UNIT- VI: Industrial Chemistry & Introduction to Nanotechnology

Industrial Chemistry: Glass, Ceramics, Cement – Classification, ingredients and their role, Manufacture of cement and the setting process, quick setting cements. Alloys: Classification of alloys, Ferrous and Non-Ferrous alloys, Specific properties of elements in alloys.

Introduction to Nanotechnology: Introduction and classification of nanomaterials (0D, 1D, 2D, and 3D nanostructures) – Overview on synthesis of nanomaterials (Bottom-up and top-down methods) – chemical reduction, sol-gel, hydrothermal, solvothermal, ball-milling. Applications of nanotechnology in catalysis and surface coatings.

Glass:

The glass is one of most the modern popular material used in construction. Glass is used extensively in interior partitions, railings for stairs and balconies, etc. Nowadays glass has become a versatile material due to its advantages in various engineering fields. It is the mixture of number of metallic silicates. It may be represented as $xR_2O.yMO.6SiO_2$, where R is an atom of a monovalent alkali metal like Na, K, etc, M is an atom of a bivalent metal like Ca, Mg, Pb, Zn etc., x and y are whole numbers.

Glass is a homogeneous mixture of super-cooled molten sodium silicate and calcium silicate. This consists of silica sand (SiO_2), sodium oxide (Na_2O) from soda ash, calcium oxide (CaO) from limestone, dolomite (MgO) and feldspar (Al_2O_3). These ingredients are mixed in the right proportion. The entire batch is flown into a furnace heated to 1500^oC.

Glass is defined as a super cooled liquid. Glass is an amorphous, hard, brittle, transparent super cooled liquid. Glass is manufactured by fusion process. In this process sand is fused with lime, soda and some other admixtures and then cooled rapidly. The silica is cooled from its liquid state, and it does not solidifies even when the temperature is dropped below freezing point. Hence, glass is a super cooled liquid. (Super cooling, also known as undercooling, is the process of lowering the temperature of a liquid below its freezing point without it becoming a solid).

The raw materials used in the manufacture of glass are 71% silica (sand), 14% soda ash (sodium carbonate), 11% limestone (calcium) and 4% other ingredients. To this mixture a very important component is added which is known as cullet.

Cullet is waste glass or broken pieces of glass. It increases the fusibility of glass and prevents the loss of alkali by volatilization during the reaction in forming of new glass. The use of cullet can reduce the energy consumption because cullet has a lower melting energy requirement than the constituent raw materials. The use of cullet improves energy efficiency and reduces the need to produce raw materials.

Properties of glass: Amorphous, brittle, transparent, good electrical insulator, unaffected by air, water, acid or chemical reagents and no definite crystal structure.

Classification:

Different types of glass are used for different day-to-day activities. Properties of glass are also suitably changed by changing the composition of principal constituents and adding few more ingredients. Following are various types of glass depending upon the principal constituent used during the manufacturing process.

Silica glass: It is pure Silica SiO_2, without any additives. A very clear, strong glass produced when pure silica is fused at high temperature, used as in optical instruments. It is also used in making bulb of ultraviolet lamp, in making container of chemical reagents, used in a telescope as surface mirrors etc.

Soda lime glass: This is the most common type of glass used extensively for domestic purpose. It is also called soft glass which is brittle and the cheapest and most commonly existing glasses. In making tube light, bottles, windows, equipment of laboratory, daily useable domestic utensils. It is composed of SiO_2, Na_2O, CaO,

Potash-lead glass: It is also known as flint glass or lead glass. It is obtained from the fusion of a mixture of silica, lead, and potash, in which the content of lead is around 18-40%. Potash- lead glass is used for high-quality glassware, cut glass, bulbs, lenses and prisms. Lead is also known to block x-rays and gamma radiations, thus they are used in making shields for personnel working in the nuclear science industry.

Common glass: This is also known as bottle glass is prepared from cheap raw materials like sodium silicate, iron silicate and calcium silicate. Bottle glass is available in different colors like green, brown and yellow. They have moderate resistance to chemicals. Bottle glass allows less light to enter and thus prevents fading or degradation of products stored in it. Common glass is mainly used to manufacture household bottles, medicine bottles, glassware used for drinking, packaging of drugs, etc.

Potash-lime glass: It is also known as hard glass. Potash-lime glass has a high melting point and hence can withstand high thermal stresses. Hard glass has good resistance towards acids and alkalis as compared to soda lime glass. It is used for making laboratory apparatus and combustion tubes. They are also used as window glass, electric bulbs, plate glass, bottles, jars etc.

Borosilicate glass (Pyrex): It is special type of glass made by adding boron oxide as the chief additive with silica at the time of manufacturing. This glass can be heated or cooled again & again without any risk of damage. Modern laboratories now use glassware made from borosilicate glass. They are also used in packaging of medicines and drugs. Borosilicate glass has many applications such as making glass cookware, microwave and ovens, semiconductors, flashlights, telescopes, etc.

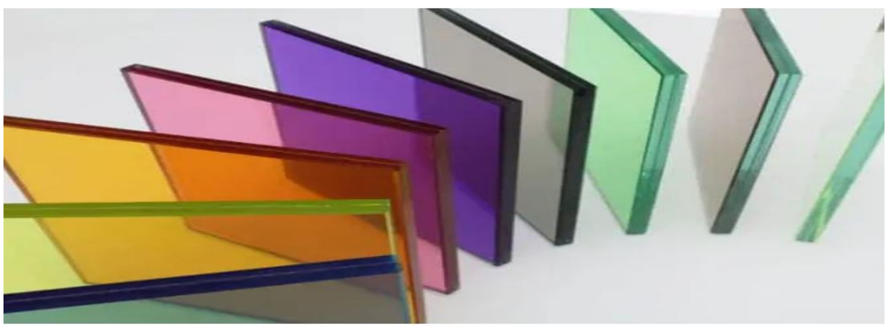
Laminated glass: Laminated glass is the combination of layers of ordinary glass. So, it has more weight than a normal. It involves large glass panels. It can be used to create huge glass installations. It has more thickness and is UV proof and soundproof. These are used for aquariums, bridges, front doors, windscreens, floors etc.

Chromatic glass: Chromatic glass is used in ICU’s, meeting rooms etc. It can protect the interior from daylight. Photo chromatic glass is a special type of glass which turns black in sharp shining light thus such glasses are used as light protector and eyes reliever and thereby utilized in making eye lenses and goggles. The main reason of being black of such glasses is the presence of silver iodide.

Shatterproof glass: Shatterproof glass resists shattering or breaking down into small edged pieces when it is destroyed either naturally or purposely. The non-formation of sharp-edged pieces of glass in shatterproof glass is due to the addition of plastic polyvinyl butyrate during the process of its manufacturing. Shatterproof glass is used for window glass, floors, and skylights respectively.

Extra clean glass or Self-cleaning glass: Self-cleaning glasses are mostly used or locations where cleaning & maintenance is a bit difficult or where it is difficult to reach.

Tinted glass: Tinted glass is colored glass that is manufactured by adding some additives to the mixture while manufacturing glass, without compromising the properties of glass. By adding different additives, different colors are obtained.

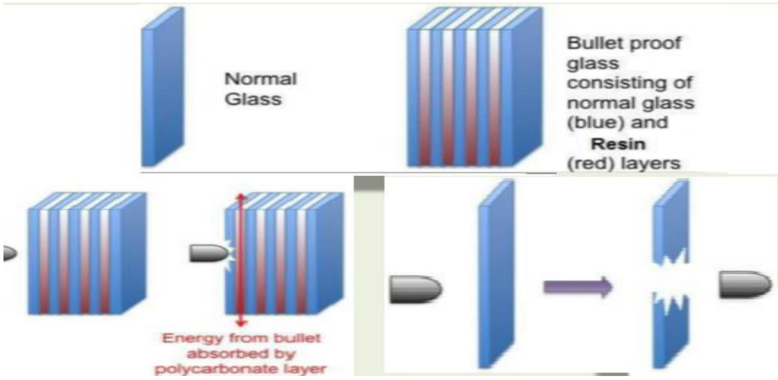


Substance used for colouring the glass	**Colour of glasses**
Cobalt Oxide	Deep Blue
Sodium Chromate or Ferrous Oxide	Green
Selenium Oxide	Orange red
Ferric Salt or Sodium Uranet	Fluorescent Yellow
Gold Chloride or Purple of Cassias	Ruby red
Cuprous Oxide, Cadmium Sulphide	Glitter red
Cupric salt	Peacock Blue
Potassium dichromate	Green and green yellow
Manganese dioxide	Blue to light orange
Cuprous salt	Red
Cadmium sulphide	Yellow like lemon
Carbon	Brownish black

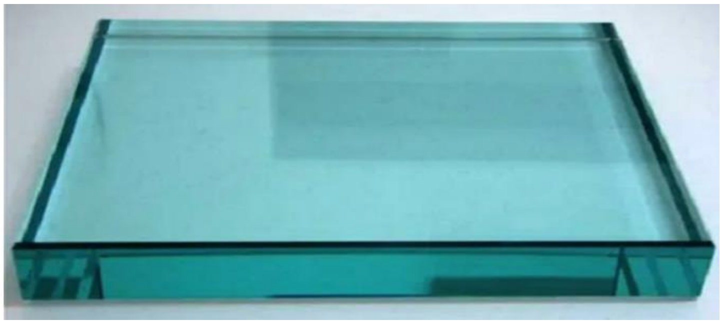
Glass building blocks: These blocks are used in brickwork construction for permitting transmission of light without being transparent and without bearing any load.

Glass fibres: It has been found that very thin fibres of glass possess very high tensile strength. Glam wool helps to keep out the heat and is also used as a soundproofing material.

Bullet resistant glass: This is used for security reasons. It is in fact a variety of laminated glass which is made by pressing together several layers of glass and vinyl resins in alternate manner.



Toughened glass: Toughened glass is a type of safety glass. It is also known as tempered glass. This type of glass is very tough and does not break easily. Toughened glass is mostly seen in kitchens, swimming pools etc.



Gorilla glass: The chemicals used in gorilla glass are aluminium oxide, calcium oxide and magnesium oxide. The shape is flat and thickness up to 8mm. Used in cell phones to protect the screen.

- Uses of glass: Glass has a very wide field of industrial applications.
  - For an architect: Glass is an essential architectural material.
  - For a civil engineer: It is one of the most important material for construction.
  - For an electrical engineer: Glass is a useful insulating material in many situations, and is used for making tubes and valves.
  - For a mechanical engineer: Glass alone or in a composite material is an integral part in automobiles and railway wagons etc.
  - For a chemical engineer: centrifuges, distillation systems, heat exchangers, mass spectrometers and all laboratory equipment etc.
  - Glass finds its application from the kitchen of poor man to most advanced scientific devices. It can be made in varieties possessing a combination of mechanical, electrical, optical, and chemical resistant properties that make them ideal industrial material for variety of applications.

Ceramics:

The word ceramics is derived from Greek word "Keramos" which means burnt stuff. These are inorganic, complex chemical compounds containing both metallic and non-metallic elements. Most ceramic materials contain silicates, metallic oxides and their combinations.

The characteristic features of ceramics are: Resistance to high temperature, Hard and brittle in nature, have low electrical and thermal conductivity and act as insulators and resistance to chemicals and weathering.

Basic raw materials of ceramics:

- Plastic materials - clay which impart the necessary plasticity and workability. Kaolinite (Al_2O_3. $2SiO_2$. $2H_2O$) is an important clay mineral.
- Non-plastic or leading admixtures – silica and crushed chamotte (calcined clay containing a high proportion of alumina) contributes to mechanical strength.
- Fluxes or glassy materials-feldspar (K_2O. Al_2O_3. $6SiO_2$) is a fluxing constituent. This helps in bonding and cementing the ingredients together.
- Colorants to impart color.

Classification of ceramic materials: Two important classifications are known

(1) Application base classification, (2) Composition base classification

(1) Application base classification

Traditional Ceramics	Advanced Ceramics	
	1. Electro ceramics	2. Advanced Structural ceramics
White wares	Electronic substrate, package Ceramics	Nuclear ceramics
Structural clay products		Bio ceramics
Brick and Tile	Capacitor Dielectric, Piezoelectric ceramics	Tribiological ceramics Automotive ceramics
Abrasives	Magnetic ceramics	
Refractories	Optical ceramics	
Cement	Conductive ceramics	

2. Composition base classification

Based on composition of *raw materials and type of ceramic materials:*

a) Silicate ceramics:

compounds containing the anionic complex (SiO_4) e.g. the silicate group.

- **Porcelain**
- **Magnesium Silicates ($MgO.SiO_2$)**
- **Mullite (or Porcelainite : $3Al_2O_3.2SiO_2$)**

b) Advanced ceramics:

i) Oxide ceramics:

- **Aluminum Oxide (Al_2O_3)**
- **Titanium Oxide (TiO_2);**
- **Magnesium Oxide (MgO)**
- **Zirconium Oxide (ZrO_2)**
- **Lead Zirconate Titanate ($Pb(Zr_xTi_{1-x})O_3$)**
- **Lead oxide (PbO)**
- **Aluminum Oxide -Titanium Oxide (Al_2O_3 . TiO_2)**

ii) Non-oxide ceramics: carbides and nitrides are the most important compounds of this group.

- **Carbide ceramics**
- **Nitride ceramics**
- **Boride ceramics**
- **Silicide ceramics**

Carbide ceramics:

- Aluminum carbide (Al_4C_3)
- Silicon carbide (SiC)
- Boron carbide (CB_4)
- Calcium carbide (CaC2)
- Chromium carbide (Cr_3C_2)
- Hafnium(IV) carbide (HfC)
- Molybdenum carbide (Mo_2C)
- Niobium(IV) carbide (NbC)
- Tantalum(IV) carbide (TaC)
- Titanium carbide (TiC)
- Tungsten(IV) carbide (WC)

Nitride ceramics

- Aluminum nitride (AlN)
- Magnesium nitride (Mg_3N_2)
- Silicon aluminum oxynitride ($Al_5N_6O_2Si$)
- Silicon nitride (Si_3N_4)
- Barium nitride (Ba_3N_2)
- Boron nitride (BN)
- Calcium nitride (Ca_3N_2)
- Gallium nitride (GaN)
- Germanium(III) nitride(Ge_3N_4)
- Indium(III) nitride (InN)
- Lithium nitride (Li_3N)
- Strontium nitride (Sr_3N_2)
- Tantalum nitride(TaN)
- Titanium carbonitride (Ti_2CN)
- Titanium nitride (TiN)
- Zirconium nitride (ZrN)

Silicide ceramics

- Calcium silicide technical ($CaSi_2$)
- Magnesium silicide (Mg_2Si)
- **Molybdenum disilicide ($MoSi_2$)**
- Niobium silicide ($NbSi_2$)
- Tungsten silicide (WSi_2)

Boride ceramics

- Aluminum diboride (AlB_2)
- Aluminum dodecaboride (AlB_{12})
- Calcium hexaboride (CaB_6)
- Gadolinium boride (GdB_6)
- Hafnium boride (HfB_2)
- Lanthanum boride (LaB_6)
- Lanthanum hexaboride(LaB_6)
- Magnesium boride (MgB)
- Nickel boride (Ni_2B)
- Niobium diboride (NbB_2)
- Niobium monoboride (NbB)
- Silicon tetraboride (SiB_4)
- Tantalum boride (TaB)
- Tantalum boride (TaB_2)
- Tungsten boride (WB)
- Vanadium boride (VB_2)

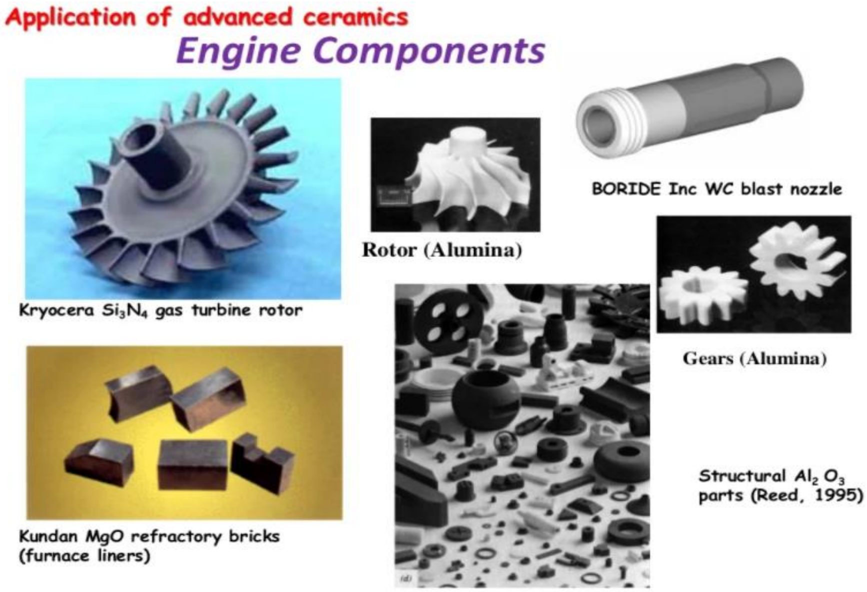
Application of ceramics:

Clay products:

- Structural clay product: Ceramic products are used in building construction. Typical structural clay products are building brick, paving brick, terra-cotta tile, roofing tile etc.
- White wares: Any of a broad class of ceramic products that are white to off-white in appearance and frequently contain a significant glassy, component.

  Dinnerware, Crockery, Floor and wall tiles, Sanitary-ware, Dental implants, Electrical porcelain (spark-plug insulators), Decorative ceramics etc.
- Refractories: Firebricks for furnaces and ovens. Have high Silicon or Aluminium oxide content. Brick products are used in the manufacturing plant for iron and steel, non-ferrous metals, glass, cement, petroleum, and chemical industries.

Advanced ceramics:



As ceramic bearings

(a) Hybrid ceramic bearings consist of ceramic balls (or rollers) and steel races.

(b) Full ceramic bearings are made only of ceramics (contain no steel parts)

- Ceramics have been extensively used for hip replacement (eg: alumina ceramic) and for joint implants, eg zincoina ceramics in the form of tetragonal zirconia doped with yttria, Y_2O_3 (about 5.15%)
- Recent advances have been made in ceramics which include bio-ceramics such as dental implants.
- High tech ceramic is used in watch making for producing watch cases because of its lightweight, scratch resistance, durability and smooth touch.
- Ceramics of UO_2 is used in nuclear applications as fuel containers.
- Ceramic ware: Plates, Bowles, drinking vessels, decorative wall surfaces, floor tiles etc.

Cement:

Cement is main constituent of concrete. Concrete is the most widely used non-metallic material of construction. It is used for the construction of buildings, bridges, highways, dams, run-ways for the air-craft, etc. The essential bonding material which binds sand and rock when mixed with water in concrete is cement. Cement is described as a building material which possesses adhesive and cohesive properties to bind rigid masses like stones, bricks, building blocks etc.

The essential constituents of cement used for constructional purposes are compounds of calcium (calcarious) and Al + Si (argillaceous), materials.

Classification of cement: Based on different chemical compositions, cement is classified into four types. They are

Natural cement: It is made by calcining a naturally occurring argillaceous limestone at high temperature and subsequently, pulverizing the calcinated mass. During calcination, silica and alumina, present in sufficient quantities, combine with the calcium oxide to form the corresponding calcium silicates and aluminates. It is used in large masses of concretes such as dams and foundations.

Pozzolana cement: It is one of the ancient cements in the world and was invented by Romans. It was used by them in making concrete for the construction of walls and domes. The name has come from the place Pozzuoli, where volcanic ash of Mount Vesuvius, Italy. Used by mixing with Portland cement for different applications.

Slag cement: It is made from hydrated lime and blast furnace slag. The blast furnace slag consisting largely of a mixture of calcium and aluminium silicates is granulated by pouring it into a stream of cold water. Subsequently, it is dried and mixed with hydrated lime. Then the mixture is pulverized to fine powder. Slag cements, are slow to harden, so an accelerator like clay or caustic soda are added to accelerate the hardening process. Slag cements are used, to a limited extent, for making concrete in bulk construction.

Portland cement: Portland cement is also known as ‘magic powder’. It consists primarily of compounds of lime, silica, alumina and iron. It was so named, because a paste of cement with water on setting and hardening resembled in color and hardness to Portland stone, a limestone quarried in Dorset, an island of Portland, England.

Manufacture of Portland cement: Raw materials required are:

- Calcareous materials: CaO (such as Limestone, chalk, etc).
- Argillaceous materials: Al_2O_3 and SiO_2 (such as clay, slate, aluminium ore etc).
- Gypsum: ($CaSO_4.2H_2O$)
- The iron component, Fe_2O_3 (i.e. ferriferrous materials such as clay, iron ore etc.)
- Powdered coal

Functions of the ingredients of cement:

- Lime is the principal constituent of cement whose proportion must be regulated. Excess or lesser amount of lime than required reduce the strength of cement. Excess makes the cement to expand and disintegrate and lesser amount makes it quick- setting.
- Silica imparts strength to cement.
- Alumina makes the cement quick- setting. Excess, however, weakens the cement.
- Gypsum (Cacium sulphate) helps to retard the setting action of cement. It actually enhances the initial setting time of cement.
- Iron oxide provides strength and hardness to the cement.

- Methods of manufacturing process involves the following steps:

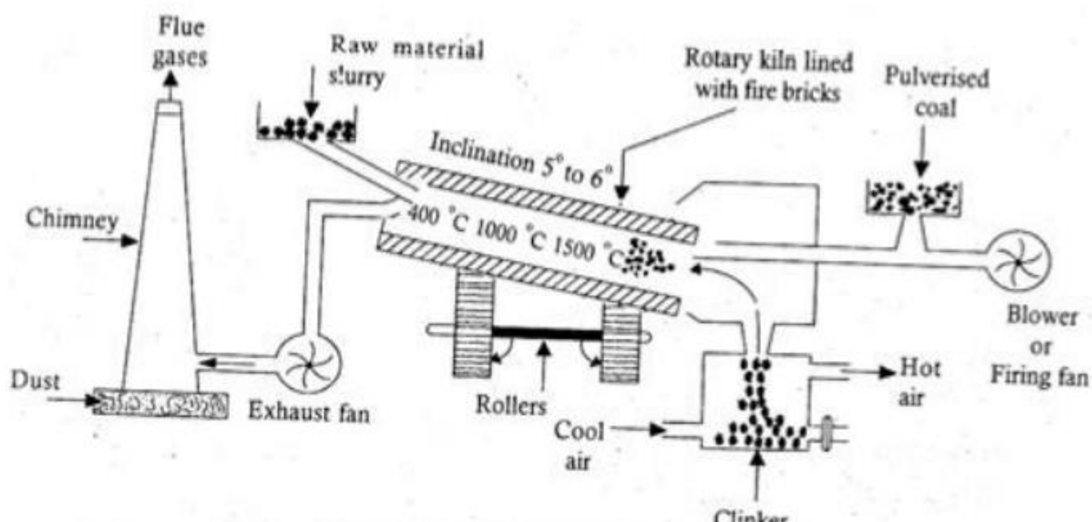
- Mixing of raw materials can be done by

✓ *Dry process:* This process is used when the raw materials are quite hard (lime- stone and clay). Initially limestone is crushed into pieces and then mixed with clay in the proportion of 3:1. This mixture is pulverized to a fine powder and is stored in storage bins and later it is introduced into the upper end of the rotary kiln.

✓ *Wet process:* The raw materials (calcareous) are crushed and ground to particles of suitable size and mixed with water (30-40%) to get a free flowing slurry. This slurry is led to a 'correcting basin', where its chemical composition may be adjusted, if necessary and finally stored in storage tanks.

- *Burning:* is usually done in rotary kiln. The rotary kiln is a steel tube, about 2.5 to 3.0 m in diameter and 90 to 120 m in length, lined inside with refractory bricks and is laid in slightly inclined position. This rests on roller bearings, which are supported on column of concrete.

The kiln is capable of rotating at 1 rpm (revolution per minute) about its longitudinal axis. Burning fuel (usually powdered coal) and air are injected at the lower end. A long hot flame is produced, which heats the interior of the kiln up to a maximum temperature of about 1750°C.



Rotary kiln for cement manufacture

- *Process:*
  - The raw mix or corrected slurry is injected into the kiln at its upper end, while hot flames are forced into the kiln from the lower end. Due to slope and slow rotation of the kiln, the materials fed in move continuously towards the hottest end at a speed of about 15m per hour. As the mixture or slurry gradually descends, the temperature rises.
  - The chemical reactions which take place in the kiln are divided into different zones.

✓ *Drying zone:* In the upper part of the kiln, where the temperature is around 400°C, most of the water in the slurry gets evaporated.

✓ *Calcination zone or decarbonizing zone:* In the central part of kiln, where the temperature is around 1000°C, limestone of dry mix or slurry undergoes decomposition to form quick-lime and carbon-dioxide, and the latter escapes out. The material forms small lumps, called nodules.

$$\underset{\text{lime stone}}{CaCO_3} \leftrightarrows \underset{\text{quick lime}}{CaO} + CO_2\uparrow$$

✓ *Clinkering zone:* In the lower part of the kiln, the temperature is between 1500 to 1700°C. Here lime and clay (of nodules) undergo chemical interaction or fusion yielding calcium aluminates and silicates.

$$2CaO + SiO_2 \rightarrow Ca_2SiO_4 \quad \text{Dicalcium silicate } (C_2S)$$

$$3CaO + SiO_2 \rightarrow Ca_3SiO_5 \quad \text{Tricalcium silicate } (C_3S)$$

$$3CaO + Al_2O_3 \rightarrow Ca_3Al_2O_6 \quad \text{Tricalcium aluminate } (C_3A)$$

$$4CaO + Al_2O_3 + Fe_2O_3 \rightarrow Ca_4Al_2Fe_2O_{10} \quad \text{Tetracalcium alumino ferrite } (C_4AF)$$

- ✓ The aluminates and silicates of calcium then fuse together to form small (of about 0.5 to 1cm diameter) hard grayish stones, called clinkers. These clinkers are very hot (at about 1000^oC).
- ✓ The rotary kiln at the base is provided with another small rotary kiln. In this, hot clinkers fall and cool air is admitted from opposite direction. Hot air so-produced is used for burning powdered coal. The cooled clinkers are collected in small trolleys.

- o *Grinding:* The cooled clinkers are ground to a fine powder in ball mills. During final grindings a small quantity (2-3%) of powdered gypsum is added, so that the resultant cement does not set very quickly, when it comes in contact with water. Gypsum, thus, acts as a retarding agent for early setting of cement.
- o *Packing:* The general cement is stored in silos (storage bins), from which it is fed to automatic packing machines. Each bag, usually, contains 50 kg of cement.

Setting of cement:

- The hardening of cement by the addition of water is known as setting of cement.
- The setting and hardening of cement are mainly due to hydration and hydrolysis reactions of the different constituents present in cement. The dicalcium silicate (C_2S), tricalcium silicate (C_3S), tricalcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4AF) present in cement undergoes hydration.
- During this process, anhydrous soluble compounds are converted into hydrated insoluble compounds. The hydrated insoluble gel hardens due to dehydration.
- Finally, after dehydration, the insoluble gel sets into hard mass.
- It surrounds the sand and binds it strongly with interlocking crystals of $Ca(OH)_2$.
- This process is known as setting of cement.

Quick setting cements:

- As the name indicates, these types of cements are used where quick setting is needed, i.e., where, quick strength is needed in short span of time.
- The quick setting cement is manufactured by adding a small percentage of aluminium sulphate and then it is finely grinded with cement.
- The aluminium sulphate is mainly added to accelerate the setting time fast.
- Quick setting cement when mixed with water starts to set in five minutes and become hard like stone in just 30 minutes.
- Uses:
  - It is used in under water construction.
  - It is also used in rainy & cold weather conditions.
- Disadvantages:
  - When water is added the work should be completed fast or else it sets and difficult to mix.
  - It is not widely available.
  - It is expensive.

Alloys:

An alloy refers to a combination of two or more metals, or a metal combined with one or more elements. The resulting alloy has different properties than the original elements altogether, like increased strength and hardness. Alloys are usually produced when the mixture of its constituents is melted.

Metals are generally malleable, which means that they can be easily hammered into thin sheets. They are also ductile, meaning that they can be drawn into wires as well. Most of the pure metals are either very brittle, soft, chemically reactive to be practically used. When different ratios of metals are combined as alloys, it modifies the original properties of metals to give desirable characteristics. Alloys are generally made to keep them less brittle, corrosion-resistant, harder, or even have a more desirable luster and color. Therefore, alloying of metal helps us to use the metal in daily life application. There are several alloys of various metals, such as alloys of Aluminium, Potassium, Iron, Cobalt, Nickel, Copper, Gallium, Silver, Tin, Gold, Mercury, Lead, Bismuth, Zirconium, and rare earth.

Alloy Examples:

Steel: Steel is an alloy of carbon and iron. However, many different types of steels consist of different amounts of carbon along with several other elements like manganese, phosphorus, sulfur, chromium, copper, nickel, and molybdenum. Since steel has higher tensile strength and affordability, it is used in the infrastructure and construction of buildings, bodies of vehicles and electrical appliances.

Bronze: Bronze is known to be an alloy of tin and copper. It is commonly used in heavy tools and gears, coins, medals, trophies and even in different forms of electrical hardware.

Nichrome: Nichrome is an alloy of chromium and nickel. Nichrome is primarily used in resistance wires. It also has its application in several electrical appliances like bread toasters and space heaters. Nichrome alloys are also used in dental fillings.

Brass: It is a very common and useful alloy of copper. In this, the quantity of zinc is kept at 45%. Along with zinc, metals such as Sn, Mn, Al, Fe, Pb etc are also added in a small amount to obtain some special properties. Brass is used in making jewelry, forgings, rivets, screws. These alloys are also used in making decorative articles and marine propeller shafts.

Gold when combined with Copper becomes suitable to make to make jewels.

Solder: It is an alloy of tin and lead. The melting point of lead is 327^{o}C and for tin is 231^{o}C. The melting point of solder is 183^{o}C. The low melting point of solder is made use of in electrical connections.

Purpose of alloying

To increase the hardness of the metal.
To increase the tensile strength of the metal.
To make it corrosion resistant.
To enhance the malleability and ductility.
To get attractive surface and appearance.
The machinability of the metal can be improved.
Melting point of the metal can be decreased.
The colour and metallic luster can be improved.

Based on the presence or absence of Iron, alloys can be classified into:

Ferrous alloys:

Alloys which contain containing iron as the main (major) constituent are called as ferrous alloys.

Examples: Stainless steel, chromium steel and vanadium steel.

Sl. No.	Name of the alloy	Composition	Uses
1	Stainless steel	Chromium = 14% Nickel = 1% Carbon = 1% Iron = 84%	1. Used for making kitchen utensils. 2. Used for making surgical instruments 3. Used for making automobile parts
2	Chromium steel	Chromium = 0.5-18% Carbon = 0.15 - 1.3% Iron = 80.7 - 99.35%	1. Used for making rock cutting machines 2. Used for making files 3. Used for making ball bearings 4. Used for making connecting rods
3	Vanadium steel	Vanadium = 0.5% Chromium = 1.1 - 1.5% Carbon = 0.4 - 0.5% Iron = 97.5 - 98%	1. Used for making gears and bearings 2. Used for making axles 3. Used for making springs and pistons

Non-ferrous alloys

Alloys which do not contain containing iron as the main constituent are called as non-ferrous alloys.

Examples: Nichrome, Dutch metal, German silver, gun metal and duralumin

Sl. No.	Name of the alloy	Composition	Uses
1	Nichrome	Nickel = 60% Chromium = 12% Manganese = 02% Iron = 26%	1.Used in making resistance coils 2.Used for making heating elements in stoves, electric irons, water heater and toasters
2	Dutch metal	Copper = 80% Zinc = 20%	1.Used for making cheap jewellery 2.Used for making musical instruments 3.Used for making battery caps 4.Used for making flexible hoses
3	German silver	Copper = 50% Nickel = 30% Zinc = 20%	1.Used for making coins 2.Used for making ornaments 3.Used for making decorative materials
4	Gun metal	Copper = 88% Tin = 10% Zinc = 02%	1.Used for making bearings 2.Used for making coins 3.Used for making hydraulic Fittings 4.Used in foundry works
5	Duralumin	Aluminium = 95% Copper = 04% Magnesium = 0.5% Manganese = 0.5%	1.Used in building aircrafts 2.Used for making automobile parts and locomotive parts 3.Used for making surgical instruments 4.Used for making cables

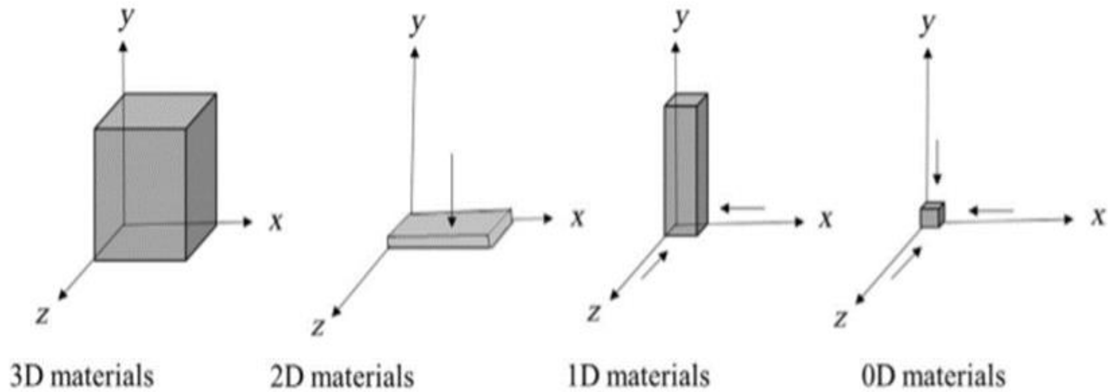
Introduction to Nanotechnology:

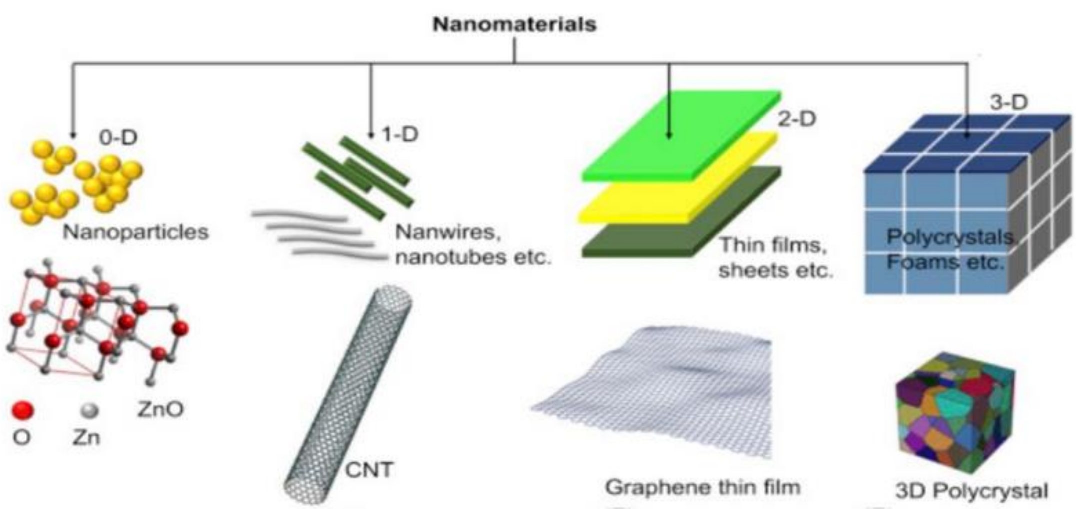
- The origin of the term “nano” comes from the Greek word “nanos” (or Latin “nanus”), meaning “Dwarf,” (small) but scientifically “nano” means one in a billion or 10^{-9}. 1 nm equal to 10^{-9} m. Nano materials means particles of very minute size.
- A nanometer is used to measure things that are very small such as atoms and molecules.
- In recent years, nano materials have become one of the most important and exciting fields of research in physics, chemistry, biology, medicine, engineering and technology.
- The technology of design, synthesis, characterization and applications of materials on nanoscale is called nanotechnology.
- Nanoparticles can be made of materials of diverse chemical nature, the most common being metals, metal oxides, silicates, non-oxide ceramics, polymers, organics, carbon and biomolecules.
- Nanomaterials are the materials with at least one dimension measuring less than 100 nm.
- Silver, Aluminum, Gold, Zinc, Carbon, Titanium, Palladium, Iron and Copper have been routinely used for the synthesis of NPs.
- The nanotechnology has a variety of applications in the areas of medicine, biology, physics, chemistry, electronics, optics, mechanics, material science, space industries, agriculture, cosmetics, food and feed, etc.
- There are also various eco-friendly nanoproducts available in commercial market with high efficiency such as water purifier, bone and teeth cement, facial cream etc.

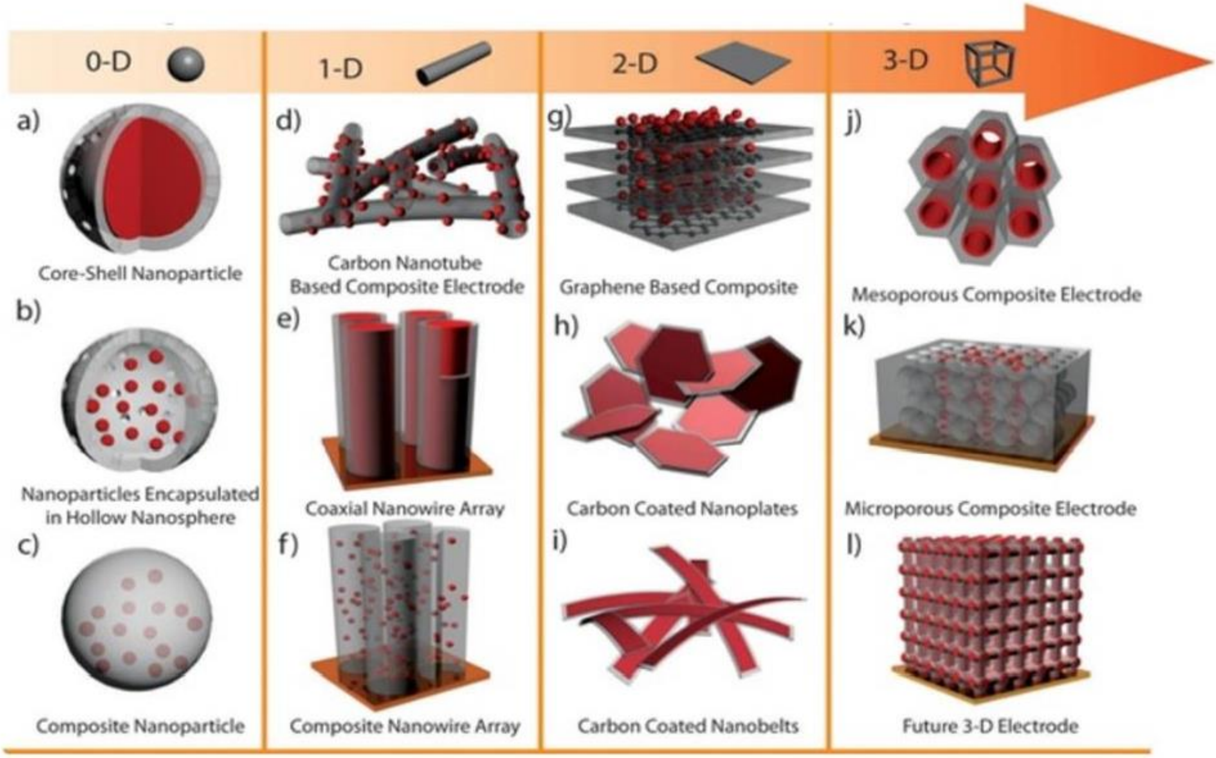
Classification of nanomaterials (0D, 1D, 2D, and 3D nanostructures):

- This classification is based on the number of dimensions of a material, which are outside the nanoscale (>100 nm) range.
- Zero-dimensional (0D) nanomaterials: All dimensions (x, y, z) are at nanoscale, i.e., no dimensions are greater than 100 nm. Most commonly, 0D nanomaterials are nanoparticles.
- One-dimensional nanomaterials (1D): One dimension is outside the nanoscale. Here, two dimensions (x, z) are at nanoscale and the other is outside the nanoscale. This leads to needle shaped nanomaterials. This class includes nanotubes, nanorods, and nanowires.

- Two-dimensional nanomaterials (2D): Two dimensions are outside the nanoscale. Here, one dimension (y) is at nanoscale and the other two are outside the nanoscale. The 2D nanomaterials exhibit plate like shapes. It includes nanofilms, nanolayers and nanocoatings with nanometer thickness.
- Three-dimensional nanomaterials (3D): These are materials are not confined to the nanoscale in any dimension. These materials have three arbitrary dimensions above 100 nm. The bulk (3D) nanomaterials are composed of a multiple arrangement of nanosize crystals in different orientations. This class can contain bulk powders, bundles of nanowires etc.



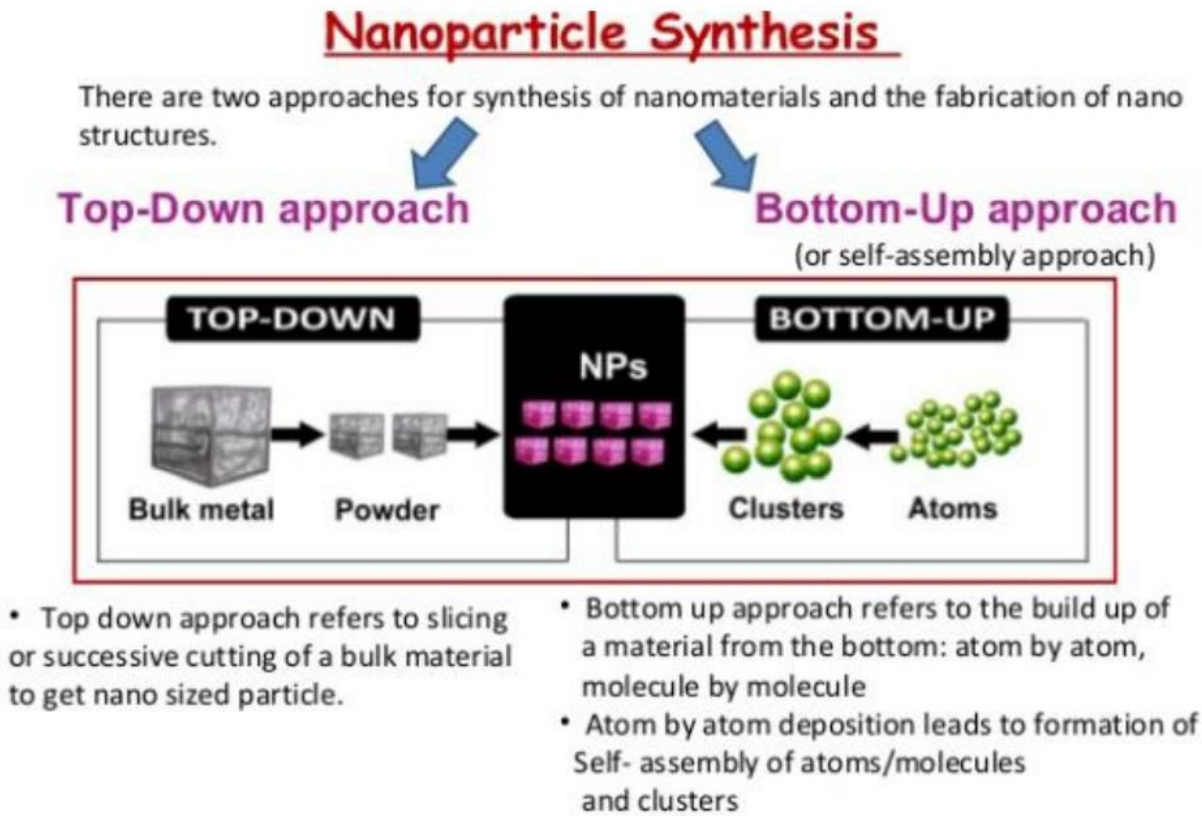




Overview on synthesis of nanomaterials (Bottom-up and top-down methods):

- In general, top-down and bottom-up are the two main approaches for nano materials synthesis.
    - Top-down: size reduction from bulk materials.
    - Bottom-up: material synthesis from atomic level.
- Top-down approach:
    - As the name suggests, the top-down approach means from top (larger) to bottom (smaller).
    - This approach is similar to making a statue made of stone. As in making of a statue, a bulk or big piece of stone is taken, similarly in top-down approach; a bulk piece of material is taken.
    - Then breaking up these larger particles by the use of physical processes like crushing, milling or grinding until desired shape is achieved.
    - Usually this route is not suitable for preparing uniformly shaped materials. The biggest problem with top-down approach is the imperfection of the surface structure.
    - Such imperfection would have a significant impact on physical properties and surface chemistry of nanostructures and nano materials.

- Bottom-up approach:
  - As the name suggests, the bottom-up approach means from bottom (smaller) to top or up (larger).
  - Bottom - up approach refers to the build-up of a material from the bottom: atom-by-atom, molecule-by-molecule or cluster-by-cluster.
  - This route is more often used for preparing most of the nano-scale materials with the ability to generate a uniform size, shape and distribution.
  - It effectively covers chemical synthesis and precisely controlled the reaction to inhibit further particle growth.

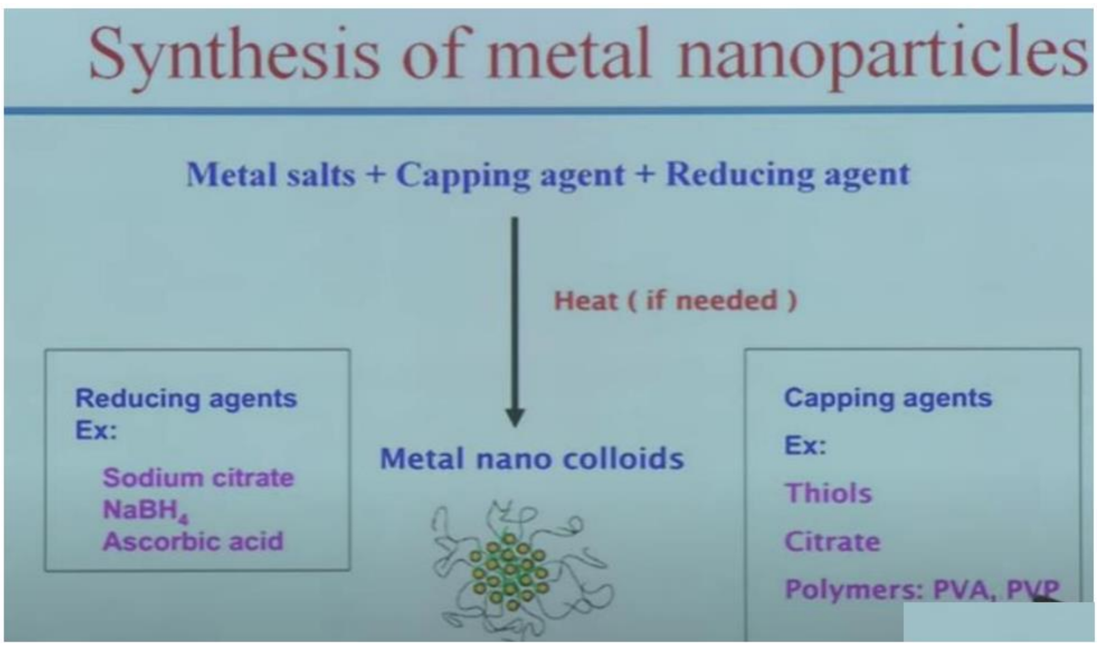


Chemical reduction method:

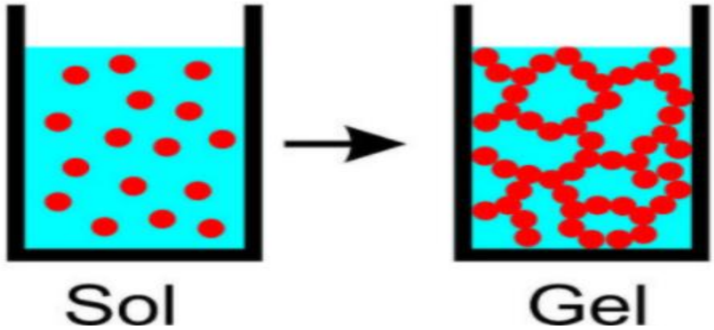
- Chemical reduction methods are a cost-effective and widely available methods.
- In chemical methods, a reduction agent in the form of gas or liquid is added.
- Some of these reduction agents are phenyl hydrazine, ascorbic acid, hydroxylamine, hydroquinone, glucose, sodium borohydride, alkaline solutions, and pyrrole.

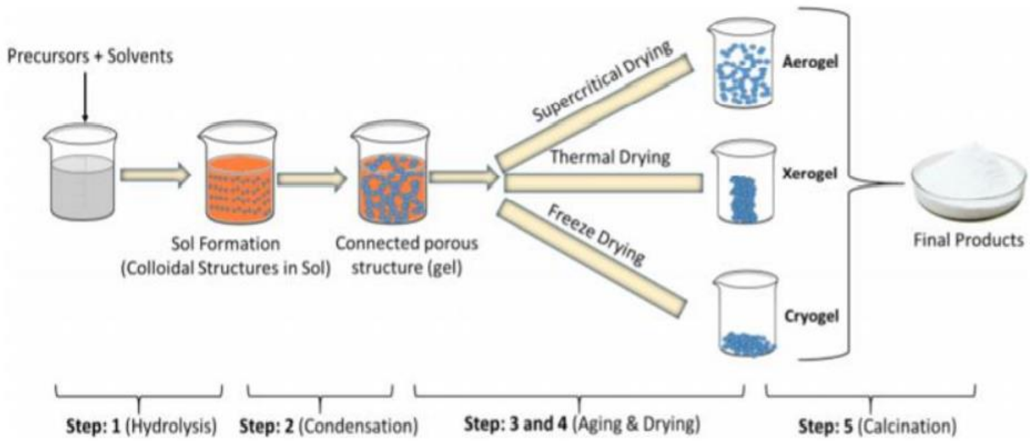
Ex: Synthesis of silver nanoparticles by chemical reduction:

- Different reducing agents such as; Sodium citrate, Ascorbate, Sodium borohydride ($NaBH_4$), Elemental hydrogen, Tollens reagent are used for reduction of silver ions.
- The reducing agents reduce silver ions (Ag^+) and lead to the formation of metallic silver (Ag^0), which is followed by agglomeration into clusters.
- It is important to use capping agents to stabilize nanoparticles during the course of metal nanoparticle preparation, and protect the nanoparticles, avoiding their agglomeration.
- The presence of capping agent can stabilize the particle growth and protect the particles from sedimentation and/or agglomeration.
- Polymeric compounds such as polyvinyl alcohol (PVA) and polyvinyl pyrrolidone (PVP) have been reported to be effective protective agents to stabilize nanoparticles.



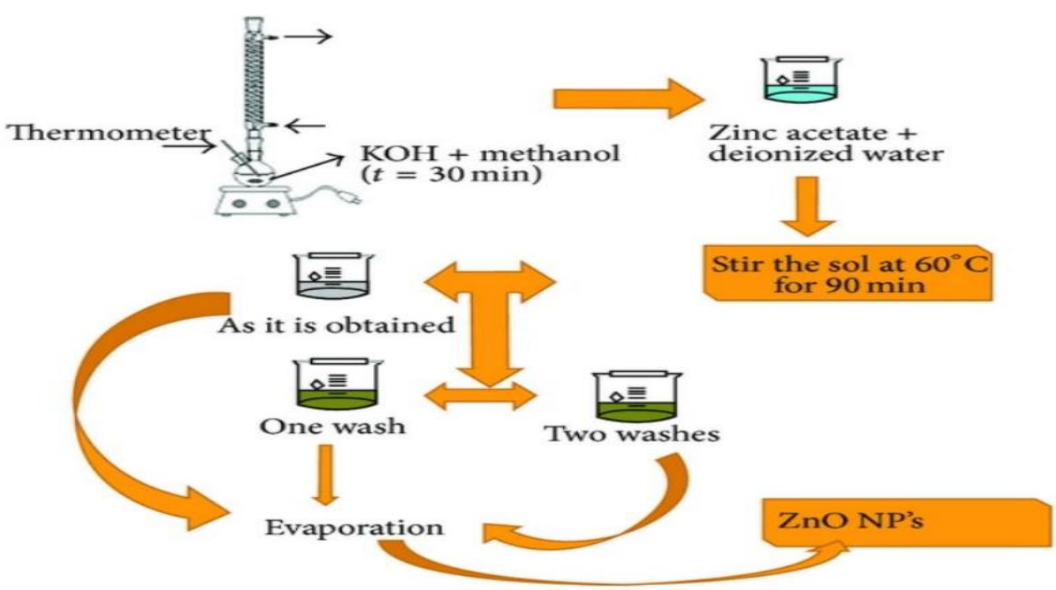
- **Sol-gel method:**
- The sol-gel process is a wet chemical technique also known as chemical solution deposition.
- The sol-gel transition (also known as gelation) is simply a change from a liquid state to a gel state.
- In the liquid state, components dispersed in the liquid are relatively free to move about.
- In the gel state, these subunits bond together to form a network extending throughout the whole substance.





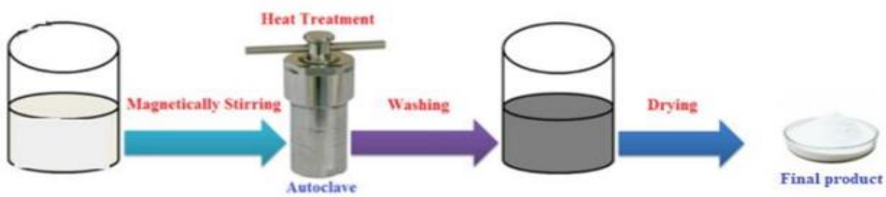
Ex: Synthesis of ZnO nanoparticles via sol-gel method

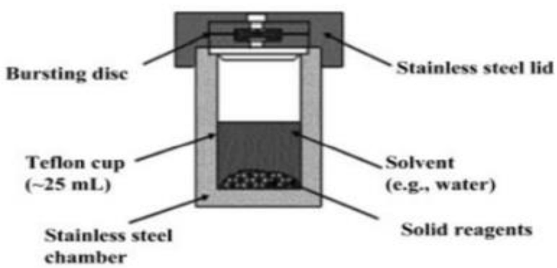
- Zinc acetate dihydrate ($Zn(CH_3COO)_2 . 2H_2O$) as a precursor and methanol (CH_3OH) was used as a solvent. NaOH or KOH and distilled water were used as a medium.



Hydrothermal synthesis:

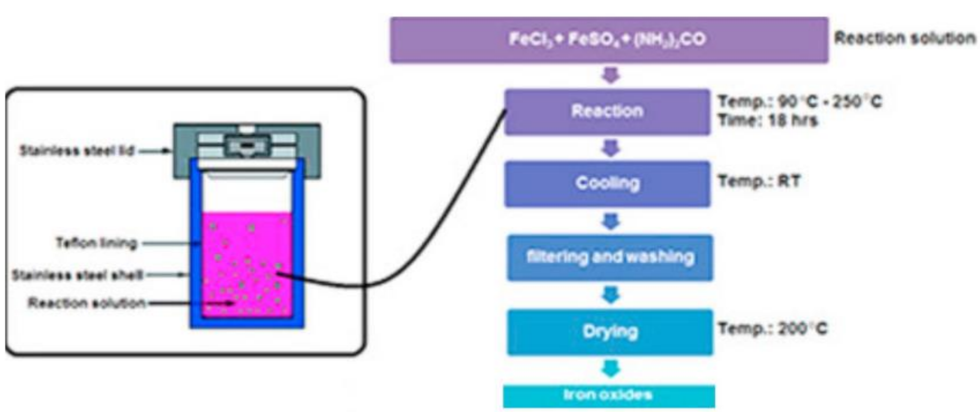
- Hydrothermal synthesis is one of the most commonly used methods for preparation of nano materials. Reaction of chemicals in an aqueous solution at elevated temperature and pressure.
- Hydrothermal synthesis can be considered a chemical precipitation in which the aging step is conducted at a high temperature (typically above the boiling point of water) inside an autoclave or pressure vessel.
- The mixing is then allowed to age, and subsequently washed and filtered. Finally, it is dried in an oven.
- The starting reagents and H_2O should occupy 50–60% of the autoclave volume.





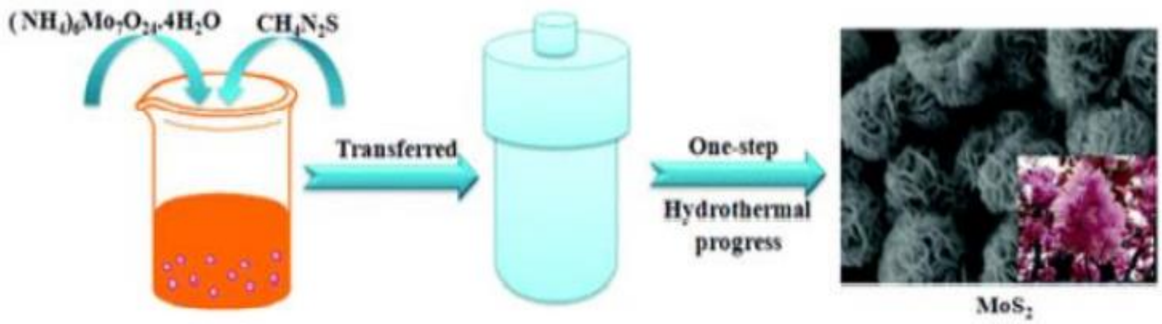
Ex 1: Synthesis of Magnetite (Iron Oxide, Fe_3O_4) nanoparticles by hydrothermal method.

Ferric chloride ($FeCl_3$ $6H_2O$), Ferrous sulfate ($FeSO_4$ $7H_2O$) and Urea ($(NH_2)_2CO$) were used.



Ex 2: Synthesis of Molybdenum disulfide (MoS_2) nanoparticles by hydrothermal method.

Ammonium Molybdate ($(NH_4)_6Mo7O_{24}\cdot 4H_2O$) and Thiourea ($CH_4N_2S$) were used.



Solvothermal process:

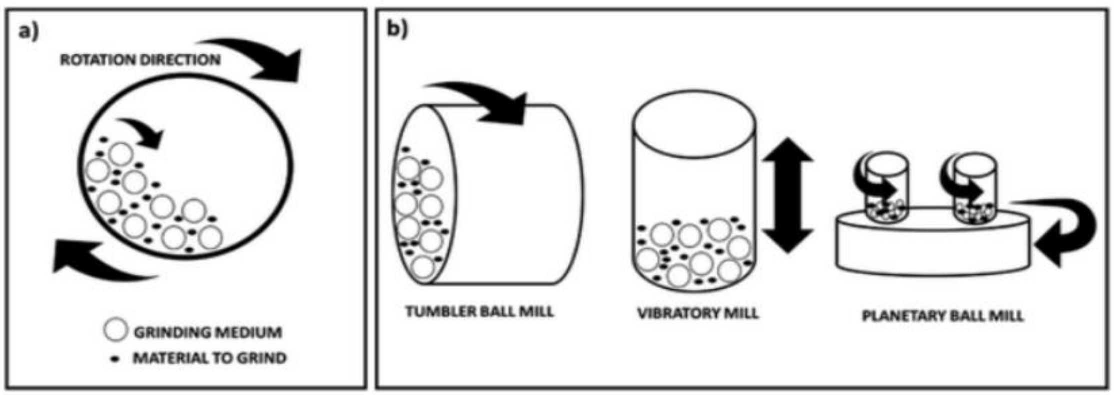
- Solvothermal method is very similar to hydrothermal method. Both synthesis methods are performed in an autoclave which can bear high temperatures and pressures.
- However, in hydrothermal method the solution is aqueous (solvent is water), while in solvothermal method the solution is non-aqueous (solvent other than water).
- Solvothermal synthesis involves the use of solvent under high temperature (between 100^0C to 1000^0C) and moderate to high pressure (1 atm to 10,000 atm) that facilitate the interaction of precursors during synthesis.
- Solvothermal process can be defined as a process in a closed reaction vessel inducing chemical reaction between precursors in the presence of a solvent at a temperature higher than the boiling temperature of this solvent.

  Ex: ZnO nanoparticles were prepared by a simple solvothermal route by using ethylene glycol–ethanol solvent system.

Ball Milling:

- Ball milling is a method of production of nano materials. A ball mill is a type of grinder used to grind materials into extremely fine powder.
- A ball mill mainly consists of a rotating drum lined from inside with a hard material.
- Generally consists of a hollow cylindrical shell rotating around its axis, which is partially filled with balls made of e.g. steel, stainless steel, ceramic.

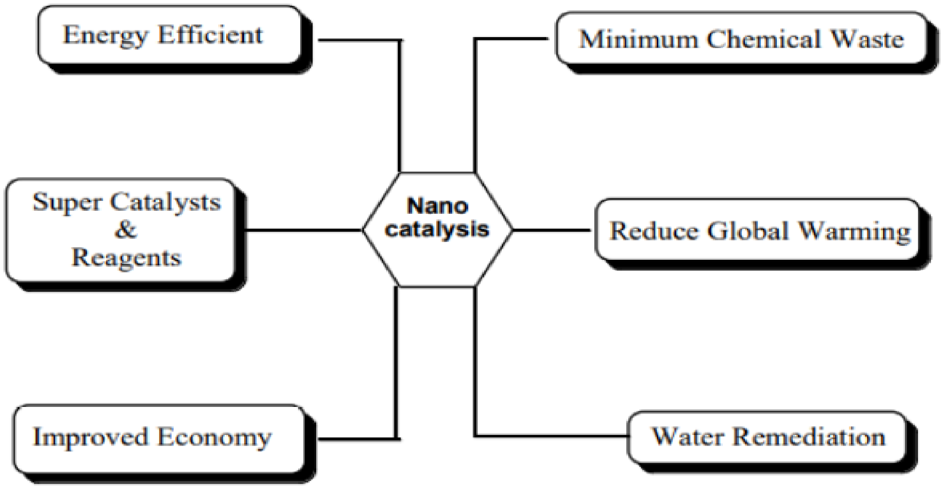
- Hard balls, as a grinding medium, which continue to impact the material inside the drum as it rotates.
- Ball mills rotate around a horizontal axis, partially filled with the material to be ground plus the grinding medium.
- The balls rotate with high energy inside a container and hence crush the solid into nano crystallites.
- It is a preferred method for preparing metal oxide nano crystals like Cerium (CeO_2) and Zinc Oxide (ZnO).



- Advantages: cost-effective, reliability, ease of operation, applicability in wet and dry conditions on a wide range of materials.
- Disadvantages: The possibility of contamination, formation of nano materials with irregular shape, noise, long milling and cleaning times.

Applications of nanotechnology in catalysis:

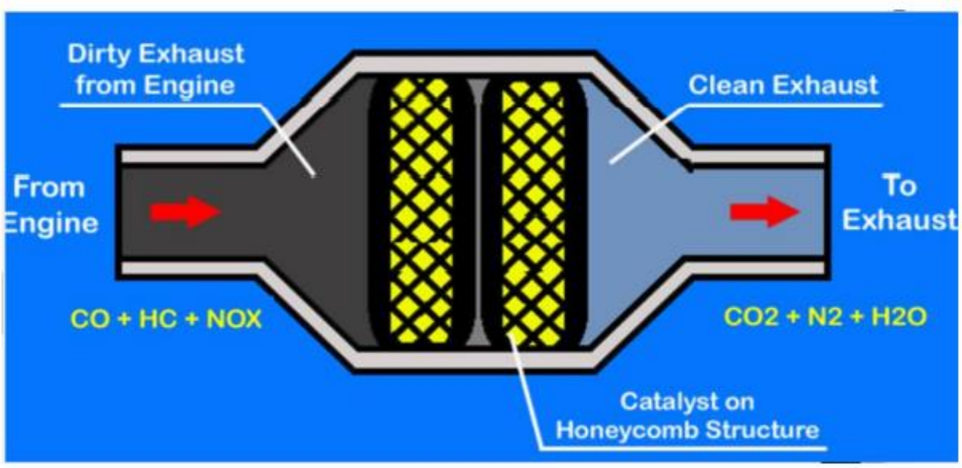
- The field of nanocatalysis (the use of nanoparticles to catalyze reactions) has undergone an explosive growth during the past decade, both in homogeneous and heterogeneous catalysis.
- Nanocatalysis is a process in which catalysis process use products of nanotechnology as a catalyst which are referred as “Nanocatalyst”.
- Nanocatalyst is a catalyst composed of nanoparticles. Smaller than 100 nm in at least one dimension. Porous compounds having pore diameters not bigger than 100 nm.
- Various elements and materials like aluminium, iron, titanium dioxide, clays, and silica all have been used as catalysts in nanoscale for many years. Recent examples include copper, ruthenium; rhodium, silver, palladium, iron, gold, nickel and platinum nanoparticles.



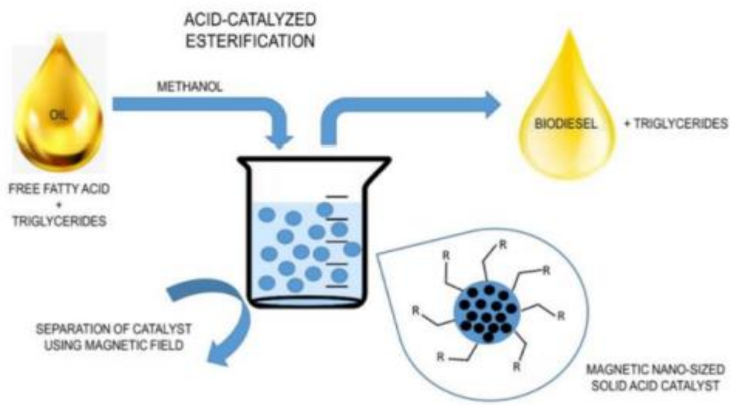
Benefit's of nanocatalysis

Some examples to nanoparticle catalyzed reactions:

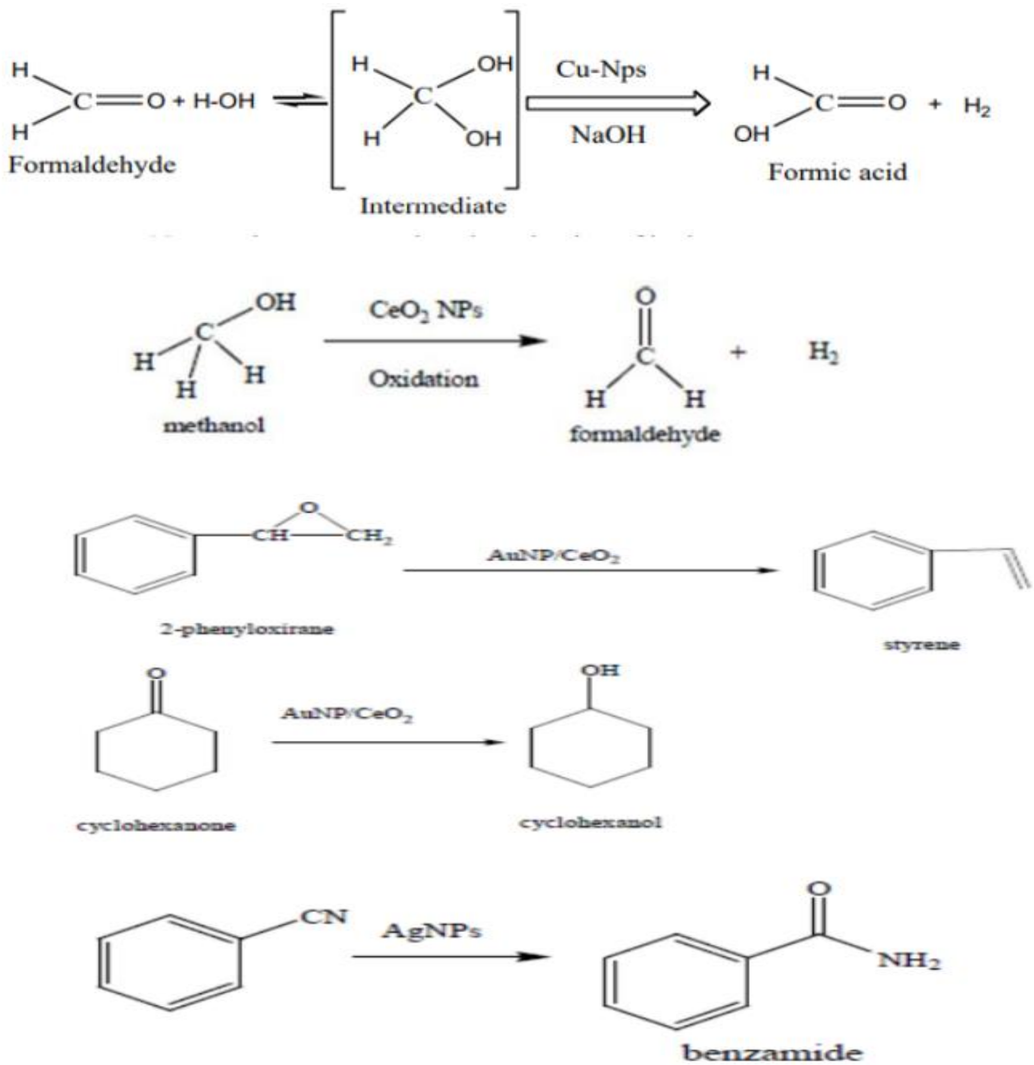
- **A catalytic converter** is an exhaust emission control device that reduces toxic gases and pollutants in exhaust gas from an internal combustion engine into less-toxic pollutants by catalyzing a redox reaction. Modern catalytic converters contain nanoparticles of platinum, palladium, rhodium and other metals on inert supports. Each metal catalyzes certain desired reactions in the process of treating the exhaust stream.



- **Biodiesel** is produced from vegetable oils or animal fats. The fuel is produced by transesterification-a process that converts fats and oils into biodiesel and glycerin (a co-product). Solid acid catalysts, based on metal oxides and different magnetic nanoparticles, are promising for the transesterification reactions of different oils for biodiesel production. Biodiesel can be used in any diesel engine with little or no modifications.

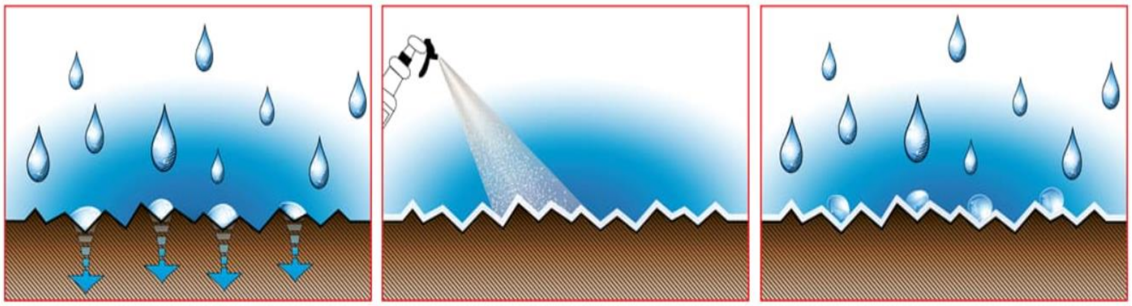


- Nano-aluminum is utilized as a solid-fuel in rocket propulsion. Nano-aluminum becomes highly reactive and supplies the required push to send off pay loads in space.
- Nanoparticle catalyzed organic reactions:



Applications of nanotechnology in surface coatings:

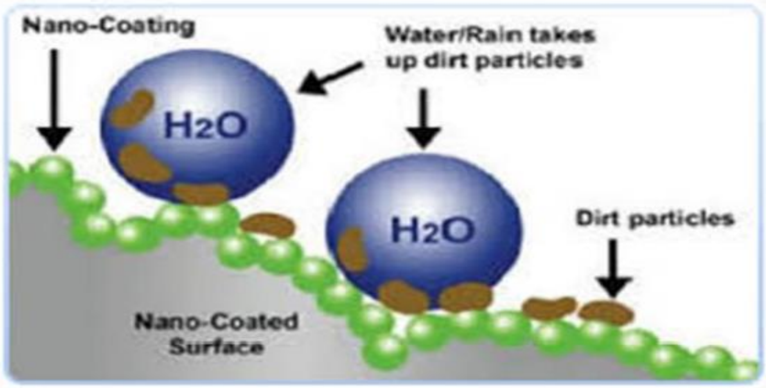
- The term nanocoating refers to nanoscale thin-films that are applied to surfaces in order create or improve a material's functionalities such as corrosion protection, water and ice protection, friction reduction, antifouling and antibacterial properties, self-cleaning, heat and radiation resistance, and thermal management.



1. Uncoated surface material allows water to absorb in. 2. Nanoman protective coating by spray application. 3. Nanoman coated surface repels liquids preventing staining and permanent marks from developing.

- Addition of nanoparticles to coatings can upgrade many properties of coating system.
- Main advantages of nano-coatings:
    - Better surface appearance
    - Good chemical resistance
    - Optical clarity
    - Increase in thermal stability
    - Easy to clean surface.
    - Anti-skid, anti-fogging, anti-fouling properties.
    - Better retention of luster and scratch resistance.
    - Good adherence on different type of materials
- Nanoparticles allow for innovative products such as:
    - Easy-to-clean coatings
    - Antibacterial coatings
    - Scratch-resistant coatings
    - Paints with UV protection
    - Wall coatings as screens against high-frequency electromagnetic radiation
    - Nano-primers for anti-corrosive coatings and paints
    - Heat-insulating coatings.

- The most prominent application of nanotechnology in the household is self-cleaning or "easy-to-clean" surfaces on ceramics or glasses.



- Nanoparticles used in the coatings industry include:
  - Titanium dioxide: is found in wall paints for removing organic pollutants from ambient air.
  - Silicon dioxide: is used in self-cleaning wall paints.
  - Iron oxide & Zinc oxide: UV protection
  - Silver: is a constituent of wall paints for hospitals and food processing operations, in order to prevent attack by bacteria and other microorganisms.
- Anti-corrosion nanocoatings:

  Nanoparticles such as nano silica, clay, ZnO, Fe_2O_3 and TiO_2 are typically used in organic coatings for improving corrosion resistance.

  Applications: Pipelines, Oil and Gas, Shipping and Shipyard sector, Infrastructures, Lifting equipment, Port machinery etc.
- Abrasion and wear-resistant nanocoatings:

  Nanoparticles such as ZrO_2, SiO_2 have been embedded in varnishes, resulting in improved abrasion resistance.

  Applications: Cars and aircrafts parts, engine parts and production areas for food technology.
- Anti-icing nanocoatings:

  The icing of surfaces is a major problem which impairs the function of those surfaces and experiences significant costs.

  Applications: Transportation (aircrafts, cars and trains), cooling units, wind energy plants, bridges, antennas and transmission lines.

- UV-resistant nanocoatings:

  Zinc oxide (ZnO), titanium dioxide (TiO_2) and cerium oxide (CeO_2), Al_2O_3, nanoparticles are used for UV light protection products. Nano-TiO_2 and ZnO is being applied for UV protection in textiles.

  Applications: Electronics, textiles, varnishes, cosmetics and the paint industry.

- Anti-fouling nanocoatings:

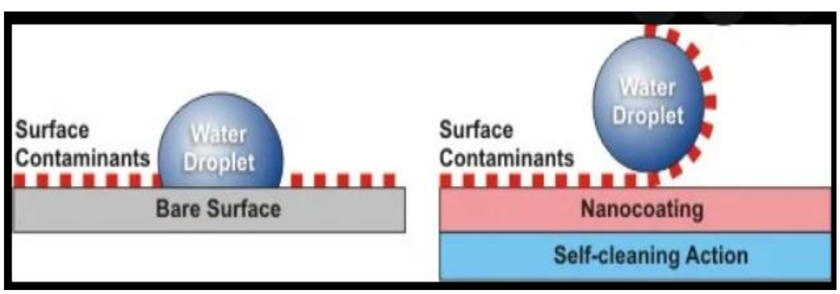
  ZnO and TiO_2 nanoparticles are most commonly used, while Cu_2O, CuO and Al_2O_3 are also incorporated into nanocomposite coatings. Especially in the aquaculture, marine and household (mainly bathroom) sectors. These coatings allow for improvement in the appearance of machinery and equipment, hygiene in different environments.

  Applications: Machinery and equipment operating in dirty process conditions, packaging.

- Self-cleaning nanocoatings:

  Self-cleaning surface is done in accordance with the Lotus effect phenomenon in which the surface becomes a super-hydrophobic. A super hydrophobic surface is able to repel water droplets completely. They are used not only for resisting water and fog condensation, but also for preventing contamination. SiO_2, TiO_2-based materials have been used to provide self-cleaning.

  Applications: Architectural glass, building materials, food production and packaging, high humidity areas (e.g. bath rooms), clinical surfaces, pharmaceutical packing, solar panel glass covers, traffic signals, displays etc.



- Anti-fouling, easy-to-clean and self-cleaning nanocoatings have gained market traction, especially in the building materials (anti-graffiti), marine and household (mainly bathroom) sectors. Applications are on surfaces for which contaminants harm the aesthetic, hygienic or technical operation. The goal is both a better level of cleanliness as well as a reduction of cleaning costs. Anti-fouling, easy-to-clean and self-cleaning nanocoatings have been developed for application in consumer electronics (smartphone waterproof coatings).