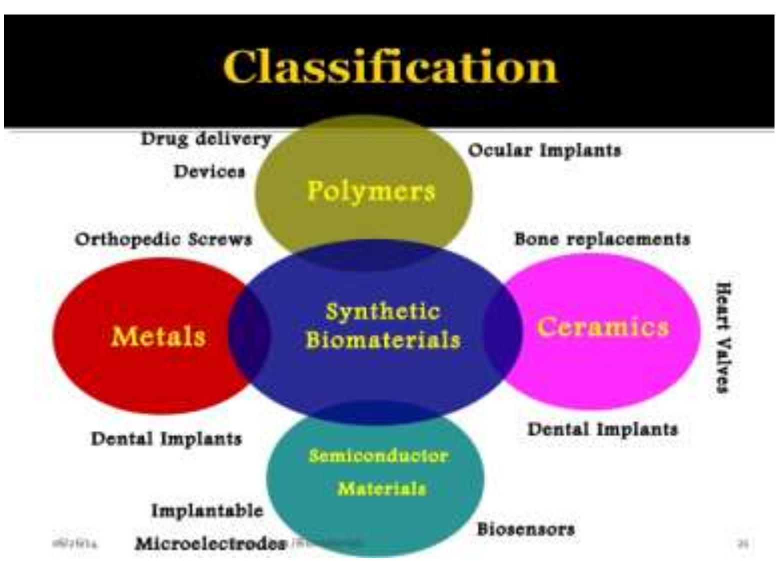
UNIT I

BIOMATERIALS AND ITS APPLICATIONS

Definition of Biomaterial

- A biomaterial can be defined as any material used to make devices to replace a part or a function of the body in a safe, reliable, economic and physiologically acceptable manner.
- A biomaterial is a synthetic material used to replace part of a living system or to function in intimate contact with living tissue.



Shape Memory Alloys (SMA)

- A shape-memory alloy is an alloy that can be deformed when cold but returns to its pre-deformed ("remembered") shape when heated.
- It may also be called memory metal, memory alloy, smart metal, and smart alloy.
- The most widely used shape memory material is an alloy of nickel and titanium called Nitinol.
- This particular alloy has excellent electrical and mechanical properties, long fatigue life, and high corrosion resistance.
- **Phases of SMA**

  The two phases, which occur in shape memory alloys, are **Martensite**, and **Austenite**.
- Martensite, is the relatively soft and easily deformed phase of shape memory alloys, which exists at lower temperatures.

CLASSIFICATION OF BIOMATERIALS

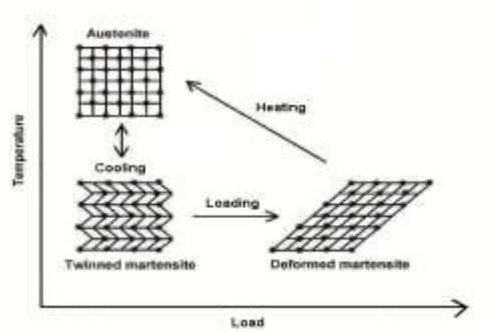
S.No.	Type	Examples	Application
1	Metallic implant materials	Ti and its alloys,Co–Cr alloys, stainless steels	Joint replacements,dental root implants,bone plates and screws
2	Ceramic implant materials	alumina zirconia, calcium phosphates including hydroxyapatite, carbon	Dental and orthopedic inplants
3	Polymeric implant materials	nylon, silicone rubber polyester	Sutures, blood vessels, soft tissues ,hip socket, ear, nose
4	Composite implant materials	carbon-carbon, wire or fiber reinforced bone cement	Bone cement, Dental resin

Characteristics of Biomaterials

- **Physical Requirements**
  - Hard Materials.
  - Flexible Material.
- **Chemical Requirements**
  - Must not react with any tissue in the body.
  - Must be non-toxic to the body.
  - Long-term replacement must not be biodegradable.

Nitinol (NiTi Alloy)

- The shape memory and superelasticity properties are the most unique properties of this alloy.
- The shape memory property allows this metal to “remember” its original shape and retain it when heated above its transformation-temperature.
- It happens due to the different crystal structures of nickel and titanium.
- This pseudo-elastic metal also shows incredible elasticity which is approximately 10 to 30 times more than that of any ordinary metal.



- When a SMA is in martensite form at lower temperatures, the metal can easily be deformed into any shape.
- When the alloy is heated, it goes through transformation from martensite to austenite. In the austenite phase, the memory metal "remembers" the shape it had before it was deformed.

Properties of Nitinol

Physical Properties

1. Appearance: This is a bright silvery metal.
2. Melting Point:
   Its melting point is around 1310 °C.
3. Resistivity:
   It has a resistivity of 82 ohm-cm in higher temperatures and 76 ohm-cm in lower temperatures.
4. Thermal Conductivity:
   The thermal conductivity of this metal is 0.1 W/ cm-°C.

Medical Applications of nitinol

- This alloy is very useful in dentistry, especially in orthodontics for wires and brackets that connect the teeth. Sure Smile (a type of braces) is an example of its orthodontic application.
- It is also used in endodontic mainly during root canals for cleaning and shaping the root canals.
- In colorectal surgery, it is used in various devices for the purpose of reconnecting the intestine after the pathology is removed.
- Nitinol stents are another significant application of this metal in medicines.
- Its biocompatible properties make useful in orthopedic implants.
- Nitinol wires can be used for marking and locating breast tumors.
- The use of Nitinol tubing for various medical purposes is increasing in popularity.

Mechanical Properties

1. Ultimate Tensile Strength:

   The ultimate tensile strength of this material ranges between 754 and 960 MPa.

2. Typical Elongation to Fracture: 15.5 percent
3. Typical Yield Strength:

   560 MPa in high temperature; 100 MPa in low temperature

4. Approximate Elastic Modulus:

   75 GPa in high temperature; 28 GPa in low temperature

5. Approximate Poisson's Ratio: 0.3

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ALUMINUM OXIDES

ALUMINA (Al_2O_3)

Properties of Alumina

1. Alumina has high corrosion and wear resistance.
2. α-alumina has hcp crystal structure.
3. High density alumina has good biocompatibility and reasonable strength.
4. Strength, fatigue resistance and fracture toughness of polycrystalline α-alumina are function of grain size and purity. An increase in grain size from 4 μm to 7 μm can decrease mechanical properties by 20%.
5. Alumina is not cytotoxic and there is no activation of body's immune response. Alumina implants do not show inflammatory or progressive fibrotic reactions.

Applications of Alumina

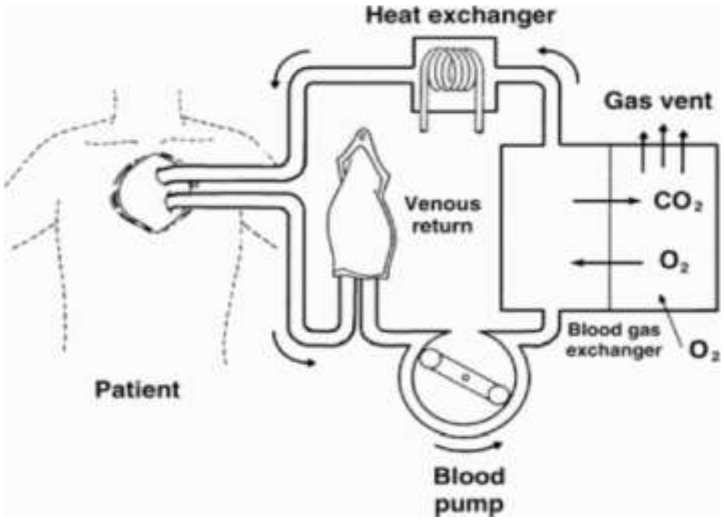
1. Aluminas are mainly used in orthopedic surgery.
2. High-density alumina is used in load-bearing hip prostheses and dental implants because of its combination of excellent corrosion resistance, good biocompatibility, high wear resistance and reasonable strength.
3. Orthopedic uses of alumina consist of hip and knee joints, tibial plate, femur shaft, shoulders, radius, vertebra, leg lengthening spacer and ankle joint prostheses.
4. Alumina finds applications in dentistry as well as in a reconstructive maxillofacial surgery to cover bone defects. Porous alumina is also used in teeth roots.

Polymers in Biomedical use

- Biomedical polymers can be classified into either elastomers or plastics.
- Elastomers are able to withstand large deformations and return to their original dimensions after releasing the stretching force.
- Plastics on the other hand are more rigid materials and can be classified into two types: thermoplastic and thermosetting.
- Thermoplastic polymers can be melted, reshaped and reformed.
- The thermosetting plastics cannot be remelted and reused, since the chemical reactions that have taken place are irreversible.

S.No.	Polymer	Biomedical uses
1	Polyethylene	Tubes for various catheters, hip joint, knee joint prostheses
2	Polypropylene	Yarn for surgery, sutures
3	Tetrafluoroethylene	Vascular and auditory prostheses, catheters, tubes
4	Polyvinylchloride	components of dialysis installation and temporary blood storage devices.
5	Polyacetals	Hard tissue replacement
6	Polymethyl methacrylate	Bone cement, intraocular lenses, contact lenses,
7	Polyurethane	Adhesives, dental materials, blood pumps, artificial heart and skin
8	Silicone rubber	Encapsulant for pacemakers, burn treatment, shunt,Mammary prostheses, foam dressing,valve, catheter, contact lenses, membranes, maxillofacial implants
9	Polyamide	surgical suture, films for packages, dialysis devices components,
10	Polycarbonate	Syringes, arterial tubules, hard tissue replacement

Heart and lung machine



- The combination of a blood pump and an oxygenator is known as the *heart-and-lung* machine.
- Every heart lung machine consists of a blood pump to replace the heart's function and gas exchange device to substitute for the natural lungs.
- While the blood is circulated by pump, it can be oxygenated by patient's own lungs or through an artificial oxygenator
- The machine oxygenates up to 5 liters/minute of venous blood to 95-100% hemoglobin saturation for the required period. It simultaneously removes enough carbon dioxide to avoid respiratory acidosis.
- It is simple, dependable, safe, easily cleaned and assembled, easily sterilizable and conveniently, quickly and smoothly connected to and disconnected from the patient.

- In an oxygenator,blood is contacted with oxygen gas and simultaneously waste gas (CO_2) is removed.
- The membranes are usually made of silicone rubber or teflon.
- There are basically three types of oxygenators. They are membrane oxygenator, bubble oxygenator and film oxygenator.
- A heat exchanger is connected in series to cool or re-warm the blood.

CONTACT LENSES

- Ophthalmology is a field that has rapidly advanced as a result of the development of new techniques and materials.
- Biomaterials are an important component of the procedures that are used to improve and maintain vision.
- These biomaterials include viscoelastic solutions, intraocular lenses, contact lenses, eye shields, artificial tears, vitreous replacements, correction of corneal curvature and scleral buckling materials.

Uses of Contact lenses

1. Contact lenses are used most often for the correction of short sight
2. They are also used cosmetically to improve the appearance of damaged eyes and to change or enhance eye color.
3. Contact lenses are also used for the therapeutic purpose such as nonhealing chronic corneal ulcers, recurrent erosions, pain in bulbous keratopathy,entropion etc.
4. Therapeutic contact lenses may be considered a bandage on the nea and thus they have also been called bandage lenses.

Properties of contact Lenses

1. High oxygen permeability, to minimize lens interference with corneal respiration.
2. Good wetability by tears.
3. Resistance to deposition of protein, mucus, lipid, microorganisms and other foreign substances on the lens surfacernea and thus they have also been called bandage lenses.

Unit - II

INTRODUCTION

to

NANO

Nanometer:

A nanometer (10^{-9}m) is **one millionth of a millimeter**

(or)

one thousandth of a micron

(or)

one billionth of a meter. ie.,*one* ***billion*** *nanometers in a meter*.

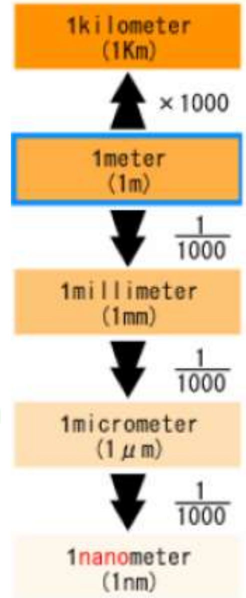
1 nm = 10^{-3} μm = 10^{-6} mm = 10^{-9}m

(one billionth of a meter)

1 nm is only three to five ***atoms*** wide.

The size of Hydrogen atom 0.04 nm

•The size of Proteins ~ 1-20 nm



NANOSCIENCE

Nanoscience is the study of structures and materials on the atomic or molecular scale (between 1 and 100 nanometers)

An emerging, interdisciplinary science Integrates chemistry, physics, biology, materials engineering, earth science, and computer science

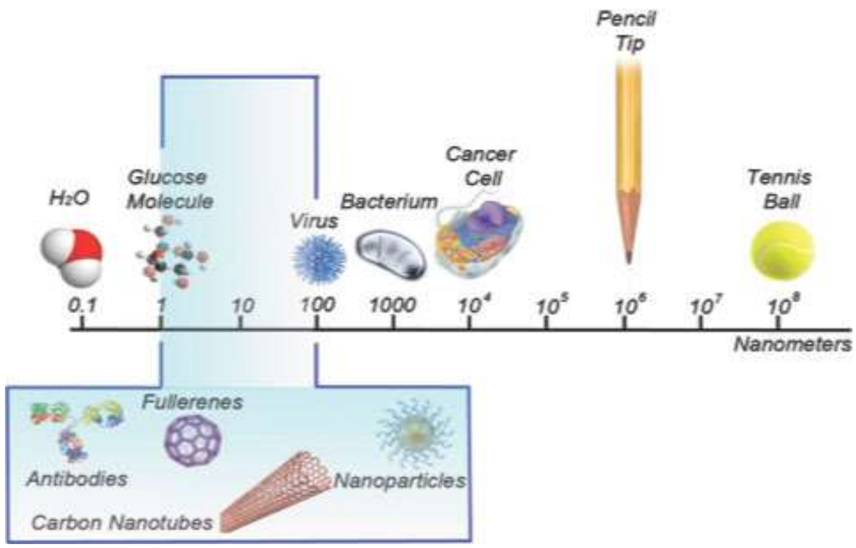
NANOTECHNOLOGY

Nanotechnology is the ability to create and manipulate structures and materials on the atomic or molecular scale (between 1 and 100 nanometers)

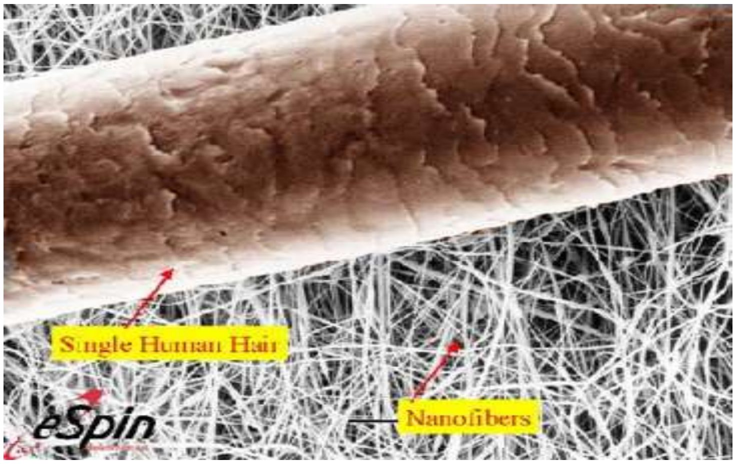
This is not to be confused with the term **"Nanoscience",**

which does not describe a practical application but rather the scientific study of the properties of the nanometric world.

HOW SMALL IS NANO?



COMPARED TO HUMAN HAIR



A Human Hair is about 1,00,000 µm wide

NANOTECHNOLOGY- BIRTH

"There's plenty of room at the bottom" (1959)

Prof. Dr. R. P. Feynman
Noble Laurent

"Why cannot we write the entire 24 volumes of the Encyclopedia Britannica on the head of a pin?"

"The process by which the ability to manipulate individual atoms and molecules might be developed, using one set of precise tools to build and operate another proportionally smaller set, so on down to the needed scale"

NANOTECHNOLOGY- NAMING

"Nanotechnology"

Prof. Dr. Norio Taniguchi
Tokyo science University

*Introduced the term **"Nanotechnology"** in the year 1974*

According to him "Nanotechnology mainly consists of the process of separation, consolidation and deformation of materials by one atom or by one molecule".

NANOTECHNOLOGY- SIGNIFICANCE

"molecular manufacturing"

Dr. Eric Drexler

"By working along molecule by molecule and structure by structure, repair machines will be able to repair whole cells. By working along cell by cell and tissue by tissue, they…will be able to repair whole organs…they will restore health." - Drexler, 1986

Did Scientists “Create” Nano?

No, it was already in nature!

centimeters to micrometers

micrometers

nanometers

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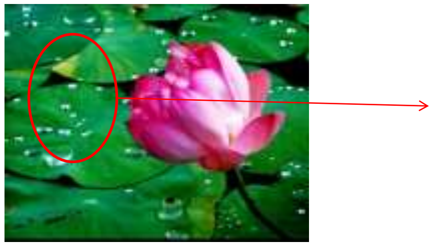


Did Nanotechnology use before Feynman?

Licurgo’s pot – 9th century

Reflection **Transmission**

Silver and Gold nanoparticles – 70 nm

Properties of Nano Materials

- Enhanced electrical or heat conductivity
- Increased strength, tensile properties
- Different magnetic properties
- Altered light reflection – color changes with size

Materials at Nano Scale

Bulk Gold

Nano Gold

Material properties don't change with size

Materials properties are change with respect to size.

What can cause the properties Materials at nano scale?

We are interested in the nanoscale materials because at this scale the properties of materials are very much different from those at a larger scale.

Two principal factors cause the properties of nano- materials to differ significantly from other materials:

i) *Surface to Volume ratio*
ii) Quantum effects.

These factors can change or enhance properties such as reactivity, strength, electrical, magnetic and optical characteristics.

Surface to volume ratio

Definition:

The amount of surface area per volume is called as **surface-to-volume ratio**.

Importance:

✓ **If Surface area is larger** then a greater amount of the material comes into contact with surrounding materials and increases reactivity.

✓ **Surface-to-volume ratio** defines the properties of materials,

- Optical (e.g. color, transparency)
- Electrical (e.g. conductivity)
- Physical (e.g. hardness, melting point)
- Chemical (e.g. reactivity, reaction rates)

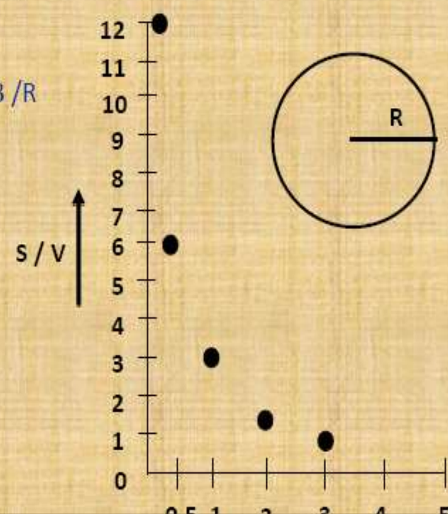
SURFACE TO VOLUME RATIO

Why nano will change the properties of materials?

Sphere

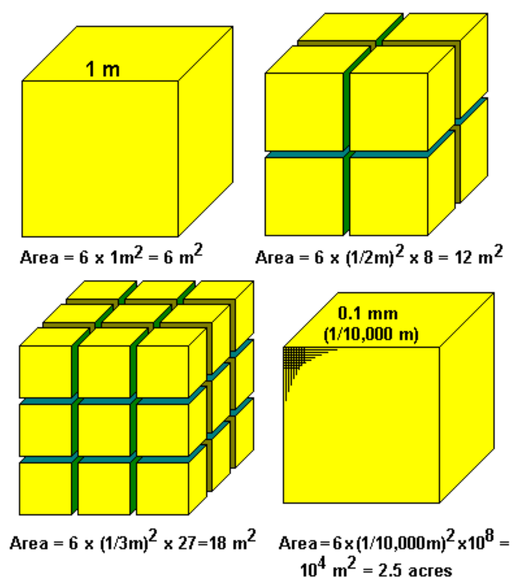
- Volume, $V = 4/3 \pi R^3$
- Surface Area, $S = 4\pi R^2$
- Ratio $(S/V) = (4/3)\pi R^3 / 4\pi R^2 = 3/R$
  $\alpha\ 1/R$

R	S/V
3	1
2	1.5
1	3
0.5	6
0.25	12



Surface to volume ratio

- All cubes have same volume.
- The surface area is increases when breaking into small cubes.
- Hence the surface to volume ratio is increases



Classification of Nanomaterials

- **Nanomaterials as those which have structured components with atleast one dimension less than 100nm.**
- **One dimension in nanoscale (Other two dimensions are extended)**

  Thin films

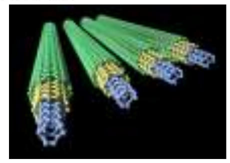
  Surface Coatings

  Computer chips

- **Two dimensions in nanoscale (Other one dimension is extended)**

  Nanowires

  Nanotubes



- **Three dimensions in nanoscale**

  Nanoparticles

  Precipitates

  Colloids

  Quantum dots (tiny particles of semiconductor material)

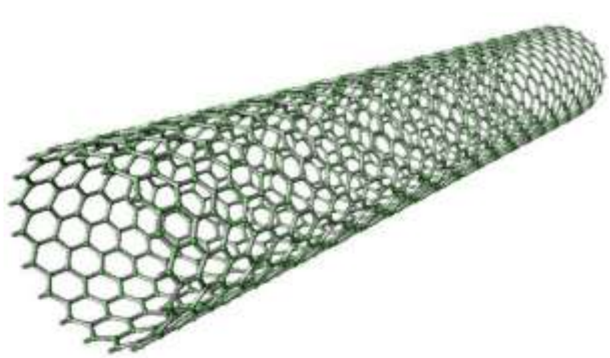
Applications of Nanotechnology

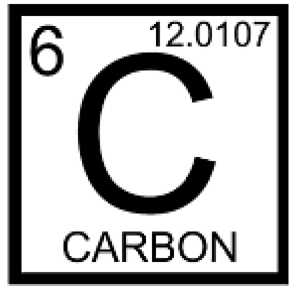
Automotive industry	Chemical industry	Engineering
• lightweight construction • painting (fillers, base coat, clear coat) • catalysts • tires (fillers) • sensors • Coatings for wind-screen and car bodies	• fillers for paint systems • coating systems based on nanocomposites • impregnation of papers • switchable adhesives • magnetic fluids	• wear protection for tools and machines (anti blocking coatings, scratch resistant coatings on plastic parts, etc.) • lubricant-free bearings
Electronic industry	**Construction**	**Medicine**
• data memory (MRAM, GMR-HD) • displays (OLED, FED) • laser diodes • glass fibres • optical switches • filters (IR-blocking) • conductive, antistatic coatings	• construction materials • thermal insulation • flame retardants • surface-functionalised building materials for wood, floors, stone, facades, tiles, roof tiles, etc. • facade coatings • groove mortar	• drug delivery systems • active agents • contrast medium • medical rapid tests • prostheses and implants • antimicrobial agents and coatings • agents in cancer therapy

Nanotechnology in future everyday life

- The technology is being used to create novel imaging agents, polymers, electronics, paints, batteries, sensors, fuel cells, solar cells, coatings, computers and display systems.

Unit-V
CARBON NANOMATERIALS





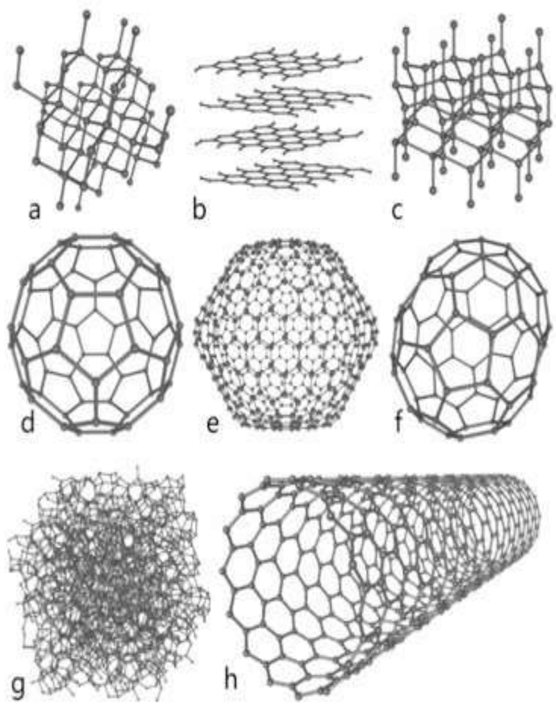
Carbon nanotubes (CNTs) are an allotrope of carbon.

CNT is a tubular form of carbon with diameter as small as 1nm.
Length: few nm to microns.

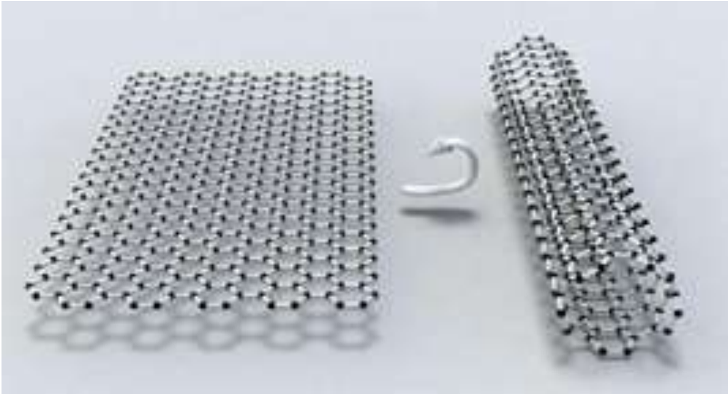
CNT is configurationally equivalent to a two dimensional graphene sheet rolled into a tube.

Allotrope: each of two or more different physical forms in which an element can exist.

a) Diamond
b) Graphite
c) Lonsdaleite
d) C_{60} (Buckminsterfullerene)
e) C_{540}
f) C_{70}
g) Amorphous carbon
h) single-walled carbon nanotube
i) nanobud



- CNTs are long, thin cylinders of carbon.
- They can be thought of as a sheet of graphite (a hexagonal lattice of carbon) rolled into a cylinder.
- Nanotubes have been constructed with length-to-diameter ratio of up to 132,000,000:1.



CNTs were discovered in 1991 by Sumio Iijima

The structure of carbon nanotube is formed by a layer of

carbon atoms that are bonded together in a hexagonal (honeycomb) mesh. This one-atom thick layer of carbon is called *graphene*, and it is wrapped in the shape of a cylinder and bonded together to form a carbon nanotube.

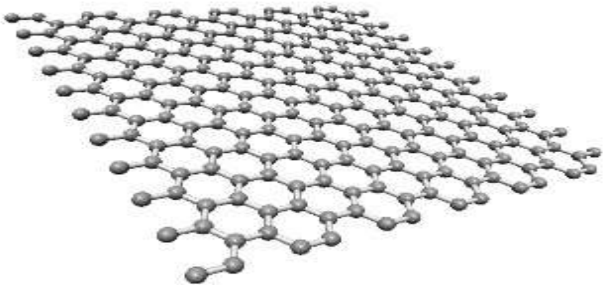
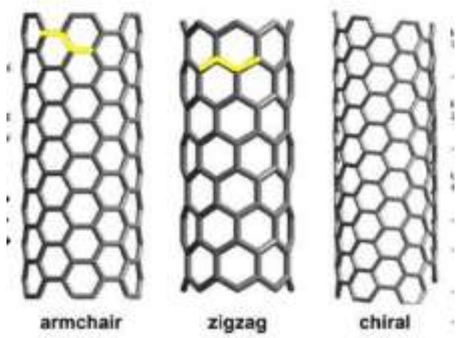


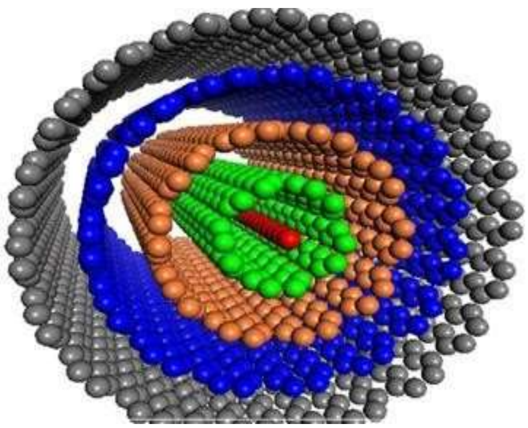
Fig.: Graphene

Single-walled carbon nanotube structure

- Single-walled carbon nanotubes can be formed in three different designs: Armchair, Chiral, and Zigzag.
- The design depends on the way the graphene is wrapped into a cylinder.



- In the **Russian Doll model**, a carbon nanotube contains another nanotube inside it (the inner nanotube has a smaller diameter than the outer nanotube).



Arc Discharge method

First method successfully used to synthesize CNTs in small quantities

Opposing anode and cathode terminals made of 6-mm and 9-mm

typically around 100 A (DC or AC), is passed between the terminals generating arc-induced plasma that evaporates the carbon atoms in the graphite. The nanotubes grow from the surface of these terminals.

A catalyst can be introduced into the graphite terminal.

Although MWNTs can be formed without a catalyst, it has been found that SWNTs can only be formed with the use of a metal catalyst such as iron or cobalt.

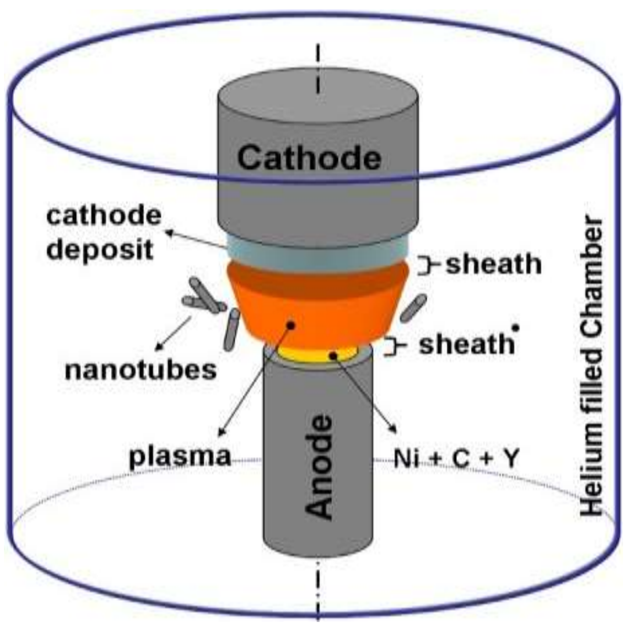


Fig: Set-up for Arc Discharge method

Laser Ablation

- First developed in 1995.
- Uses a similar principle as Arc Discharge method.
- Carbon is evaporated at high temperatures from a graphite target using a powerful and focused laser beam.
- In the most basic laser ablation technique, a 1.25-cm diameter graphite target is placed in a 2.5-cm diameter, 50- cm long quartz tube in a furnace controlled at 1200°C and filled with 99.99% pure argon to a pressure of 500 Torr. A pulsed Nd:Yag laser beam at 250mJ (10 Hz) is focused using a circular lens and the beam is swept uniformly across the graphite target surface. The nanotubes, mixed with undesired amorphous carbon, are collected on a cooled

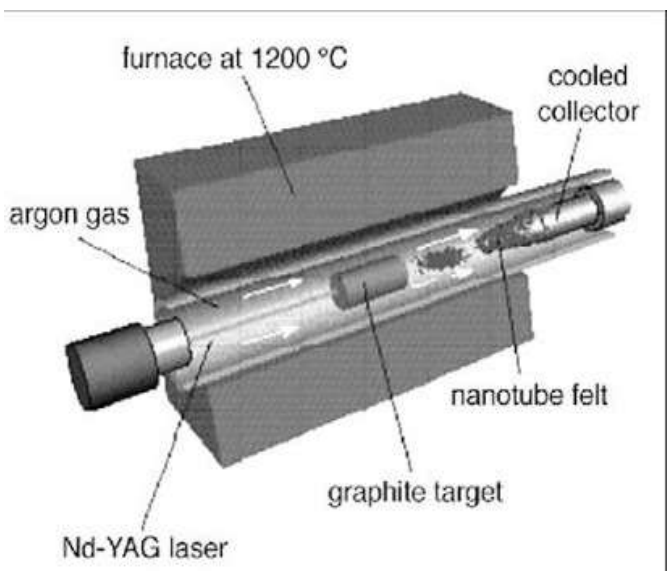


Fig.: Set-up for Laser Ablation method

Chemical Vapor Deposition (CVD)

- CVD has the highest potential for mass production of carbon nanotubes.
- It can produce bulk amounts of defect-free CNTs at relatively low temperatures.
- Method:
  - → A substrate material (e.g. alumina, quartz), is cleaned in preparation for the catalyst deposition.
  - → A porous substrate may be desired, so electrochemical etching with a hydrofluoric acid/methanol solution may be performed. Nanotubes can grow at a higher rate on a porous substrate, suggesting that carbon can diffuse through the porous substrate layer and feed growing nanotubes.
  - → A catalyst (e.g. iron, nickel)is deposited onto the substrate by thermal evaporation.
  - → The furnace is raised to a temperature between 500-1200°C and a hydrocarbon gas such as acetylene, ethylene, or carbon monoxide is slowly pumped into the reactor. At these high temperatures carbon dissociates
  - → on the substrate, combined with impurities such as amorphous carbon, fullerenes, as well as the catalyst material.
  - → In most cases these impurities must be removed using a purification step. An acid treatment followed by sonification is popular.

Strength

- Carbon nanotubes have a higher tensile strength than steel and Kevlar.
- The strength comes from the sp^2 bonds between the individual carbon atoms. This bond is even stronger than the sp^3 bond found in diamond.
- Under high pressure, individual nanotubes can bond together, trading some sp^2 bonds for sp^3 bonds. This gives the possibility of producing long nanotube wires.

Nano-Electronics

- One of the most significant potential applications of SWNTs is believed to be in the domain of nano-electronics. This is as a result of SWNTs being highly-conductive.
- SWNT ropes are the most conductive carbon fibers known.
- Conductivity in nanotubes is based on the degree of chirality – i.e. the degree of twist and size of the diameter of the actual nanotube - which results in a nanotube that is actually extremely conductive (making it suitable as an interconnect on an integrated circuit) or non-conductive (making it suitable as the basis for semi-conductors).
- Alternative configurations of a carbon nanotube can result in the resultant material being semi-conductive like silicon.

Waste water treatment

- CNTs have a very large surface area (e.g., 500 m^2 per gram of nanotube) that gives them a high capacity to retain pollutants such as water soluble drugs.
- A team at the University of Vienna found that at concentrations likely to occur in the environment, the tubes removed 13 tested Polycyclic Aromatic Hydrocarbons (PAHs) from contaminated water. The results were recently published in the journal Environmental Science and Technology.
- However, there are still many health and environmental questions to answer before such filters find their way into municipal water treatment plants.

Solar cells

- Due to their strong UV/Vis-NIR absorption characteristics, SWNTs are a potential candidates for use in solar panels.
- Research has shown that they can provide a sizable increase in efficiency, even at their current unoptimized state.

Hydrogen storage

- By taking advantage of the capillary effects of the small carbon nanotubes, it is possible to condense gases in high density inside single-walled nanotubes. This allows for gases, most notably hydrogen (H_2), to be stored at high densities without being condensed into a liquid. Potentially, this storage method could be used on vehicles in place of gas fuel tanks for a hydrogen-powered car.

Drug delivery

- Systems being used currently for drug delivery include dendrimers, polymers, and liposomes, but carbon nanotubes present the opportunity to work with effective structures that have high drug loading capacities and good cell penetration qualities.
- These nanotubes function with a larger inner volume to be used as the drug container, large aspect ratios for numerous functionalization attachments, and the ability to be readily taken up by the cell.

Biosensors

- A biosensor consists of a receptor that interacts with the biological analyte, and this interaction is detected by a transducer that transforms the signal (electrical, optical, etc.) into a form that can be easily measured.
- Biosensors modified with CNTs have the advantages of high signal-to-volume ratio, miniaturization from the CNTs' size being comparable to many biological species, function at ambient temperatures, low surface fouling and high specificity.

Diagnostic and imaging tools

- Tools for imaging and tracking the location and movement of biological objects such as proteins, cells and tissues are critical in understanding their functionalities and activities in the host biological system.
- Such tools also provide us the ability to diagnose and possibly cure various diseases.
- The current techniques use organic fluorophores or quantum dots (QDs, i.e. luminescent semiconducting nanoparticles).
- However, these organic fluorophores and QDs show serious photobleaching effect.
- They also have a limited lifetime in aqueous solutions (approximately 1–2 weeks).

Space elevator

- A space elevator is a proposed type of space transportation system.
- The main component would be a cable (also called a tether) anchored to the surface and extending into space.
- The design would permit vehicles to travel along the cable from a planetary surface, such as the Earth's, directly into space or orbit, without the use of large rockets.
- To construct a space elevator on Earth the cable material would need to be both stronger and lighter (have greater specific strength) than any known material.

Recent Success story....

Research Proves Carbon Nanotube Transistors to be Better than Silicon Transistors

Published on September 6, 2016 at 10:20 AM

Written by AZoNano Sep 6 2016

> *"This achievement has been a dream of nanotechnology for the last 20 years. Making carbon nanotube transistors that are better than silicon transistors is a big milestone. This breakthrough in carbon nanotube transistor performance is a critical advance toward exploiting carbon nanotubes in logic, high-speed communications, and other semiconductor electronics technologies.*
>
> *Michael Arnold, Professor, UW-Madison"*