UNIT -V: Material Chemistry

Nano materials –Introduction- Top-down and Bottom- up approaches, Sol-gel method. Characterization by BET and TEM methods. Carbon nano tubes and fullerenes - Types, Preparation (Arc discharge Laser ablation and Chemical Vapour Deposition methods) Properties and Applications.

Liquid crystals - Introduction – Types – Applications.

Superconductors - Type-I & Type-II, Properties &Applications.

Green chemistry- Principles and Applications.

Material with any external dimension in the nanoscale (size range from approximately 1 – 100 nm) or having internal structure or surface structure in the nanoscale'.

In 2011, the European Commission released a specific recommendation on the definition of a nanomaterial (EC, 2011) which should be used in European Regulations, including REACH and CLP. According to this Recommendation, a "nanomaterial" means:

A natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm - 100 nm.

In specific cases and where warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50 % may be replaced by a threshold between 1 and 50 %.

By derogation from the above, fullerenes, graphene flakes and single wall carbon nanotubes with one or more external dimensions below 1 nm should be considered as nanomaterials.

Nanomaterials that are naturally occurring (e.g., volcanic ash, soot from forest fires) or are generated as incidental (unintentional) by-products of combustion processes (e.g., welding, diesel engines) are usually physically and chemically heterogeneous and often termed 'ultrafine particles'. Engineered nanomaterials, on the other hand, are intentionally produced and designed with physico-chemical properties for a specific purpose or function.

What are the uses of Nanomaterials?

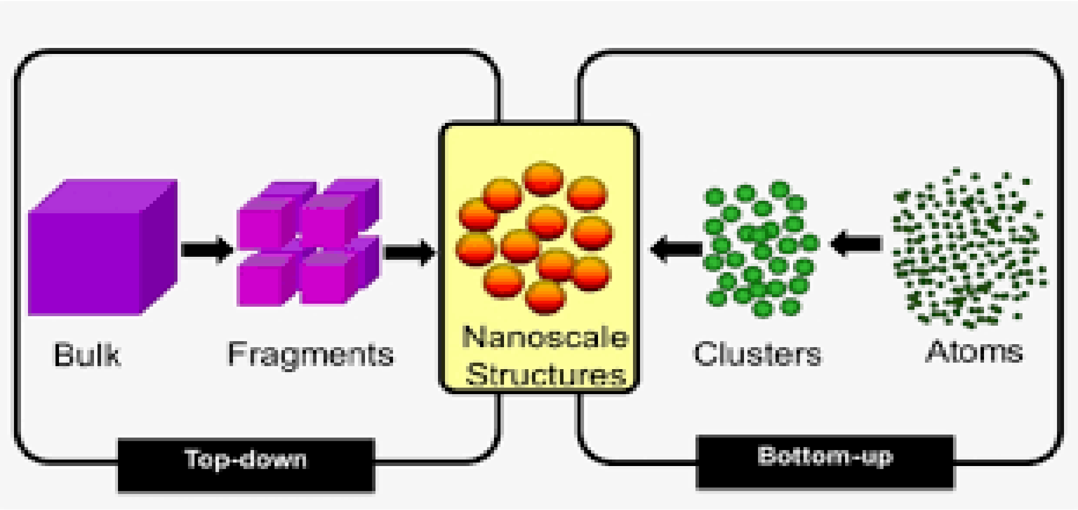
Due to the ability to generate the materials in a particular way to play a specific role, the use of nanomaterials spans across various industries, from healthcare and cosmetics to environmental preservation and air purification.

The healthcare field, for example, utilises nanomaterials in a variety of ways, with one major use being drug delivery. One example of this process is whereby nanoparticles are being developed to assist the transportation of chemotherapy drugs directly to cancerous growths, as well as to deliver drugs to areas of arteries that are damaged in order to fight cardiovascular disease. Carbon nanotubes are also being developed in order to be used in processes such as the addition of antibodies to the nanotubes to create bacteria sensors.

In aerospace, carbon nanotubes can be used in the morphing of aircraft wings. The nanotubes are used in a composite form to bend in response to the application of an electric voltage.

Elsewhere, environmental preservation processes make use of nanomaterials too - in this case, nanowires. Applications are being developed to use the nanowires - zinc oxide nanowires- in flexible solar cells as well as to play a role in the treatment of polluted water.

Top-down and Bottom- up approaches



Top-down approach

Top-down approach involves the breaking down of the bulk material into nanosized structures or particles. Top-down synthesis techniques are extension of those that have been used for producing micron sized particles. Top-down approaches are inherently simpler and depend either on removal or division of bulk material or on miniaturization of bulk fabrication processes to produce the desired structure with appropriate properties.

. Examples of such techniques are high-energy wet ball milling, electron beam lithography, atomic force manipulation, gas-phase condensation, aerosol spray, etc.

Bottom-up approach

✓ The alternative approach, which has the potential of creating less waste and hence the more economical, is the 'bottom- up'.

✓ Bottom-up approach refers to the build up of a material from the bottom: atom-by-atom, molecule-by-molecule, or cluster-by cluster.

✓ Many of these techniques are still under development or are just beginning to be used for commercial production of nanopowders.

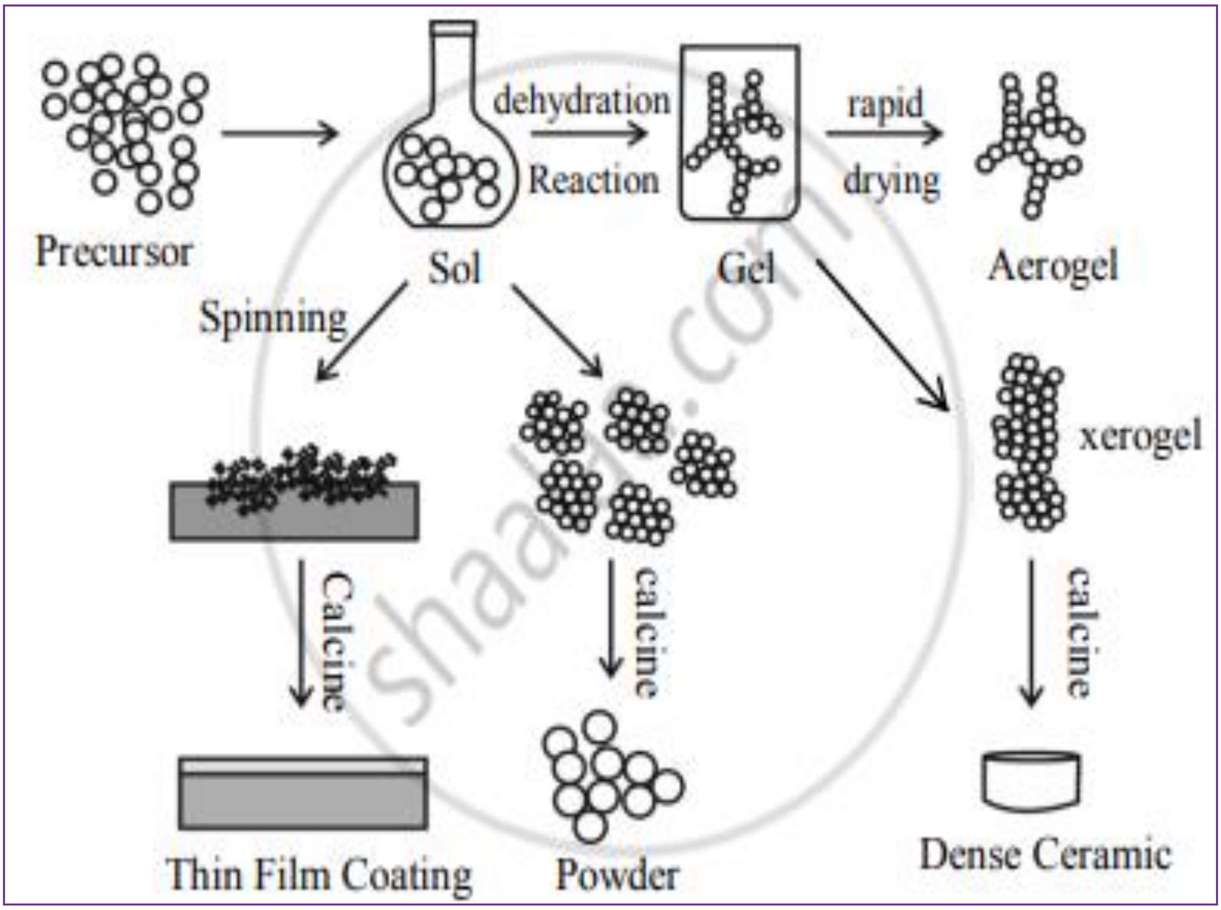
✓ Oraganometallic chemical route, revere-micelle route, sol-gel synthesis, colloidal precipitation, hydrothermal synthesis, template assisted sol-gel, electrodeposition etc, are some of the well- known bottom–up techniques reported for the preparation of luminescent nanoparticals.

sol-gel technique.

the **sol–gel** process is a method for producing solid materials from small molecules. The method is used for the fabrication of metal oxides, especially the oxides of silicon (Si) and titanium (Ti). The process involves conversion of monomers into a colloidal solution (sol) that acts as the precursor for an integrated network (or gel) of either discrete particles or network polymers. Typical precursors are metal alkoxides,inorganic metal salts.

This allows the production of nanomaterials from alkoxides or colloidal based solution. They take the form of monoliths, crystallized nano pigments, and thin layers. They are centered on reactions in polymerization.

In a typical sol-gel process, the precursor is subjected to a series of hydrolysis and polymerization reactions to form a colloidal suspension, or a "sol".
Further processing of the "sol" makes it possible to make materials in different forms



Advantages of Sol-gel process

This is widely used for synthesizing non-metallic inorganic materials such as glasses, glass ceramics, or ceramic materials at very low temperatures as compared to the traditional high temperature processes that require melting glass or firing ceramics.

Characterization by BET and TEM methods

By BET (Brunauer, Emmett and Teller) the *specific surface area* of a sample is measured – including the pore size distribution. This information is used to predict the dissolution rate, as this rate is proportional to the specific surface area. Thus, the surface area can be used to predict bioavailability. Further it is useful in evaluation of product performance and manufacturing consistency.

aims to explain the physical adsorption of gas molecules on a solid surface and serves as the basis for an important analysis technique for the measurement of the specific surface area of materials

The BET theory applies to systems of multilayer adsorption and usually utilizes probing gases that do not chemically react with material surfaces as adsorbates to quantify specific surface area.

Nitrogen is the most commonly employed gaseous adsorbate used for surface probing by BET methods.

For this reason, standard BET analysis is most often conducted at the boiling temperature of N_2 (77 K).

Applications of the BET principle

Any solid material may be characterized using gas adsorption for the determination of its surface area.

Common applications in which knowledge of the surface area is critical include the production and further processing of carbon, pharmaceuticals, catalysts, batteries, ceramics, and minerals.

Conclusion

As the BET principle employs gas adsorption data it is equally applicable to porous and non-porous materials regardless of particle size and shape. As such, it is a useful tool for the investigation and manufacture of a wide variety of solids.

Transmission electron microscopy (TEM)

Transmission electron microscopy technique in which a beam of electrons is transmitted through a specimen to form an image.

The specimen is most often an ultrathin section less than 100 nm thick or a suspension on a grid.

An image is formed from the interaction of the electrons with the sample as the beam is transmitted through the specimen.

The image is then magnified and focused onto an imaging device, such as a fluorescent screen, a layer of photographic film, or a sensor such as a scintillator attached to a charge-coupled device.

Applications of TEM

A TEM is ideal for a number of different fields such as life sciences,nanotechnology,medical,biological and material research,forensic analysis and metallurgy as well as industry and education.

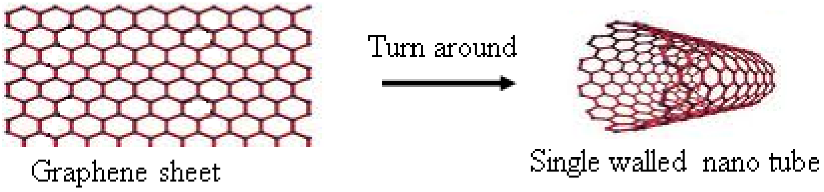
TEMs can be used in semiconductor analysis and production and the manufacturing of computer and silicon chips.

Technology companies use TEMs to identify flaws, fractures and damages to micro-sized objects; this data can help fix problems and/or help to make a more durable, efficient product.

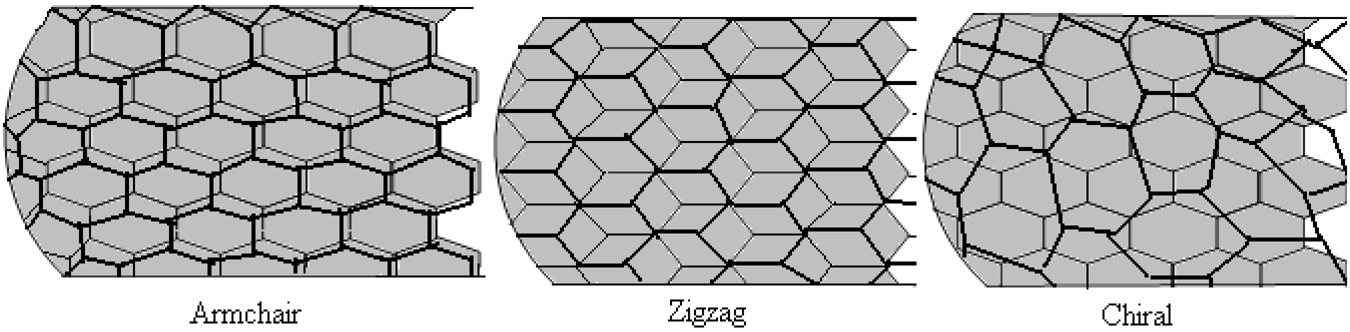
1. What are carbon nano tubes? Explain their types.

Carbon nano tubes (CNTs):

- CNTs are made up of carbon and look like a long, thin cylinders.
- In CNT, each carbon atom is covalently bonded to three other nearby carbon atoms(SP2)
- CNTs are very big molecules having very small size, shape and rare physical properties.
- CNT is one of the physical forms (allotropes) of carbon and others are diamond, graphite fullerenes etc.
- Length to diameter ratio of a CNT is greater than 100,000.
- CNT is formed, when hexagonal graphene sheet is turned around into a cylinder and its edges joined
- So the CNTs are longer tubes of graphite sheet.



- **Types of CNTs:**
  - There are two types of CNTs depends on their arrangement.
    - Single walled nano tubes (SWNTs)
    - Multi walled nano tubes (MWNTs)
- **Single walled nano tubes (SWNTs):**
  - SWNT is formed, when single one atom thick graphene sheet is turned around into a cylinder and its edges joined.
  - SWNTs have a diameter of 1 nm.
  - The length of SWNT is many millions times of its diameter.
  - SWNT show electrical conductivity.
  - It is used to make field affect transistors (FETs).
  - There are three types of SWNTs based on the arrangement of single one atom thick graphene sheet.
    - Armchair
    - Zigzag
    - Chiral
  - Graphene sheet is represented by a pair of indices (n,m) called Chiral vector. Where n and m are number of unit vectors along two directions in the hexagonal crystal lattice of graphene.
    - If n = m, the nano tubes are called “armchair”.
    - If m = 0, the nano tubes are called “zigzag”.
    - Otherwise, they are called “Chiral”. It has a bend shape around the nano tube.



Multi walled nano tubes (MWNTs):

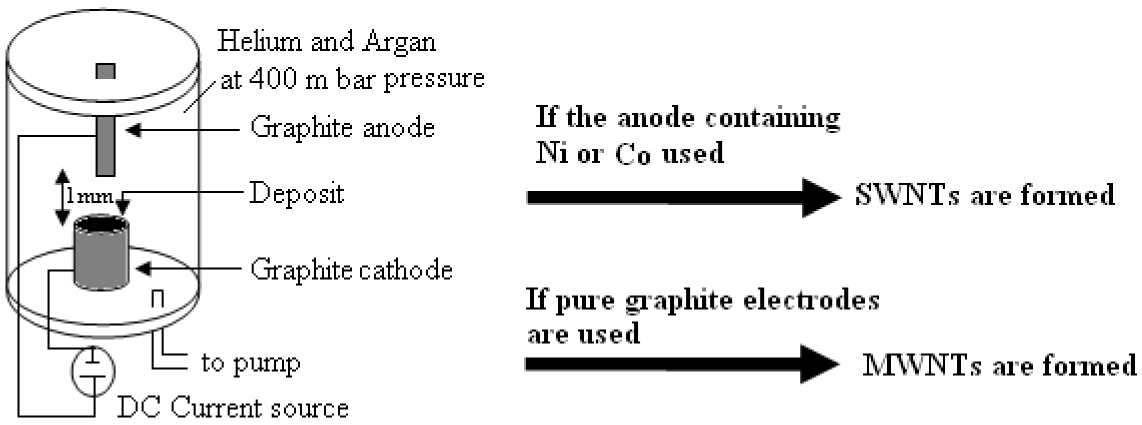
- MWNT is formed, when more than two one atom thick graphene sheets are turned around into a cylinder and its edges joined.
- These are concentric tubes of graphene.
- The distance between graphene layers of MWNT is ≈ 3.3 A^0.
- New function groups are inserted on the surface of DWNTs to add new properties to it.
- This type of DWNTs shows both metallic and semiconducting properties.
- It the **Russian doll model**, sheets of graphene are arranged in concentric cylinders, for example: a large (0, 10) SWNT in a small (0, 8) SWNT.
- In the **parchment** (means animal skin) **model**, a single sheet of graphene is turned around itself, like a roll of news paper.

2. Discuss the methods for synthesis of carbon nano tubes.

Synthesis (means preparation) **of Carbon nano tubes:**

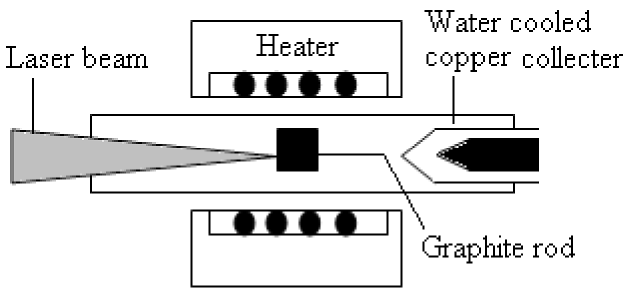
1. <u>Arc Discharge method:</u>

- This method is used to make C-60 fullerenes initially.
- A mixture of nano tubes is formed in this method. Hence nano tubes must be separated.
- In this method two graphite electrodes are placed end to end, separated by 1mm in a closed chamber.
- The chamber is filled with a mixture **of helium and argon at 400 mbar pressure.**
- **A direct current of 100 A is passed to create a high temperature discharge between two electrodes**.
- The discharge vaporizes one of the graphite electrodes and forms a nano tube on the other electrode.
- The diffusion coefficient and thermal conductivity depends on the ratio of Helium and argon.
- These properties affect the diameter of nano tubes.
- If the anode containing Ni or Co used, SWNTs are formed.
- If pure graphite electrodes are used, MWNTs are formed.



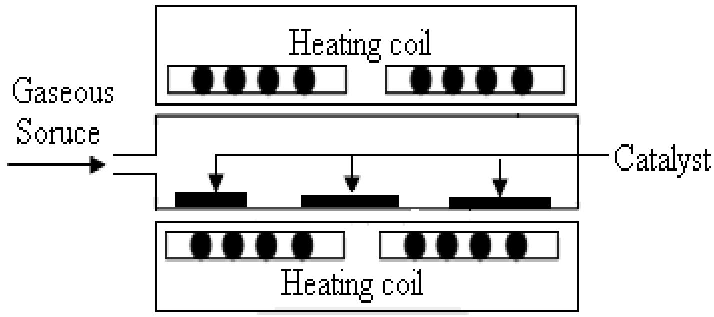
2. Laser ablation technique:

- Smalley's group developed preparation of CNTs by laser ablation technique in 1995.
- In this method, a closed chamber is fitted with graphite rod at the center, filled with **Helium gas at a pressure of 500 Torr** and a laser beam is focused on the graphite rod.
- When a laser beam is focused on the graphite rod, the temperature increases to **1200^0C.**
- It vaporizes carbon atoms from graphite.
- As the vaporized carbon atoms cool, carbon atoms deposit to form a big group (Clusters) on Copper collector.
- The catalyst also starts to deposit slowly and attached to the big group.
- The SWNTs are formed on the surface of the big group of catalyst and C atoms.



3. Chemical vapour deposition (CVD):

- It is done in two steps
  - Catalyst preparation
  - Nano tube preparation
- **Catalyst preparation:**
  - It is done by depositing a metal like Fe, Ni or Co on a substrate and then it is toughen by heat and slow cooling.
- **Nano tube preparation:**
  - In CVD, carbon source is in the gaseous phase and an energy source like heating coil is used to heat the gaseous carbon molecule at 600-950^0C.
  - **Gaseous carbon sources are methane, carbon monoxide and acetylene.**
  - The energy source is used to decompose the molecule into reactive atomic carbon.
  - Then the atomic carbon diffuses towards the catalyst.
  - CNTs are formed on the surface of catalyst.
  - Maximum yield in CVD is 30%.



3. Explain the properties and applications of carbon nano tubes or nano materials.

Properties of CNTs (or Nano materials):

- **Mechanical properties:**
    - **Strength:**
        - The strength of SP^2 C-C bonds gives CNTs a special type of properties.
        - CNTs are strongest and stiffest materials than diamond in terms of tensile (extension) strength and elastic modulus.
        - This strength is due to the SP^2 bonds formed between the carbon atoms.
        - It has low density than diamond.
    - **Hardness:**
        - CNTs have highest elastic modulus and harder than diamond.
        - CNTs can withstand damage from physical forces.
        - Young's modulus of MWNTs is 1200 G Pa where as for diamond it is 600 G Pa.
- **Electrical properties:**

    CNTs are metallic or semiconducting depending on the structure of graphene sheet.

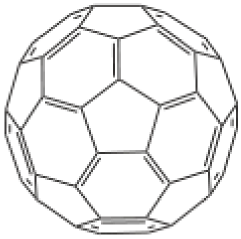
Engineering applications of CNTs:

- **Uses in fuel cells:**
    - The SWNTs are used to store hydrogen.
    - The SWNTs are used to make fuel cell electrodes.
    - CNTs are used as catalysts in fuel cell.
    - Pt/CNT electrodes produce more electricity than Pt/CB (carbon black) electrodes.

- **Uses in catalysis:**
    - When catalyst having CNTs used, the reaction takes place with a medium rate and gives the required product.
    - CNTs are used as both catalyst and catalyst supportive materials.
    - CNTs containing nitrogen are used as cathodes in highly alkaline solution.
    - Oxidizable CNTs containing phosphorous are used in oxidative dehydrogenation of butane and butadiene.
    - Some chemical reactions are also done inside the nano tubes. For example:
        - Reduction of Nickel oxide (NiO) to Ni.
        - Reduction of $AlCl_3$ to Al.
- Uses in medicine:
    - Drug molecules joined to the CNTs are used to leave the drug molecule at the required part of the body; for testing and control of diseases.
    - This is very useful in cancer treatment.
    - CNTs are used to check the presence of DNA.

4. Discuss the preparation, properties and applications of fullerenes.

- Fullerene is the third newly discovered physical form (allotrope) of carbon.
- The structure of C-60 fullerene looks like a circular building (dome) constructed by Buckminster Fuller.
- It is also called as Buckminster fullerene.
- This chemical compound is named as fullerene by considering the hard work of Buckminster fuller in the construction of the circular building (Dome).
- The structure of C-60 fullerene:



- **Types of fullerenes:**
  - There are three types
    - **Spherical fullerenes:** They look like a soccer ball and many times called as Bucky balls.
    - **Cylindrical fullerenes:** These are called CNTs of Bucky tubes.
    - **Planar fullerenes:** Graphene is an example of planar fullerene sheet.

- **Preparation:**
  - Fullerenes are made by vaporizing a graphite rod in a helium atmosphere.
  - Mixture of fullerenes like C-60, C-70 etc. is formed.
  - These are separated by solvent extraction.
  - C-60 is gotten from this mixture by column chromatography using alumina and hexane.

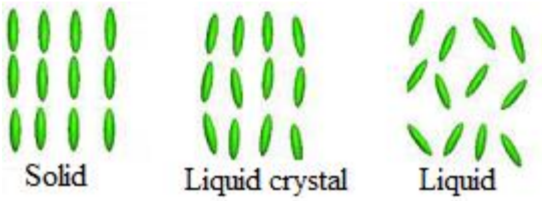
- **Structure:**
  - Fullerenes have closed cage structure like the structure of C-60 and it has chemical formula C_n.
  - Every fullerene contains (constant number of) 12 pentagons and changeable number of hexagons.
  - C-60 fullerene contains even number of SP^2 carbon atoms and its crystals are spherical in shape.
  - Each atom is connected to its nearby carbon atoms through covalent bonds to form polyhedron cage structure.
  - The C-60 molecule has bent icosohedron structure.
  - An icosohedron is a polygon with 60 vertices and 32 faces, 12 of which are pentagonal and 20 hexagonal.

- **Properties:**
  - Fullerene is different type of molecule.
  - C-60 is brown to black color solid.
  - It is soluble in aromatic hydrocarbons.
  - It dissolves in benzene to form purplish red solution.
  - It is very tough and it can be pushed against a tough surface without damaging it.
  - It is stable up to 600^0C and it becomes liquid under vacuum at 600^0C.
  - It has highest tensile (extension) strength.
  - It has highest packing density.
  - It can be pressed to lose 30% of its volume without spoiling its cage like structure.

- **Engineering applications:**
  - Fullerenes are used to
    - Carry charge in batteries
    - Make photovoltaic cells
    - Make lubricants
    - Make protective covering in wars
    - Stop cell damages in human body
    - Make catalyst that is used in hydrogenation and dealkylations.
    - Make alkali metal fullerides that are superconductors
    - Make soft ferromagnets.

Liquid crystals:

- Liquid crystal is a liquid that has some of the properties of crystals (solids) like reflection light from different directions in different ways and hence liquid crystals are anisotropic.
- The order of the molecules of the liquid crystal is in between solid state and liquid state as shown in diagram and hence these have the physical properties of both solids and liquids.
- Liquid crystals look like highly turbid, very thick and different from liquids.
- In the solid state, molecules are highly ordered and thus they have different properties in different directions (anisotropic properties)
- In the liquid state, molecules are highly disordered and thus they have same properties in all directions (isotropic properties)
- The order of the molecules of each state is as follows:



Properties:
A rod like molecular structure
Rigidness (rigid meant not bending)
Strong dipoles and easily polarizable groups (polarizable groups can separated their charges)

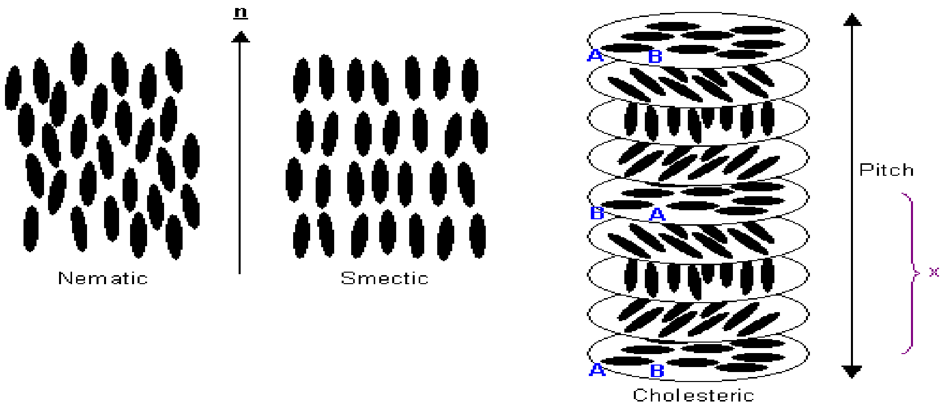
Types:
These are two types
1. Thermotropic liquid crystals
2. Lyotrophic liquid crystals

Thermotropic liquid crystals:
These are formed when a solid is heated to a certain temperature
These are 3 types
1.Nematic 2. Cholesteric 3. Smectic
These have different types of molecular order.

Nematic liquid crystal:
In this, molecules are parallel to each other along the long molecular axes.

- They are moved in three directions and can rotate about one axis. They have one – dimensional structure. So, small amount of energy is enough to spoil the order of a nematic liquid crystal.

- **Cholesteric liquid crystal:**
  - Many compounds of cholesterol show nematic liquid crystal structure. Hence it is called Cholesteric liquid crystal.
  - This structure can be seen like thin nematic layers are placed on top of the one below as shown in diagram.
- **Smectic liquid crystal:**
  - A thick, oily substance seen at the bottom of a soap dish is an example of smectic liquid crystal.
  - In the Smectic liquid crystal, the molecules have the same order of nematic liquid crystal.
  - But the molecules are not moved and hence there are eight smectic structures. These are named as A to H.



Lyotropic Liquid Crystals:
In concentrated solutions, lyotropic liquid crystals can be formed and the solvent should be isotropic.
Examples: 1. Sodium laurate in water and
2. Dhosphatidyl choline in water.
Lyotropic liquid crystals are available in soaps, gels and colloids, and in biological systems. Soap films are formed by many types of lyotropic liquid crystals.

Applications of liquid crystals:

- Liquid crystals are used in science, medicine and engineering.
- **Displays:**
  - These are mainly used as displays in many instruments and devices (LCD i.e., liquid crystal display), used in digital wrist – watches, calculators, television screens, computer monitors.
- **Medicinal Thermography:**
  - In this, the temperature of the different parts of the body is recorded and analyzed.
  - Cholesteric substances show one color at a particular temperature. But by changing the temperature, the color also changes. So these are useful to find changes in veins (tubes that carry blood from body towards heart) and arteries (tubes that carry blood from heart towards body), diseases, tumors etc.
- **Radiation and Pressure sensors:**
  - Cholesteric liquid crystals are also used in radiation and pressure sensors.
- **In research work:**

  Nematic liquid crystals are good solvents for NMR spectra. Some liquid crystals can also be used as solvents for chromatographic separations to know how much reaction has completed.

  Liquid crystals are used in electronic industry and in aerodynamic testing.

Green chemistry

The people working on chemistry (chemists) play an important role to develop green chemical methods to stop the pollution in the environment.

- **Green chemistry uses the chemical products and possesses that decrease the use and formation of dangerous substances so that they should not damage human health and environment.**

Green chemistry's 12 principles

These principles demonstrate the breadth of the concept of green chemistry:

1. Prevent waste: Design chemical syntheses to prevent waste. Leave no waste to treat or clean up.

2. Maximize atom economy: Design syntheses so that the final product contains the maximum proportion of the starting materials. Waste few or no atoms.

3. Design less hazardous chemical syntheses: Design syntheses to use and generate substances with little or no toxicity to either humans or the environment.

4. Design safer chemicals and products: Design chemical products that are fully effective yet have little or no toxicity.

5. Use safer solvents and reaction conditions: Avoid using solvents, separation agents, or other auxiliary chemicals. If you must use these chemicals, use safer ones.

6. Increase energy efficiency: Run chemical reactions at room temperature and pressure whenever possible.

7. Use renewable feedstocks: Use starting materials (also known as feedstocks) that are renewable rather than depletable. The source of renewable feedstocks is often agricultural products or the wastes of other processes; the source of depletable feedstocks is often fossil fuels (petroleum, natural gas, or coal) or mining operations.

8. Avoid chemical derivatives: Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.

9. Use catalysts, not stoichiometric reagents: Minimize waste by using catalytic reactions. Catalysts are effective in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and carry out a reaction only once.

10. Design chemicals and products to degrade after use: Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.

11. Analyze in real time to prevent pollution: Include in-process, real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.

12. Minimize the potential for accidents: Design chemicals and their physical forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

Engineering applications of Green Chemistry:

- Engineers use scientific and engineering principles to decrease the air pollutants level and burning of chemical wastes during their preparation.
- Engineers have developed different processes to remove nitrogen oxides, sulfur oxides, volatile (vaporizable) organic compounds (VOC), reactive organic gases (ROG) and other air pollutants from smoke gases.
- scientists have developed methods to remove air pollutants like waste gases from industries and cars, motor bikes etc.
- Engineers and chemists try to stop waste and decrease the usage of organic solvents.
- Engineers developed new method to change
- Lignin into useful chemicals, antioxidants, medicines.
- Biomass into fermentable sugars in presence of enzymes.
- Engineers developed a process to make ethanol from corn and ethanol is used as fuel in place of petrol.
- The chemical processes using microorganisms are not costly, eco-friendly and gives more yield.
- Many polymers are produced from the by-product of the starch industry.
- For example:
- Adipic acid is used in the making of nylon, polyurethane, lubricants etc.
- Benzene is the starting material for the preparation of adipic acid but benzene is cancer causing.
- In other way, the Adipic acid is made from glucose and glucose is gotten from cane sugar etc.

A superconductor is an element or metallic alloy which, when cooled below a certain threshold temperature, the material dramatically loses all electrical resistance. In principle, superconductors can allow electrical current to flow without any energy loss (although, in practice, an ideal superconductor is very hard to produce). This type of current is called a supercurrent.

The threshold temperature below which a material transitions into a superconductor state is designated as T_c, which stands for critical temperature. Not all materials turn into superconductors, and the materials that do each have their own value of T_c.

Type I and Type II superconductors

Depending upon their behavior in an external magnetic field, superconductors are divided into two types:

a) Type I superconductors and

b) Type II superconductors

Let us discuss them one by one:

1) **Type I superconductors**:

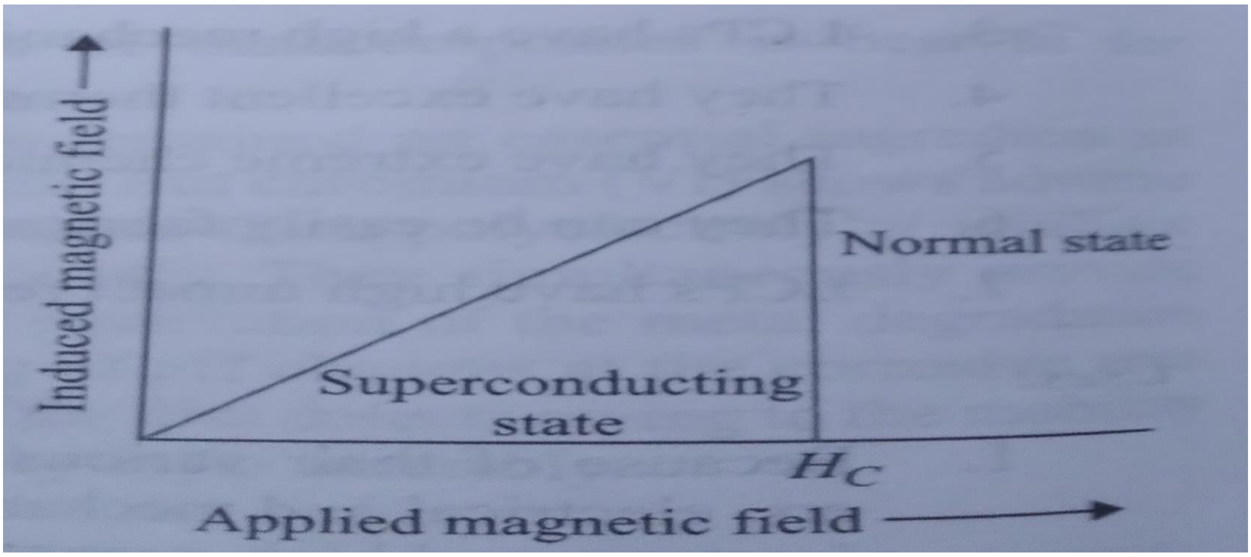
a)Type I superconductors are those superconductors which loose their superconductivity very easily or abruptly when placed in the external magnetic field.

As you can see from the graph of intensity of magnetization (M) versus applied magnetic field (H), when the Type I superconductor is placed in the magnetic field, it suddenly or easily looses its superconductivity at critical magnetic field (Hc) (point A). After Hc, the Type I superconductor will become conductor.

b)Type I superconductors are also known as **soft superconductors** because of this reason that is they loose their superconductivity easily.

c) Type I superconductors perfectly obey Meissner effect.

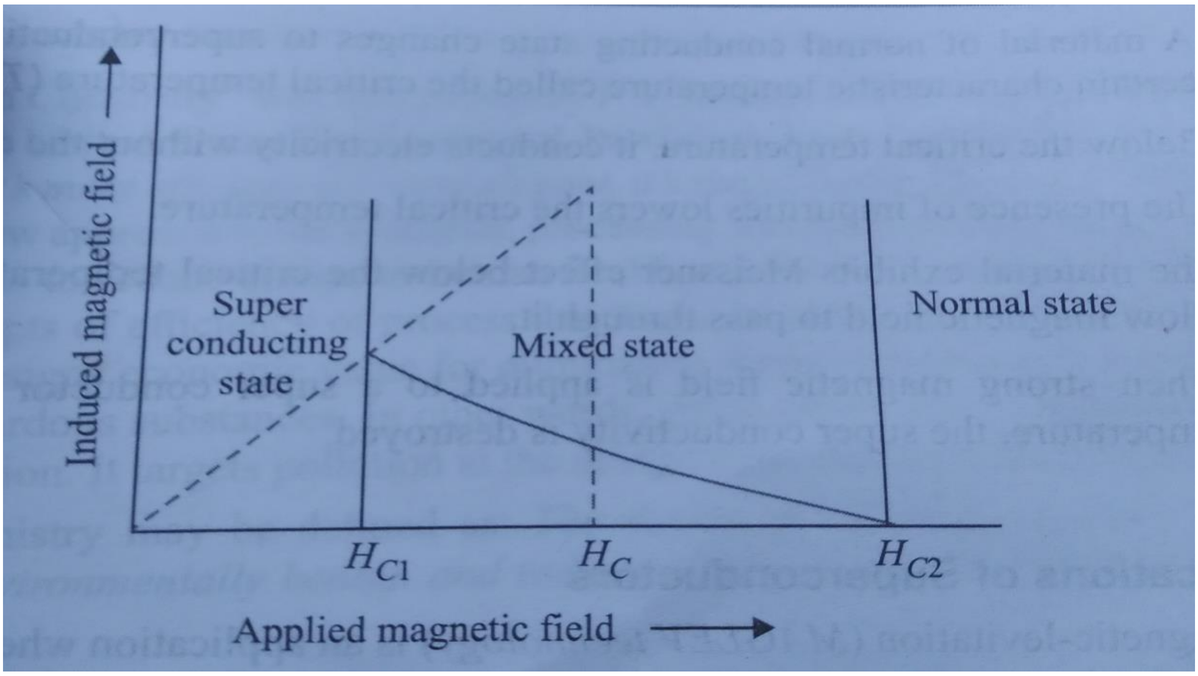
d) Example of Type I superconductors: Aluminum (Hc = 0.0105 Tesla), Zinc (Hc = 0.0054),Lead, mercury, tin etc.



2) **Type II superconductors**:

a). Type II superconductors are those superconductors which loose their superconductivity gradually but not easily or abruptly when placed in the external magnetic field. As you can see from the graph of intensity of magnetization (M) versus applied magnetic field (H), when the Type II superconductor is placed in the magnetic field, it gradually looses its superconductivity.

Type II superconductors start to loose their superconductivity at lower critical magnetic field (Hc1) and completely loose their superconductivity at upper critical magnetic field (Hc2).



b) The state between the lower critical magnetic field (Hc1) and upper critical magnetic field (Hc2) is known as vortex state or intermediate state.

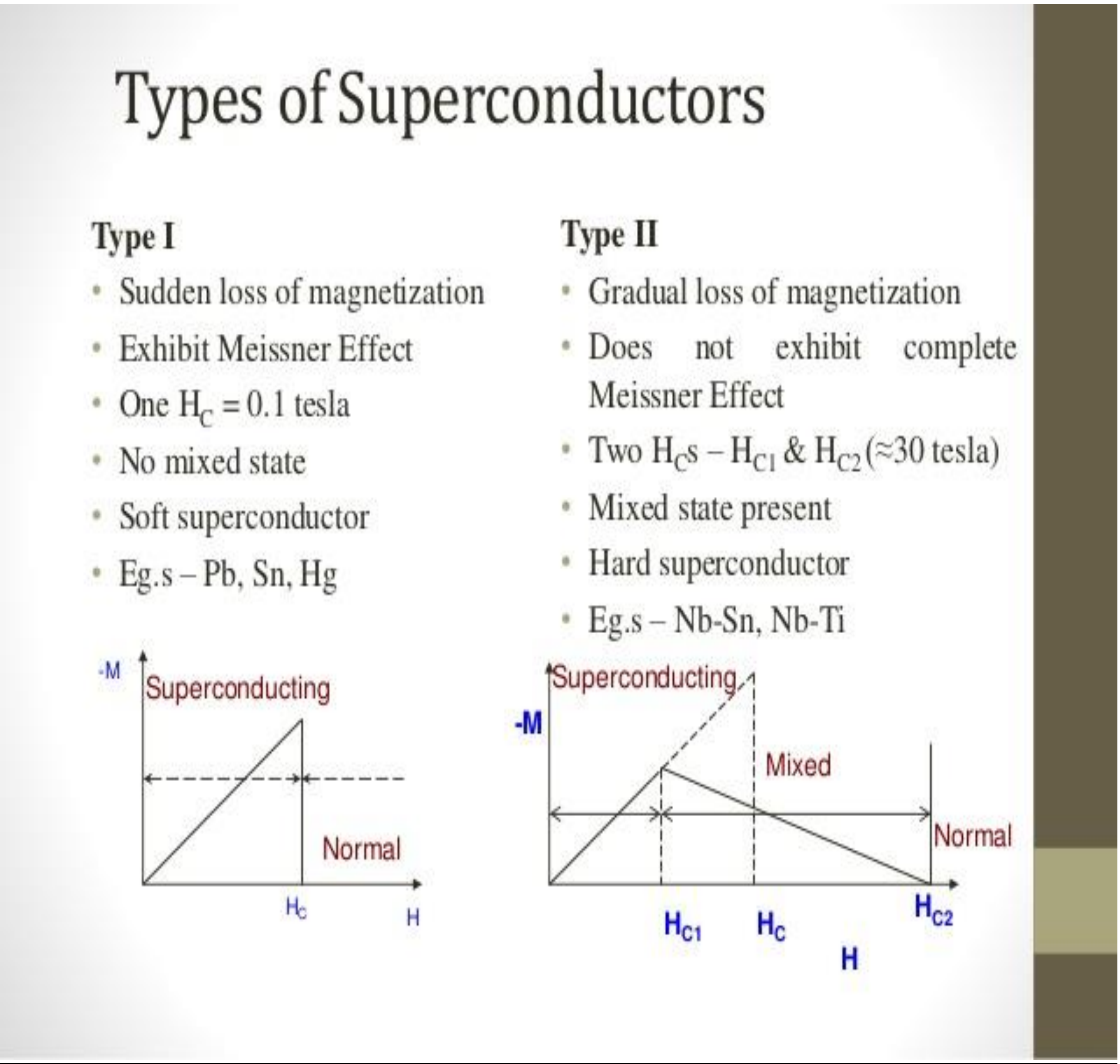
After Hc2, the Type II superconductor will become conductor.

c)Type II superconductors are also known as **hard superconductors** because of this reason that is they loose their superconductivity gradually but not easily.

c) Type II superconductors obey Meissner effect but not completely.

d) Example of Type II superconductors: NbN (Hc = 8 x 10^6 Tesla), Babi$_3$ (Hc = 59 x 10^3 Tesla)

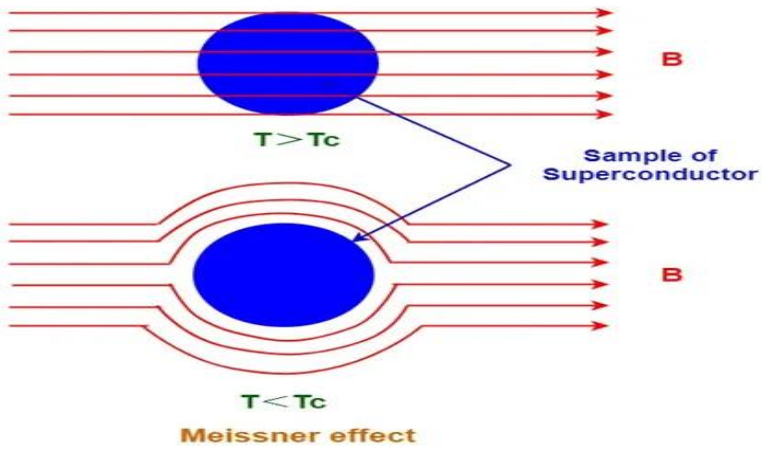
.Nb-Sn, Nb-Zr, Nb- Ti etc.



Meissner effect
When Superconductors, are cooled below the critical temperature, they expel magnetic field and do not allow the magnetic field to penetrate inside them. This phenomenon in superconductors is called **Meissner effect**. This phenomenon was discovered by German physicists "Walther Meissner" and "Robert Ochsenfeld" in 1933

Meissner State

This state of the superconductor is also called Meissner state. An example of **Meissner effect** is shown in figure below.
This Meissner state breaks when the magnetic field (either external or produced by current flowing superconductor itself) increases beyond a certain value and sample starts behaving like an ordinary conductor.
This certain value of magnetic field beyond which superconductor returns to ordinary state is called Critical Magnetic Field. The value of the critical magnetic field depends on temperature. The value of the critical magnetic field increases when the temperature below the critical temperature reduces. The figure below shows the variation in the critical magnetic field with temperature.



Application of Meissner Effect
This effect of superconductivity, is used in magnetic levitation which is the base of modern high-speed bullet trains. In superconducting state (phase), due to expulsion of external magnetic field, the sample of superconducting material levitates above magnet or vise-versa. Modern high-speed bullet trains use the phenomenon of magnetic levitation.

Properties of super conductors
The superconducting material shows some extraordinary properties which make them very important for modern technology. The research is still going on to understand and utilise these extraordinary properties of superconductors in various fields of technology. Such properties of superconductors are listed below-

1. Zero Electric Resistance (Infinite Conductivity)
2. Meissner Effect: Expulsion of magnetic field
3. Critical Temperature/Transition Temperature
4. Critical Magnetic Field
5. Persistent Currents
6. Josephson Currents
7. Critical Current

3.2 Applications of Superconductors

1. Magnetic-levitation (*MAGLEV technology*) is an application where superconductors play an important role. Transport vehicles such as trains can be made to "float" on strong superconducting magnets, virtually eliminating friction between the train and its tracks.

2. An area where superconductors can perform a life-saving function is in the field of biomagnetism used for medical diagnosis. Magnetic resonance imaging (MRI) was actually discovered in the mid 1940s, the principle being impinging a strong superconductor-derived magnetic field into the body; the hydrogen atoms that exist in the body's water and fat molecules are forced to accept the energy from the magnetic field. They then release this energy at a frequency that can be detected and displayed graphically by a computer.

3. Type-II superconductors can be used for storing and retrieving digital information. Scientists dream for "petaflop" computers in the next generation with the help of superconductors. A petaflop is a thousand-trillion floating point operations per second. Today's fastest computers have only recently reached "petaflop" speeds—quadrillions of operations per second. Currently, the fastest is China's Tianhe-1A, operating at 2.67 petaflops per second.

4. Power generation and transmission is another field where superconductors find wide application. Electric generators made with superconducting wire are far more efficient than conventional generators wound with copper wire. In fact, their efficiency is above 99% and their size about half that of conventional generators.

5. In the electronics industry, ultra-high-performance filters are now being built with superconducting materials. These filters have an ability to pass desired frequencies and block undesirable frequencies in high-congestion radio frequency applications such as cellular telephone systems.

6. Superconductors have also found widespread applications in the military. High-temperature SQUIDs (superconducting quantum interference devices) are being used by NAVY to detect mines and submarines. SQUIDs are capable of sensing a change in a magnetic field over a billion times weaker than the force that moves the needle on a compass.

7. Now scientists are thinking of "E-bombs". These are devices that make use of strong, superconductor-derived magnetic fields to create a fast, high-intensity electro-magnetic pulse (EMP) to disable an enemy's electronic equipment.