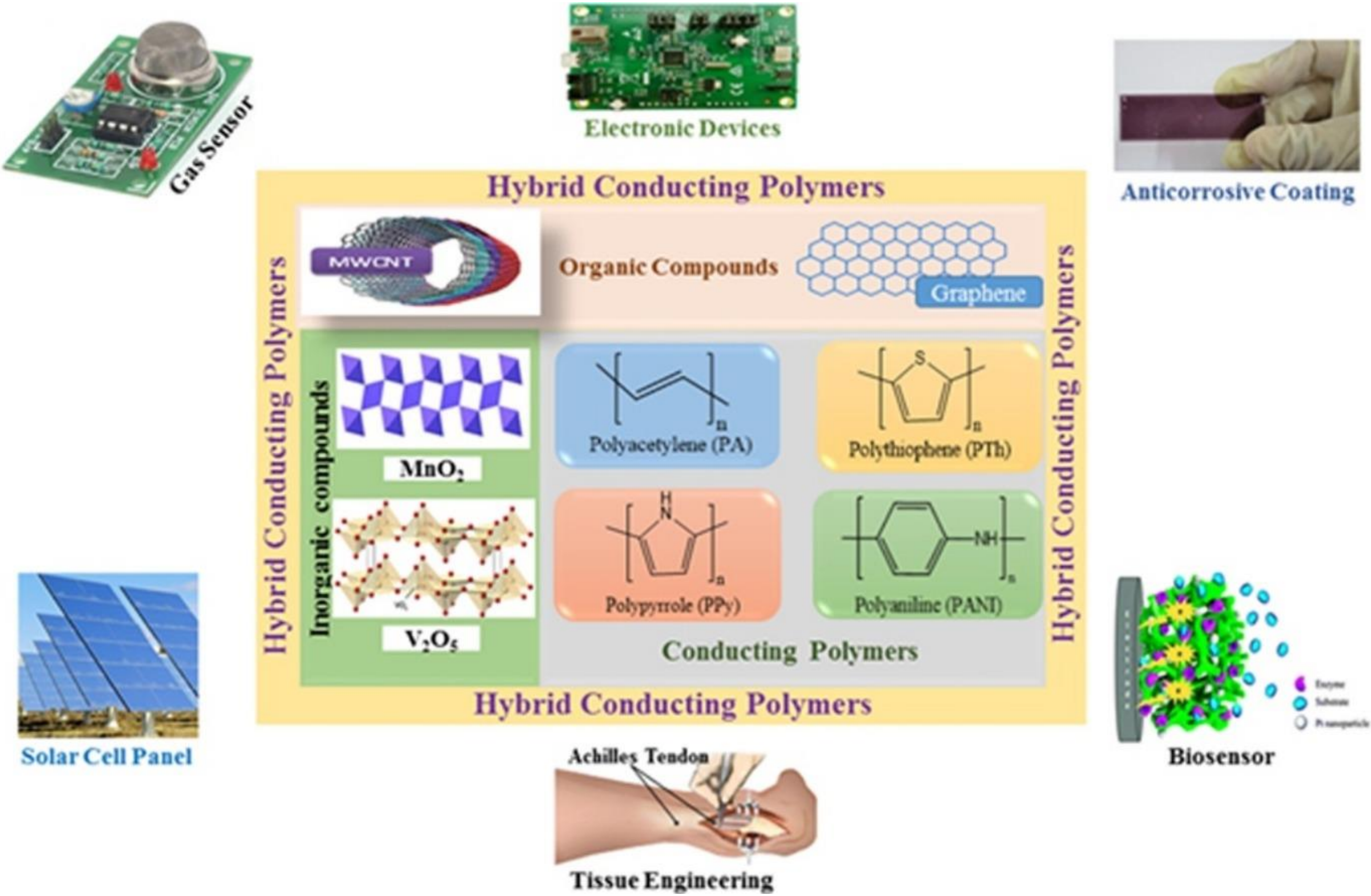
- These polymers are obtained by blending a conventional polymer with a conducting polymer.
- The polymer thus obtained has good chemical, physical, electrical properties and mechanical strength.

Ex; 40% pyrrole when blended with a conventional polymer, the combination gives conducting polymer with good impact strength.


A
Ca2+
Alginate
GelMA
Silver nanowire (AgNW)
Conductive blended hydrogel patch
B
Electrical stimulation
DOX-loaded conductive blended hydrogel patch


a
Supramolecular solvents
Elastic polymer networks
Conductive polymer
Self-adhesive conductive polymer (SACP)
i) Mixing
ii) Drying
Supramolecular interactions
Covalent interactions
Electrostatic interactions
Hydrogen bonds interactions
b
t=0 min
Drying
t=60 min
t=120 min
t=240 min
CA=65.9 °
CA=99.8 °
PI
PTFE
c
0.5 kg
5 kg
d


Supercapacitor
Nanocoatings
Catalysis
Biomedical
Sensors
Conducting Polymers



Gas Sensor
Electronic Devices
Anticorrosive Coating
Hybrid Conducting Polymers
MWCNT
Organic Compounds
Graphene
Inorganic compounds
MnO2
V2O5
Polyacetylene (PA)
Polythiophene (PTh)
Polypyrrole (PPy)
Polyaniline (PANI)
Conducting Polymers
Solar Cell Panel
Biosensor
Achilles Tendon
Tissue Engineering

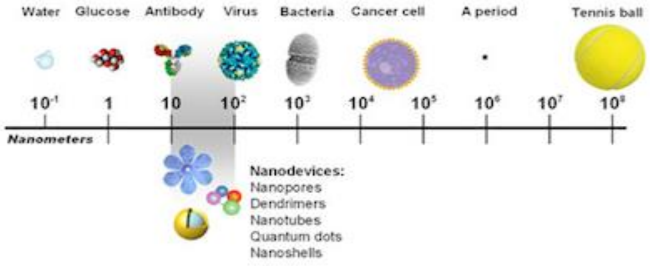
What is nano?

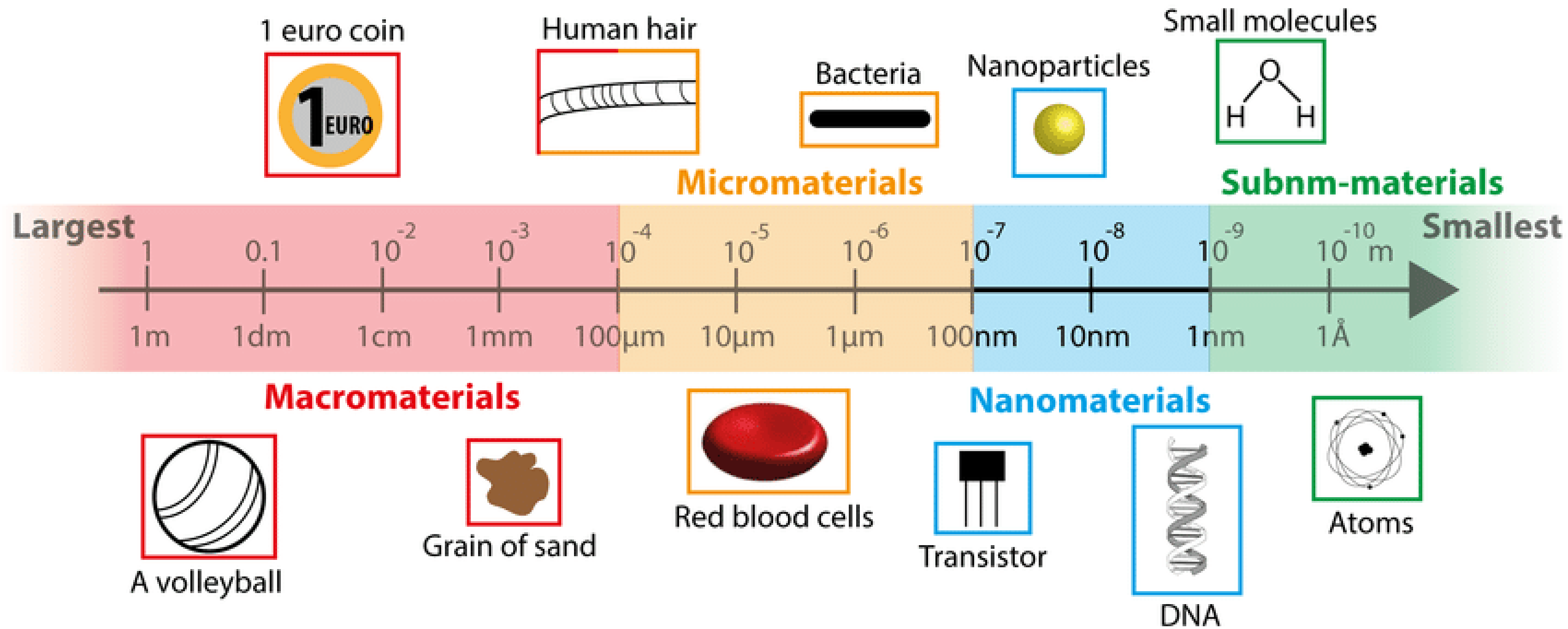
The prefix ‘nano’ is derived from the Greek word for dwarf. One nanometre (nm) is equal to one-billionth of a metre, 10^{-9}m

Nano can refer to technologies, materials, particles, objects – we are focusing on ***nanomaterials*** as these are already being used in workplaces more widely

A sheet of paper is about 100,000 nm thick, a human hair is around 80,000 nanometers wide, a red blood cell approximately 7000nm wide

- ➢ At the nanometer scale, materials may behave differently.
- ➢ We can harness this new behavior to make new technologies.




1 euro coin
1 EURO
Human hair
Bacteria
Nanoparticles
Small molecules
O
H H
Micromaterials
Subnm-materials
Largest
Smallest
1
0.1
10 -2
10 -3
10 -4
10 -5
10 -6
10 -7
10 -8
10 -9
10 -10 m
1m
1dm
1cm
1mm
100µm
10µm
1µm
100nm
10nm
1nm
1Å
Macromaterials
Nanomaterials
A volleyball
Grain of sand
Red blood cells
Transistor
DNA
Atoms

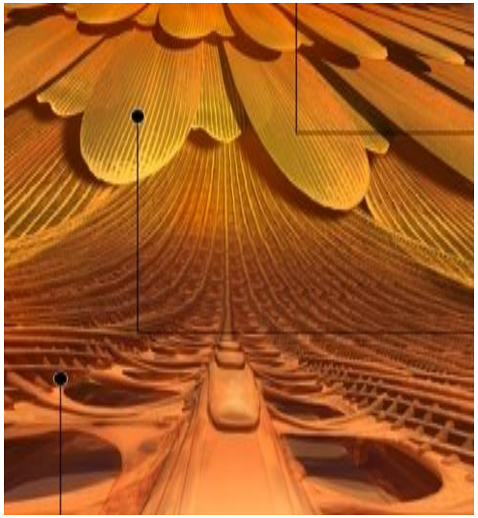
How Big is a Nanometer?

To cover a football field with a 1nm thick layer of paint, you would need just **1 teaspoon** of paint!

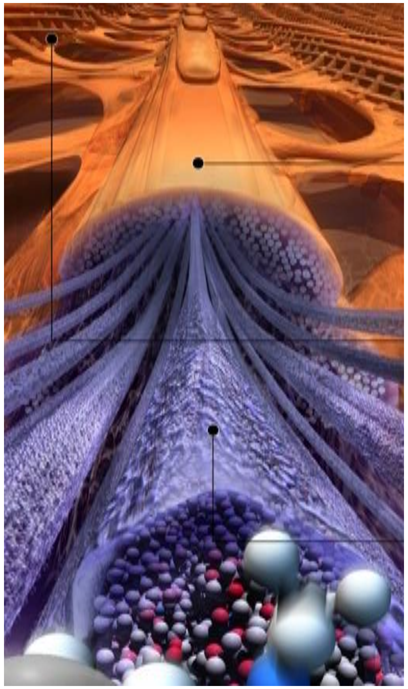
Did Scientists “Create” Nano?

- No, it was already in nature!

centimeters to micrometers



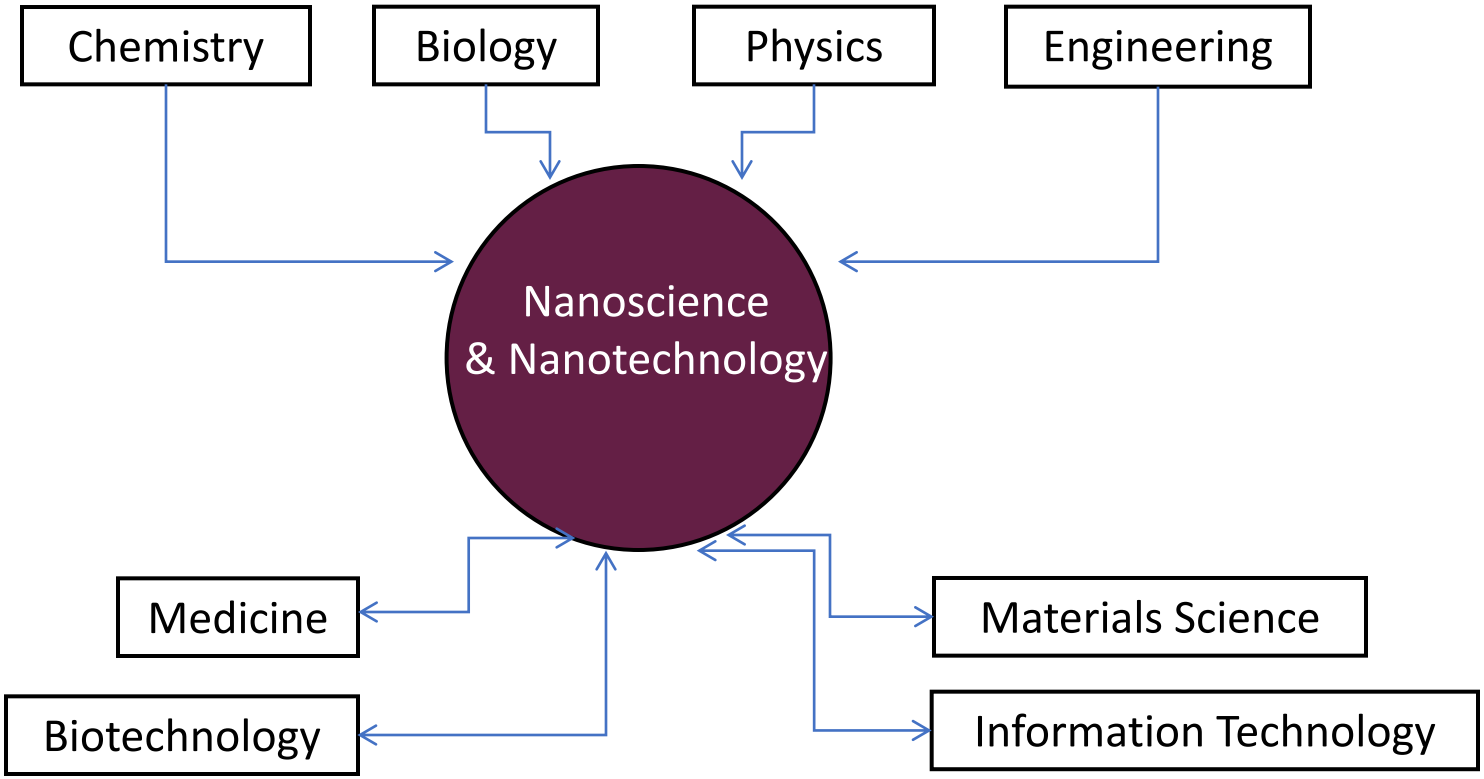
micrometers



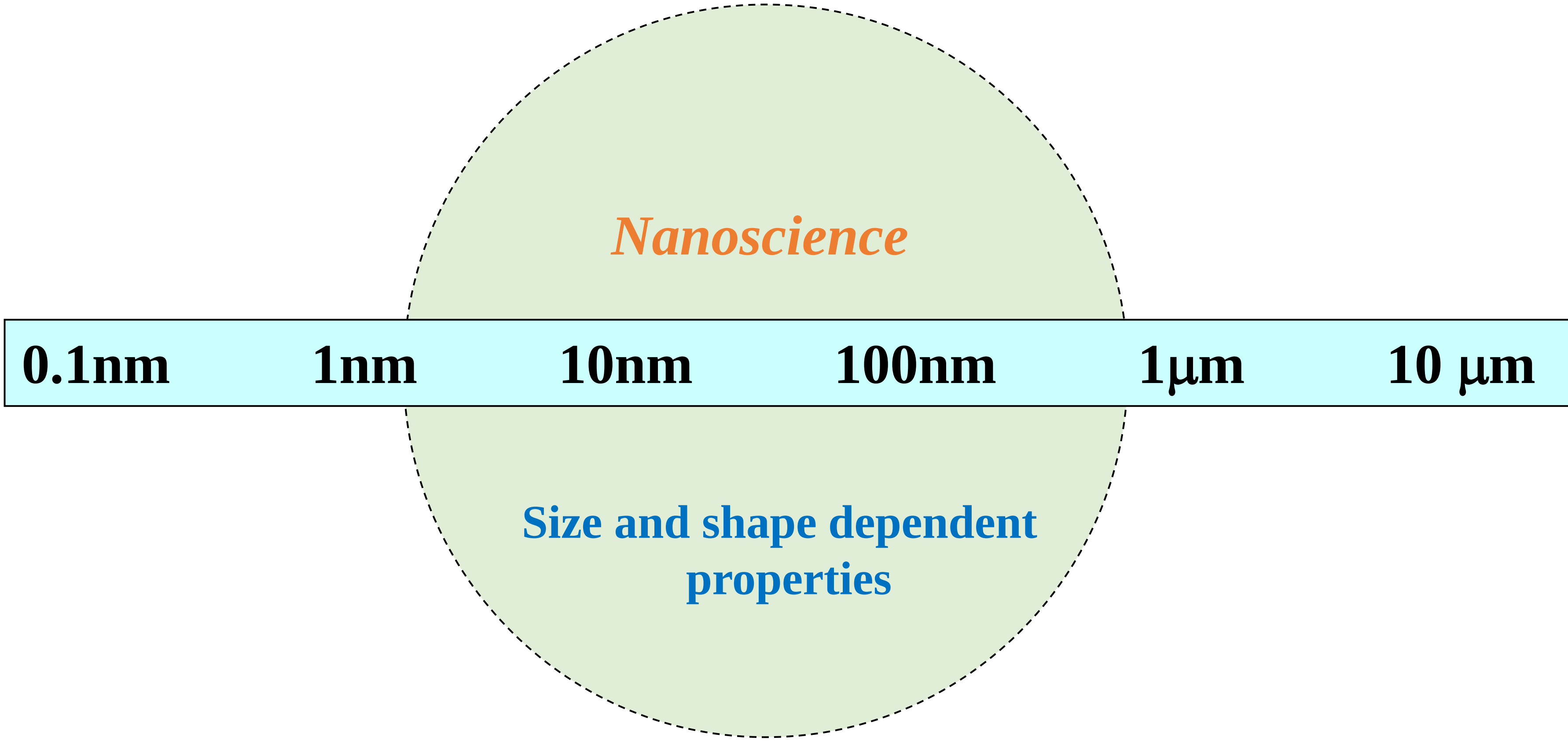
nanometers

1) Wing and wing scale
2) Wing scale
3) Scale ridge, ridge microrib, chitin fibrils and molecules

An Interdisciplinary Endeavor

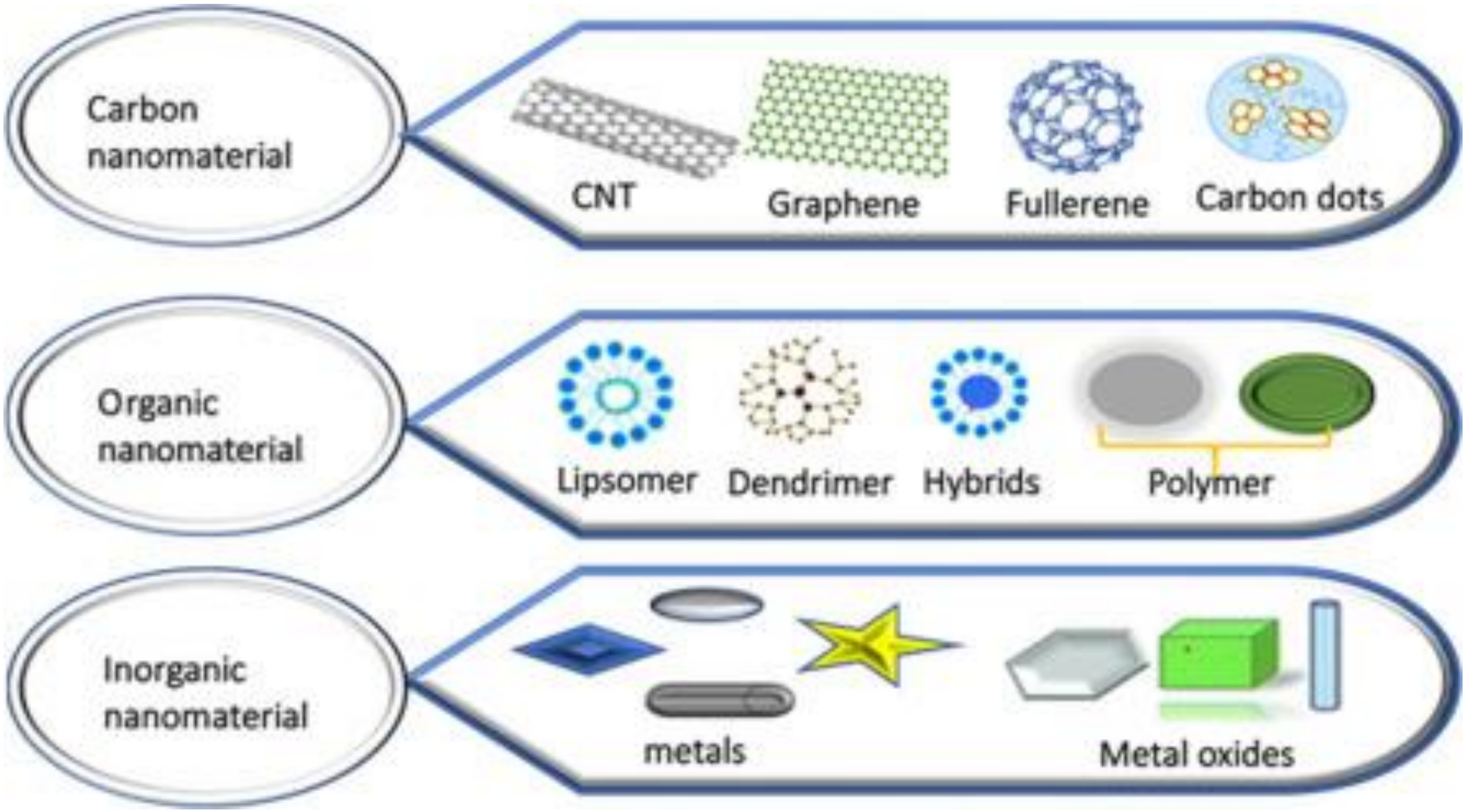


Actual physical dimensions relevant to Nanosystem

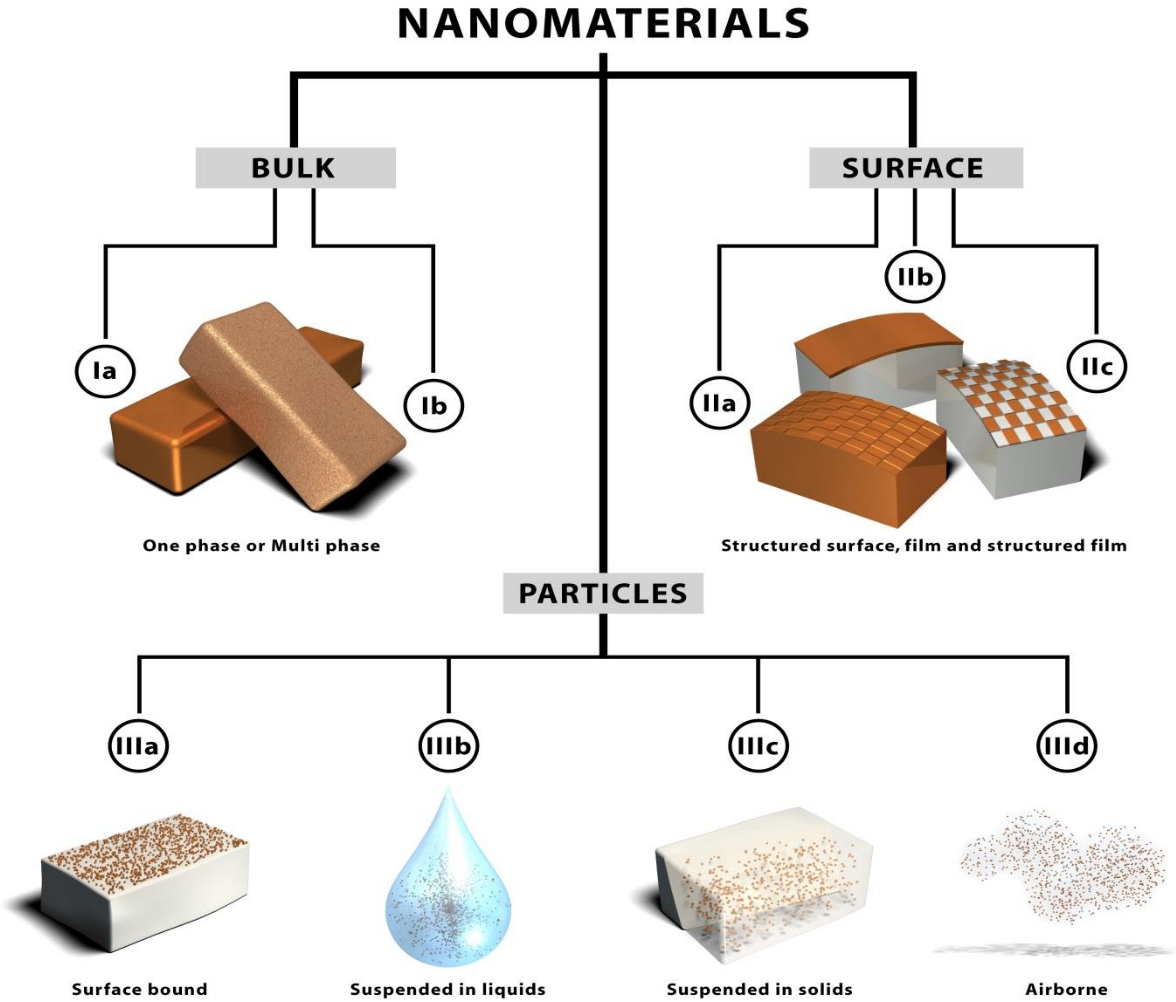


Nanometer scale : The length scale where corresponding property is size & shape dependent.

Types of nanomaterials



Classes of nanomaterials



Why are nanomaterials used?

- At nano-scale,
  - The material **properties change** - melting point, fluorescence, electrical conductivity, and chemical reactivity
  - **Surface size is larger** so a greater amount of the material comes into contact with surrounding materials and increases reactivity
- Nanomaterial properties can be **'tuned'** by varying the size of the particle (e.g. changing the fluorescence colour so a particle can be identified)
- Their **complexity** offers a variety of functions to products

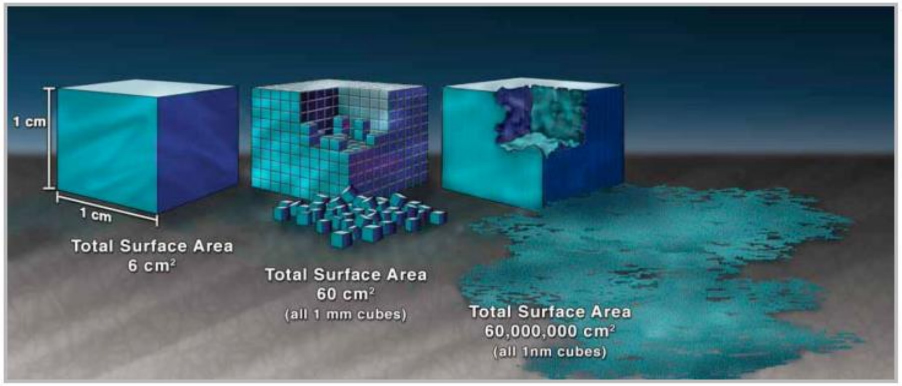
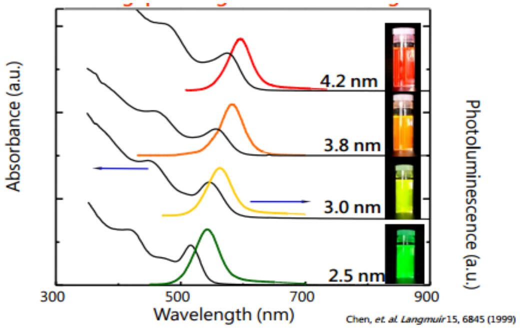
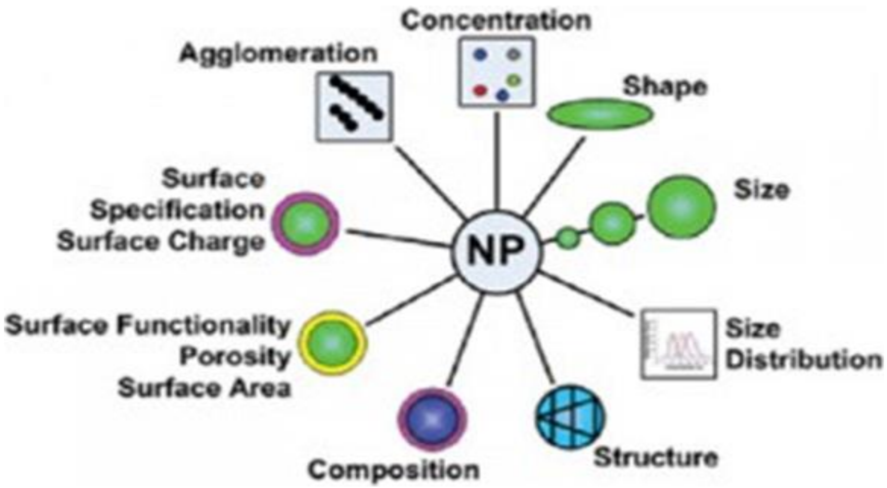


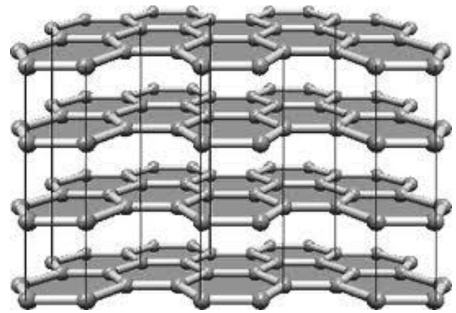
Illustration demonstrating the effect of the increased surface area provided by nanostructured materials





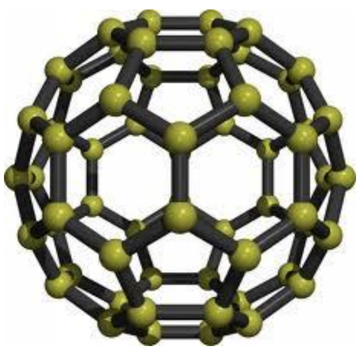
Introduction to Carbon Materials

Diamond

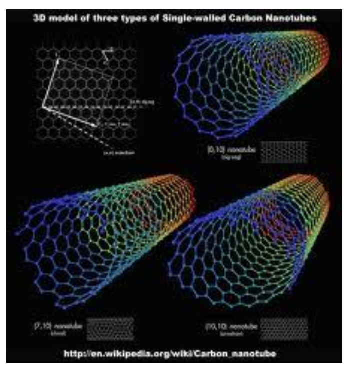


Graphite

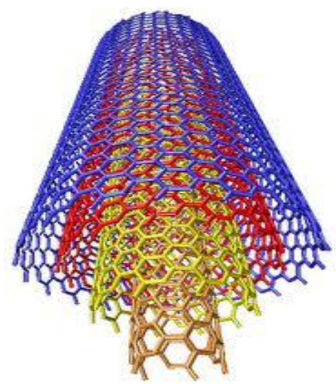
Amorphous Carbon



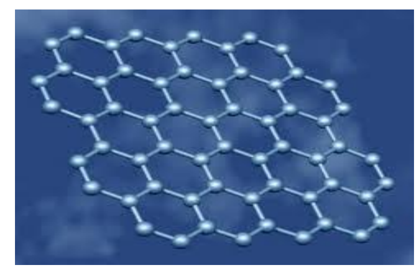
Fullerene



SWCNT

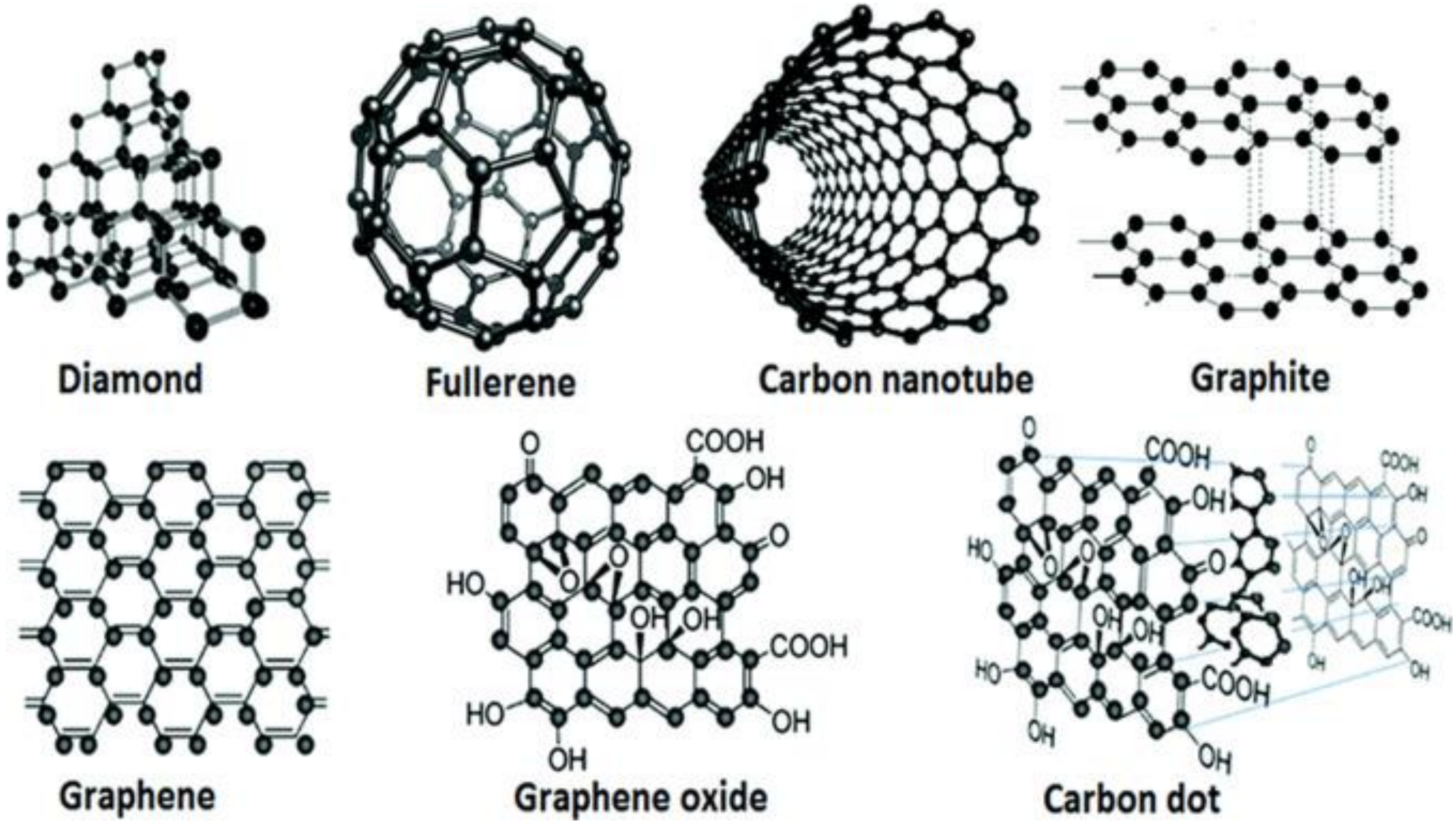


MWCNT



Graphene

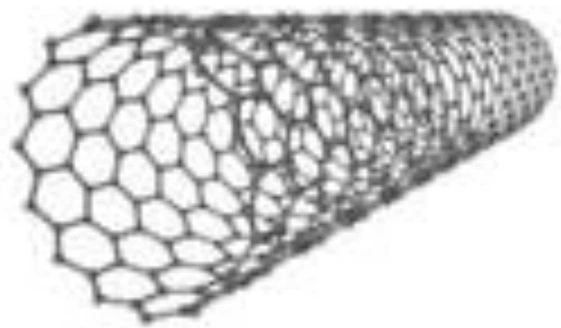
- **The advantages of carbon materials include low cost, wide potential window and electrocatalytic activity for a variety of redox reactions.**

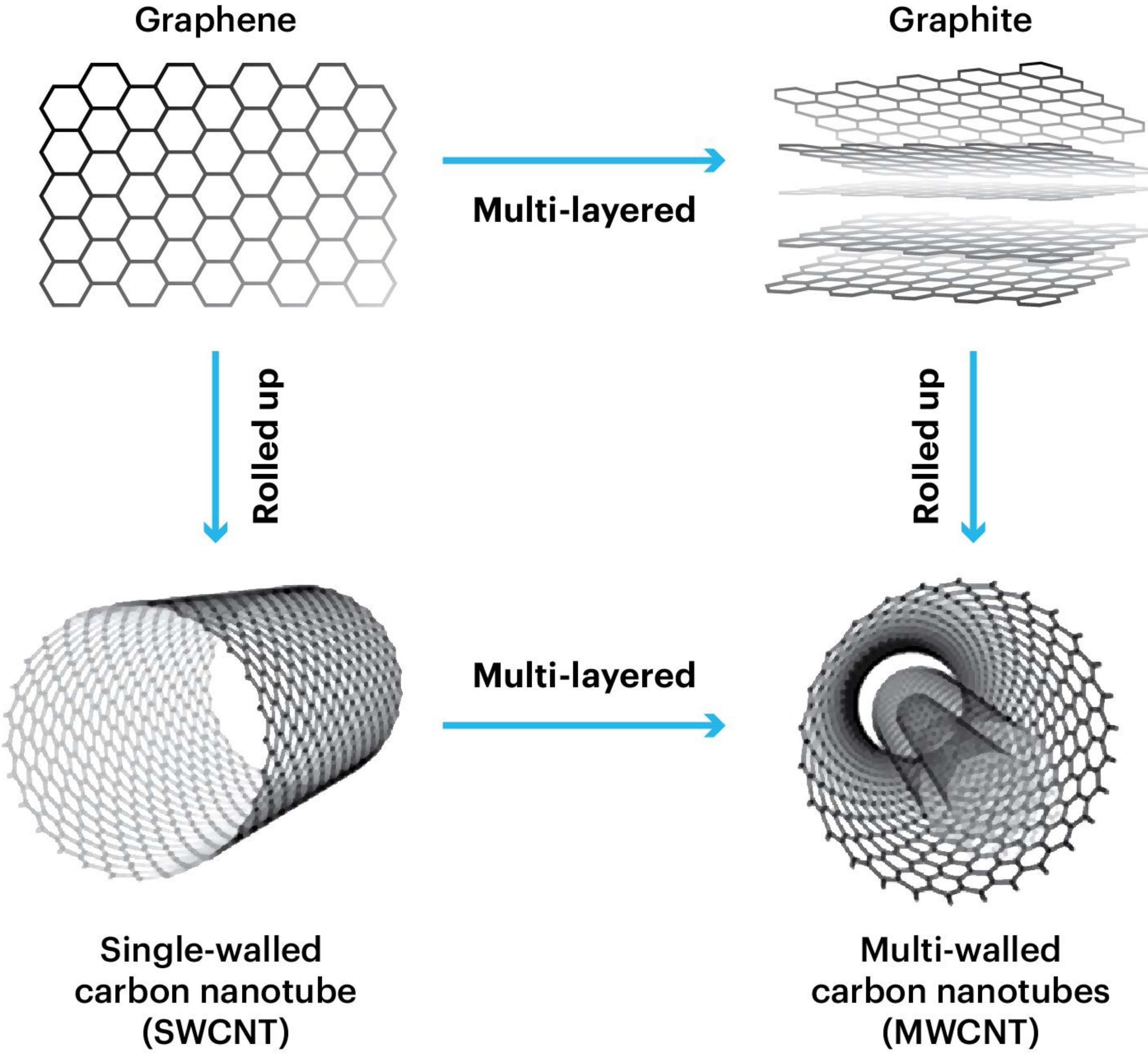

Diamond
Fullerene
Carbon nanotube
Graphite
Graphene
Graphene oxide
Carbon dot

WHAT ARE CARBON NANOTUBES?

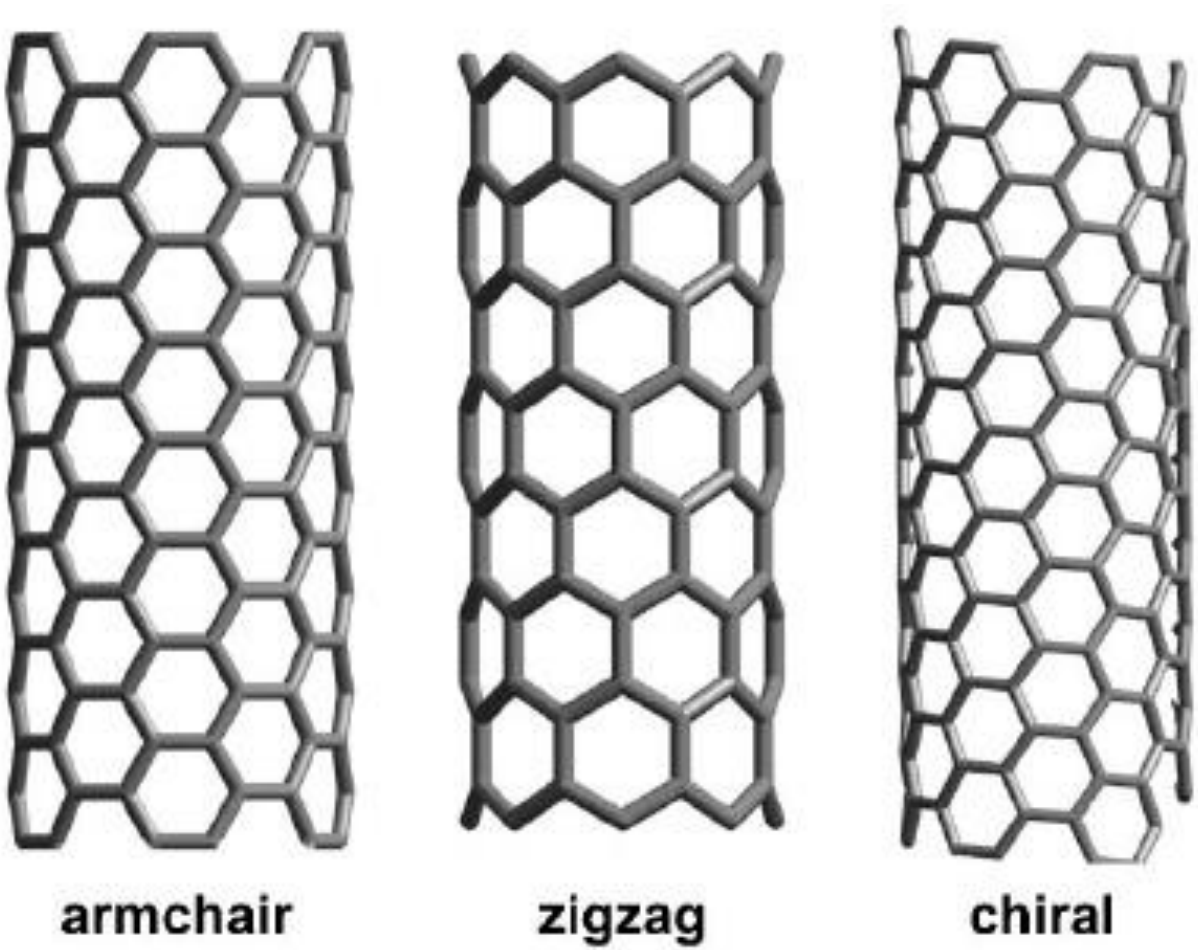
- Carbon nanotubes (CNTs) are small cylindrical molecules of graphene.
- Consist of rolled-up sheets of single-layer carbon atoms (graphene).

- Have very small diameter
- (1nm-100nm).



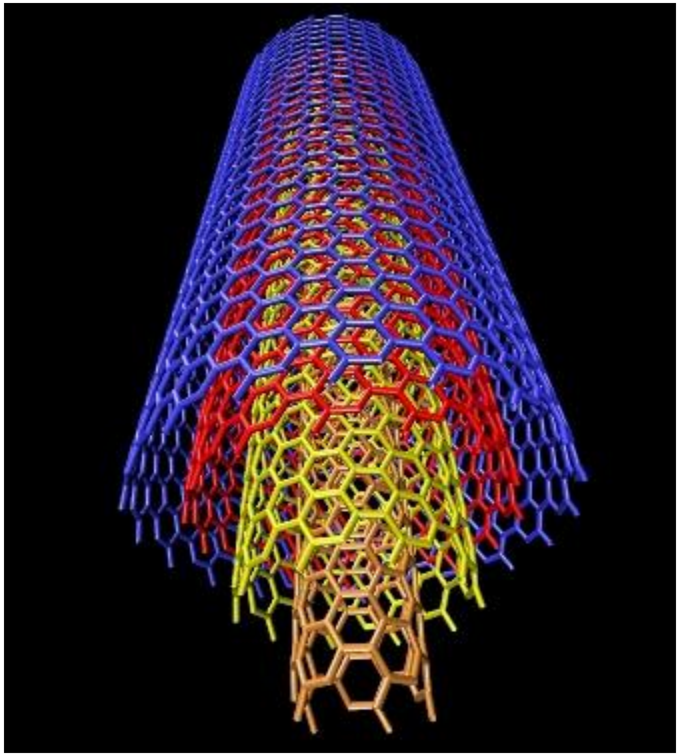

Graphene
Graphite
Multi-layered
Rolled up
Rolled up
Multi-layered
Single-walled
carbon nanotube
(SWCNT)
Multi-walled
carbon nanotubes
(MWCNT)

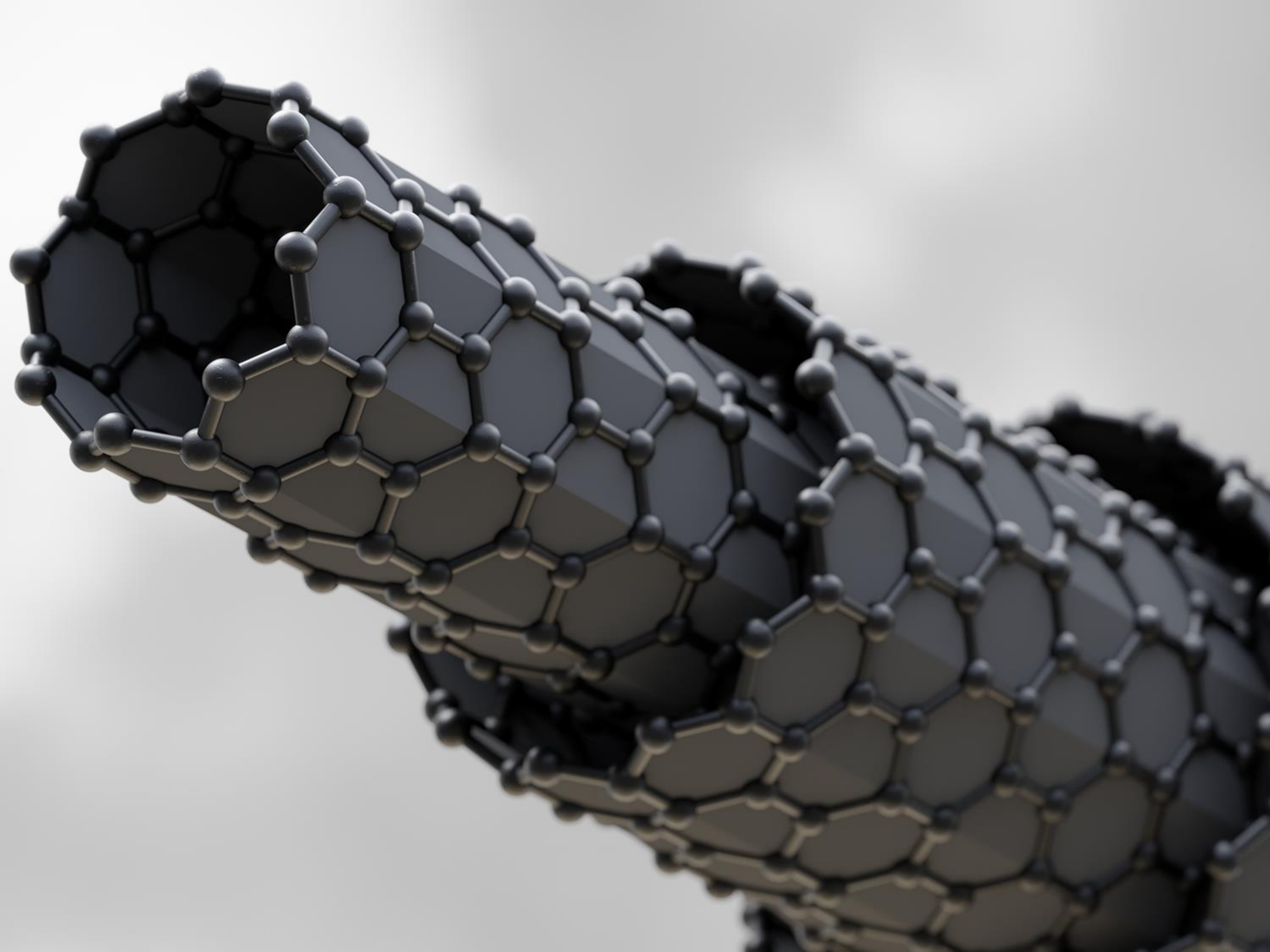
Single-Wall Nanotube (SWNT)



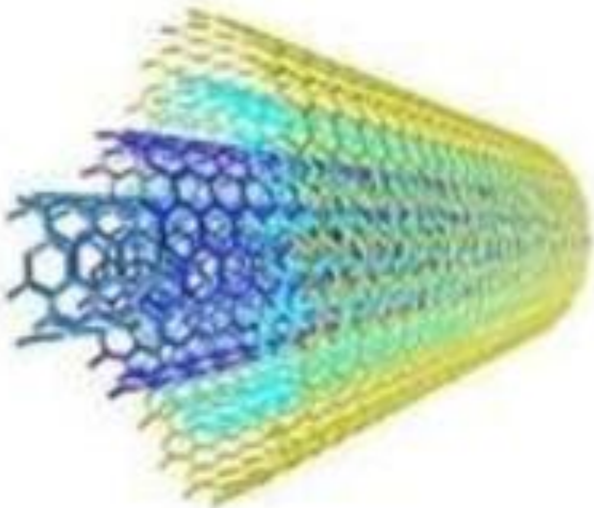
Multi-Walled Nanotubes (MWNT)

- Multiple rolled layers of S WCN sheets
- More resistant to chemic al changes than SWNTs





Multi-Walled Nanotubes (MWNT)

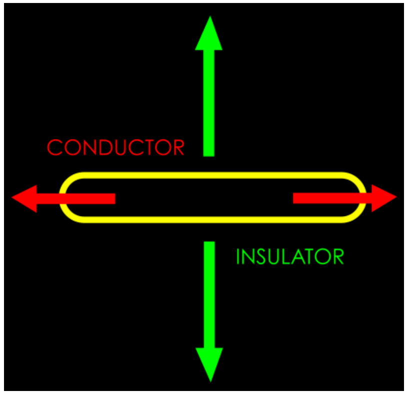


Russian doll model
(concentric cylindrical arrangement of various graphite sheets)

Parchment Model
(single sheet of graphite is rolled in around itself)

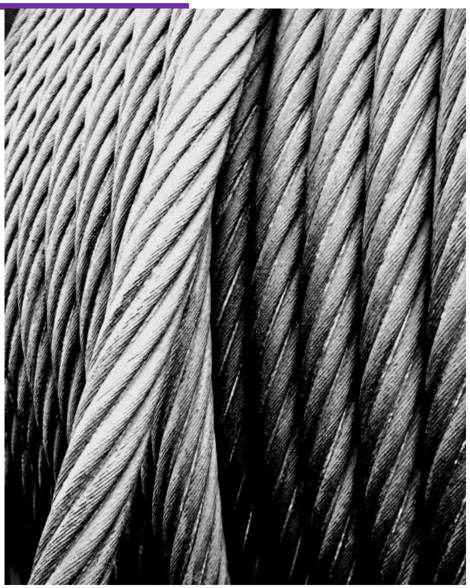
Why Should We Care of these materials ?

Thermal Properties



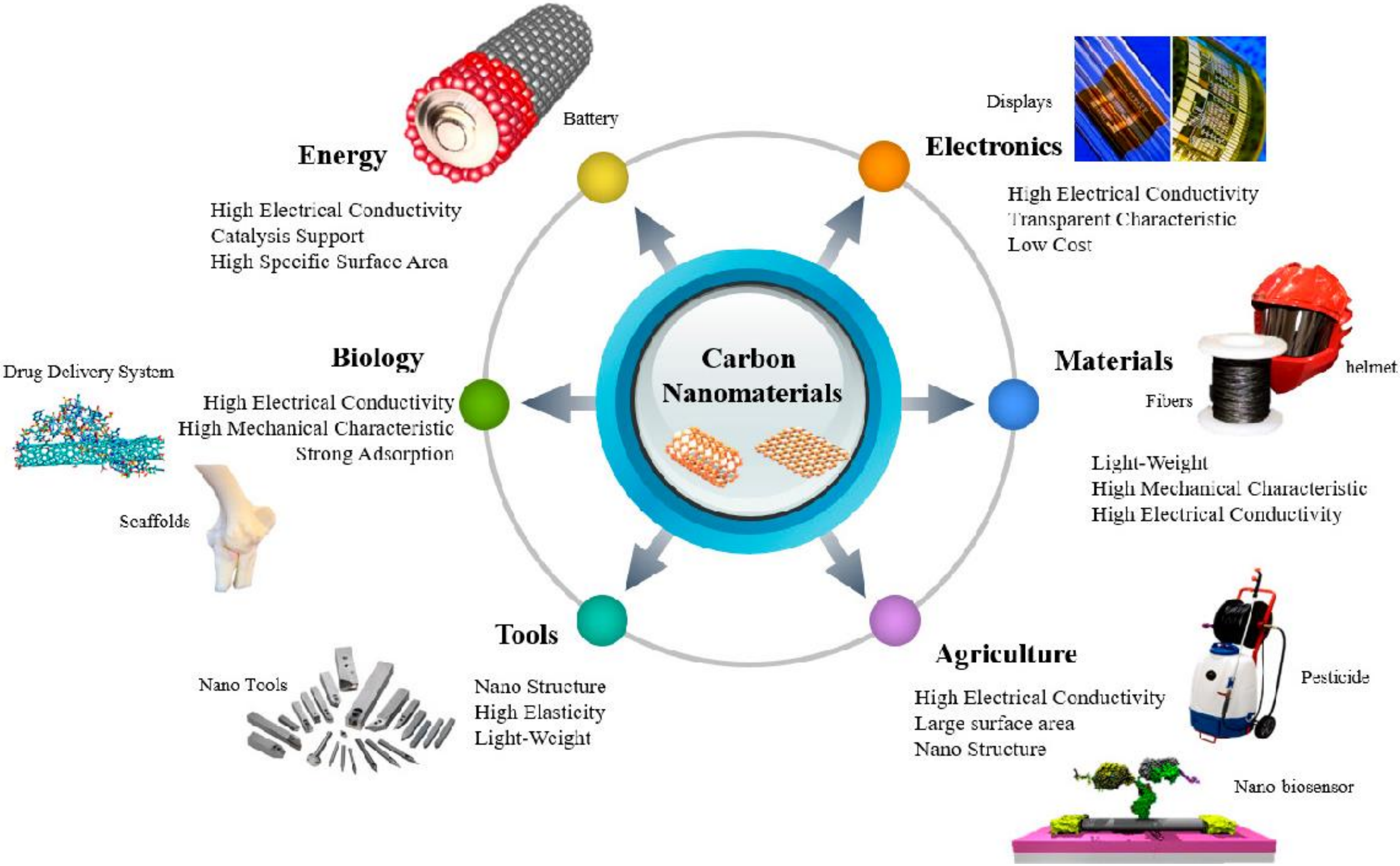
- Unique properties
- Material of the future
- Seemingly infinite appl ications
- Possible health issues

Mechanical Properties



- Strong Like Steel
- Light Like Aluminum
- Elastic Like Plastic


Biosensors
Bioimaging
Tissue regeneration
Live imaging
Cancer therapy
Protein
microassays
DNA biomotors
Drug transporters
Therapeutics,
Drug delivery
Cosmetics
Gene therapy
Fungicides
Immunoassays
Vaccines



Battery
Energy
High Electrical Conductivity
Catalysis Support
High Specific Surface Area
Displays
Electronics
High Electrical Conductivity
Transparent Characteristic
Low Cost
Drug Delivery System
Biology
High Electrical Conductivity
High Mechanical Characteristic
Strong Adsorption
Scaffolds
Carbon Nanomaterials
Materials
helmet
Fibers
Light-Weight
High Mechanical Characteristic
High Electrical Conductivity
Tools
Nano Tools
Nano Structure
High Elasticity
Light-Weight
Agriculture
Pesticide
High Electrical Conductivity
Large surface area
Nano Structure
Nano biosensor