

Chemistry-CHY104

CHEMISTRY OF MATERIALS

What is an alloy?

- Alloys are mixtures of two or more metals or a metal and a non-metal and cannot be separated into their components by physical methods.
- But still, an alloy is considered as a mixture because it shows the properties of its constituents and can have variable composition. For example, brass is a mixture of approximately 30% zinc and 70% copper.



Steel is a common example of an alloy. It contains iron mixed with carbon and other elements

By changing the amount of each element in an alloy and the final alloy may have very different properties to the original metal.

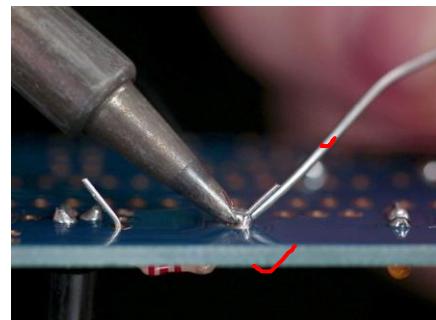
The final alloy may have very different properties to the original metal

What types of alloys are there?

Alloys have been used for thousands of years. Bronze, an alloy of copper and tin, was commonly used by civilization before iron extraction methods were developed.

Other well-known alloys include:

- Brass : An alloy of copper and zinc. It does not tarnish and is used for door knobs, button and musical instrument.
- Solder : An alloy of zinc and lead. It is used in electronics to attach components to circuit boards.
- Amalgam : An alloy of mercury and silver or tin. It is used for dental fillings because it can be shaped when warm and resists corrosion.

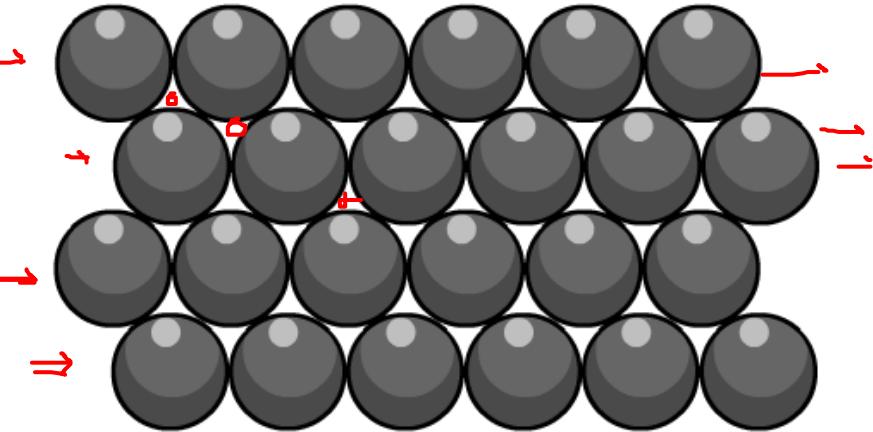


Importance or need of making alloys

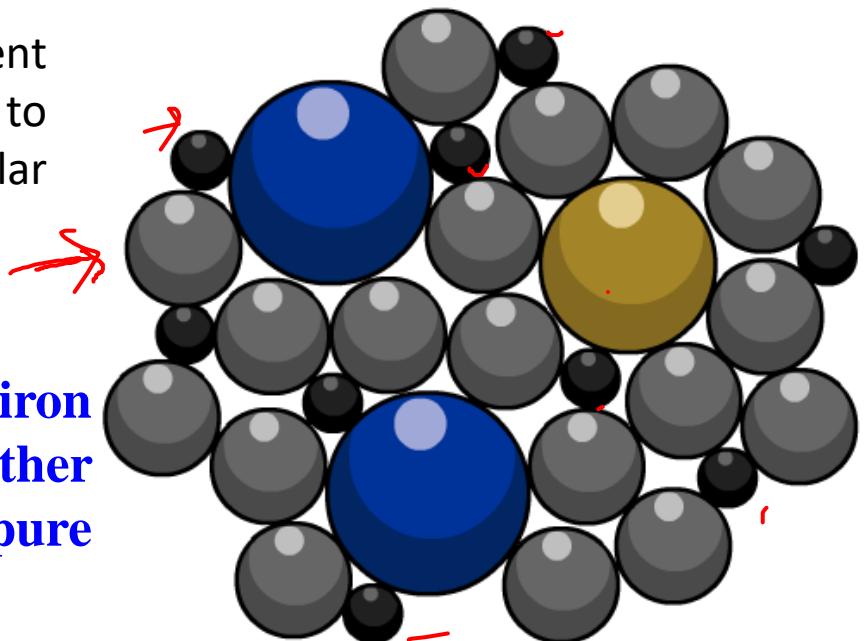
- 1) **To improve hardness:** Hardness of a metal is considerably increased on alloying it. Conversion of soft gold into hard gold by alloying it with copper is an example . The tensile strength of iron is increased ten times by alloying with 1% carbon.
- 2) **To lower the melting point:** It is lower for an alloy compared to the melting points of its constituents . e.g. ; Melting point of solder (1830C) is less than those of its constituents ; pb (3270C) and Sn (2320C) . Alloying makes the metallic system easily fusible and so alloys can be molded at lower temperatures compared to molding temperatures of pure metal.
- 3) **To resist the corrosion of the metal:** The most important and useful property of alloying is its ability to resist corrosion in it's alloying. Generally, alloys are more resistant to corrosion than pure metals . eg : stainless steel (alloy of Fe , C , Ni and Cr) which is not corroded by the atmospheric conditions though pure Fe easily corrodes (rusted) in moist air.
- 4)

Why is steel stronger than iron?

The atoms in pure iron are arranged in densely-packed layers. These layers can slide over each other. This makes pure iron a very soft material.



The atoms of other elements are different sizes. When other elements are added to iron, their atoms distort the regular structure of the iron atoms.

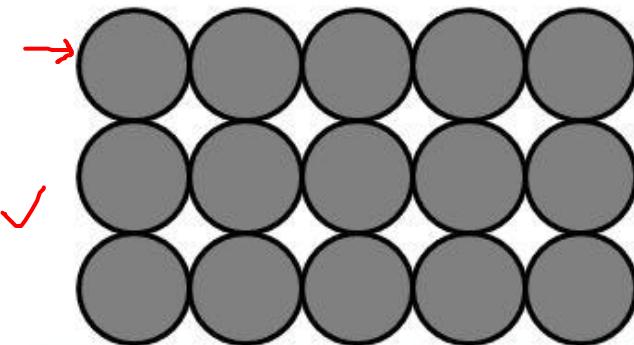


It is more difficult for the layers of iron atoms in steel to slide over each other and so this alloy is stronger than pure iron.

Pure Metals vs Alloys

Pure metals:

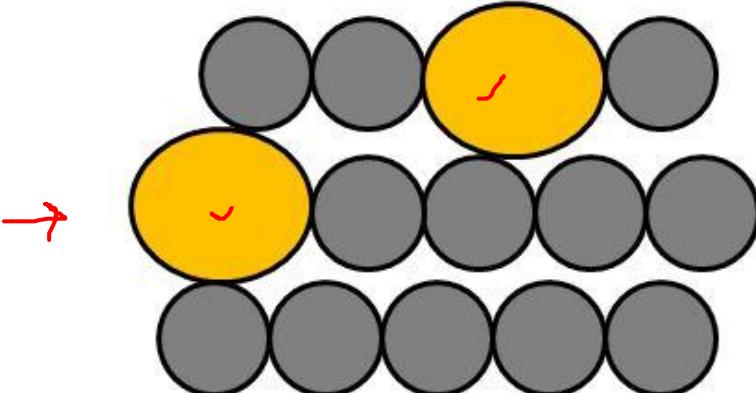
- One type of atom only
- Regular layers
- Layers can slide easily
- Malleable (soft)



Pure Metal e.g. iron

Alloys:

- Mixture of metals
- Distorted layers
- Cannot slide easily
- Much harder



Alloy e.g. steel

The ability of two metals to form a solid solution can be predicted by a set of rules known as the **Hume- Rothery rules** , which can be stated as follows:

Hume - Rothery Rules

The **Hume-Rothery rules** are basic conditions for an element to dissolve in a metal, forming a substitutional solid solution.

1. The atomic radius of the solute and solvent atoms must differ by no more than 15% ($\Delta r < 15\%$). 
2. The solute and solvent should have similar electronegativities. $\Delta E \approx 0$
3. Same crystal structure for “pure” metals.
4. Maximum solubility occurs when the solvent and solute have the same valence. Metals with lower valence will tend to dissolve metals with higher valence.

The ability of two metals to form a solid solution can be predicted by a set of rules known as the **Hume- Rothery rules** , which can be stated as follows:

Example Applications Si-Ge semiconductor, Cu-Ni and Cu-Ag metal alloys.
Is solid-solution favorable, or not?

• **Si-Ge Alloys**

Rule 1: $r_{\text{Si}} = 0.117 \text{ nm}$ and $r_{\text{Ge}} = 0.122 \text{ nm}$.

$\text{DR\%} = \frac{r_{\text{solute}} - r_{\text{solvent}}}{r_{\text{solvent}}} \times 100\% = 4\%$ *<15%* **favorable ✓**

Rule 2: Si and Ge have the diamond crystal structure. **favorable ✓**

Rule 3: $E_{\text{Si}} = 1.90$ and $E_{\text{Ge}} = 2.01$. Thus, $\text{DE\%} = 5.8\%$ **favorable ✓**

Rule 4: Valency of Si and Ge are both 4. **favorable ✓**

Expect Si and Ge to form S.S. over wide composition range.

In fact, S.S. forms over entire composition at high temperature.

Application of Hume–Rothery rules – Solid Solutions

1. Would you predict more Al or Ag to dissolve in Zn?

2. More Zn or Al in Cu?

<u>Element</u>	<u>Atomic Radius (nm)</u>	<u>Crystal Structure</u>	<u>Electro-negativity</u>	<u>Valence</u>
Cu	0.1278	FCC	1.9	+2
C	0.071			
H	0.046			
O	0.060			
Ag	0.1445	FCC	1.9	+1
Al	0.1431	FCC	1.5	+3
Co	0.1253	HCP	1.8	+2
Cr	0.1249	BCC	1.6	+3
Fe	0.1241	BCC	1.8	+2
Ni	0.1246	FCC	1.8	+2
Pd	0.1376	FCC	2.2	+2
Zn	0.1332	HCP	1.6	+2

Hume-Rothery Empirical Rules In Action

Is solid-solution favorable, or not?

- Cu-Ag Alloys

- Rule 1: $r_{\text{Cu}} = 0.128 \text{ nm}$ and $r_{\text{Ag}} = 0.144 \text{ nm}$.

$$\text{DR\%} = \frac{r_{\text{solute}} - r_{\text{solvent}}}{r_{\text{solvent}}} \times 100\% = 9.4\% \quad \cancel{< 5\%}$$

favorable ✓

- ✓ Rule 2: Ag and Cu have the FCC crystal structure.

favorable ✓

- Rule 3: $E_{\text{Cu}} = 1.90$ and $E_{\text{Ni}} = 1.80$. Thus, $\text{DE\%} = -5.2\%$

favorable ✓

- ✓ Rule 4: Valency of Cu is +2 and Ag is +1.

NOT favorable

Expect Ag and Cu have limited solubility.

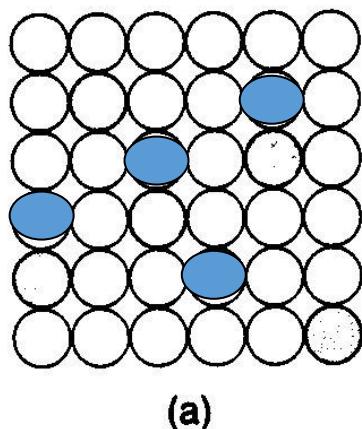
In fact, the Cu-Ag phase diagram (T vs. c) shows that a solubility of only 18% Ag can be achieved at high T in the Cu-rich alloys.

Alloys are Solid Solutions

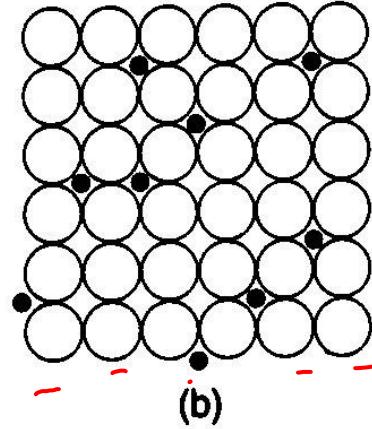
Alloys are classified broadly in two categories, *single-phase alloys* (homogeneous) and *multiple-phase alloys*.

Generally, metals do not like to mix. When they do they form in one of two ways:

Substitution



Interstitial



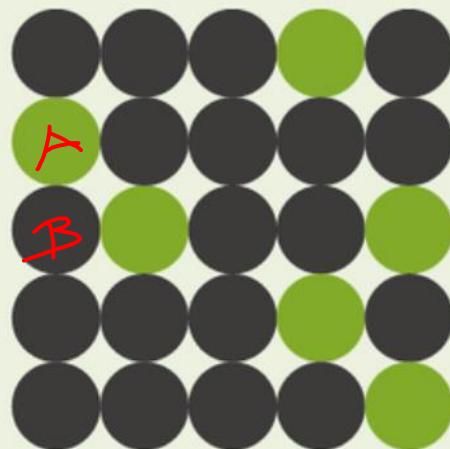
- More abundant element is referred to as the solvent and the less abundant element is the solute.

Alloys are Solid Solutions

Substitutional alloys: Substitutional alloys are **metal alloys formed by substituting one metal atom for another metal atom of similar size**. To form an alloy, the two substances (metals) should be mixed. The type and size of the substances that are mixed may determine the type of alloy that is formed

A substitutional alloy is formed via atom exchange mechanism. Here, some metal atoms of a metal lattice are replaced or substituted by metal atoms of the other metal. But both types of metal atoms should be in similar or nearly similar sizes for this substitution to occur. The percentage of the difference between atoms should not exceed 15%

A well-known alloy that is a substitutional alloy is bronze.

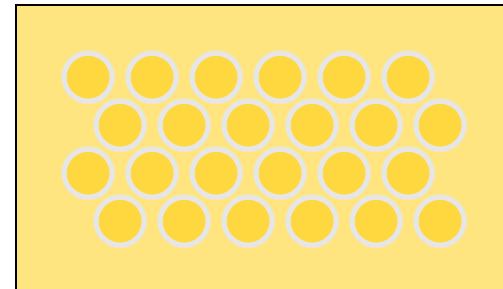
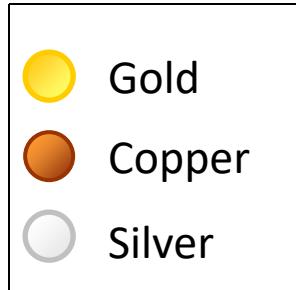


**SUBSTITUTION
ALLOY**

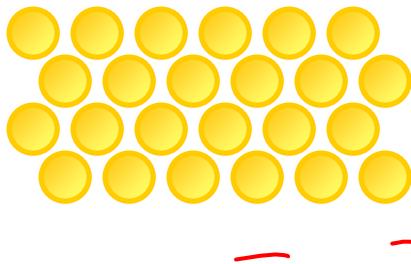
Conditions for substitutional solid solutions :

- The atomic radii of the two elements similar
- Their lattice types must be the same
- The lower valency metal becomes the solvent

Gold alloy

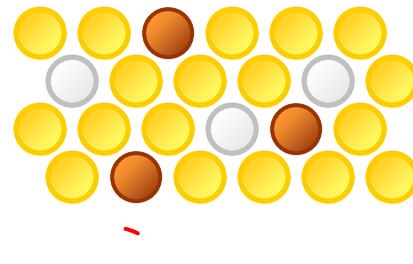


24 karat gold



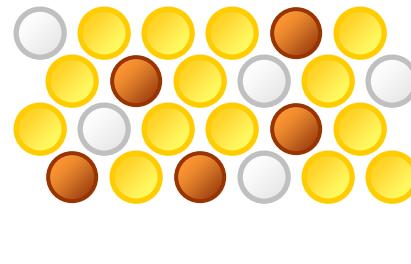
$\frac{24}{24}$ atoms Au

18 karat gold



$\frac{18}{24}$ atoms Au

14 karat gold



$\frac{14}{24}$ atoms Au

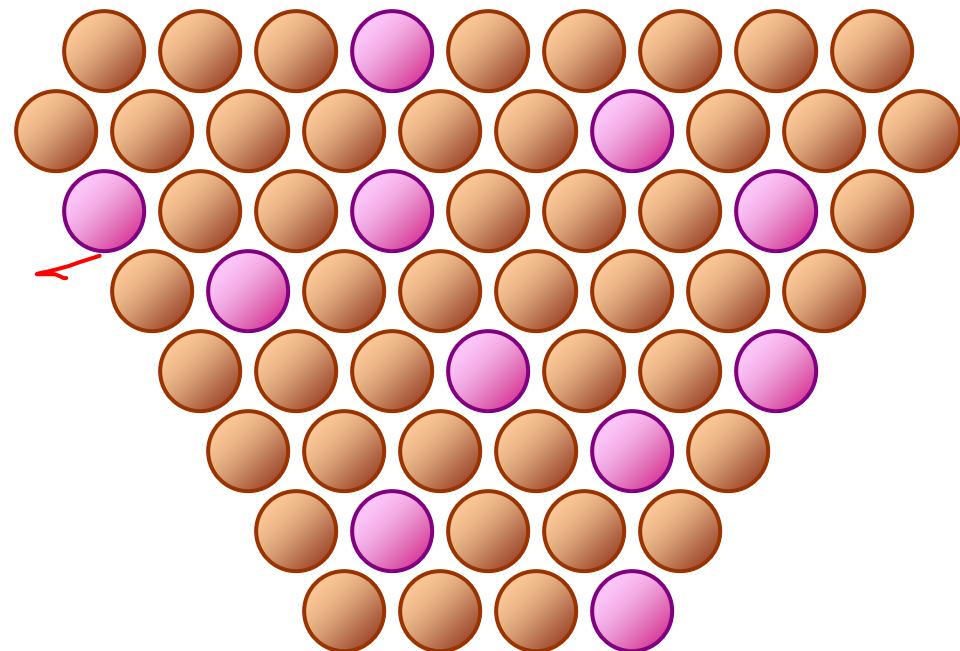


An alloy is a mixture of metals.



- Brass = Copper + Zinc
 - Solid brass
 - homogeneous mixture
 - a substitutional alloy

Solid Brass



Copper

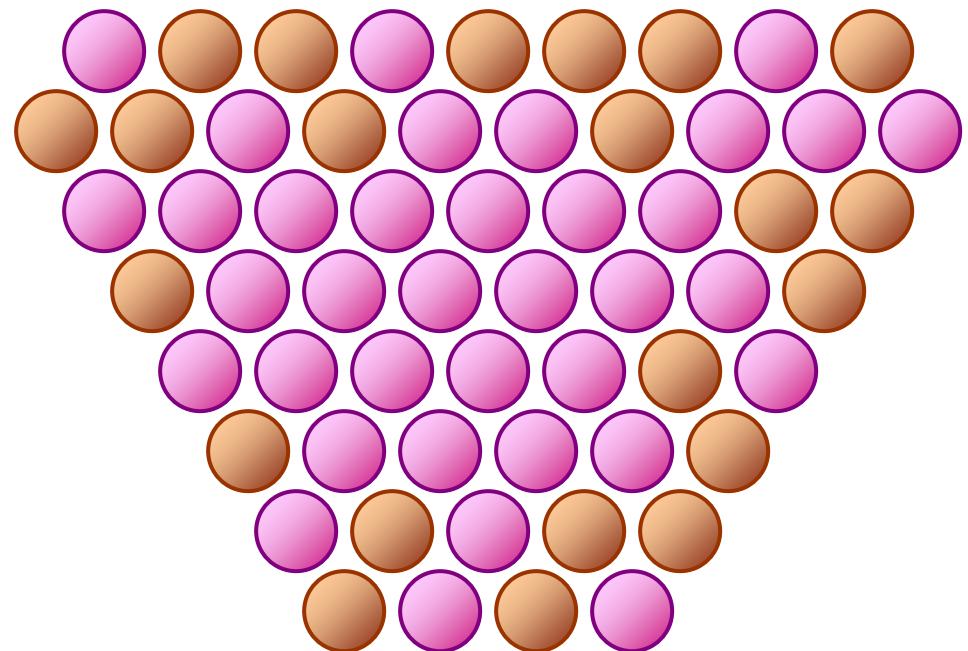
Zinc





- Brass = Copper + Zinc
 - Brass plated
 - heterogeneous mixture
 - Only brass on outside

Brass Plated



 Copper

 Zinc



Dental Alloys

Gold-Silver alloy (Type III for crowns & bridges: e.g. 75%Au-11%Ag-9%Cu3.5%Pd)

- 2.882 \AA - Gold (Au) FCC : FCC (Ag) Silver - 2.888 \AA

Silver-Copper alloy (One of the two types of particles in 'admixed' dental amalgam alloys)

- 2.888 \AA - Silver (Ag) FCC : FCC (Cu) Copper - 2.556 \AA

Silver-Tin alloy (Particles in 'low copper' dental amalgam alloys)

- 2.888 \AA - Silver (Ag) FCC : FCC (Sn) Tin - 3.016 \AA

Alloy	Composition	Properties	Uses
Bronze	<ul style="list-style-type: none"> • 90% copper • 10% tin 	<ul style="list-style-type: none"> • Hard and strong • Doesn't corrode easily • Has shiny surface 	<ul style="list-style-type: none"> • To build statues and monuments. • In the making of medals, swords and artistic materials.
Brass	<ul style="list-style-type: none"> • 70% copper • 30% zinc 	<ul style="list-style-type: none"> • Harder than copper 	<ul style="list-style-type: none"> • In the making of musical instruments and kitchenware.
Steel	<ul style="list-style-type: none"> • 99% iron • 1% carbon 	<ul style="list-style-type: none"> • Hard and strong 	<ul style="list-style-type: none"> • In the construction of building and bridges. • In the building of the body of cars and railway tracks.
Stainless steel	<ul style="list-style-type: none"> • 74% iron • 8% carbon • 18% chromium 	<ul style="list-style-type: none"> • Shiny • Strong • Doesn't rust 	<ul style="list-style-type: none"> • To make cutlery and surgical instruments.
Duralumin	<ul style="list-style-type: none"> • 93% aluminum • 3% copper • 3% magnesium • 1% manganese 	<ul style="list-style-type: none"> • Light • Strong 	<ul style="list-style-type: none"> • To make the body of aeroplanes and bullet trains.
Pewter	<ul style="list-style-type: none"> • 96% tin • 3% copper • 1% antimony 	<ul style="list-style-type: none"> • Luster • Shiny • Strong 	<ul style="list-style-type: none"> • In the making of souvenirs.

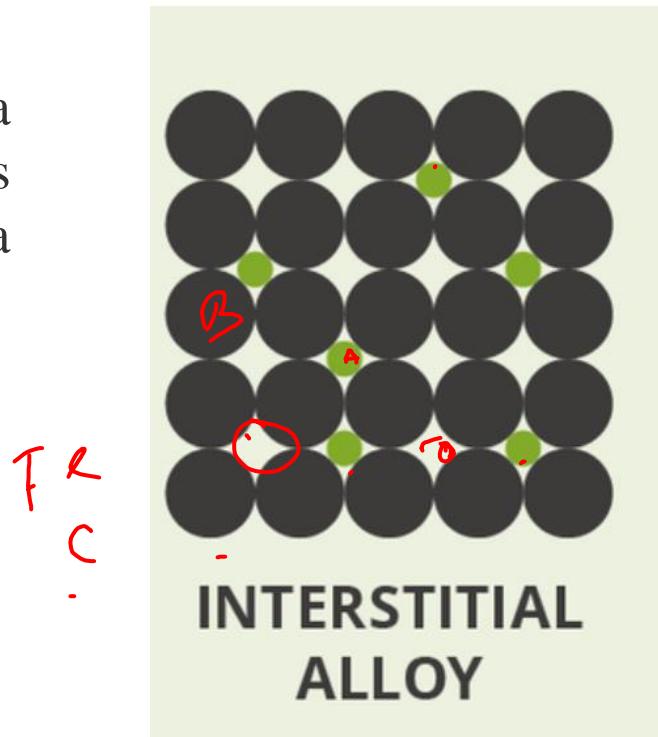
Other alloys

- *Co-Cr alloys*:
- *Co-Cr-Ni alloys*:
- Ni-Ti alloys such as Nitinol (Ti-48Ni-2Co) are *superelastic* wires

Alloys are Solid Solutions

Interstitial alloys: An interstitial alloy is formed when a metal is mixed with another substance composed of small atoms (having small radii) that can reside in the holes of the metal lattice.

Steel is a case of an interstitial alloy in which a moderately modest number of carbon molecules slip in the gaps between the gigantic atoms in a crystalline lattice of iron.



Substitutional Solid Solution Example: Copper and Nickel

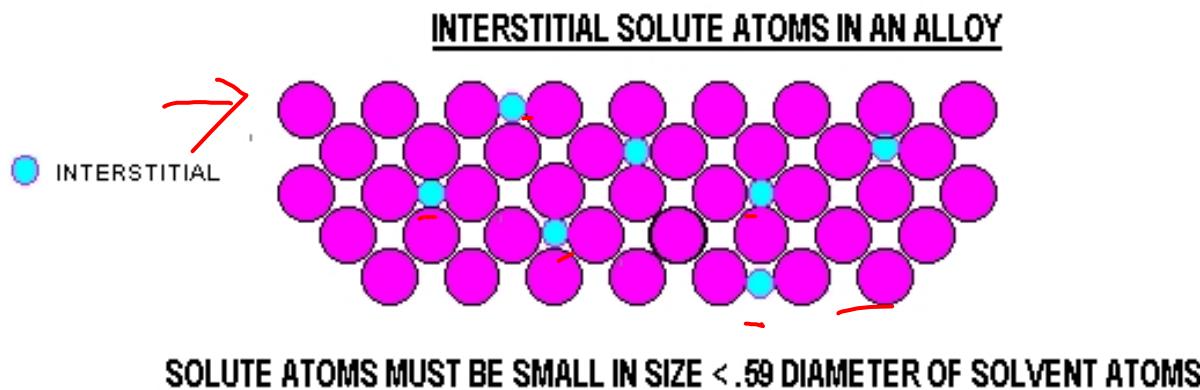
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Ni	0.1246	FCC	1.8	+2
Pd	0.1376	FCC	2.2	+2
Zn	0.1332	HCP	1.6	+2

Interstitial Solid Solution

- Carbon forms an **interstitial solid solution** when added to **iron**; the maximum concentration of **carbon** that can be added is roughly **2%**.
- The atomic radius of the carbon atom is much less than that of iron (**0.071nm vs 0.124 nm**).
- For interstitial solid solutions, the Hume-Rothery rules are:
 - ✓ – 1. Solute atoms must be smaller than the pores in the solvent lattice.
 - ✓ – 2. The solute and solvent should have similar electronegativity.

Interstitial

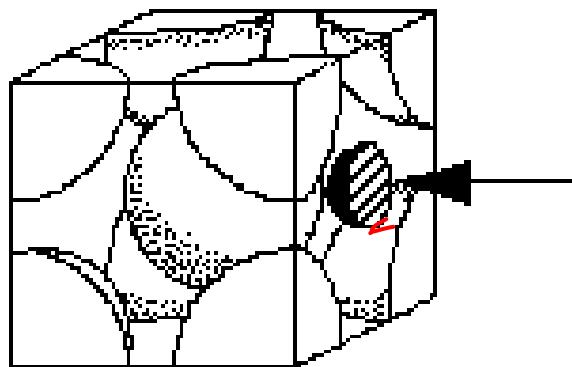
- Size of atom becomes the major factor.
- Solute atoms must be small in size to fit into the spaces between the larger solvent atoms.
- Important interstitial solute atoms are carbon, hydrogen, boron, nitrogen, and oxygen.



Solid-Solution Strengthening

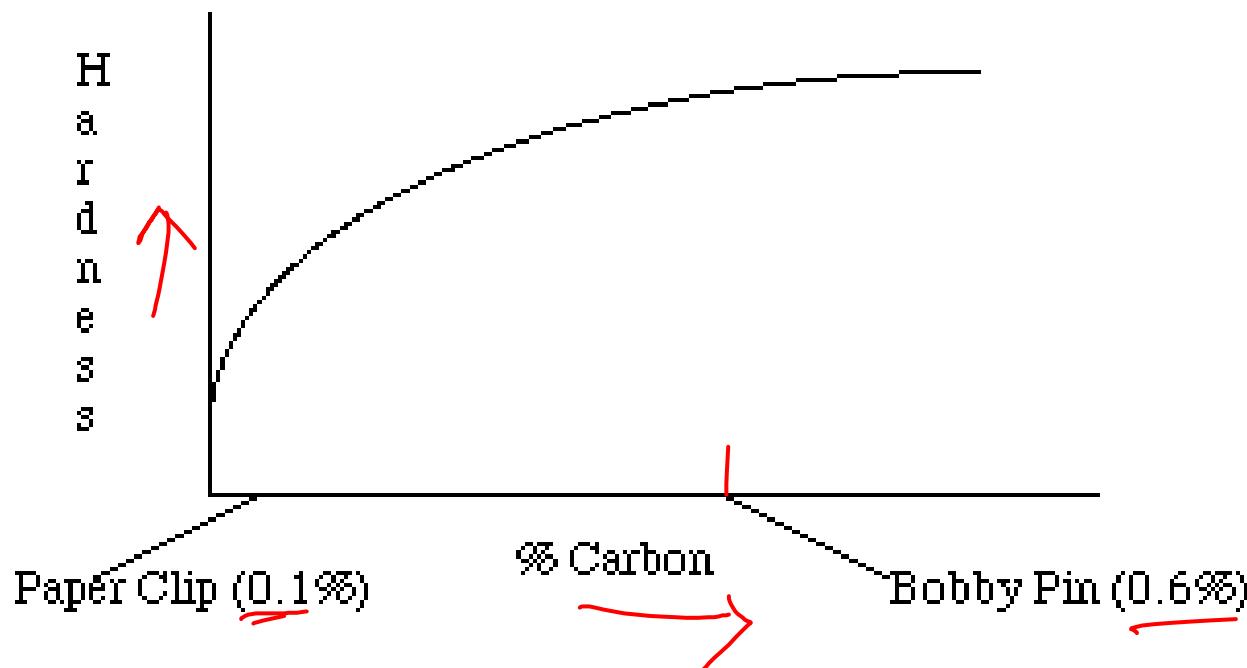
- Adding another element can increase strength.
- The impurity atoms redistribute lattice strain which can "anchor" dislocations.
- This occurs when the strain caused by the alloying element compensates that of the dislocation, thus achieving a state of low potential energy. It costs strain energy for the dislocation to move away from this state. The dissipation of energy at low temperatures is why slip is hindered.
- Pure metals are almost always softer than their alloys

Example of interstitial solid solution is steel or carbon dissolved in iron



Interstitial Carbon in Iron

Since the interstitial sites are so small, the maximum solubility in BCC iron is only one carbon atom for 5000 iron atoms.



Strain Hardening

- Ductile metals become stronger when they are deformed plastically at temperatures well below the melting point **(cold working)**.
- The reason for strain hardening is that the dislocation density increases with plastic deformation (cold work). The average distance between dislocations then decreases and dislocations start blocking the motion of each one.

Recovery -Annealing

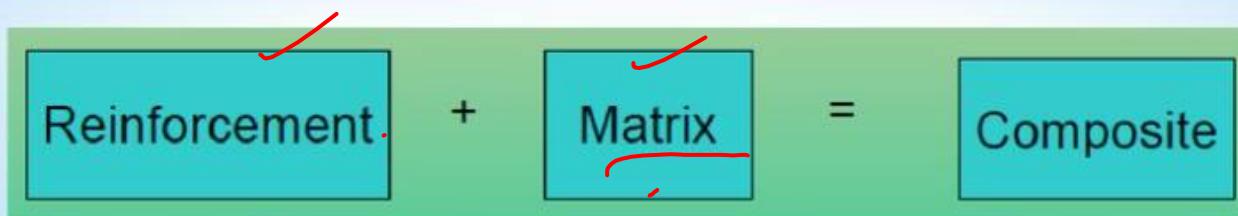
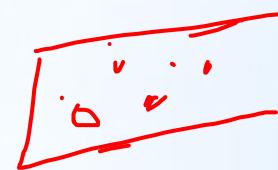
- Heating ->increased diffusion ->enhanced dislocation motion
->relieves internal strain energy and reduces the number of dislocations.

Stainless Steels

- Types 316 and 316L, are most widely used for implant fabrication
- The only difference in composition between 316L and 316 stainless steel is the content of carbon.
- A wide range of properties exists depending on the heat treatment or cold working (for greater strength and hardness).
- Even the 316L stainless steels may corrode inside the body under certain circumstances in a highly stressed and oxygen depleted region, such as contact under screws or fracture plates.
- Thus, stainless steels are suitable to use only in temporary implant devices, such as fractures plates, screws and hip nails.

Composite Materials Definition

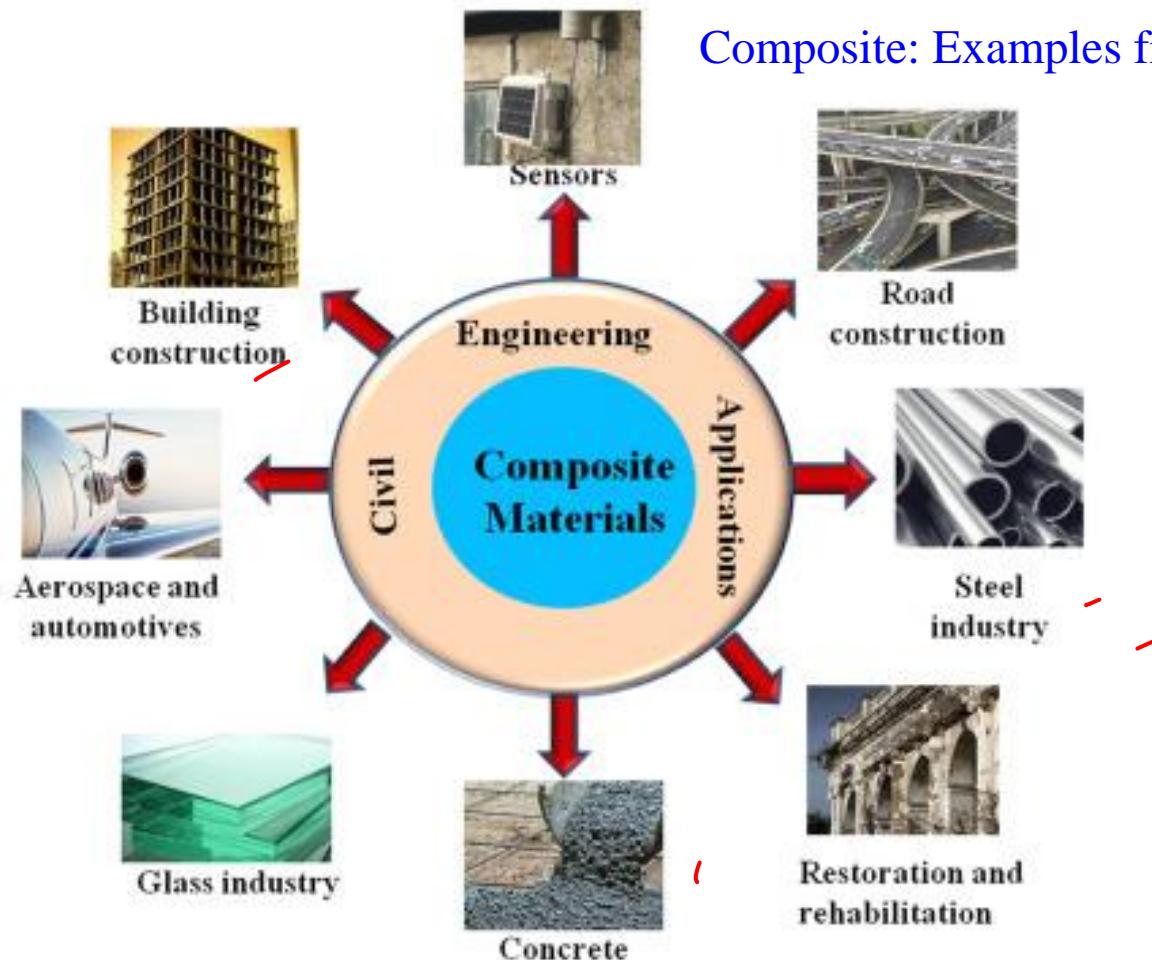
- A materials system composed of **two or more physically distinct phases** whose combination produces **aggregate properties** that are different from those of its constituents
- Generally, one material forms a **continuous matrix** while the other provides the **reinforcement**
- Examples:
 - Concrete reinforced with steel
 - Epoxy reinforced with graphite fibers.
 - Plastic molding compounds containing fillers
 - Rubber mixed with carbon black



Where are composites used?

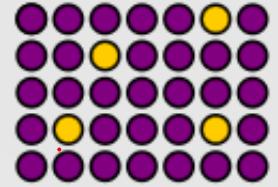
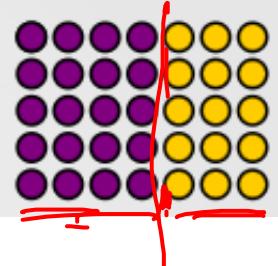
- Automotive industry: Lighter, stronger, wear resistance, rust-free, aesthetics
 - Car body, – Brake pads
 - Drive shafts, – Fuel tanks and Aerospace

Composite: Examples from Day-to-Day Life



What are “composites”?

- Composite: A material which is combination of two or more materials at *microscopic scale and have chemically distinct phase*.
- Heterogeneous at a microscopic scale but statically homogeneous at macroscopic scale.
- Constituent materials have significantly different properties.
- **Examples of naturally occurring composites**
 - **Wood**: Cellulose fibers bound by lignin matrix
 - **Bone**: Stiff mineral “fibers” in a soft organic matrix permeated with holes filled with liquids
 - **Granite**: Granular composite of quartz, feldspar, and mica

Alloy	combination of elements (at least 1 metal) in solid-solution with overall metallic properties	
Composite	combination of other materials , where the mixed materials remain physically distinct	

Why do you need composite?

Enhanced desired properties !

What are these desired properties?

- Strength • Stiffness • Toughness • Corrosion resistance
- Wear resistance • Reduced weight • Fatigue life
- Thermal/Electrical insulation and conductivity
- Acoustic insulation • Energy dissipation....

What are the constituents in a composite material?

1. Reinforcement: discontinuous, stronger and harder
2. Matrix: Continuous

✓ What are the functions of a reinforcement?

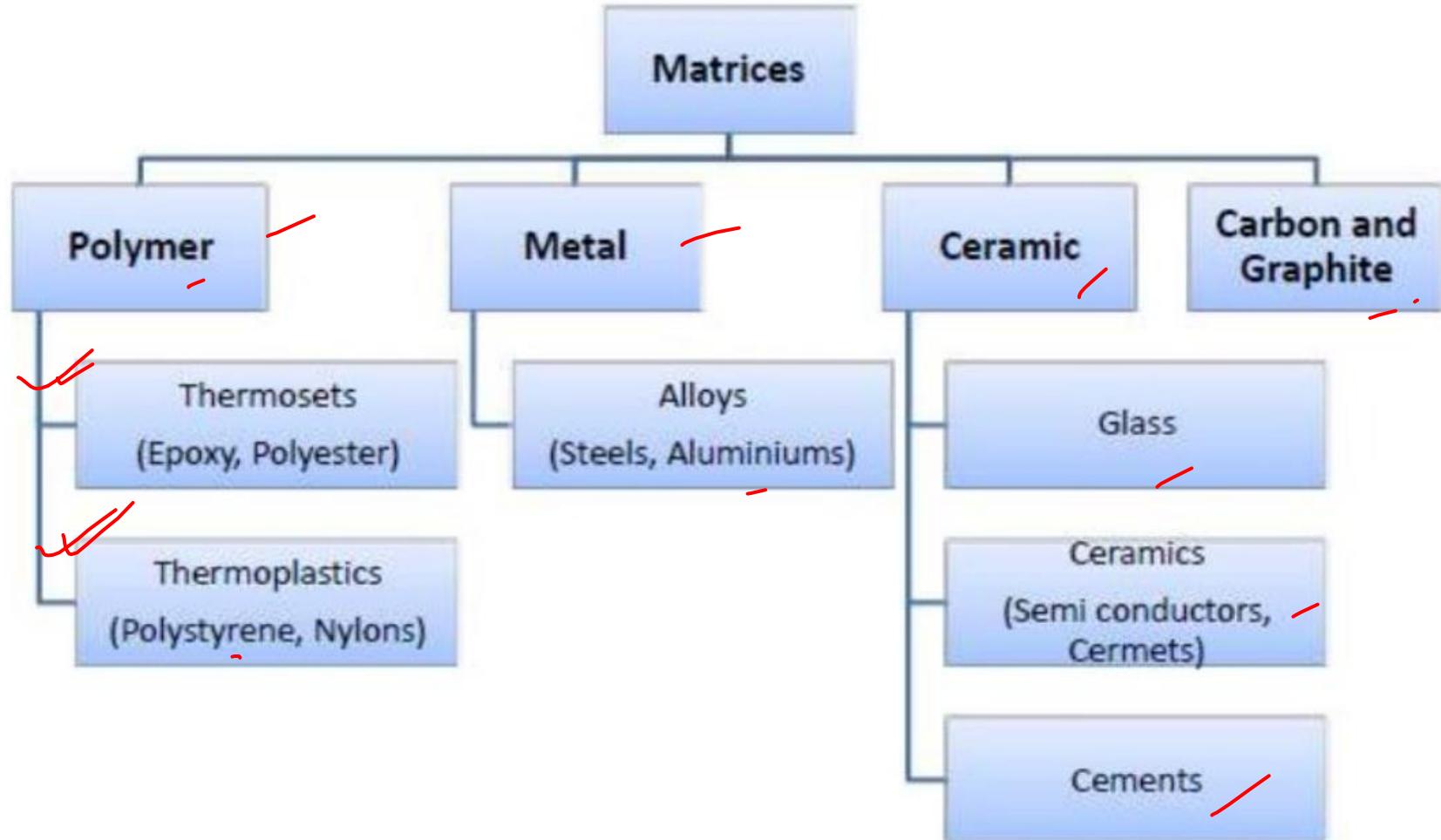
1. Contribute desired properties
2. Load carrying
3. Transfer the strength to matrix

What are the functions of a matrix?

1. Holds the fibres together and Protects the fibres from environment
2. Protects the fibres from abrasion (with each other)
3. Helps to maintain the distribution of fibres
4. Distributes the loads evenly between fibres
5. Enhances some of the properties of the resulting material and structural component component (that fibre alone is not able to impart) impart). T

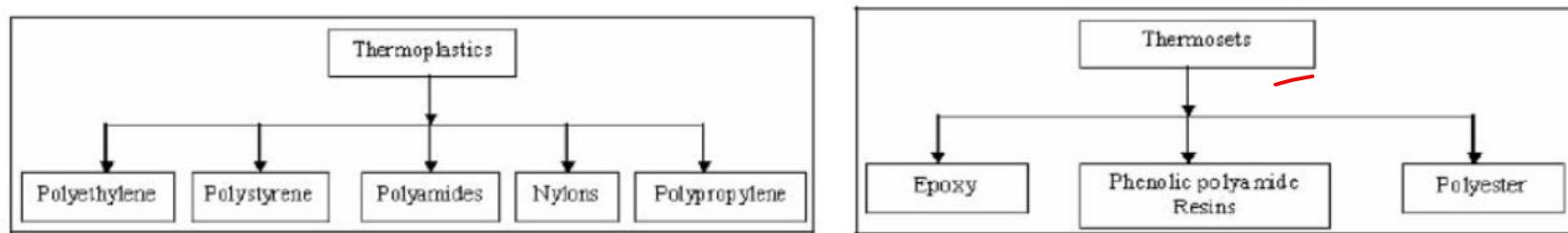
Classification

Based on the type of matrix material and Based on the form of reinforcement



ORGANIC/POLYMER MATRIX COMPOSITE (PMCs)

Two main kinds of polymers are thermosets and thermoplastics



- Thermosets have qualities such as a well-bonded three dimensional molecular structure after curing. They decompose instead of melting on hardening.
- Thermoplastics have one or two dimensional molecular structure and they tend to melt at an elevated temperature and show exaggerated melting point. Another advantage is that the process of softening at elevated temperatures can be reversed to regain its properties during cooling.

METAL MATRIX COMPOSITE (MMCs)

- ❖ Metal matrix composites are High strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites.
- ❖ MMCs are widely used in engineering applications where the operating temperature lies in between 250 °C to 750 °C.
- ❖ Matrix materials: Steel, Aluminum, Titanium, Copper, Magnesium and Super alloys.

CERAMIC MATRIX COMPOSITE (CMCs)

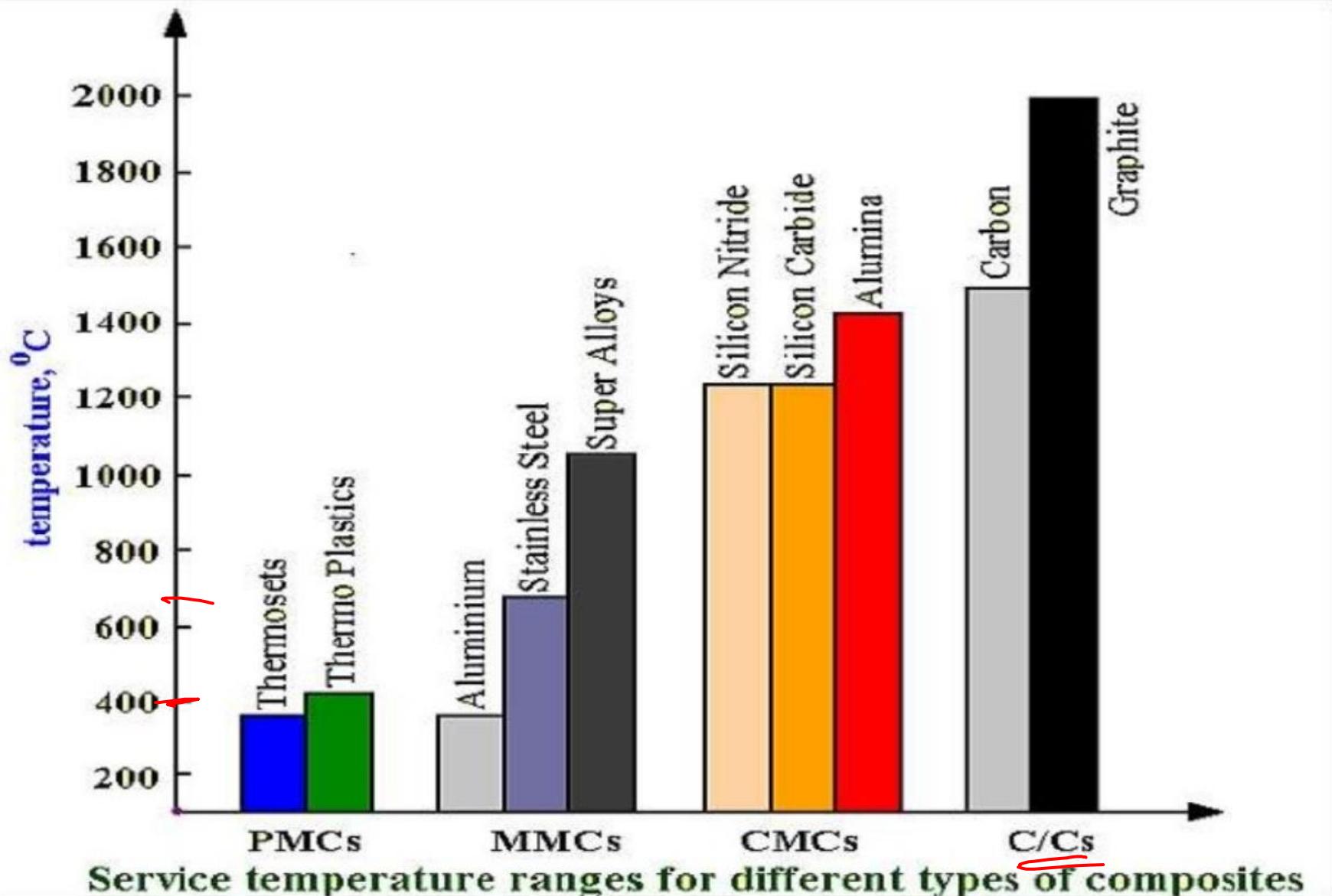
- Ceramics can be described as solid materials which exhibit very strong ionic bonding in general and in few cases covalent bonding. High melting points, good corrosion resistance, stability at elevated temperatures and high compressive strength
- CMCs are widely used in engineering applications where the operating temperature lies in between 800°C to 1650°C

CARBON/CARBON MATRIX COMPOSITE

- C/Cs are developed specifically for parts that must operate in extreme temperature ranges. Composed of a carbon matrix reinforced with carbon yarn fabric, 3-D woven fabric, 3-D braiding, etc.
- C/C composites meet applications ranging from rockets to aerospace because of their ability to maintain and even increase their structural properties at extreme temperatures.

Advantages:

- ~~Extremely high temperature resistance (1930°C – 2760°C).~~
- Strength actually increases at higher temperatures (up to 1930°C).
- High strength and stiffness.
- Good resistance to thermal shock.



FUNCTIONS OF A MATRIX

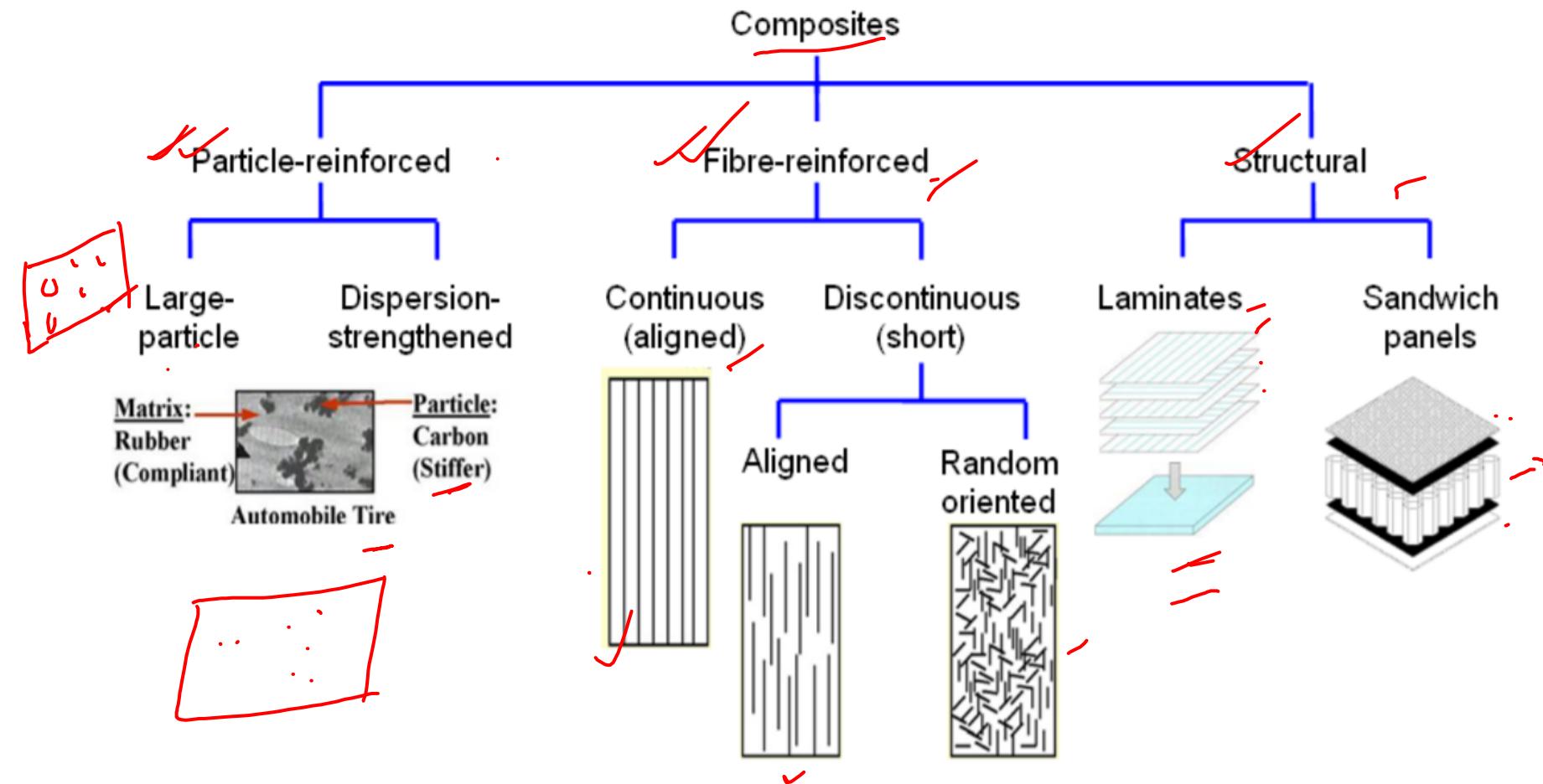
- Holds the fibers together.
- Protects the fibers from environment.
- Distributes the loads evenly between fibers so that all fibers are subjected to the same amount of strain.
- Enhances transverse properties of a laminate.
- Improves impact and fracture resistance of a component.
- Carry inter laminar shear.

DESIRED PROPERTIES OF A MATRIX

- Reduced moisture absorption.
- Low shrinkage.
- Low coefficient of thermal expansion.
- Strength at elevated temperature (depending on application).
- Low temperature capability (depending on application).
- Excellent chemical resistance (depending on application).

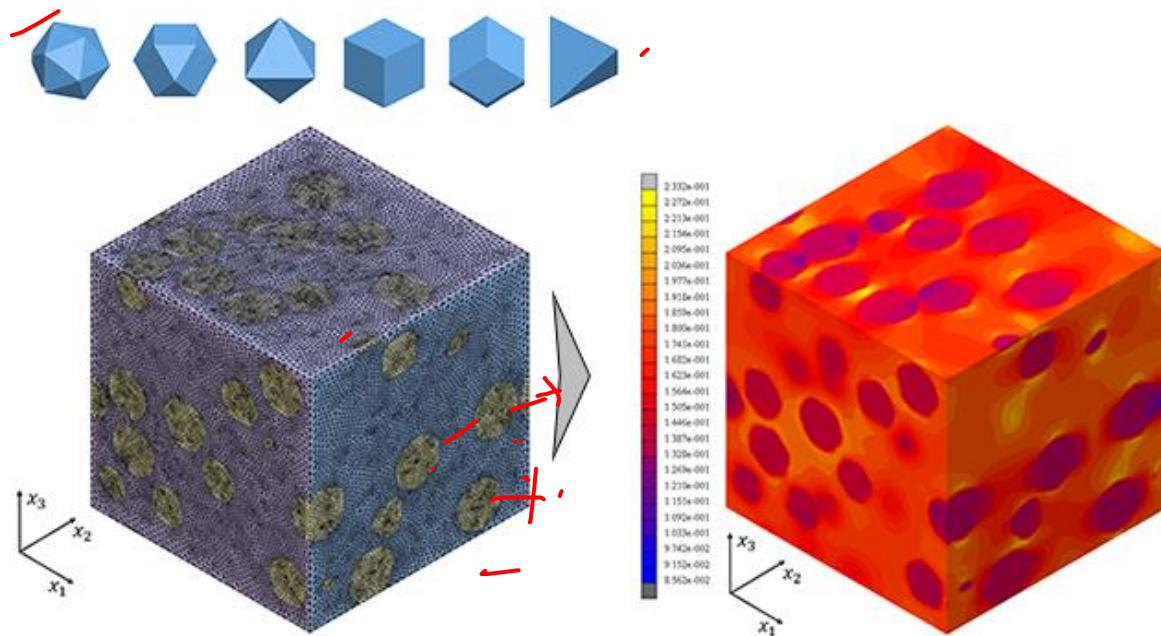
Classification

Based on the type of matrix material and Based on the form of reinforcement



Particulate composites have one or more material particles suspended in a binding matrix.

- Microstructures of **metal and ceramics composites**, which show particles of one phase scattered in the other, are known as particle reinforced composites.
- **Square, triangular and round shapes** of reinforcement are known. The size and volume concentration of the dispersoid distinguishes it from dispersion hardened materials.



In particulate composites, the particles strengthen the system by the **hydrostatic force** of fillers in matrices and by their hardness relative to the matrix.

Particulate Composites are composed of particles distributed or embedded in a matrix body. The particles may be flakes or in powder form. Concrete and wood particle boards are examples of this category.

Properties

Since it is not homogeneous, the material properties acquire sensitivity to the constituent properties, as well as the interfacial properties and geometric shapes of the array.

The composite's strength usually depends on the diameter of the particles, the inter-particle spacing, and the volume fraction of the reinforcement.

The matrix properties influence the behaviour of particulate composite too.

Large particle reinforced composites

- Particle size is $1-50\mu\text{m}$
- Concentration usually ranges from $15-40\%$ by volume
- The particulate phase is harder and stiffer than the matrix.
- Particles provide strength to the composite by restraining the movement of the matrix

- **Cermets**-tungsten carbide or titanium carbide
- **Vulcanized rubber**- carbon black in rubber
- **Concrete**- sand and gravel particulate in a surry of cement matrix.

Dispersion strengthened composites

- Uniformly dispersed fine, hard and inert particles of size less than $0.1\mu\text{m}$ are used as reinforcement
- The volume fraction is between 5-15%
- These particles are stronger than the pure metal matrix and can be metallic, inter-metallic or nonmetallic.
- Matrix is the load bearing phase
- Eg. SAP, TD-Nickel, $\text{Cu-Al}_2\text{O}_3$, $\text{Cu-Zn-Al}_2\text{O}_3$

Composite Survey: Particle-I

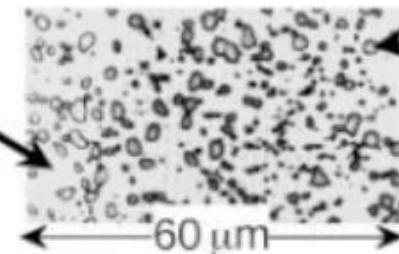
Particle-reinforced

- Examples:

- Spheroidite steel

matrix:
ferrite (α)
(ductile)

Fiber-reinforced

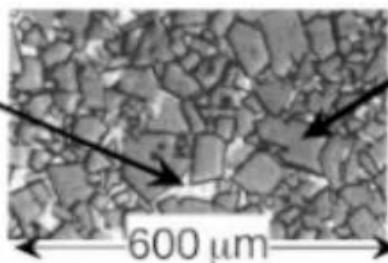


Structural

particles:
cementite
(Fe_3C)
(brittle)

- WC/Co cemented carbide

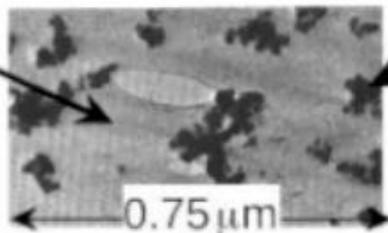
matrix:
cobalt
(ductile)
 V_m :
10-15 vol%!



particles:
WC
(brittle,
hard)

- Automobile tires

matrix:
rubber
(compliant)



particles:
C
(stiffer)

- Fibers very strong in tension
 - Provide significant strength improvement to the composite
 - Ex: fiber-glass - continuous glass filaments in a polymer matrix
 - Glass fibers
 - strength and stiffness
 - Polymer matrix
 - holds fibers in place
 - protects fiber surfaces
 - transfers load to fibers

Fiber Phase

- Smaller diameter fiber is stronger than bulk in most materials

Whiskers

- very thin single crystals that have extremely large aspect ratios.
- high degree of crystallinity and virtually flaw free – exceptionally high strength.
- usually extremely expensive.
- some whisker materials: graphite, SiC, silicon nitride, aluminum oxide.

Fibers

- polycrystalline or amorphous.
- typically: polymers or ceramics (polymer aramids, glass, carbon, boron, SiC...)

Fine Wires

- relatively large diameter, often metal wires.
- e.g. steel, molybdenum,

Fiber Orientations in Fiber Reinforced Composites



**Continuous
and aligned
fibers**



**Discontinuous
and aligned
fibers**



**Discontinuous
and randomly
oriented fibers**

Composite Survey: Fiber-III

Particle-reinforced

Fiber-reinforced

Structural

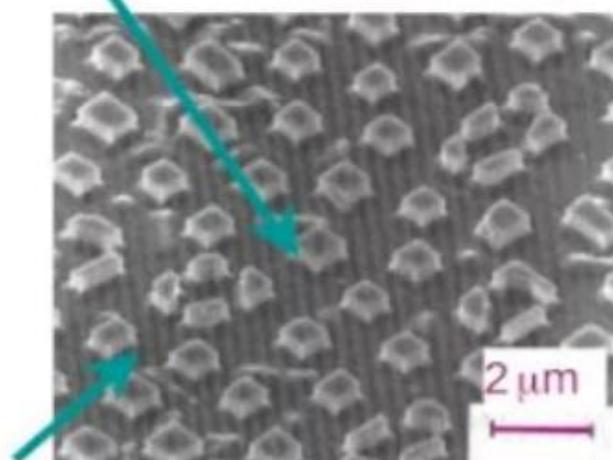
- Aligned Continuous fibers
- Examples:

-- Metal: $\gamma'(\text{Ni}_3\text{Al})$ - $\alpha(\text{Mo})$
by eutectic solidification.

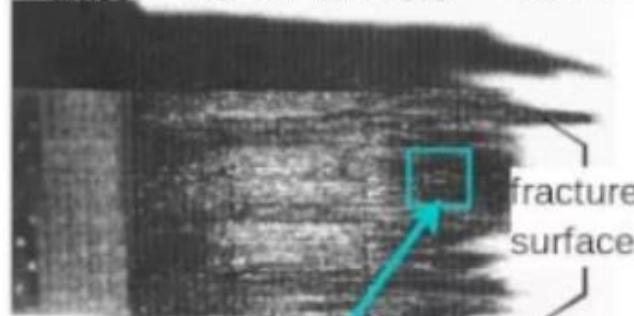
-- Ceramic: Glass w/SiC fibers
formed by glass slurry

$$E_{\text{glass}} = 76 \text{ GPa}; E_{\text{sic}} = 400 \text{ GPa.}$$

matrix: α (Mo) (ductile)



(a)



(b)



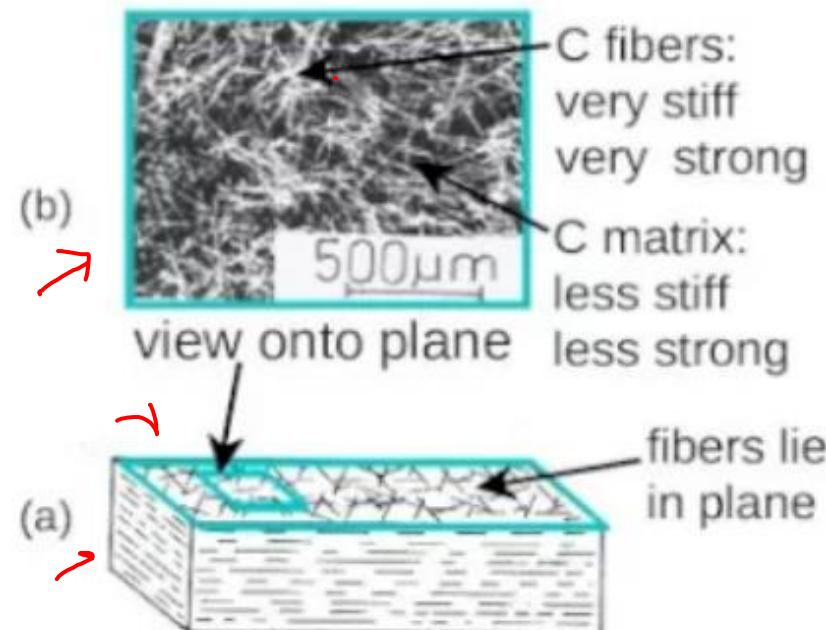
Composite Survey: Fiber-IV

Particle-reinforced

Fiber-reinforced

Structural

- Discontinuous, random 2D fibers
- Example: Carbon-Carbon
 - process: fiber/pitch, then burn out at up to 2500°C.
 - uses: disk brakes, gas turbine exhaust flaps, nose cones.
- Other variations:
 - Discontinuous, random 3D
 - Discontinuous, 1D



Types of Fibres

1. Advanced Fibres:

Fibres possessing high specific stiffness and specific strength

- a) Glass
- b) Carbon
- c) Organic
- d) Ceramic

Types of Fibres

2. Natural Fibres:

a) Animal fibres

- i) Silk
- ii) Wool
- iii) Spider silk
- iv) Sinew
- v) Camel hair
- vi)

b) Vegetable fibres

- i) Cotton
- ii) Jute
- iii) Bamboo
- iv) Sisal
- v) Maze
- vi) Hemp
- vii) Sugarcane
- viii) Banana
- ix) Ramie
- x) Kapok
- xi) Coir
- xii) Abaca
- xii) Kenaf
- xiv) Flax
- xv) Raffia palm.....

c) Mineral fibres

- i) Asbestos
- ii) Basalt
- iii) Mineral wool
- iv) Glass wool

WHAT IS FIBER GLASS

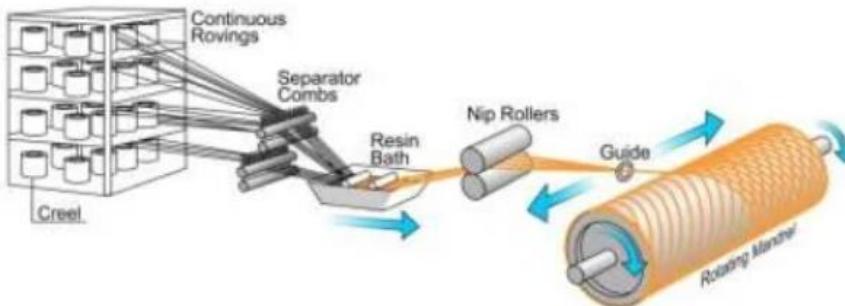
- Fiberglass (or fibreglass) is a type of fiber reinforced plastic where the reinforcement fiber is specifically glass fiber.
- Other common names for fiberglass are glass-reinforced plastic (GRP), glass-fiber reinforced plastic (GFRP)



BACKGROUND



Fiberglass really is made of glass, similar to windows or the drinking glasses in the kitchen. The glass is heated until it is molten, then it is forced through superfine holes, creating glass filaments that are very thin.



fiberglass itself may be manufactured from recycled glass

Originally, fiberglass was a glass wool with fibers entrapping a great deal of gas, making it useful as an insulator, especially at high temperatures.

TYPES OF FIBER GLASS

The following classification is known:

1. A-glass: With regard to its composition, it is close to window glass
2. C-glass: This kind of glass shows better resistance to chemical impact.
3. E-glass: This kind of glass combines the characteristics of C-glass with very good insulation to electricity.
4. AE-glass: Alkali resistant glass.

PROPERTIES

- ✓ **CHEMICAL RESISTANCE-** Fiberglass textile fabrics will not rot, mildew or deteriorate. They resist most acids with the exceptions of hydrofluoric acid and phosphoric acid.
- ✓ **DIMENSIONAL STABILITY-** Fiberglass fabrics will not stretch or shrink. Nominal elongation break is 3-4 percent. The average linear thermal expansion coefficient of "E" glass is 5.4 by $10.6 \text{ cm/cm}^{\circ}\text{C}$.
- ✓ **GOOD THERMAL PROPERTIES-** Fiberglass fabrics have a low coefficient of thermal expansion and relatively high thermal conductivity. Glass fabrics will dissipate heat more rapidly than asbestos or organic fibers.

HIGH TENSILE STRENGTH- Fiberglass yarn has a high strength-to-weight ratio. Fiberglass yarn is twice as strong as steel wire.

LOW MOISTURE ABSORPTION- Fiberglass yarn has extremely low moisture absorption.

ELECTRICAL INSULATION- High dielectrical strength and relatively low dielectrical constants make fiberglass fabrics outstanding for electrical insulation purposes.

Advanced Fibres

Carbon fibres:

- carbon- carbon covalent bond is the strongest in nature

Guess who made the first carbon fibre?

Thomas Edison made carbon fibre from bamboo when experimenting for light bulb !

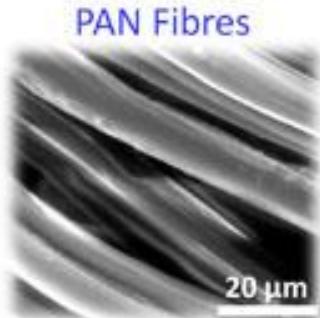
What is the difference between carbon and graphite fibres?

- Carbon fibre contains 80-95 % of carbon and graphite fibre contains more than 99% carbon
- carbon fibre is produced at 1300°C while graphite fibre is produced in excess of 1900°C

Caution ! - In general term carbon fibre is used for both fibres

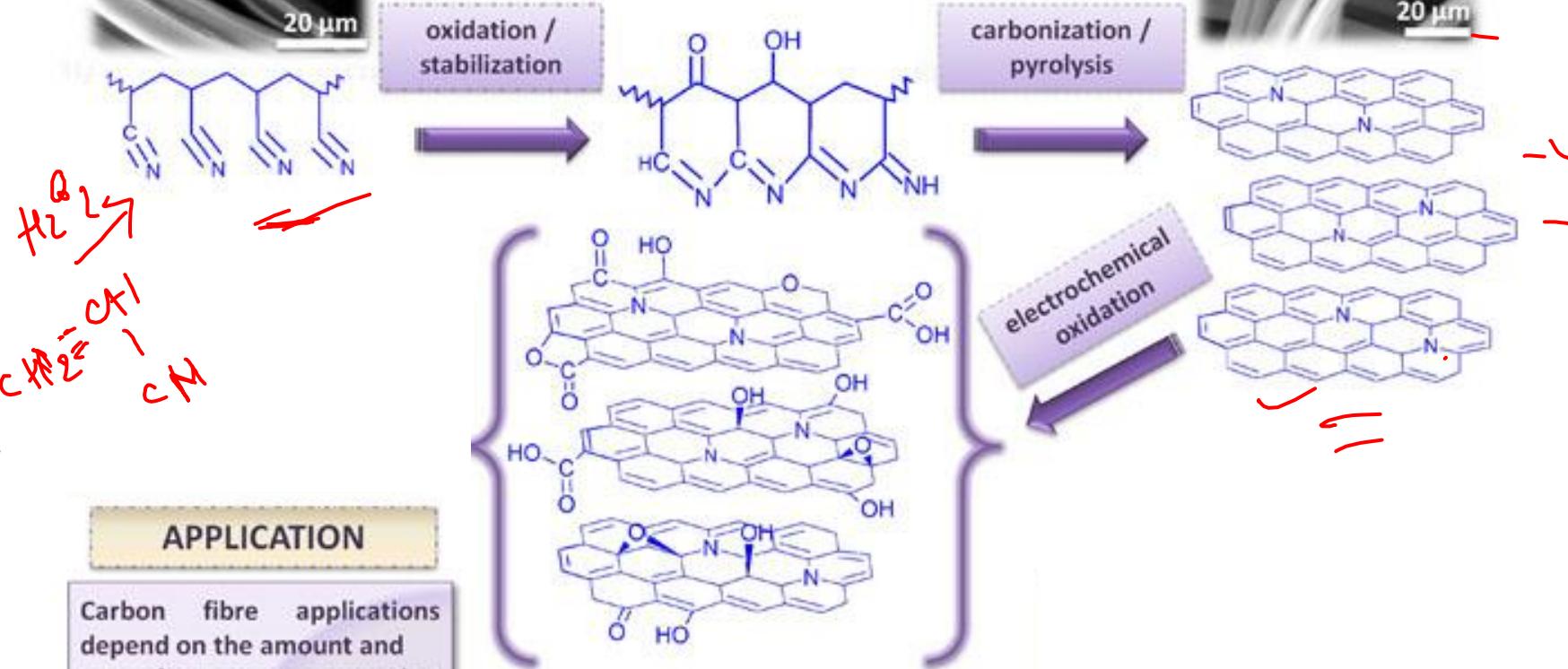
Made from two types of precursor materials:

- ✓ 1) Polyacrylonitrile (PAN) (PAN Based)
- ✓ 2) Rayon Pitch - residue of petroleum refining (Pitch Based)



PROCESSING

Carbon Fibres



Advanced Fibres

Carbon fibres:

- Precursor fiber is carbonized rather than melting
- Filaments are made by controlled **pyrolysis** (chemical deposition by heat) of a precursor material in fiber form by heat treatment at temperature 1000-3000° C
- Different fibers have different morphology, origin, size and shape. The morphology is very dependent on the manufacturing process.
- The size of individual filament ranges from 3 to 14 μm . Hence, very flexible.
- Maximum temperature of use of the fibers ranges from 250 °C to 2000 °C. Properties changes with temperature at higher temperature.
- The maximum temperature of use of a composite is controlled by the use temperature of the matrix
- Modulus and strength is controlled by the process-thermal decomposition of the organic precursor under well controlled conditions of temperature and stress
- Heterogeneous microstructure consisting of numerous lamellar ribbons
- Thus, carbon fibers are anisotropic in nature



Advanced Fibres

Organic fibres: Aramid fibres

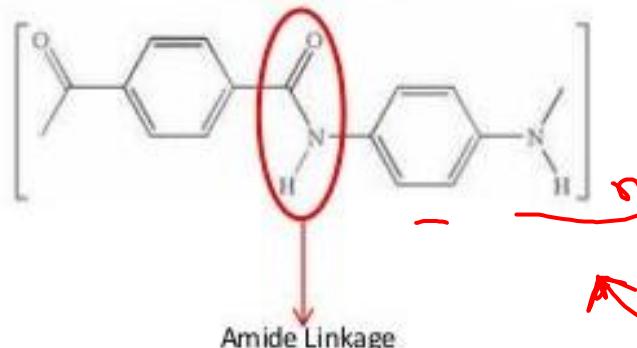
- Aromatic polyamide – family of nylons.
- Polyamide 6 = nylon 6, Polyamide 6.6 = nylon 6.6
- Melt-spun from a liquid solution
- Morphology – radially arranged crystalline sheets resulting into anisotropic properties
- Filament diameter about $12 \mu\text{m}$ and partially flexible
- High tensile strength
- Intermediate modulus
- Very low elongation up to breaking point
- Significantly lower strength in compression
- Du Pont developed these fibers under the trade name Kevlar. From poly (p-Phenylene terephthalamide (PPTA) polymer
- 5 grades of Kevlar with varying engineering properties are available
kevlar-29, Kevlar-49, Kevlar-100, Kevlar-119, Kevlar-129



Chemical Structure

Kevlar:

1. Polymer Structure:



2. Charge Distribution Over Polymer:

These Linkages are attached to para positions of aromatic rings that's why called as para-aramids.

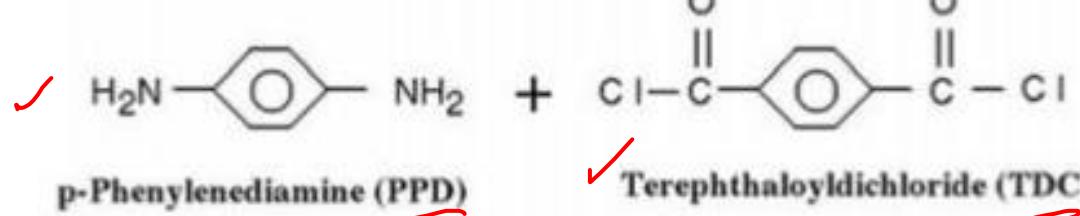
- Positive Charge
- Negative Charge



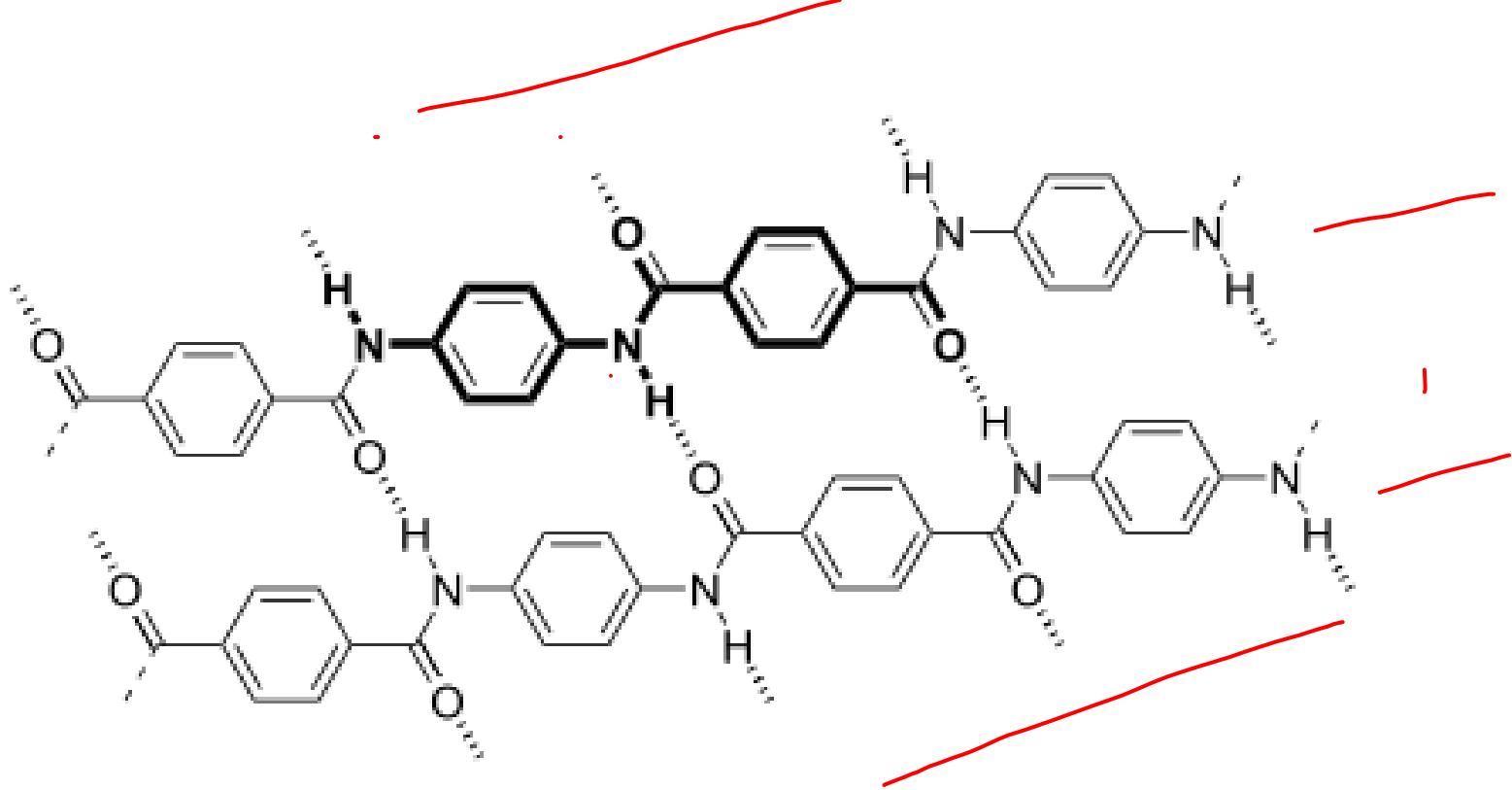
Structure Shows there is greater amount of negative charge on polymer



3. Monomers:



Due to these monomers IUPAC name of polymer is poly(para-phenylene terephthalamide)



Structure of Kevlar. The aromatic rings are attached alternately to either two NH groups or two CO groups. The attachment points on each ring are diametrically opposite each other, meaning this is classed as a para – aramid.

Structural composite

A structural composite is a multi-layered and normally low-density composite used in applications requiring structural integrity, ordinarily high tensile, compressive, and torsional strengths and stiffnesses.

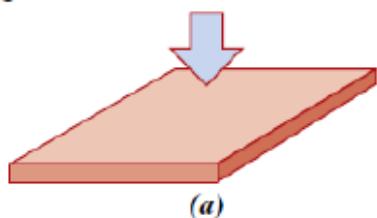
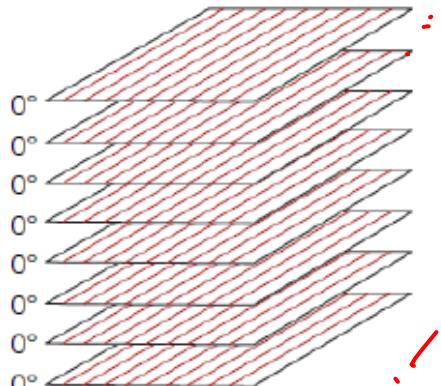
Laminar composites and sandwich panels are two of the most common structural composites.

- Advanced composite parts are produced using successive layers of fabrics. Each layer is referred to as a “**ply**”, multiple plies of resinimpregnated fabric strongly consolidated create a “**laminate**”.
- A laminar composite is composed of two-dimensional sheets or panels (**plies or laminae**) bonded to one another

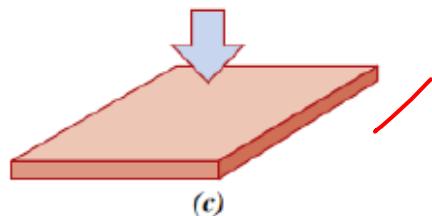
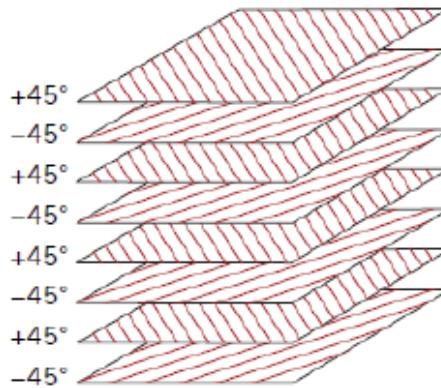
Four classes of laminar composites

Unidirectional

The orientation of the high-strength direction for all laminae is the same

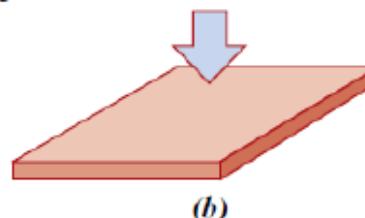
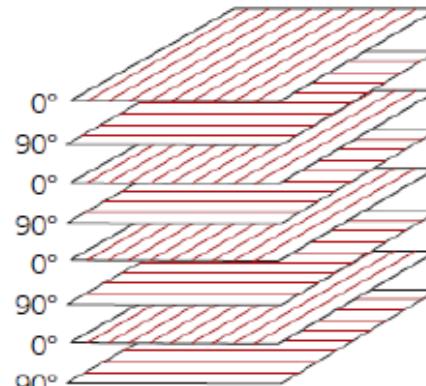


Angle-ply

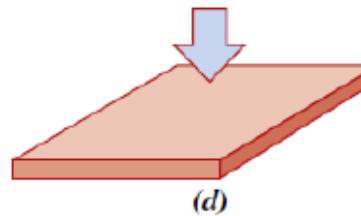
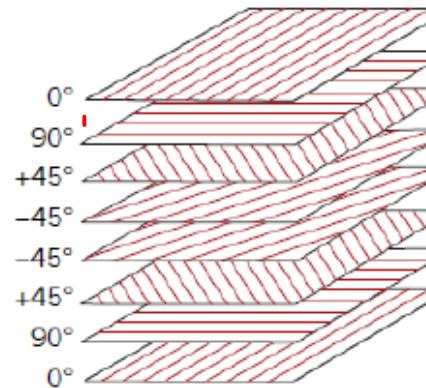


Cross-ply

alternating



Multidirectional



Laminate properties:

- The adhesive properties of the matrix system bonding the fibers and layers together.
- The fiber type used within each layer.
- The geometry or fiber angle in each layer.
- The ratio between matrix and reinforcement.

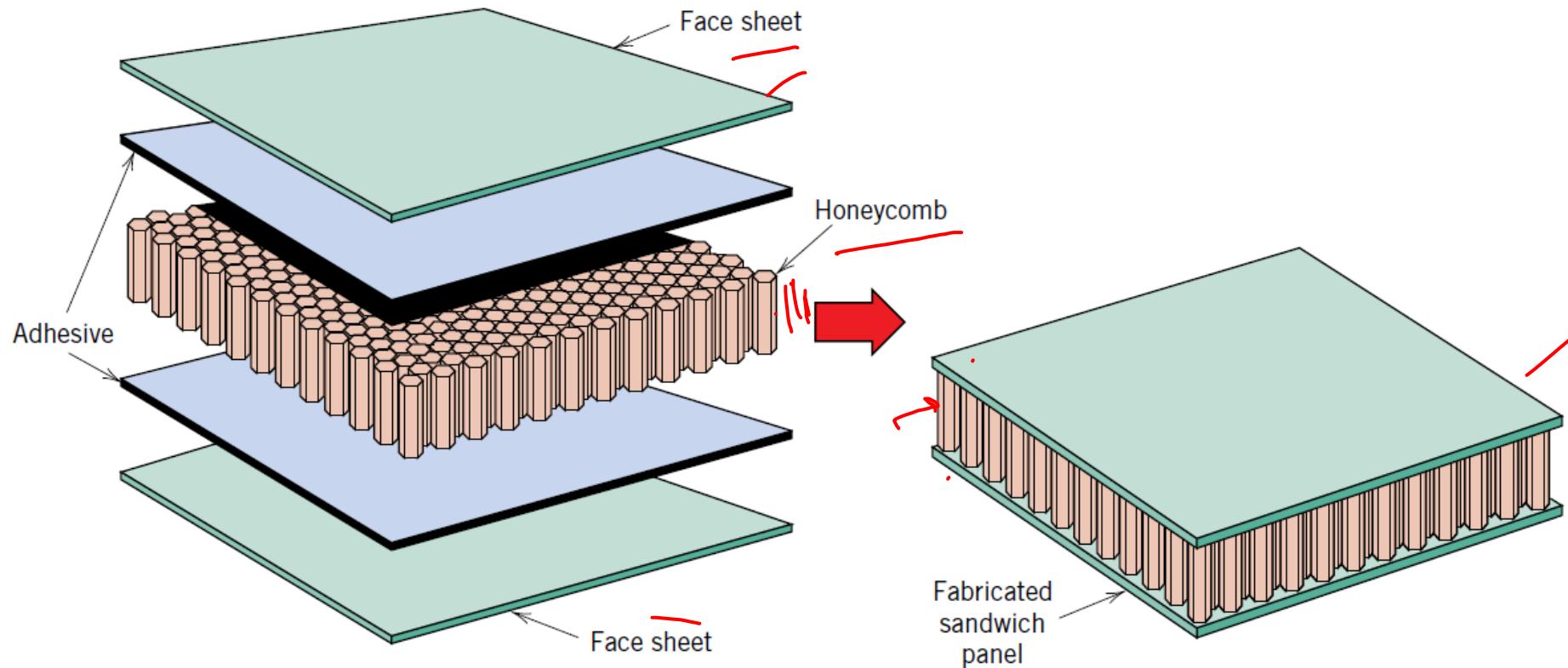
Applications:

Aircraft—fuselage, vertical and horizontal stabilizers, landing-gear hatch, floors, and rotor blades for helicopters; automotive-automobile panels, sports car bodies, and drive shafts.

Building/civil-infrastructure—**bridge components**, long-span roof structures, beams, structural panels, roof panels, and tanks

Sandwich Panels

A class of structural composites, are designed to be lightweight beams or panels having relatively high stiffnesses and strengths. A sandwich panel consists of two outer sheets, faces, or skins that are separated by and adhesively bonded to a thicker core



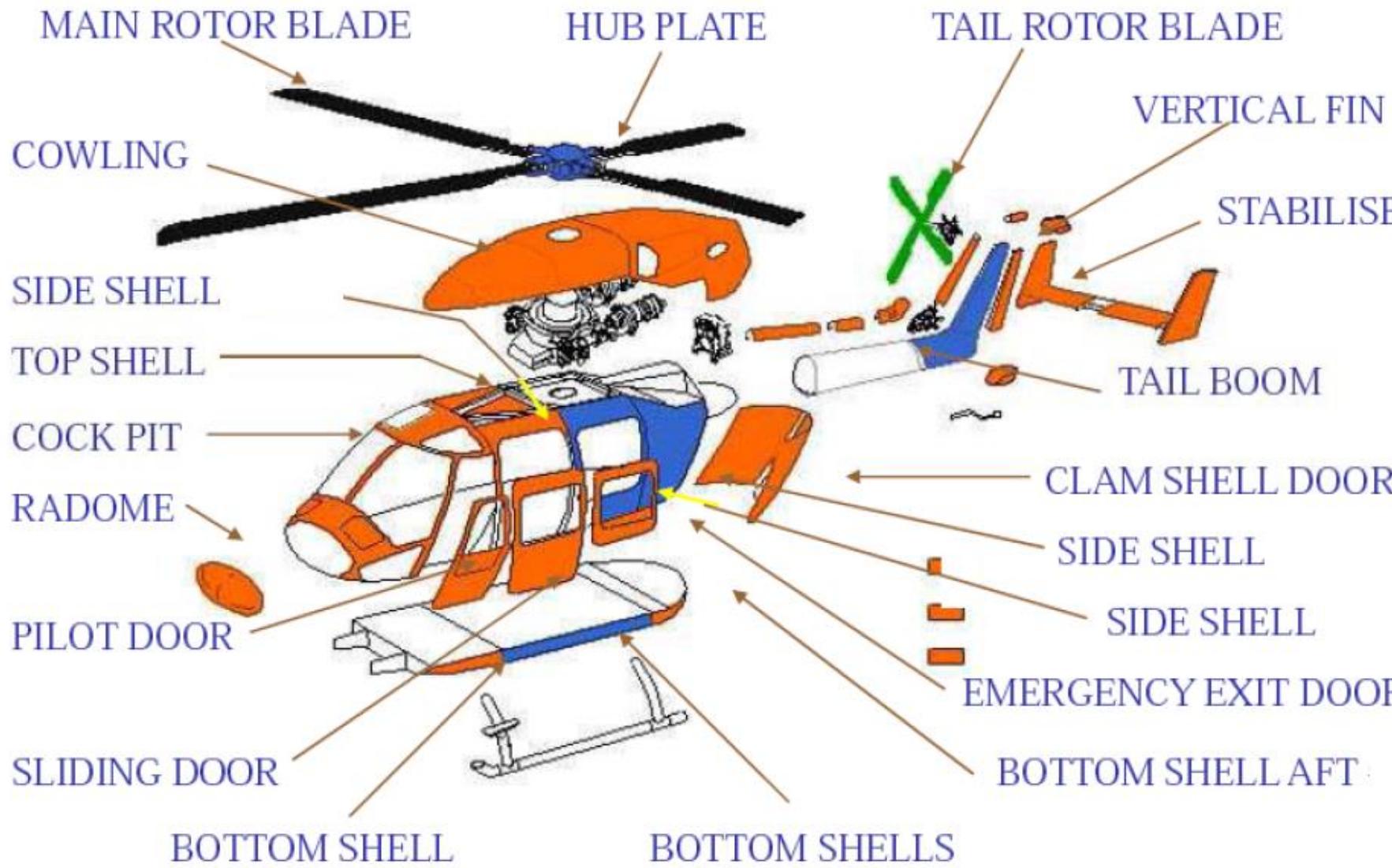
The outer sheets are made of a relatively stiff and strong material, typically aluminum alloys, steel and stainless steel, fiber-reinforced plastics,

The core material is lightweight and normally has a low modulus of elasticity. Structurally, it serves several functions.

1- Provides continuous support for the faces and holds them together.

Applications: Sandwich panels are used in a wide variety aircraft, construction, automotive, and marine applications, including the following: aircraft—leading and trailing edges, radomes, fairings, nacelles (cowlings and fan-duct sections around turbine engines), flaps, rudders, stabilizers, and rotor blades for helicopters; construction-architectural cladding for buildings, decorative facades and interior surfaces, insulated roof and wall systems, clean-room panels, and built-in cabinetry; automotive—headliners, luggage compartment floors, spare wheel covers, and cabin floors; marine—bulkheads, furniture, and wall, ceiling, and partition panels.

Aerospace: Use of composites in LCH



Nanotechnology: Designing Materials Atom by Atom

Nano = 10^{-9} or one billionth of a meter

SIZE

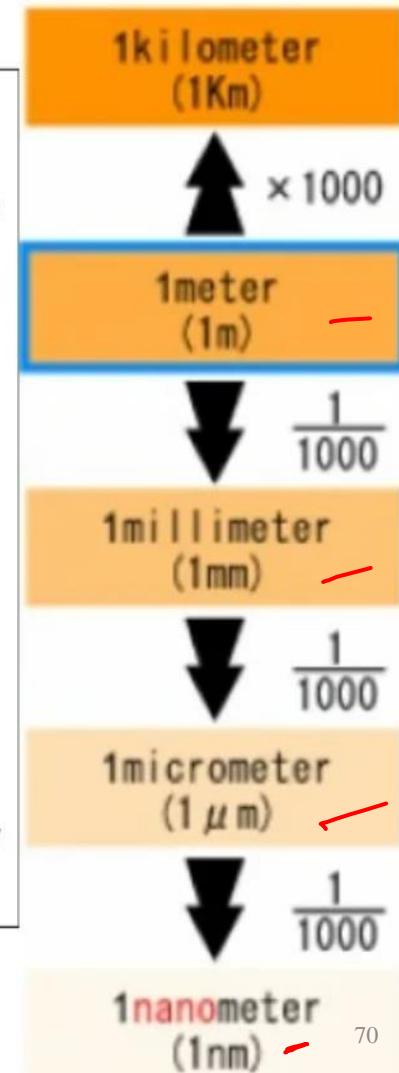
A **meter** is about the distance from the tip of your nose to the end of your hand (1 meter = 3.28 feet).

Millimeter- One thousandth of meter. (10^{-3} m)

Micron: a micron is a millionth of a meter (or) one thousandth of millimeter (10^{-6} m)

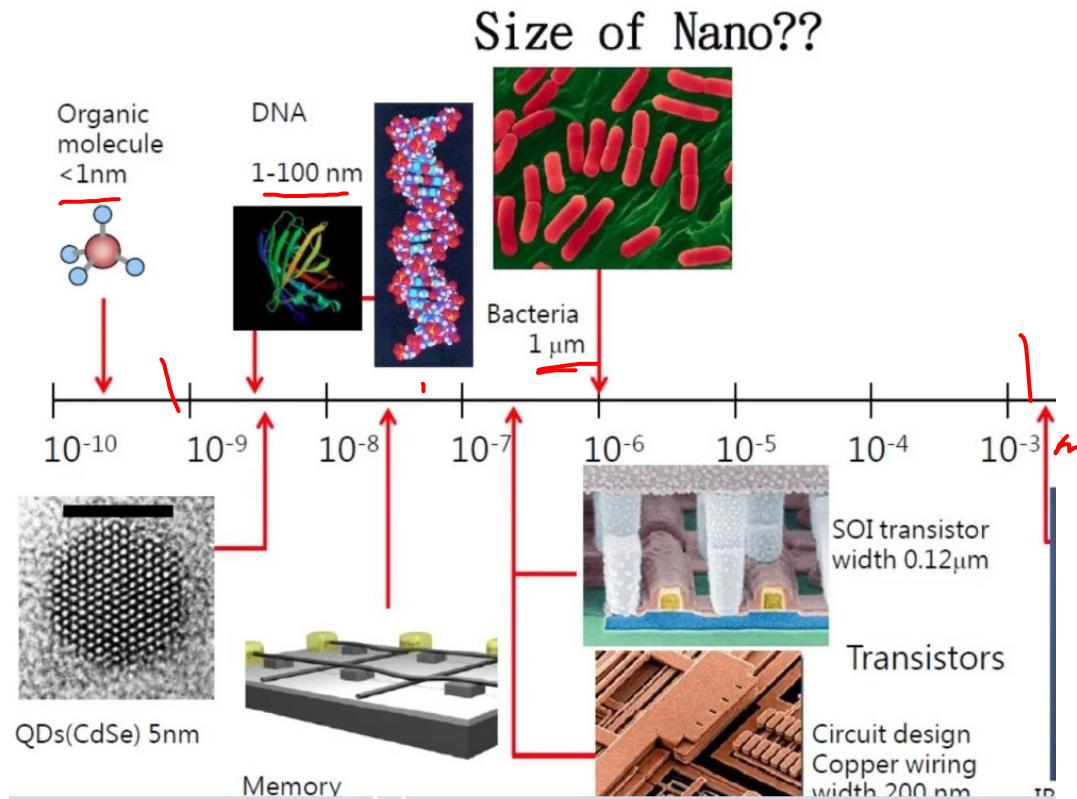
Nanometer:

A nanometer is one thousandth of a micron (10^{-9} m)
(or) a billionth of a meter. ie., **one billion nanometers in a meter.**



Nanotechnology

- **Nanotechnology** is the science and engineering of nanoscale systems, whose sizes range from 1 to 100 nm. A nanometer is one millionth of a millimeter - approximately 100,000 times smaller than the diameter of a human hair.
- Nanomaterials are of interest because at this scale unique optical, magnetic, electrical, and other properties emerge. These emergent properties have the potential for great impacts in electronics, medicine, and other fields.



Nanotechnology



Fig. (2): Nanomaterial (For example: Carbon nanotube)

Why Nano Particles ?

Nanoparticles are of interest because of the new properties (such as chemical reactivity and optical behaviour) that they exhibit compared with larger particles of the same materials.

For example, titanium dioxide and zinc oxide become transparent at the nano scale and have found applications in sunscreens.

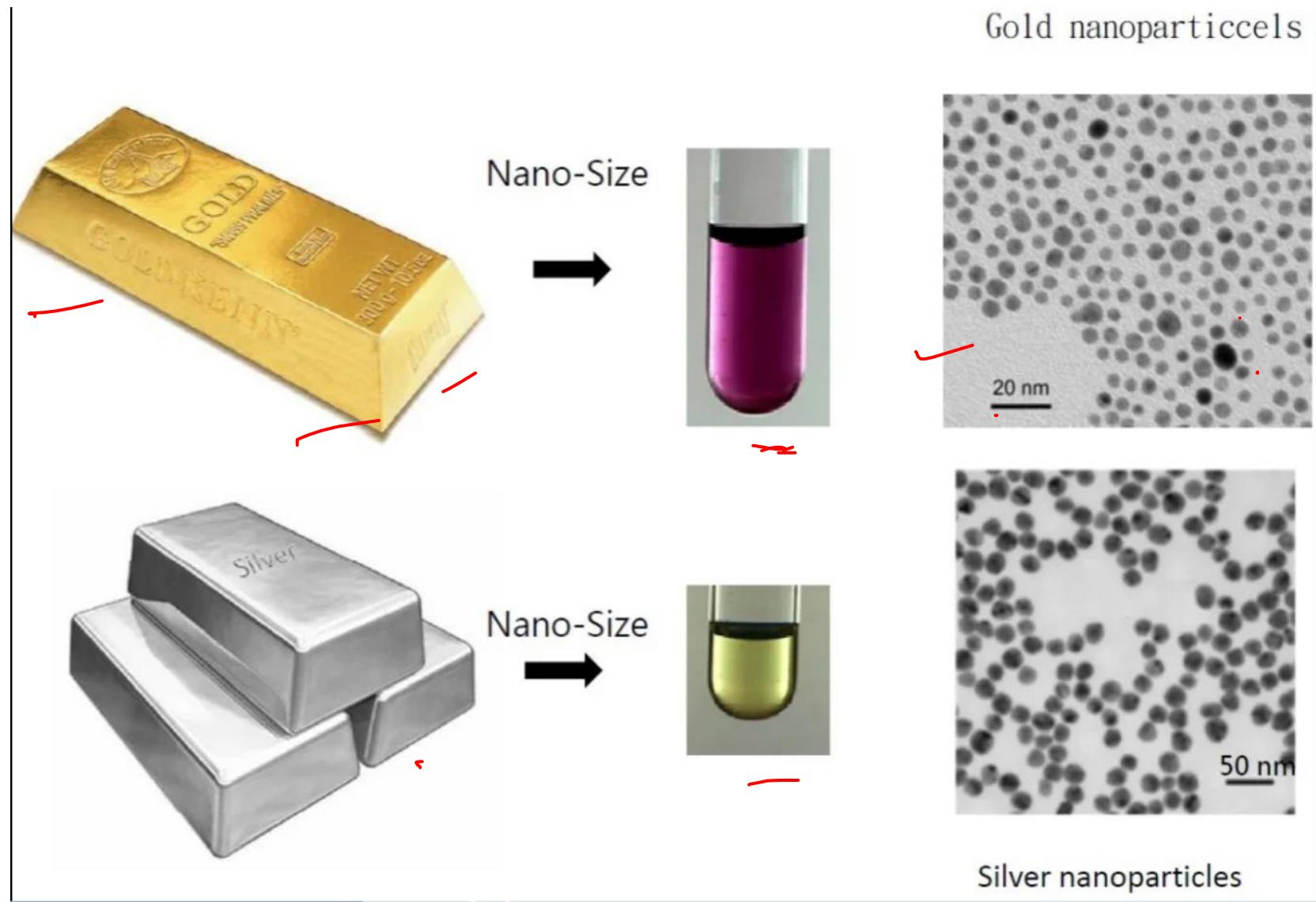
Nano particles have a range of potential applications:

In the short-term application such as in **cosmetics, textiles and paints**.

In the longer term applications such as **drug delivery** where they could be used to deliver drugs to a specific site in the body.

Nano particles can also be arranged into layers on surfaces, **providing a large surface area and hence enhanced activity, relevant** to a range of potential applications such as catalysts.

Nanoparticle

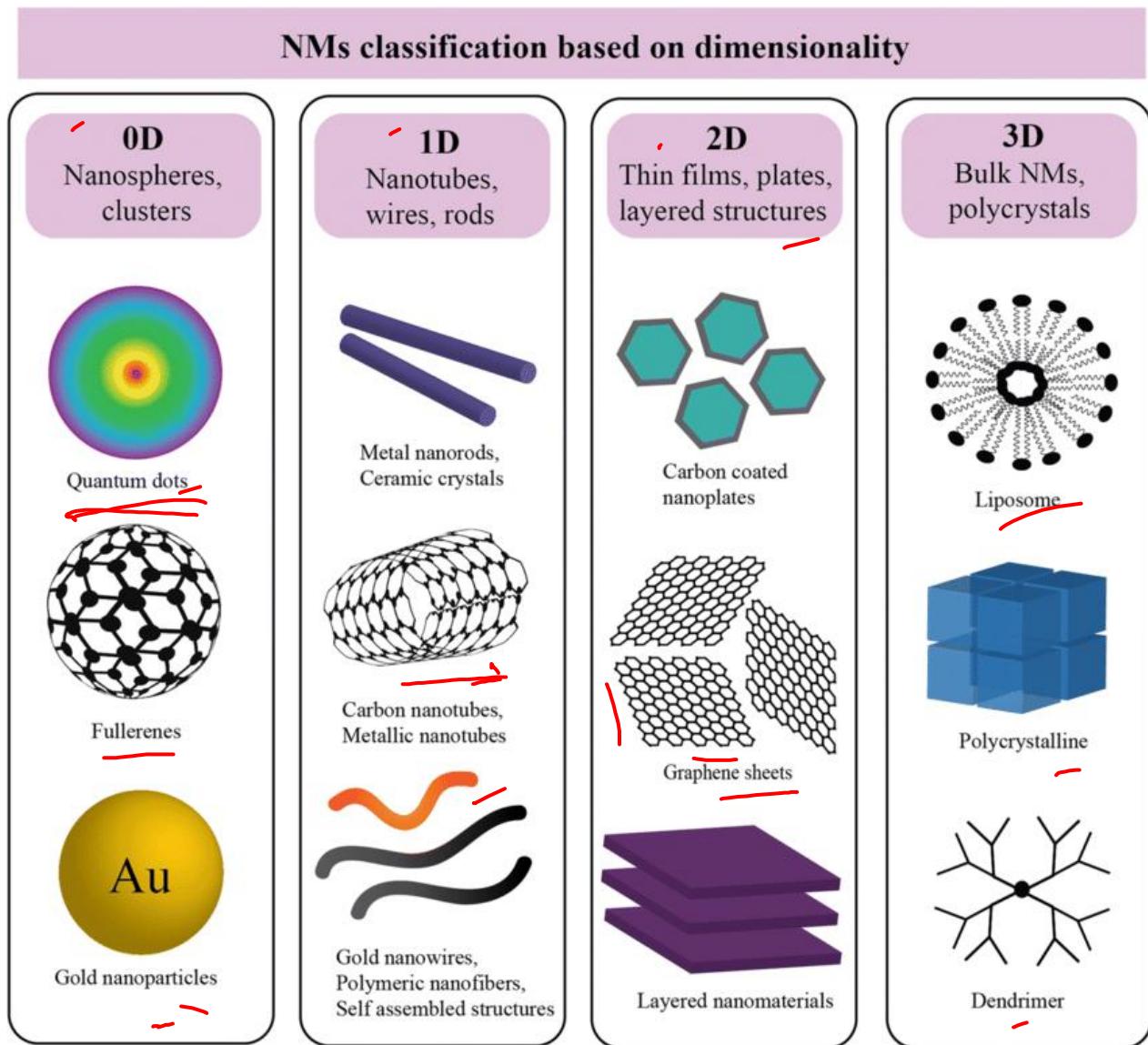


Nanomaterials

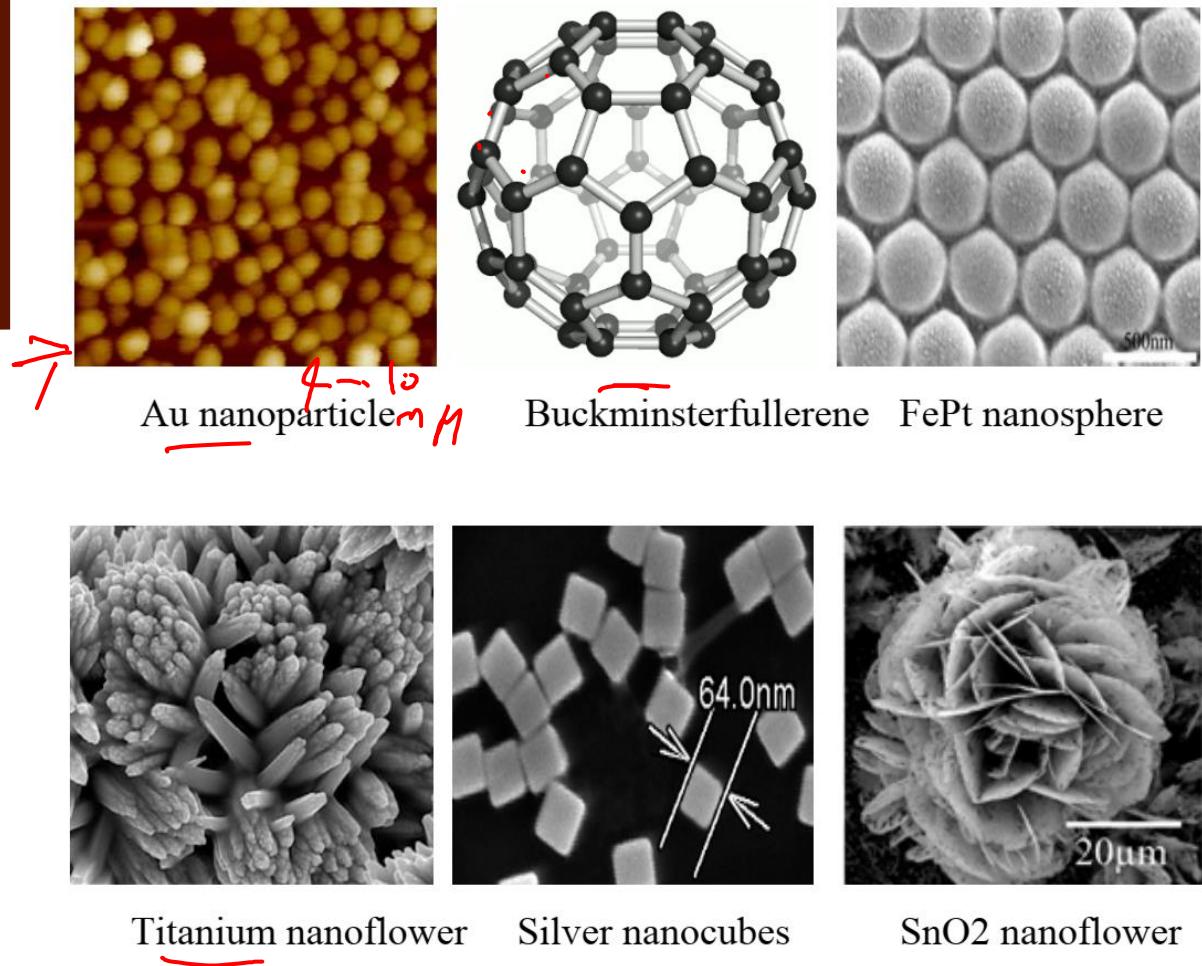
- Some nanomaterials occur naturally, but of particular interest are engineered nanomaterials (EN), which are designed for, and already being used in many commercial products and processes.
- Nanomaterials at the nano scale can have different properties than their conventional, bulk counterparts.
- The two main reasons why materials at the nano scale can have different properties are increased relative surface area and new quantum effects.
- ~~✓~~ Nanomaterials have a much greater surface area to volume ratio than their conventional forms, which can lead to greater chemical reactivity and affect their strength.
- ~~✓~~ Also at the nano scale, quantum effects can become much more important in determining the materials properties and characteristics, leading to novel optical, electrical and magnetic behaviors.
- ~~✓~~ Nanomaterials are already in commercial use, with some having been available for several years or decades. The range of commercial products available today is very broad, including stain resistant and wrinkle-free textiles, cosmetics, sunscreens, electronics, paints and varnishes.

Classification of Nanomaterials

Nanomaterials can be created with various modulation dimensionalities as defined by Richard W. Siegel: zero (atomic clusters, filaments and cluster assemblies), one (multilayers), two (ultrafine-grained overayers or buried layers), and three (nanophase materials consisting of equiaxed nanometer sized grains) as shown in the below.

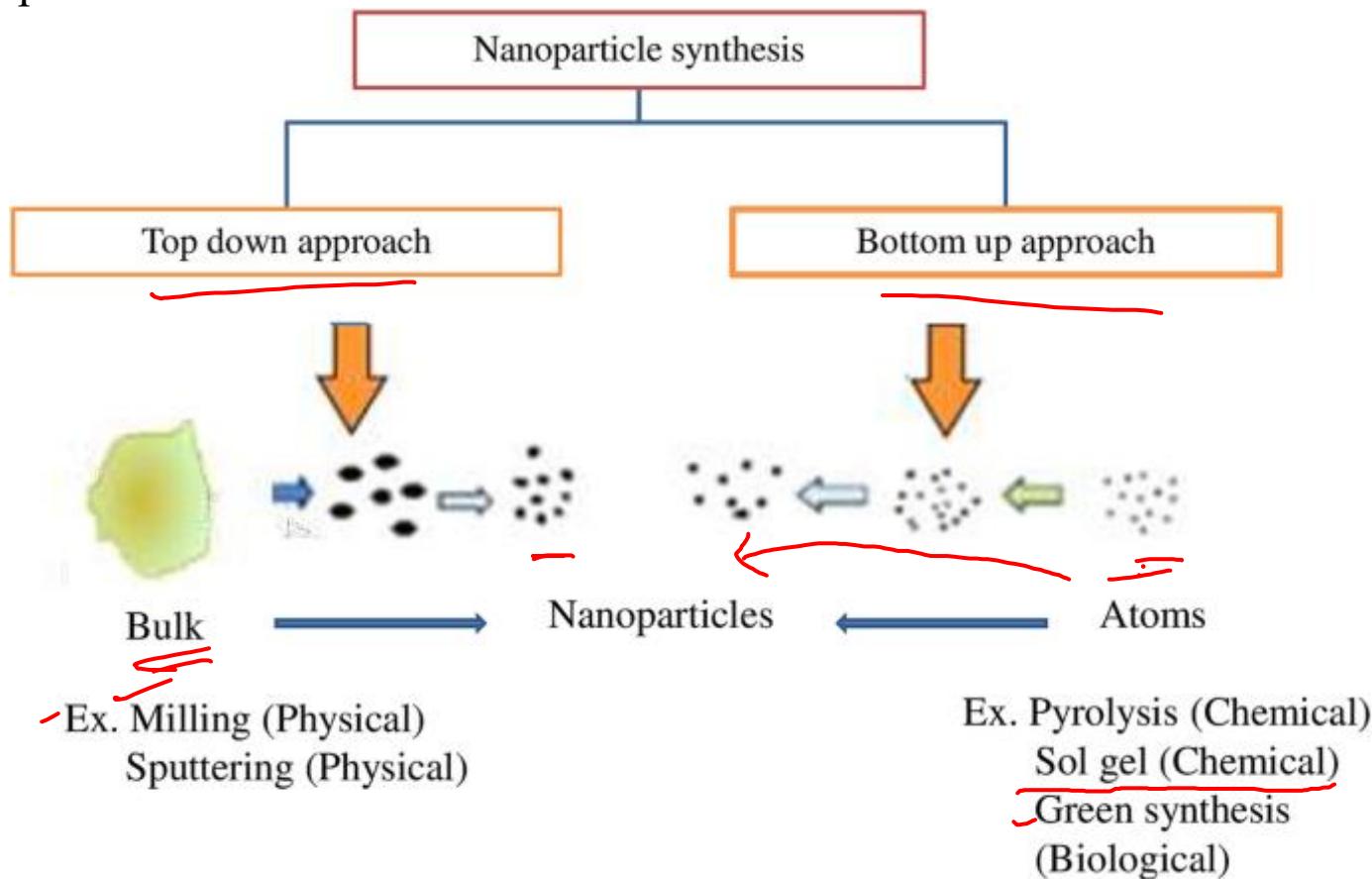


Examples of Nanomaterials



NANOMATERIAL SYNTHESIS

Both the ‘bottom up’ or the ‘top down’ approaches can be used to synthesize nanomaterials, i.e. either to assemble atoms together or to dis-assemble (break or dissociate) bulk solids into finer pieces until they are constituted of only a few atoms. This domain is a pure example of interdisciplinary work encompassing physics, chemistry, and engineering up to medicine.



Methods for creating nanostructures

- Nano-particles
 - Sol-gel; high-energy ball milling, hydrothermal
- Nano-tube, nano-wire, nano-rod and nano-belt
 - Evaporation (Science 291 (2001) p 1947)
 - Laser ablation (Science 279 (1998) p 208)
 - Anodization (J. Mater. Res. 16 (2001) p 3331)
 - Electro-spinning (Nano lett. 3 (2003) p 555)
 - **Surface modification** (Adv. Matls., 16[3] (2004) p 260, in print)
- Nano-porous structures
 - Emulsion templating (J. Mater. Res. 18 (2003) p 156)
 - Photo-electrochemical etching (Electrochem. Solid-State. Lett. 1 (1998) p 175)

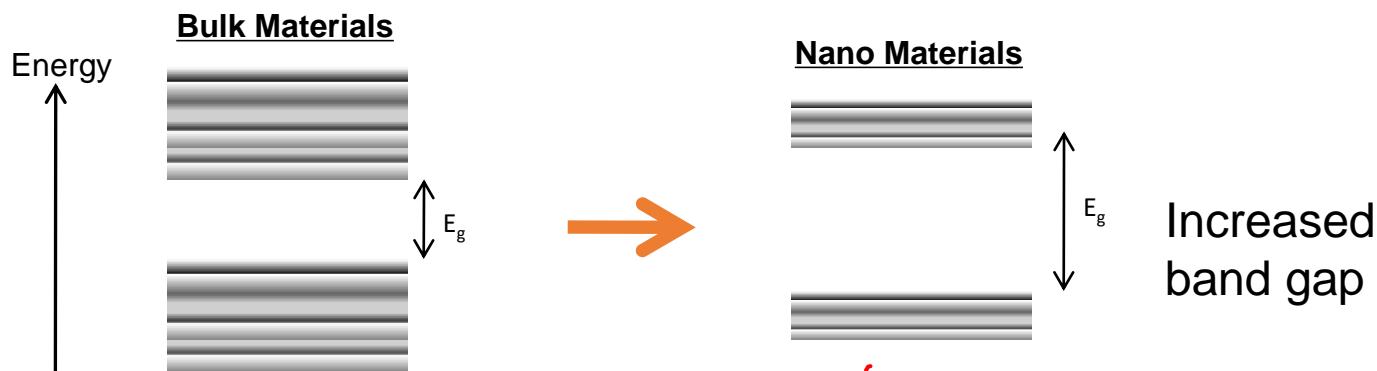
Size Dependent Properties of Nanomaterials

The various properties, which get tremendously altered due to the size reduction in at least one dimension are:

- ~~a)~~ Chemical properties: Reactivity; Catalysis.
- b) Thermal property: Melting point temperature.
- c) Electronic properties: Electrical conduction.
- d) Optical properties: Absorption and scattering of light.
- e) Magnetic properties: Magnetization.

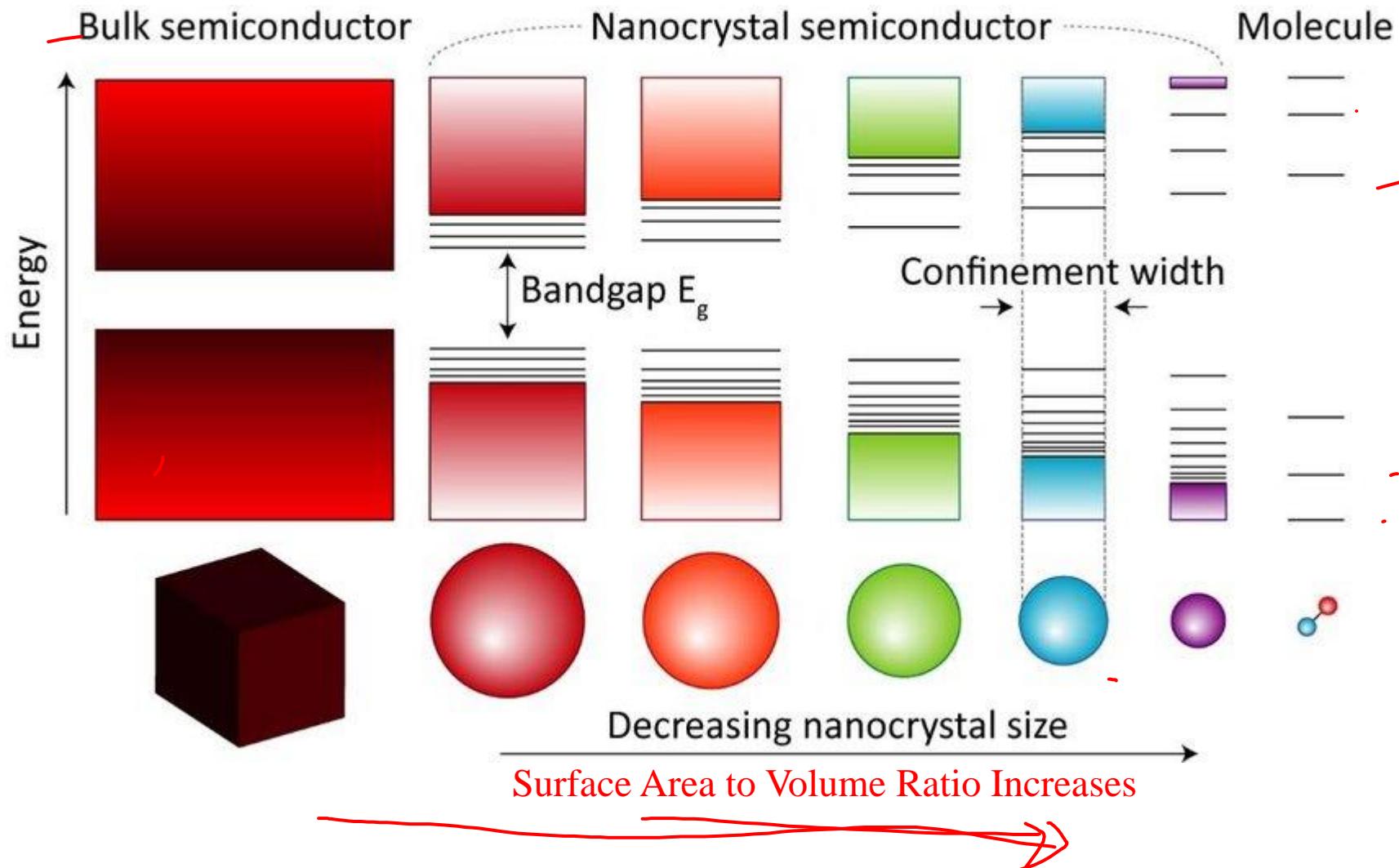
Electronic Properties

- In bulk materials, conduction of electrons is delocalized, that is, electrons can move freely in all directions.
- When the scale is reduced to nanoscale, the quantum effect dominates. Therefore no electron delocalization (freedom to move) occurs.

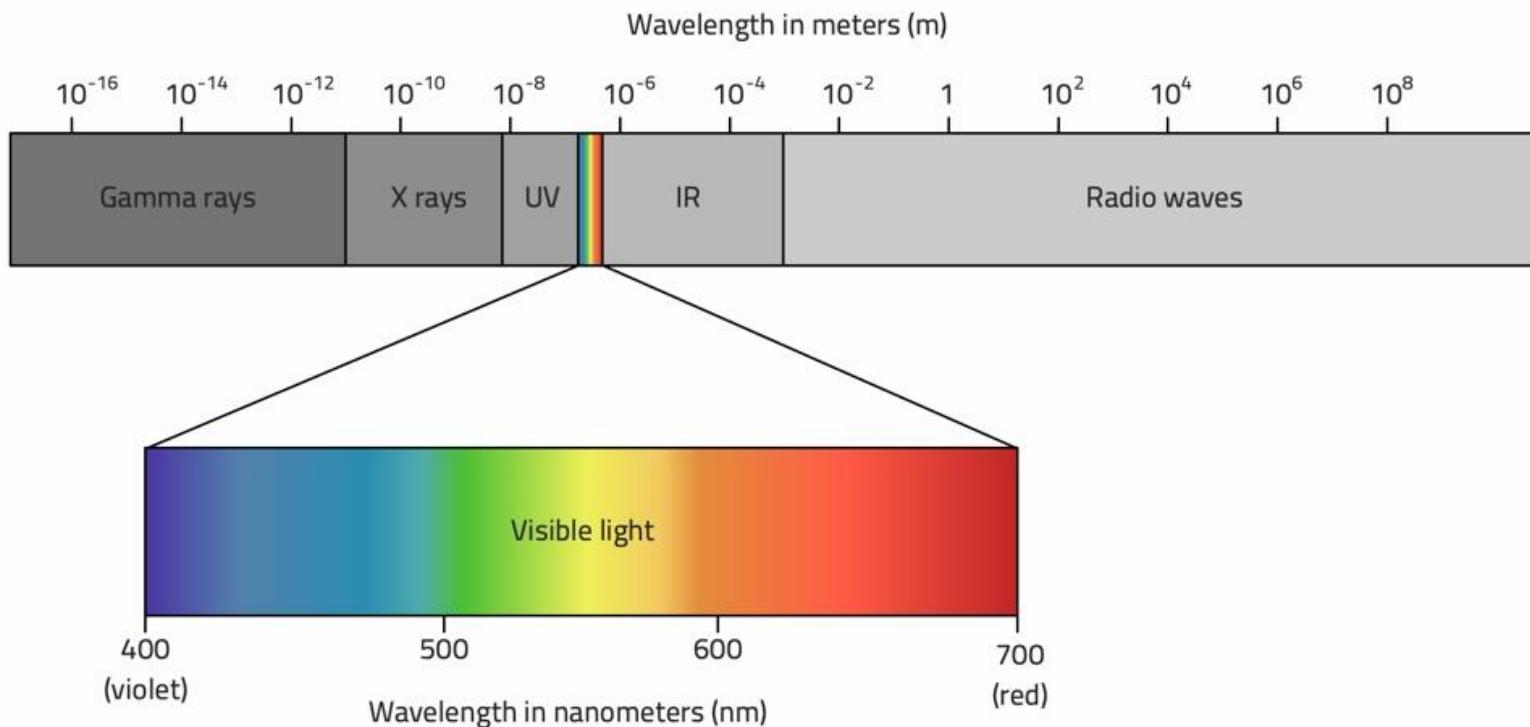


- For one dimensional nanomaterials, electrons confinement occurs in 2-D space and hence electron delocalization takes place along the axis of nanotubes/nanorods/nanowires.
- **Due to electron confinement, the energy bands are replaced by discrete energy states which make the conducting materials to behave like either semiconductors or insulators**

Size Dependent Optical Properties

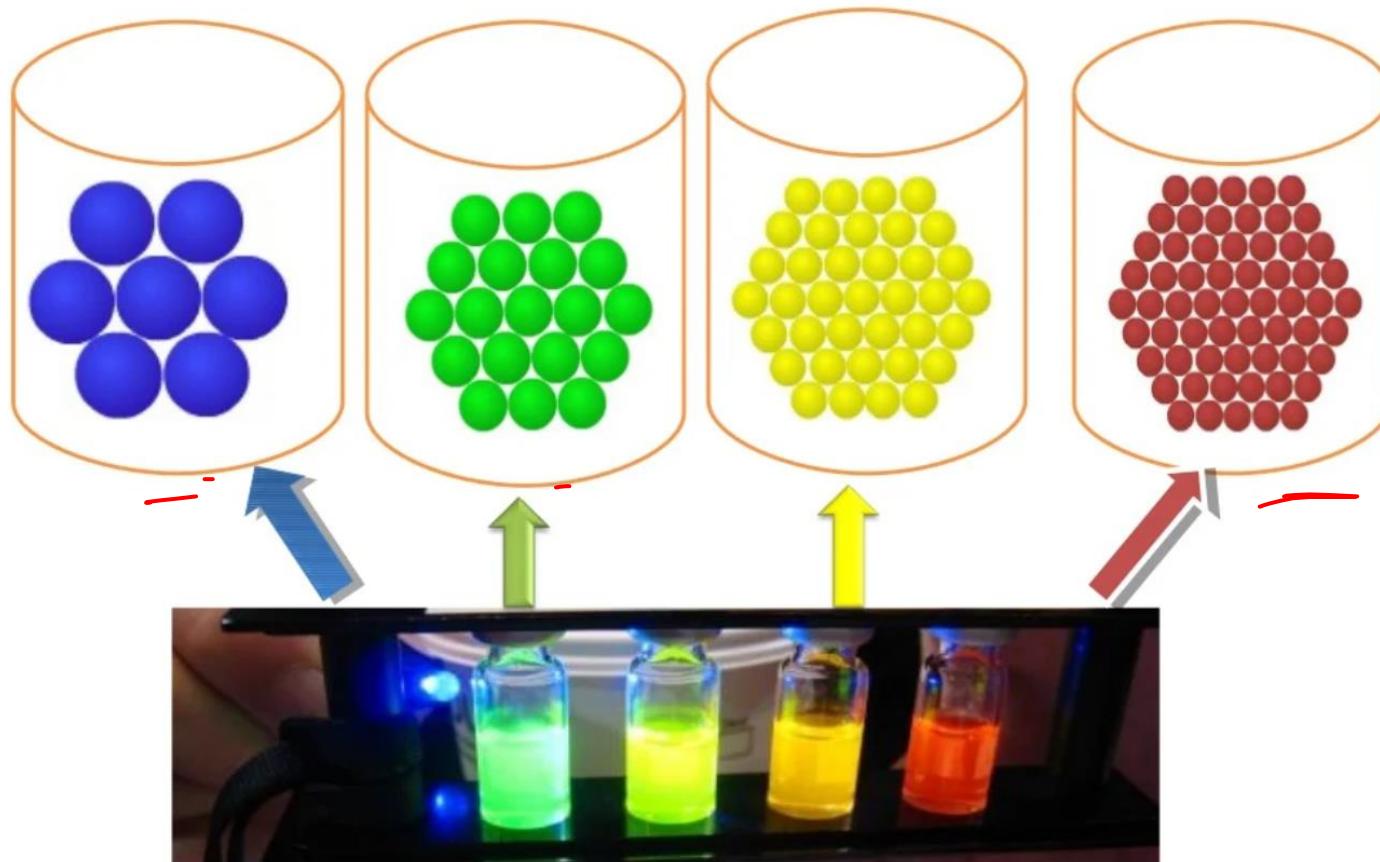


Nanocrystals are also called **Quantum Dots**



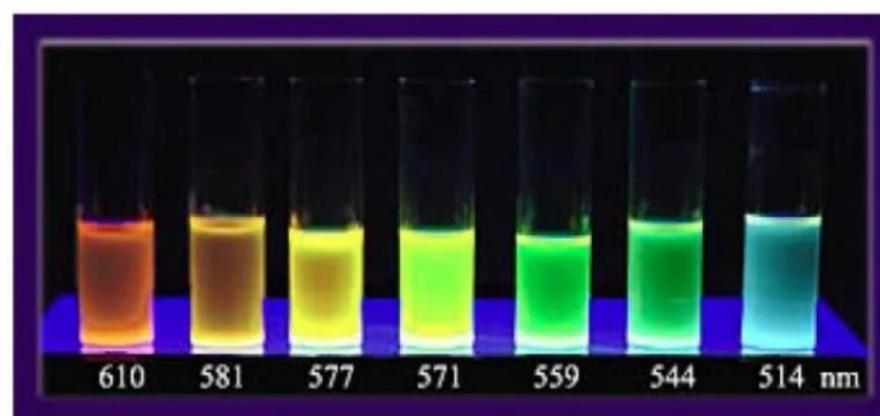
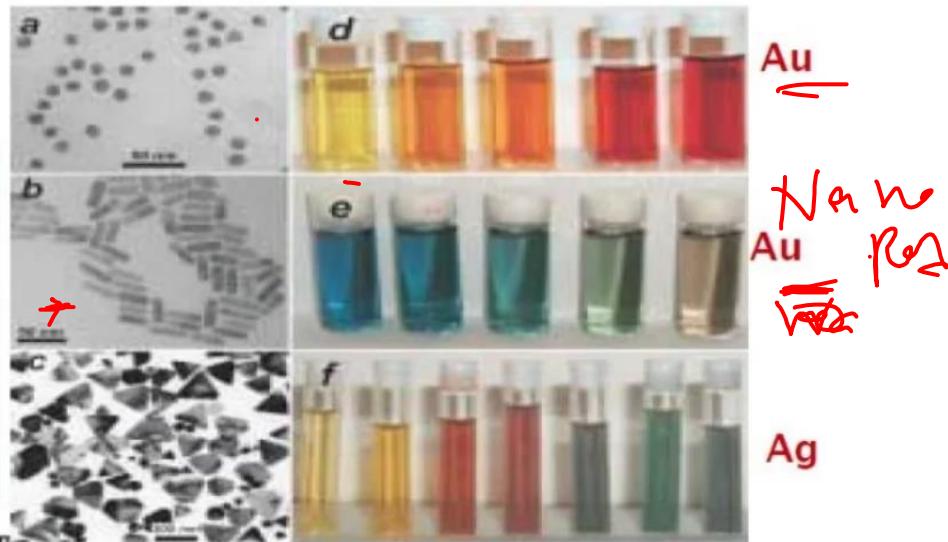
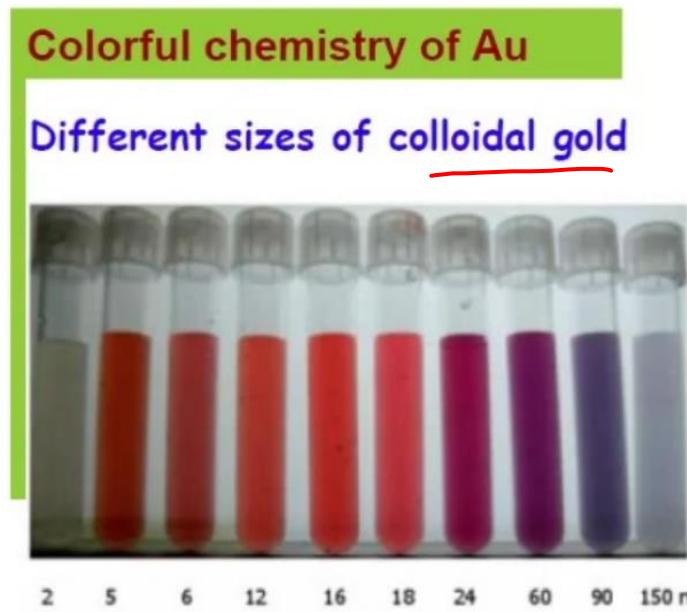
Size increases	Band gap decreases	Emission wavelength increases
Size decreases	Band gap increases	Emission wavelength decreases

Match the following nanocrystals of different sizes with their emission color



As the size of the particle decreases <10 nm, surface to volume ratio increases which alters the physical properties (optical-blue shift, energy gap increases, boiling point decreases etc.

Match the following nanocrystals of different sizes with their emission color



Band gap depends on particle size

Chemical Properties

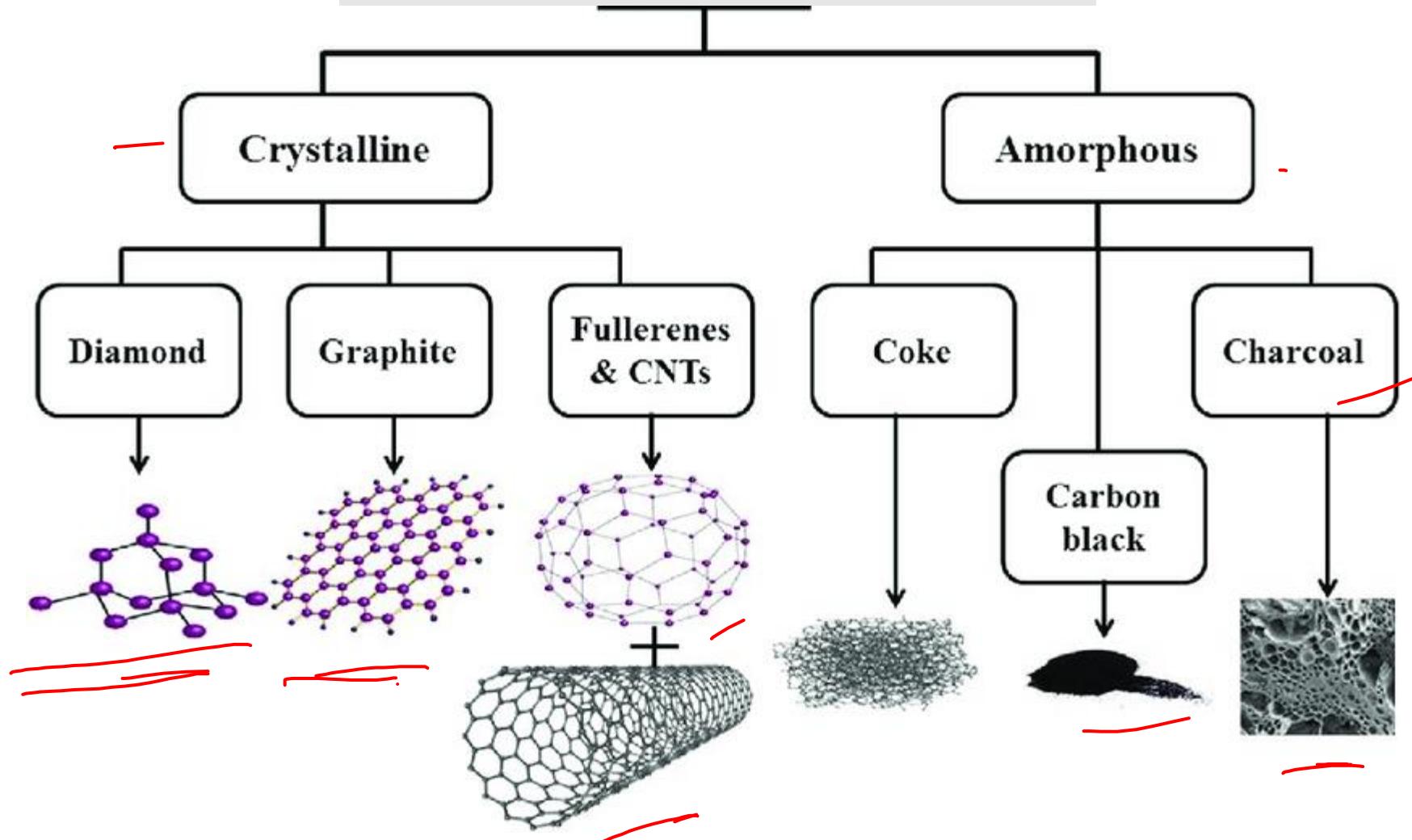
Based on the surface area to volume effect, nanoscale materials have:

- a) Increased total surface area.
- b) Increased number of atoms accessible on the surface.
- c) Increased catalytic activity of those large number surface atoms.
- d) Different/tunable surface catalytic properties by the change in shape, size and composition.

Hence, nanoscale catalysts can increase the rate, selectivity and efficiency of various chemical reactions.

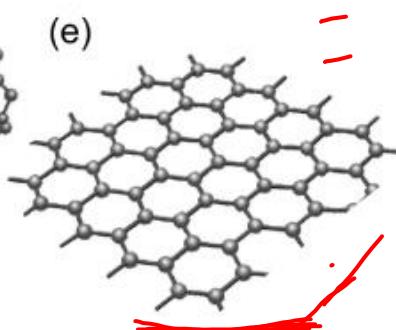
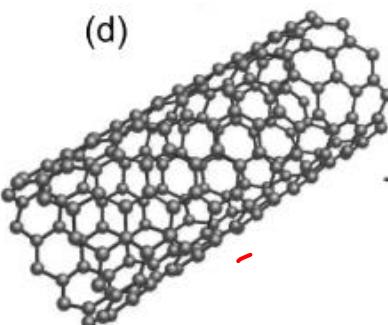
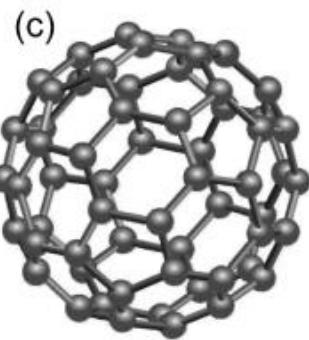
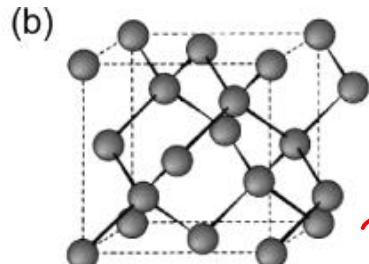
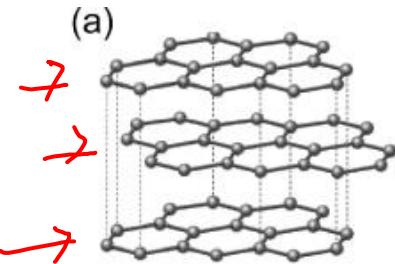


Allotropes of carbon



- **Nanoscale**: Approximately 1 to 1000 nm size range.
- **Nanoscience**: The science and study of matter at the nanoscale that deals with understanding their size and structure-dependent properties and compares the emergence of individual atoms or molecules or bulk material related differences.
- **Nanotechnology**: Manipulation and control of matter on the nanoscale dimension by using scientific knowledge of various industrial and biomedical applications.
- **Nanomaterial**: Material with any internal or external structures on the nanoscale dimension.
- **Nano-object**: Material that possesses one or more peripheral nanoscale dimensions.
- **Nanoparticle**: Nano-object with three external nanoscale dimensions. The terms nanorod or nanoplate are employed, instead of nanoparticle (NP) when the longest and the shortest axes lengths of a nano-object are different.
- **Nanofiber**: When two similar exterior nanoscale dimensions and a third larger dimension are present in a nanomaterial, it is referred to as nanofiber.
- **Nanocomposite**: Multiphase structure with at least one phase on the nanoscale dimension.
- **Nanostructure**: Composition of interconnected constituent parts in the nanoscale region.
- **Nanostructured materials**: Materials containing internal or surface nanostructure.

Carbon Materials



Forms of carbon:

- a) Graphite 3D**
- b) Diamond 3D**
- c) Buckminsterfullerene
“Buckyballs” 0D**
- d) Carbon nanotube 1D**
- e) Graphene 2D**



Andre Geim



2010 Nobel Prize in Physics

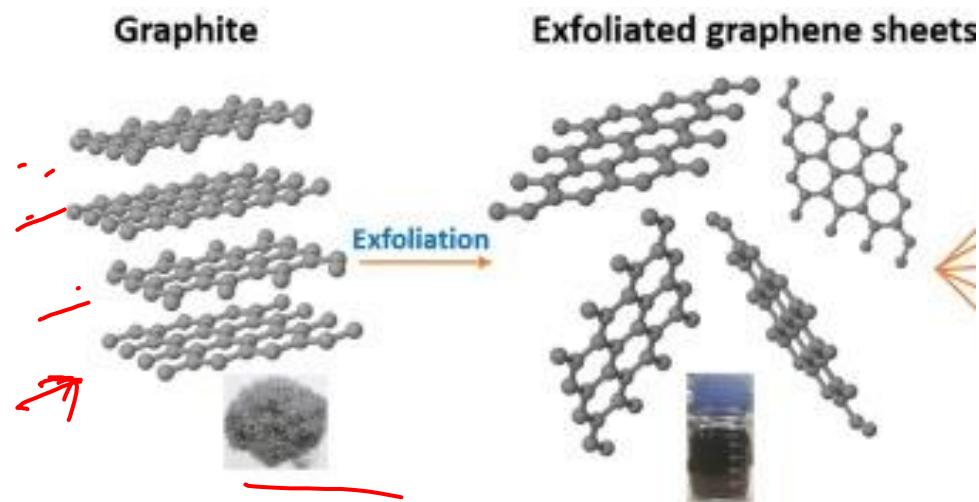


Konstantin Novoselov

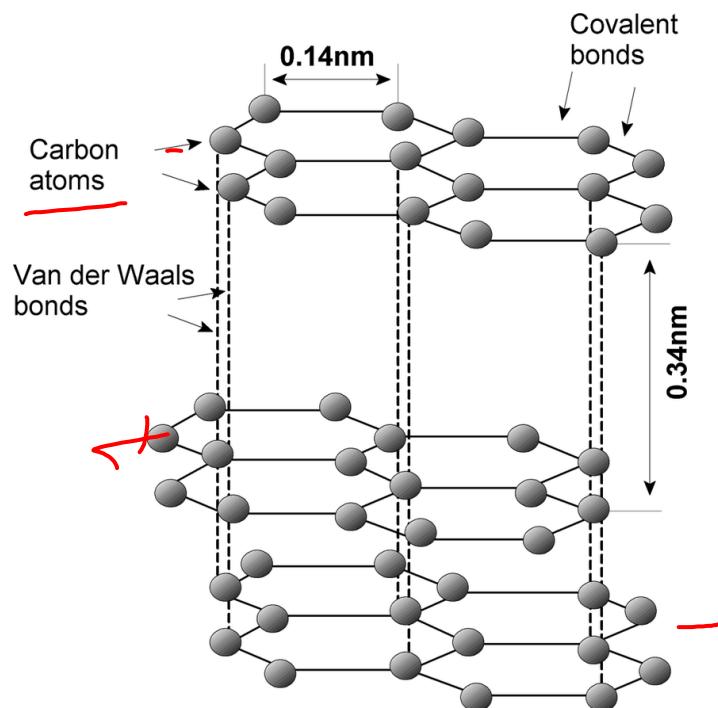
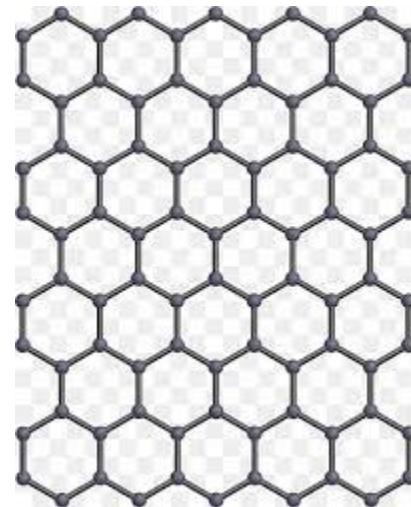
http://www.nobelprize.org/nobel_prizes/physics/laureates/2010/

Graphene

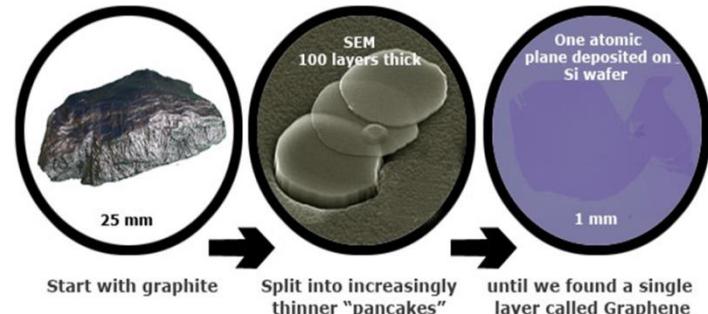
- Single layer of graphite
- Graphene physically acts as a 2-Dimensional material
- Honeycomb (hexagonal) lattice



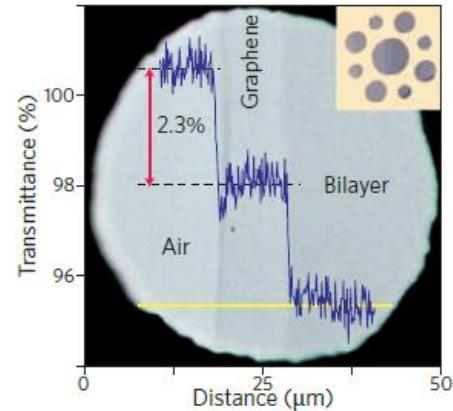
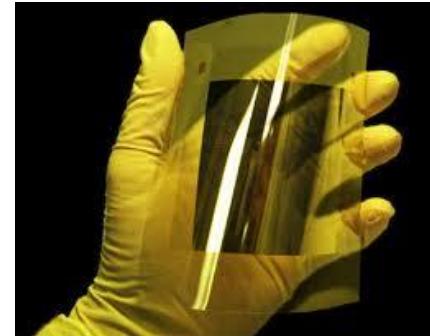
- The length of the C-C bond is $\sim 0.142, and the thickness of the layer is 0.35 nm .$
- The adjacent π bonds couple with each other to form the basis of graphene conduction



Properties of graphene

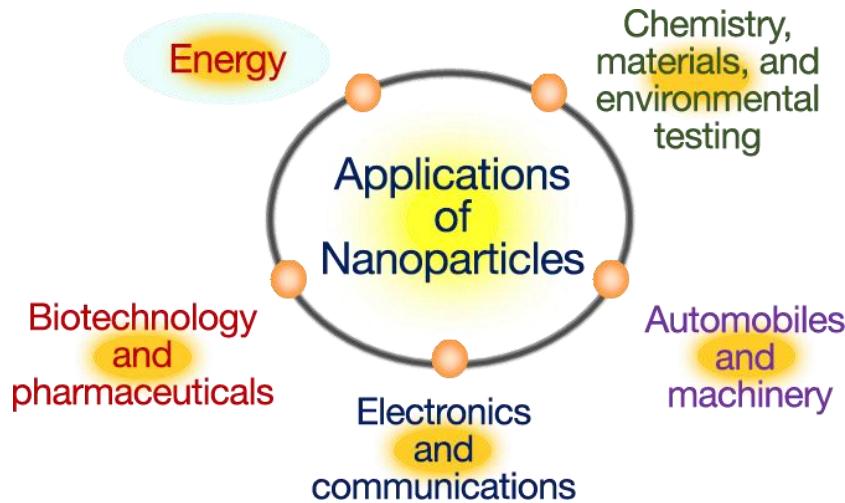


- ✓ Thinnest material possible (~0.345 nm thick)
- ✓ Strongest material ever measured
200 times more stronger than steel
- ✓ Electrical conductivity is best known
so far for any material (10,000,000 times more conductive than copper)
- ✓ Flexible and stretchable
- ✓ Transparent (~97.7% white light can pass through a single layer of graphene)



Applications of Nanoparticles

- Silver nanoparticles have good antibacterial properties, and are used in surgical instruments, refrigerators, air-conditioners, water purifiers etc.

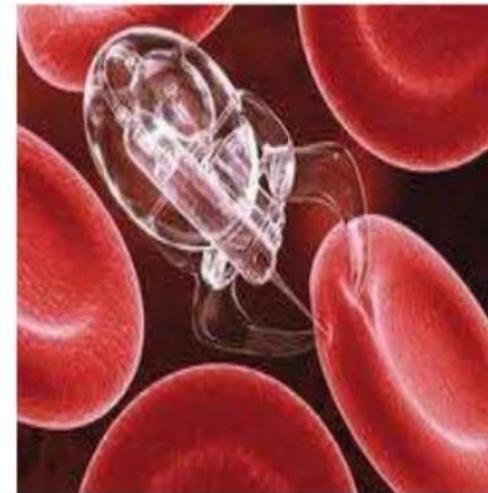


- ZnO nanoparticles are used in electronics, ultraviolet (UV) light emitters, piezoelectric devices and chemical sensors.
- TiO₂ nanoparticles are used as photocatalyst and sunscreen cosmetics (UV blocking pigment).
- Antimony-Tin-Oxide (ATO), Indium-Tin-Oxide (ITO) nanoparticles are used in car windows, liquid crystal displays and in solar cell preparations.

Applications of Nanoparticles

Nanotechnology in Drugs(Cancer)

- Provide new options for drug delivery and drug therapies.
- Enable drugs to be delivered to precisely the **right location** in the body and release drug doses on a **predetermined schedule** for optimal treatment.
- Attach the drug to a **nanosized carrier**.
- They become localized at the disease site, i.e cancer tumour.
- Then they release medicine that **kills the tumour**.
- Current treatment is through radiotherapy or chemotherapy.
- Nanobots can **clear the blockage** in arteries.



Applications of Nanoparticles

Nanotechnology in Fabrics

- The properties of familiar materials are being changed by manufacturers who are adding **nano-sized components** to conventional materials to improve performance.
 - For example, some clothing manufacturers are making water and stain repellent clothing using **nano-sized whiskers** in the fabric that cause water to bead up on the surface.
 - In manufacturing **bullet proof jackets**.
 - Making **spill & dirt** resistant, antimicrobial, antibacterial fabrics.



Applications of Nanoparticles

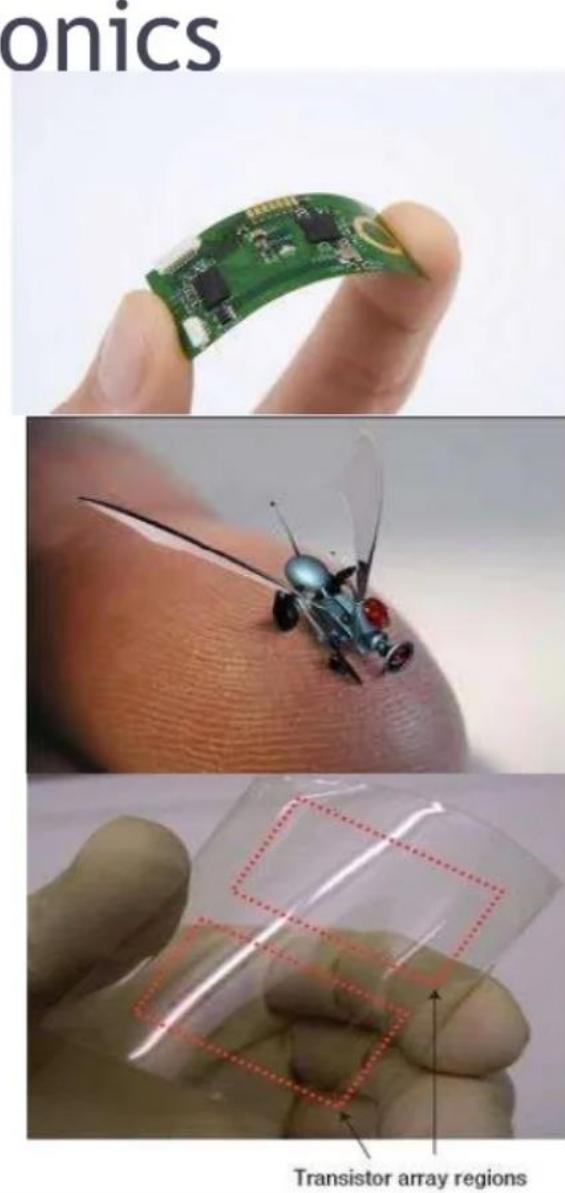
Nanotechnology in Mobile

- Morph, a nanotechnology concept device developed by Nokia Research Center (NRC) and the University of Cambridge (UK).
- The Morph will be **super hydrophobic** making it **extremely** dirt repellent.
- It will be able to **charge itself** from available light sources using photovoltaic **nanowire grass** covering it's surface.
- Nanoscale electronics also allow **stretching**. Nokia envisage that a nanoscale mesh of fibers will allow our mobile devices to be bent, stretched and folded into any number of conceivable shapes.



Applications of Nanoparticles Nanotechnology in Electronics

- Electrodes made from **nanowires** enable flat panel displays to be flexible as well as thinner than current flat panel displays.
 - **Nanolithography** is used for fabrication of chips.
 - The transistors are made of nanowires, that are assembled on glass or thin films of **flexible plastic**.
 - E-paper, displays on sunglasses and map on car windshields.



Applications of Nanoparticles

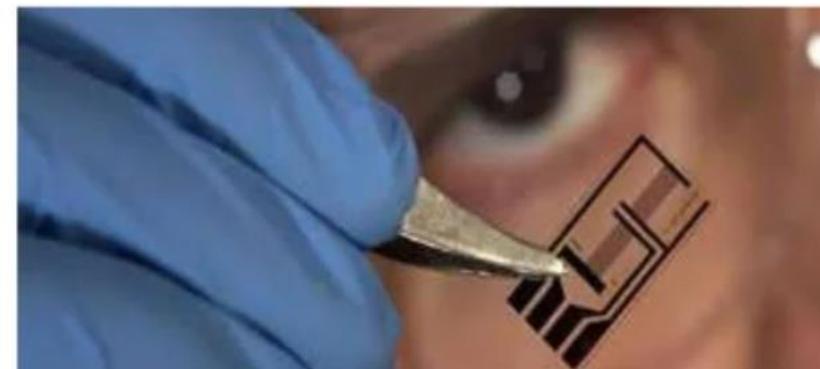
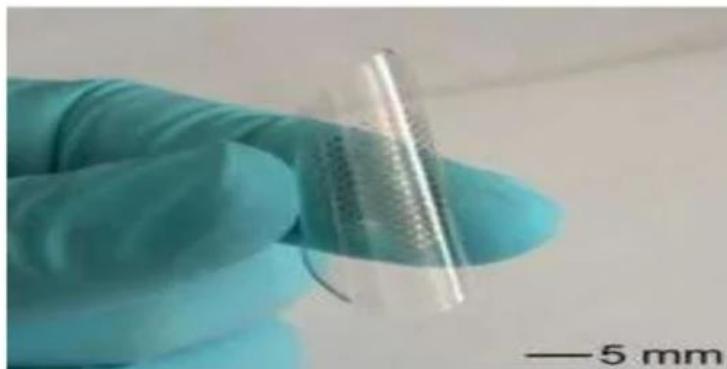
Nanotechnology in computers

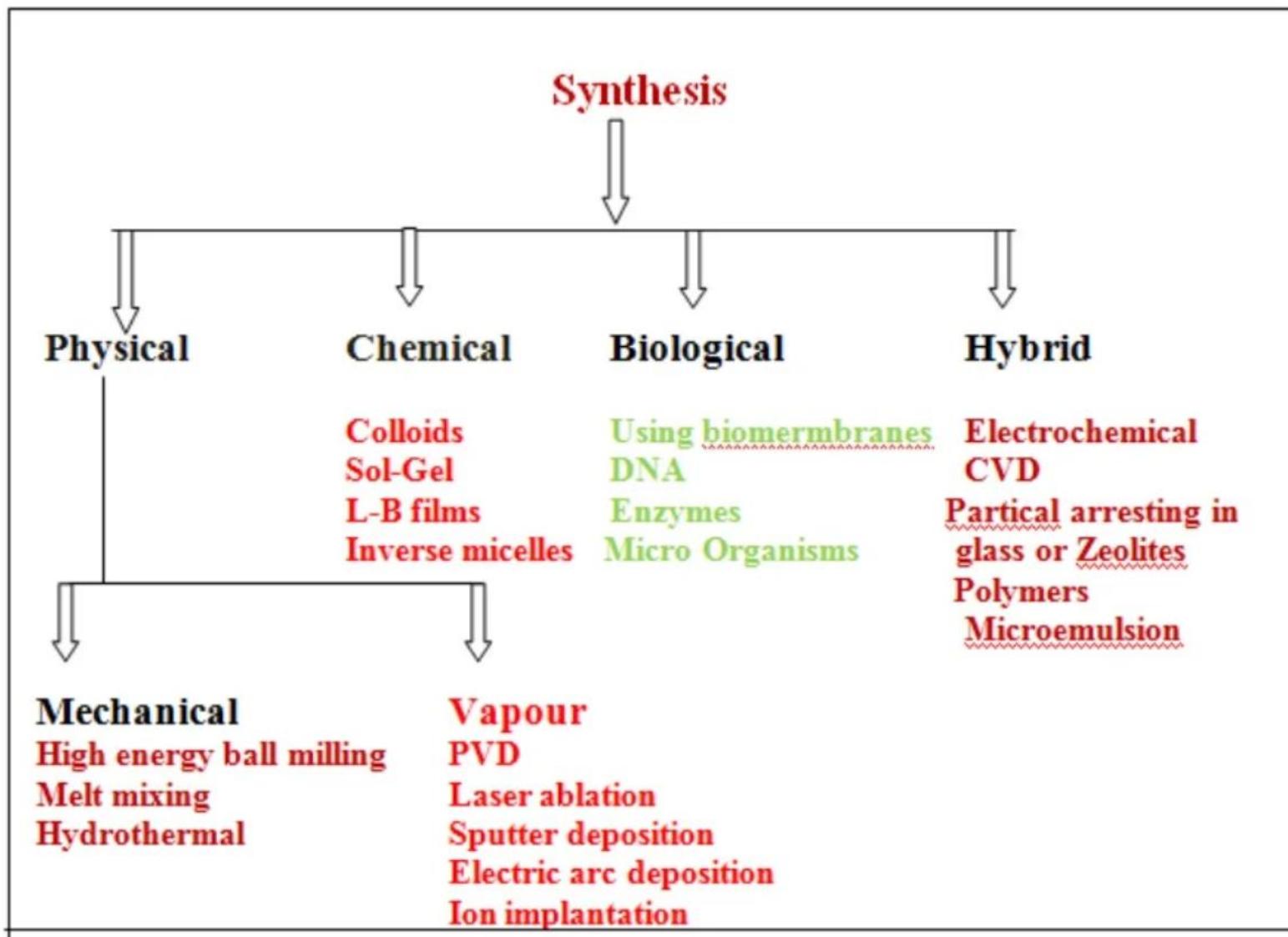
- The silicon transistors in your computer may be replaced by transistors based on **carbon nanotubes**.
- A carbon nanotube is a molecule in form of a hollow cylinder with a diameter of around a nanometer which consists of pure carbon.
- **Nanorods** is a upcoming technology in the **displays techniques** due to less consumption of electricity and less heat emission.
- Size of the microprocessors are reduced to greater extend.
- Researchers at North Carolina State University says that growing arrays of magnetic nanoparticles, called **nanodots**.



Applications of Nanoparticles

- Hewlett Packard is developing a memory device that uses **nanowires coated with titanium dioxide**.
- One group of these nanowires is deposited parallel to another group.
- When a perpendicular nanowire is laid over a group of parallel wires, at each intersection a device called a **memristor** is formed.
- A memristor can be used as a **single-component memory cell** in an integrated circuit.
- By reducing the diameter of the nanowires, researchers believe memristor memory chips can achieve **higher memory density than flash memory chips**.
- Magnetic nanowires made of an **alloy of iron and nickel** are being used to create **dense memory devices**.





Nanoparticle Synthesis Strategies

- 1 Liquid-phase synthesis
- 2 Gas-phase synthesis
- 3 Vapor-phase synthesis

Bottom -Up Approach

1 Liquid-Phase Synthesis

- ✓ Co-precipitation
- ✓ Sol-gel Processing
- ✓ Hydrothermal/Solvothermal Synthesis
 - Microemulsions
 - Microwave Synthesis
 - Sonochemical Synthesis
 - Template Synthesis
 - Biomimetic Synthesis

Sol – gel process

- The sol-gel process is a method for producing solid materials from small molecules. The method is used for the fabrication of metal oxides.
- A **sol** is a stable dispersion of colloidal particles or polymers in a solvent. The particles may be amorphous or crystalline.
- A **gel** consists of a three dimensional continuous solid network, which encloses a liquid phase.
 - In a colloidal gel, the network is built from agglomeration of colloidal particles.
 - In a polymer gel the particles have a polymeric sub-structure made by aggregates of sub-colloidal particles.
 - Generally, the sol particles may interact by van der Waals forces or hydrogen bonds. But in most gel systems used for materials synthesis, the interactions are of a covalent nature and the gel process is irreversible.

- **Solution** – Homogeneous mixture of two or more than two components.
- **Suspension** – Heterogeneous mixture in which the solute particles do not dissolve but get suspended throughout the bulk of the medium. Particles of suspension are visible to the naked eye.



Solution (salt in water)



Suspension (sand in water)

- Between the two extremes of suspensions and solutions we come across a large group of systems called colloids.
- Colloid** – A system in which one substance is dispersed as very fine particles in another substance called dispersion medium.

Types of Colloidal Systems

Dispersed phase	Dispersion medium	Type of colloid	Examples
Solid	Solid	Solid sol	Some coloured glasses and gem stones
Solid	Liquid	Sol	Paints, cell fluids
Solid	Gas	Aerosol	Smoke, dust
Liquid	Solid	Gel	Cheese, butter, jellies
Liquid	Liquid	Emulsion	Milk, hair cream
Liquid	Gas	Aerosol	Fog, mist, cloud, insecticide sprays
Gas	Solid	Solid sol	Pumice stone, foam rubber
Gas	Liquid	Foam	Froth, whipped cream, soap lather

Definition

The sol-gel process may be described as:

“Formation of an oxide network through polycondensation reactions of a molecular precursor in a liquid.”

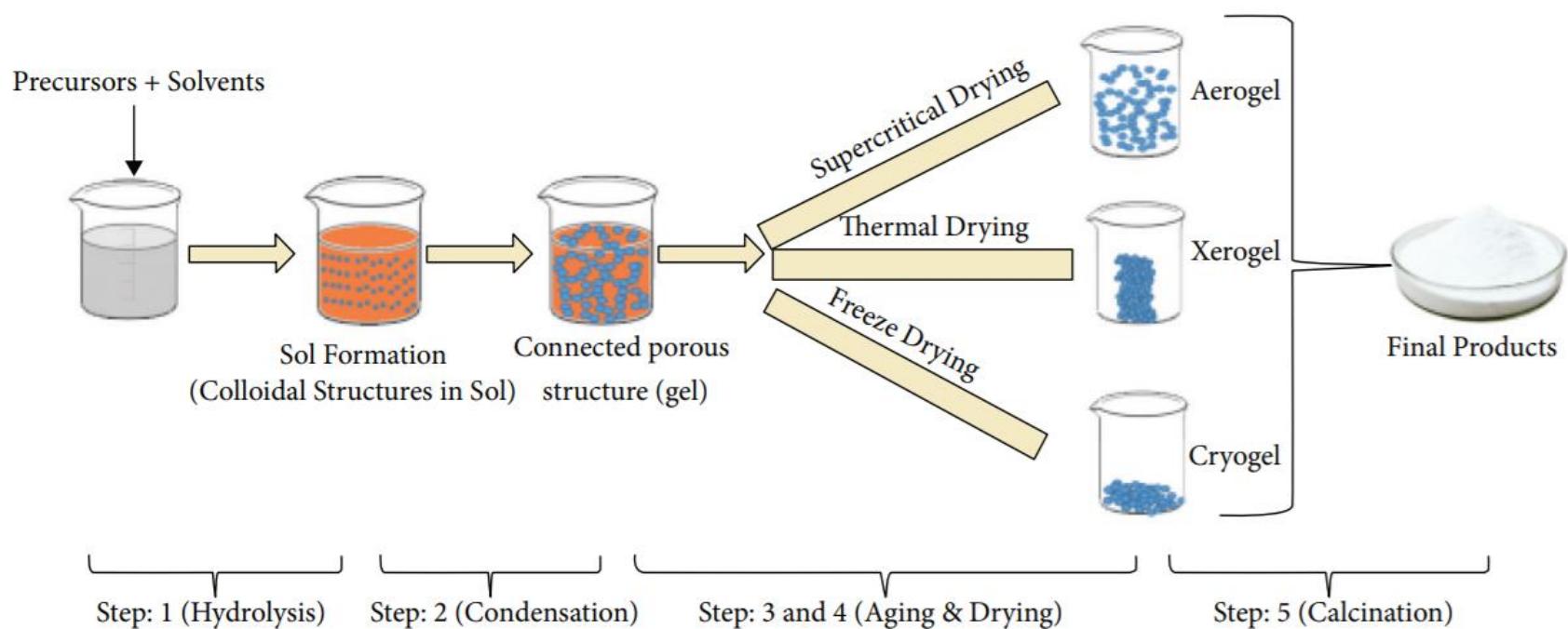
- Sol-gel is a process in which solid nanoparticles dispersed in a liquid (a sol) agglomerate together to form a continuous three-dimensional network extending throughout the liquid (a gel).
- The idea behind sol-gel synthesis is to “dissolve” the compound in a liquid in order to bring it back as a solid in a controlled manner.

Process

- Typical precursors used for sol-gel synthesis are metal alkoxides and metal chlorides.

Production of Sols

1. ***Nanoparticles are grown directly in a liquid.*** Basically you mix ingredients that contain molecules that can interconnect together to form bigger molecules and eventually nanoparticles. These nanoparticles then hook up together to form a gel network.
2. ***Nanoparticles are synthesized and then dispersed in a liquid.*** This is how more advanced gels are made. Nanoparticles such as quantum dots or carbon nanotubes are made through some process and then dissolved in a liquid directly or dispersed using the help of a surfactant (detergent).



The Sol-Gel Transition

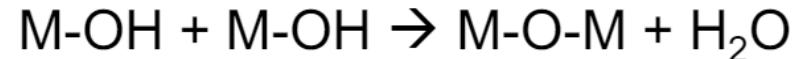
- A sol can become a gel when the solid nanoparticles dispersed in it can join together to form a network of particles that spans the liquid.
- This requires that the solid nanoparticles in the liquid, which are constantly bouncing around in random directions because of temperature (Brownian motion), bump into each other and stick together when they do.
- For some nanoparticles this is easy, almost automatic, since they contain reactive surface groups that condense together to form bonds.
- For other nanoparticles, however, this can be tricky and requires the addition of an additive to “glue” the particles together or removal something from the particle surfaces so that they stick together when collide, either by bonding together or by electrostatic forces (static electricity).

- As a sol becomes a gel, its viscosity approaches infinity and finally becomes immobile. This transition from sol to gel is called **gelation**.
- The point in time when the particle network extends across the entire volume of the liquid causing it to immobilize is called the **gel point**. The time required for a gel to form after mixing stuff together to make the gel is called the **gel time**.
- There are two distinct reactions in the sol-gel process:
 - Hydrolysis of the alcohol groups.
 - Condensation of the resulting hydroxyl groups.

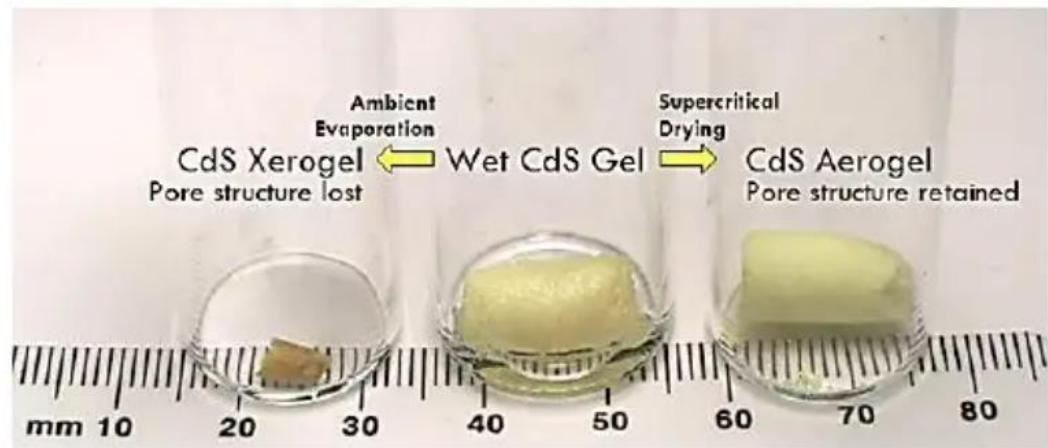
Hydrolysis



Condensation

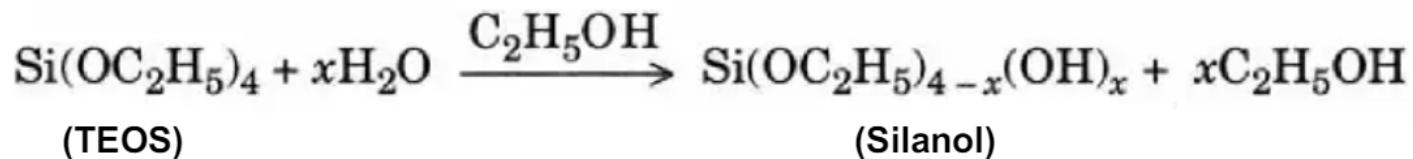


- A drying process serves to remove the liquid phase from the gel. When the liquid is removed from the gel several things may happen.
- When the liquid in the gel is replaced by air, major changes to the network structure may occur.
 - If the structure is maintained, an aerogel is formed. An aerogel is solid with air pockets dispersed throughout.
 - If the structure collapses, a xerogel is formed.

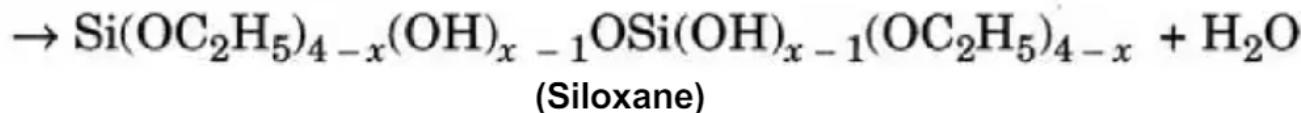
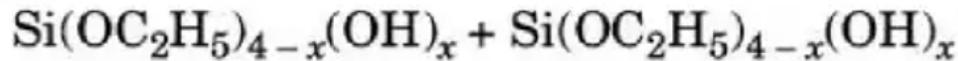


- This paper presents sol-gel preparation of silica (IUPAC: Silicon dioxide; SiO_2) using
 - Tetraethyl orthosilicate (TEOS) [IUPAC: Tetraethoxysilane; $\text{Si}(\text{OC}_2\text{H}_5)_4$]
 - Ethanol ($\text{C}_2\text{H}_5\text{OH}$)
 - Water (H_2O)
- This one-phase solution undergoes sol-gel transition to a rigid, two-phase system of solid silica and solvent-filled pores.

Preparation of silica gels



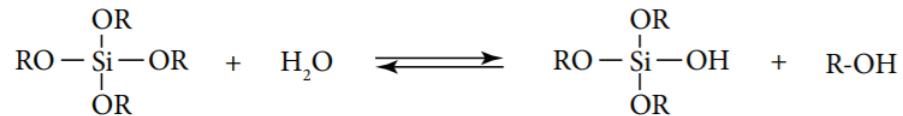
Hydrolysis



Polycondensation

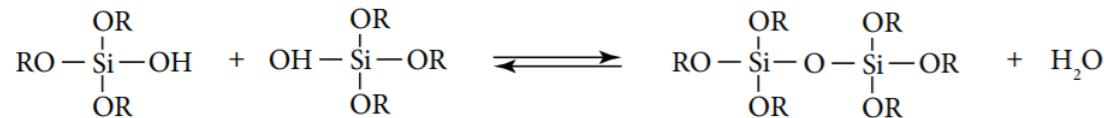
- These reactions are acid-catalysed or base-catalysed.
- The removal of solvent from the gel by conventional drying, such as evaporation, will result in the formation of xerogel. If supercritical drying is used, aerogel will form.
- Aerogels have very low densities and are excellent thermal insulators.
- Xerogels are denser than aerogels and have large surface areas. They are used as catalyst supports, ionic conductors, and precursors for glasses, ceramics, coatings, fibres, etc.

Step 1: hydrolysis

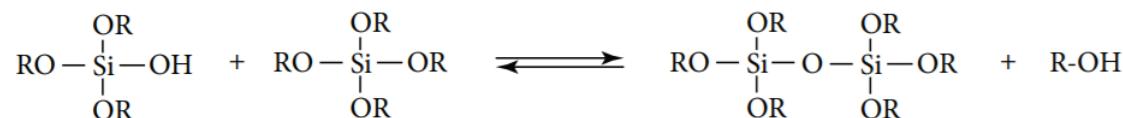


Step 2: condensation

(a) Water condensation



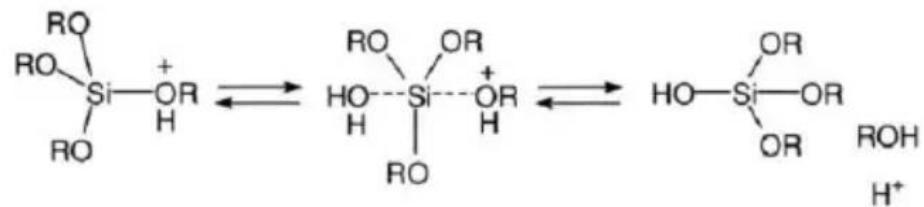
(b) Alcohol condensation



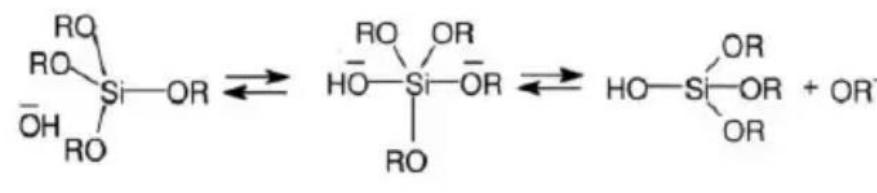
Where R is an alkyl chain. For TEOS, R = -CH₂CH₃

FIGURE 18: Hydrolysis reactions, condensation with water and alcohol to produce TB, and finally synthesis of silica gel [76].

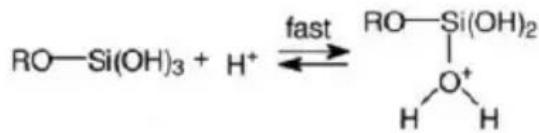
Acid-Catalyzed Hydrolysis



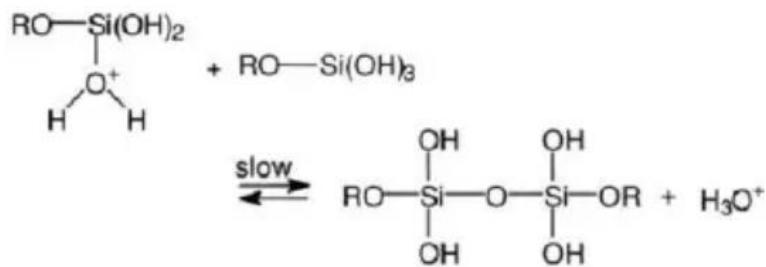
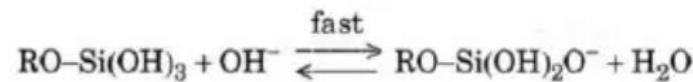
Base-Catalyzed Hydrolysis



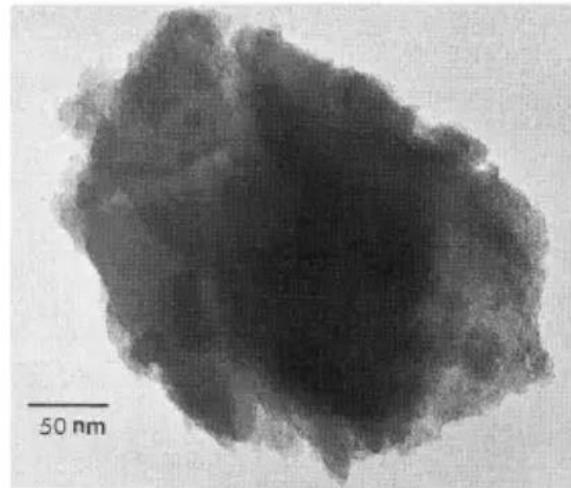
Acid-Catalyzed Condensation



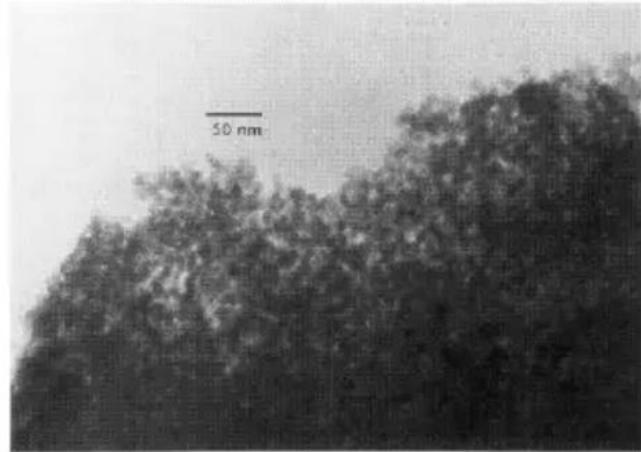
Base-Catalyzed Condensation



- The acid-catalyzed xerogels exhibit extremely fine microstructural features, and the pores are extremely small and evenly spread. The individual silica particles cannot be resolved. Hence, light incident on these gels is mostly transmitted through the solid, and the gels are observed to be transparent.
- The base-catalysed xerogels are particulate, and the individual silica particles may be resolved (10 nm). They are less tightly packed than in the acid-catalysed sample. Hence, light incident on these gels is reflected from the solid, and the gels appear more opaque.



Typical microstructure of an acid-catalyzed xerogel.



Typical microstructure of a base-catalyzed xerogel.

Advantages of sol-gel method

- Cheap and low temperature operation.
- Very thin layers of metal oxide can be obtained.
- Can produce thick coating to provide corrosion protection performance.
- Can easily shape materials into complex geometries in a gel state.
- Can produce high purity products because the composition is highly controllable.
- Can have low temperature sintering capability, usually 200-600°C.
- Can provide a simple, economic and effective method to produce high quality coatings.
- Small quantities of dopants, such as organic dyes and rare earth metals, can be introduced into the sol and be finely dispersed in the final product.
- Can be used to make glass with new compositions. High density glass can also be made at low temperatures, without high temperature recrystallization.

Disadvantages of sol-gel method

- Despite its advantages, sol-gel technique never arrives at its full industrial potential due to some limitations, e.g. weak bonding, low wear-resistance, high permeability, and difficult controlling of porosity.
- In particular the limit of the maximum coating thickness is $0.5 \mu\text{m}$ when the crack-free property is an indispensable requirement.
- The trapped organics with the thick coating often result in failure during thermal process. The present sol-gel technique is very substrate-dependent, and the thermal expansion mismatch limits the wide application of sol-gel technique.

Sol-Gel process overview

