Nanophysics

Introduction to nanomaterial's:

Materials form an integral part of our life. Advancement in our day today life leads to the discovery of many new engineering materials.

We know all materials are composed of atoms with different sizes which have movement with one another. There exist special clause of materials in which the atoms do not move away from each other and its size will be in the order of 1 to 100 nano meters. These new materials are called ***nano-materials*** and the developed technology is called ***nano-technology.*** Using the highly sophisticated latest technology the nano-materials can also be formed from metals, ceramics, and polymers and even from liquids.

Nano particles are the particles with in size ranging from 1 – 50 nm.

Nano materials are the materials having components with in size 1nm to 100 nm in one dimension.

Nano technology is the manipulation of matter on molecular scale and study the use of structures between 1 nm to 100 nm

Nano by definition:

- Nano size: Generally 1-100 nm (by definition)
- Nanoscale : ranging from 1 to 500 nm (practically considered)
- Nanophysics involves the science and properties of any man made (engineered materials) or naturally available materials confining within the nano size or scale.

Nanomaterials:

Nanomaterials (mostly particles) are the corner stones that lay a strong foundation in building nanotechnology. The science underlying with these nano particles form a fascinating nanoscience. Nanomaterials are new gateway to science for the simple reason that they exhibit different properties than the bulk materials (size larger than the nano size/scale regime). Variation of size within the nano regime leads to inhibit variable physical, chemical, electrical, mechanical, magnetic, and optical properties. Thus nanoscience and its technology are particle size dependent and fall into zero-dimensional (0D), one-dimensional (1D) and two-dimensional (2D) categories. Briefly, nanoparticles, nanotubes or rods, thin films can be classified under 0D, 1D and 2D respectively.

NANO SCALE

Nano stands for 10^{-9}. A nano meter (nm) is one billionth or one thousand millionth of a meter or 10^{-9} of a meter. For comparison the carbon-carbon bond length is the order of 0.12 – 15 nm. A human hair is 80000 nm wide.

Origin of nanotechnology:

Nanotechnology is a very old science dating back to 4th century CE. The existence of Lycurgus cup in British museum is an evidence. This Lycurgus cup is a Roman glass cage cup dating back to 4th century CE. This cup is considered as the most spectacular ancient cup having dichroic effect. It emits green color when the light is reflected, and emits red color when the light is transmitted. This dichroic effect was achieved by dispersing nanoparticles of gold and silver in the glass material. It is an astonishing fact that these nanoparticles were around 70 nm is size. Other than engineered nanomaterials, some of the naturally available nanosized materials (biological origin) are given in table below

Size	Material
1 nm	Chemical drug
2 – 3 nm	Nucleus of cell
5 nm	Protein
10 nm	DNA
20-50 nm	Blood vessel pore
5 – 300 nm	Virus
100-500 nm	Liposome nanoparticle

SURFACE TO VOLUME RATIO

When a given volume is divided into a number of small pieces the total surface area of pieces is much greater than the area of the given volume. That is nano particles have a much greater surface area per given volume of bulk mater.

Consider a sphere of radius ‘r’.

Surface area of sphere = $4\pi r^2$

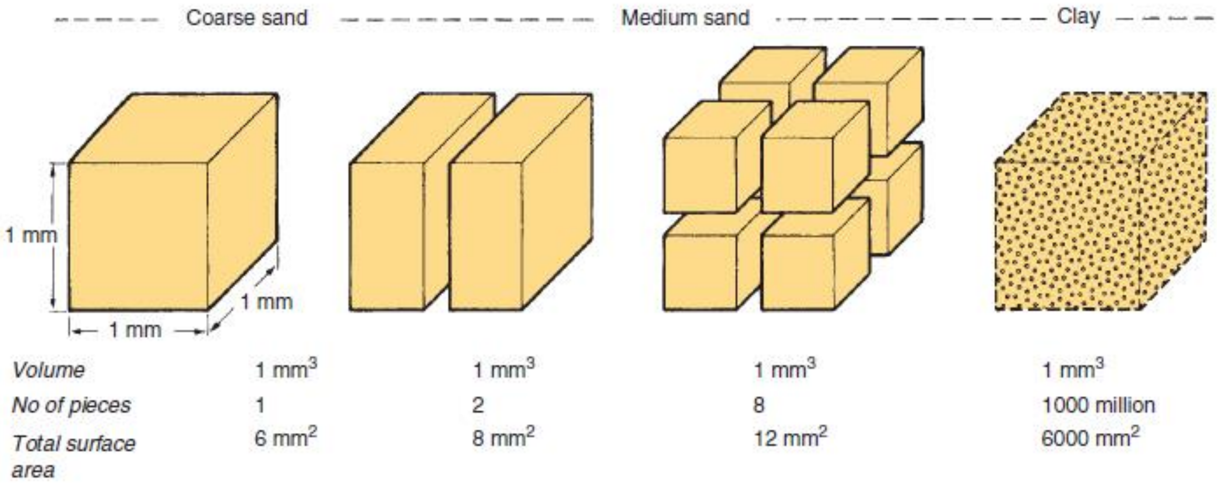
Volume of the sphere = $4/3[\pi r^3]$

Surface to volume ratio = $4\pi r^2/4/3[\pi r^3] = 3/r$

So where ‘r’ decreases its surface area to volume ratio increases. Hence as particle size decreases a greater proportion of atoms are bond at the surface compared to the inside. Thus nano particles have a much greater surface area per given volume compared with longer particles. So it makes materials more chemically reactive.

Example:-

Consider a cube having surface area $6m^2$. When it is divided in to 4 pieces its surface area become $12m^2$. When it's every face cut into 9 pieces its surface area become m^2.



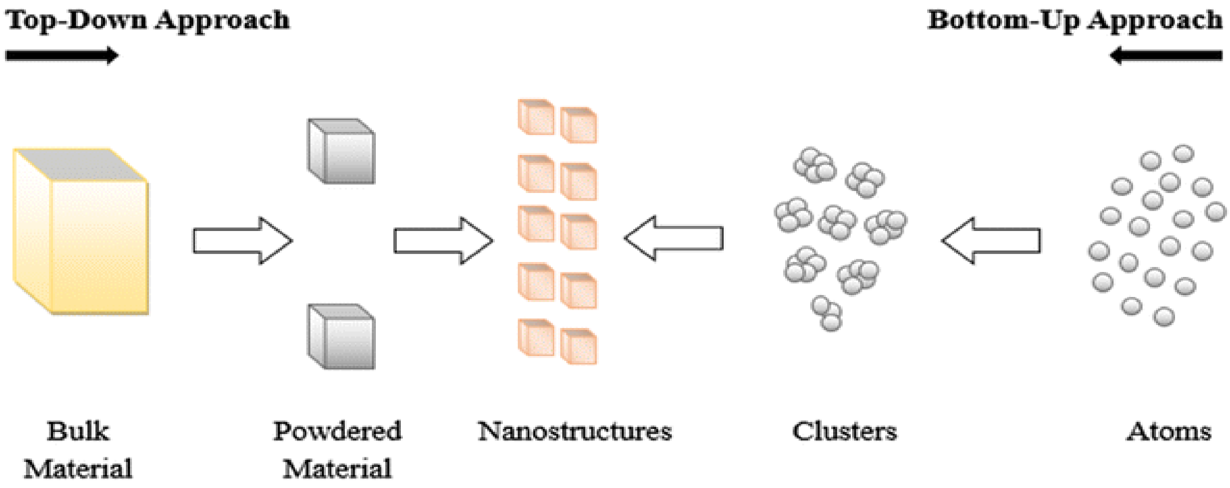
Revamping nanotechnology:

American physicist Richard Feyman's lecture on "**There's Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics**" in 1959 was an eye opener in the area of nanotechnology. He suggested the possibility of manipulating the individual atoms, directly that could result in new applications than the existing one. He insisted that it is possible to arrange the atoms the way we want. Later then, may researchers started to explore the field of nanotechnology. ***Two approaches in developing nano-technologies***

1. Top – down

2. Bottom - up

The "top-down" approach is related to conventional technologies, wherein large sized materials are crushed and milled to make fine sized powders. In contrary, the "bottom-up" approach involves the chemical synthesis of fine sized powders at nano level representing wide spread nanotechnology. However, in comparison, the “bottom-up” approach is extensively used in synthesising nanostructured materials.



❑ Top down approach (Physical methods):

- High energy ball milling,
- Photo and electron beam lithography,
- Sputtering,
- Laser ablation,
- Chemical etching,
- Physical vapour deposition – Thermal & electron beam evaporation

❑ Bottom up approach (Chemical methods):

- Chemical vapour deposition,
- Plasma Enhanced CVD ,
- sol-gel method,
- hydrothermal method,
- Co-precipitation,
- Microwave,
- Solvothermal method and Solution combustion.

Moore's law

Gordon Moore one of the founder of the Intel Corporation gave this law. 1st Law

"The amount of space required to install a transistor on a chip shrinks by roughly half every 18 months". ie, that the space that could hold one transistor 15 years ago can hold approximately 1000 transistors today….. 2nd Law

"The cost of building a chip manufacturing plant doubles with every other chip generation or roughly every 36 months".

Properties of nanomaterials

1. Very high surface to volume ratio compared to bulk
2. Surface free energy is changed and chemical potential is modified.
3. Principal parameters involved in tuning/improving the properties of nanomaterials are their shape, size, surface characteristics and morphology.
4. They have specific geometry.
5. They possess amorphous, crystalline or polycrystalline nature.
6. Nanoparticles can be as aerosols, suspensions (solids in liquids) or as emulsions (liquids in liquids).
7. Based on their method of synthesis, they exhibit variable properties.
8. Quantum effects play a dominating role in determining the nanomaterial properties
9. They exhibit novel electrical, magnetic, optical, mechanical, catalytic properties.
10. Higher the surface area, larger the number of active sites per unit area and thereby increases rate of a catalytic reaction.

11. Inter-dependent parameters like phase composition, defects, residual stress play a vital role in modifying their behaviours.

Examples of some improvement of material properties

- Quantum confinement in semiconductor nanoparticles increases the band gap and as a result different fluorescent colors comes from such nanoparticles for different band gap
- Using one dimensional confinement in semiconductor nanoparticles quantum well laser brings much more efficient laser
- Pd being nanoparticles can occlude huge volume of hydrogen which is very significant for hydrogen storage devices
- Gold particles being nano in nature the thermodynamic properties is influenced greatly and the melting temperature reduces
- The storage capacity in computer hard disk has been increased using ferromagnetic nanoparticles

Carbon nanotubes (CNT):

Carbon nanotubes are made by rolling up a graphene sheet into tube like structures at nano dimensions. They can have a length-to-diameter ratio greater than 1,000,000. Graphene is a single layered carbon atoms in a two dimensional hexagonal lattice. CNTs were discovered by Prof. Ijima in 1991. Carbon nanotubes can be ether metallic or semiconducting, based on their geometry.

Types of carbon nanotubes:

There are two types of CNTs.

1. Single walled carbon nanotubes (SWNT)
2. Multi walled carbon nanotubes (MWNT)

Single-wall Nanotubes (SWNT):

• It's a single layer of graphene rolled as a tube.

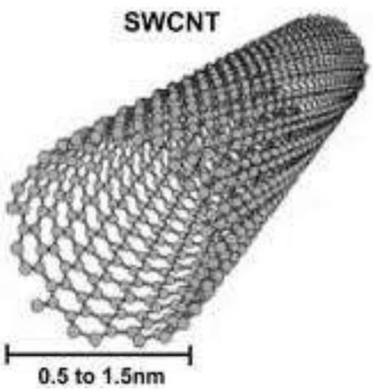
• Single-wall nanotubes (SWNT) are tubes are normally capped at the ends. They have a single cylindrical wall. The structure of a SWNT can be visualized as a layer of graphite, a single atom thick, called graphene, which is rolled into a seamless cylinder.

• Most SWNT typically have a diameter of close to 1 nm. The tube length, however, can be many thousands of times longer.

• SWNT are more pliable (flexible) yet harder to make than MWNT. They can be twisted, flattened, and bent into small circles or around sharp bends without breaking.

• SWNT have unique electronic and mechanical properties which can be used in numerous applications, such as field-emission displays, nanocomposite materials, nanosensors, and logic elements. These materials are on the leading-edge of electronic fabrication, and are expected to play a major role in the next

generation of miniaturized electronics.



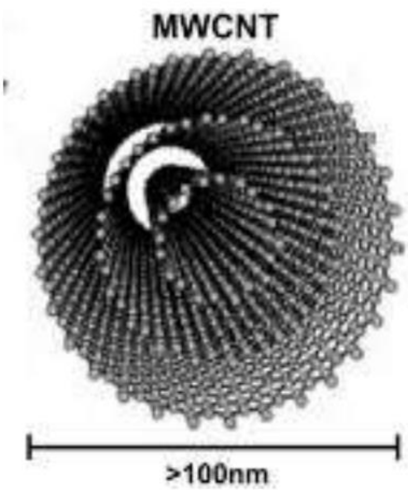
Multi-wall Nanotubes (MWNT):

• It is a multiple layer of graphene rolled as concentric cylinders.

• Multi-wall nanotubes can appear either in the form of a coaxial assembly of SWNT similar to a coaxial cable, or as a single sheet of graphite rolled into the shape of a scroll.

• The diameters of MWNT are typically in the range of 5 nm to 50 nm. The interlayer distance in MWNT is close to the distance between graphene layers in graphite.

• MWNT are easier to produce in high volume quantities than SWNT. However, the structure of MWNT is less well understood because of its greater complexity and variety. Regions of structural imperfection may diminish its desirable material properties.



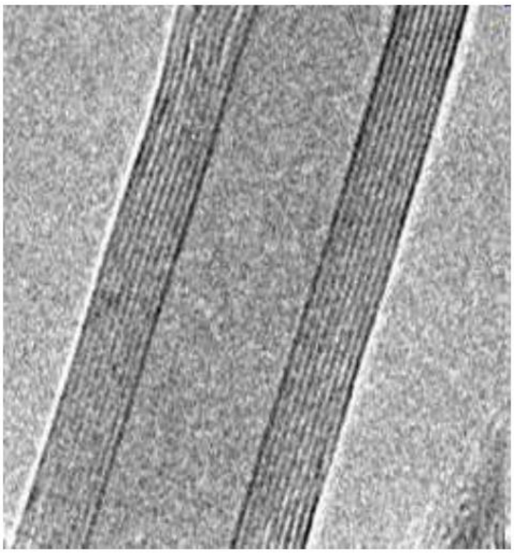
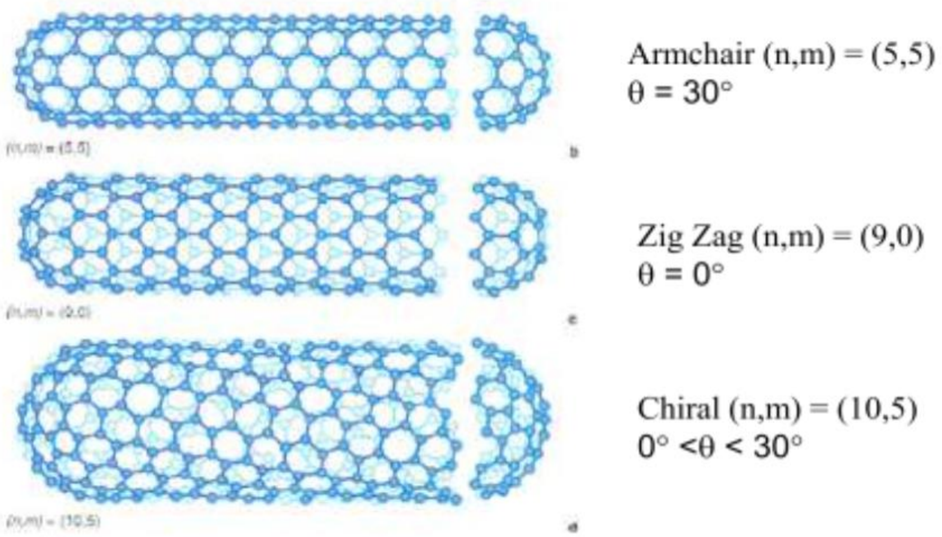


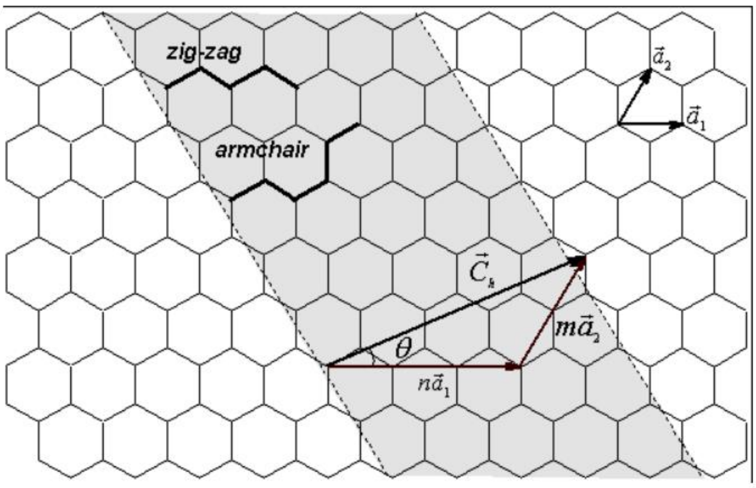
Figure (A) Figure (B)

Figure (B) show the Transmission Electron Microscopy image of a MWCNT in the arrangement of the graphene layers one inside the other.

SWNTS types based on rolling axis

The SWNT consists of a single graphene sheet, which is a planar array involving only hexagonal rings with double and single carbon-carbon bonding. The choice of rolling axis relative to the hexagonal network of the graphene sheet and the radius of the closing cylinder allows for different types of SWNTs, which vary from insulating to conducting.





CNTs may be obtained by rolling a graphene sheet in a specific direction, maintaining the circumference of the cross-section. As the microscopic structure of the CNTs is closely related to the structure of graphene, the tubes are usually labeled in terms of graphene lattice vectors. The atomic structures of the carbon nanotubes may be described by the tube chirality, or helicity, defined by the chiral vector, C_h, and the chiral angle θ. Figures below show SWNTs of three different types: armchair, zigzag, and chiral. The chiral vector can be described in terms of the lattice translational indices (n,m) and the unit vectors $\mathbf{a}_1$ and $\mathbf{a}_2$ as shown in Figure.

PREPARATION or **FABRICATION OF CARBON NANO TUBES**

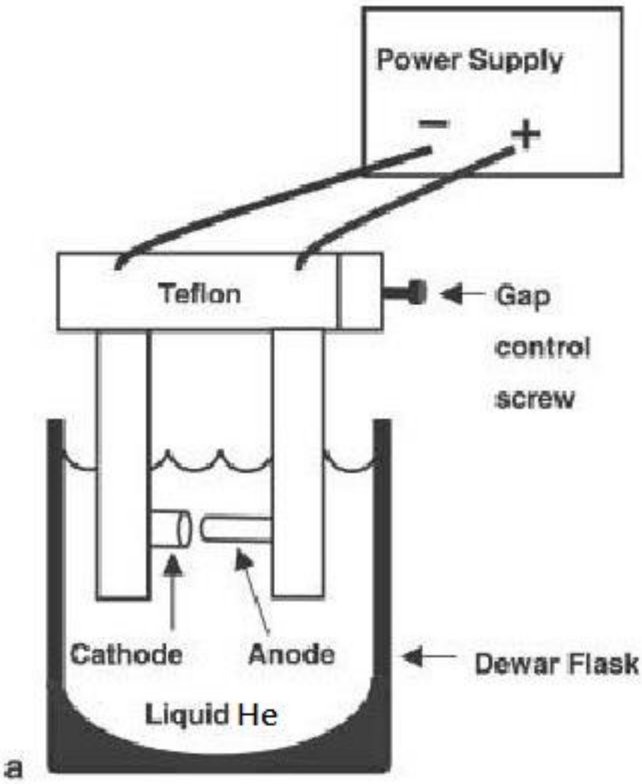
Carbon nano tubes can be fabricated by any one of the following method. i. Pulsed laser deposition or Laser synthesis ii. Carbon arc method and iii. Chemical Vapour deposition.

CARBON – ARC METHOD

Carbon arc method is used to produce Both the single walled nano tubes and multi walled nano tubes.

Instrumentation:-

It consists of positive carbon electrode (E_1) and negative carbon electrode (E_2). Liquid helium of 500 torr pressure is made to flow through electrodes to deposit carbon from E_1 to E_2.



Fabrication

The battery is switched on and a potential of about 20 to 25 volt is applied across the carbon electrodes. This potential leads to the emission of carbon atoms from the positive electrode. Now with the help of high pressure Helium, the carbon atoms are deposited over the negative electrode.

When the potential is continuously applied the length of the positive electrode start decreasing and the carbon deposit over the negative electrode starts increasing which results in the formation of carbon nano tubes layer by layer, so multi walled nano tubes formed. The single walled carbon nano tubes can also be produced by the above technique just by using cobalt Nickel or iron as a catalyst in the central region of the positive electrode.

Properties of Carbon Nanotubes

1. The strongest and most flexible molecular materials of C-C covalent bonding.
2. Youngs modulus of over 1TPa.
3. Electrical conductivity is six orders of magnitude higher than copper.
4. Electronic properties can be tailored by the application of external magnetic field.
5. Very high current carrying capacity
6. Can be metallic or semiconducting depending on chirality.
7. They have tunable band gap.

Potential Applications for Carbon Nanotubes

Carbon Nanotubes can be used for a wide range of new and existing applications such as,

- Conductive plastics
- Structural composite materials
- Flat-panel displays
- Gas storage
- Antifouling paint
- Micro- and nano-electronics
- Radar-absorbing coating
- Technical textiles
- Ultra-capacitors
- Atomic Force Microscope (AFM) tips

- Batteries with improved lifetime
- Biosensors for harmful gases
- Extra strong fibers

Applications of nanotechnology in industry

Nanotechnology is used for wider applications in various industries as listed below.

- Since they are stronger, lighter etc. they are used to make hard metals.
- Smart magnetic fluids are used in vacuum seals and magnetic separators.
- Orderly assembled nano materials are used as quantum eclectic devices and photonic crystals.
- Nano materials are used to make CD'S and semi conductor laser.
- They are used in energy storage devices.
- They are used in mobiles. Lap tops and computers.
- Recently nano tubs were designed which are used to remove the damaged cancer cells and also to modified the neutron network in human body.
- Bio-sensitive nano particles are used in the production of DNA- chips and Bio- sensors.
- Aerospace
- Medicine
- Food and Agriculture
- Defence and national security
- Biotechnology
- Information technology
- Textiles
- Solar cells
- Batteries
- Fuel Cells
- Wastewater treatment
- Chemical production
- Automobile
- Electronics
- Oil and gas

- Construction and
- Other industries

Nano-Wells or Quantum Wells:

Thin films with thicknesses in the range of nanometers are called as Nano-Wells or Quantum Wells. Examples are metal (Au or Si or any metal) Nano-Wells or Quantum Wells, where Electrons are confined to move within two axes, in the third axis they cannot move, because of very narrow metal layer.

Nano-wires or Quantum Wires:

Nano-wires or Quantum Wires are nano-fabricated from as Nano-Wells or Quantum Wells. Examples are metal (Au or Si or any metal) Nano-wires or Quantum Wires, where Electrons are confined to move within only one axis, in the other two axes they cannot move, because of very narrow metal layers.

Nano-dots or Quantum dots:

Nano-dots or Quantum dots are nano-fabricated from as Nano-Wells or Quantum Wells. Examples are metal (Au or Si or any metal) Nano-dots or Quantum dots, where Electrons are confined not to move in any direction, in all the axes they cannot move, because of very narrow metal layers.

Carbon Nano Tubes:

Carbon nano tubes are fabricated from quantum dots keeping them as seed layers. When are heated up, Nano dots deposited on glass plates in a vacuum chamber , will act as nucleation spots for carbon atoms to initiate up with hexagonal rings and these are developed to form carbon nano-tubes. Depending on the sizes of the quantum dots growth of multi wall carbon nano tubes and single wall nano-tubes are resulted.