Nanoscience and Nanotechnology

The word nano is derived from the Greek word nanus, meaning "dwarf" (a small man).

Nanoscience is the study of structures and materials on the scale of nanometers.

Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers.
Nanotechnology deals with the creation of useful materials, devices and systems using the particles of nanometer length scale and exploitation of novel properties (physical, chemical, and biological) at that length scale.

Nanomaterials: Nanoscale materials are defined as a set of substances where at least one dimension is less than approximately 100 nanometers.

Why "nano"

Nanomaterials have superior properties than the bulk substances :

- Mechanical strength
- Thermal stability
- Catalytic activity
- Electrical conductivity
- Magnetic properties
- Optical properties
- ....

A wide range of applications:

Quantum electronics, nonlinear optics, photonics, sensing, information storage and processing, adsorbents, catalysis, solar cells, superplastic ceramics...

New fields:

Nanofabrication, nanodevices, nanobiology, and nanocatalysis

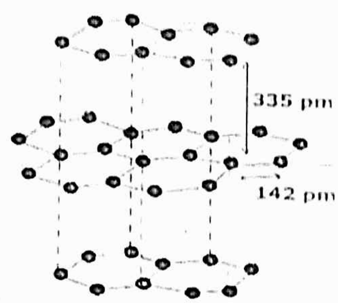
Size of hydrogen atom: 0.1 nm
Nanoparticles: Cluster of atoms or molecules having size 1 to 100 nm.
Quantum dot: A nano particle of size less than 5nm.
Carbon nano particles are found on the surface of the sword of Tipu Sultan

	Eye	Optical	SEM	TEM
Resolution (max)	0.1 mm	0.2 μm	~0.5 nm	0.5 Å

Carbon and its allotropes

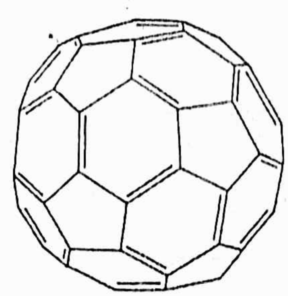
Allotropes of carbon are graphite, diamond and fullerenes.

Graphite: In graphite each carbon atom is only covalently bonded to three other carbon atoms. C-C bond length within the layer is 141.5 pm. Each carbon atom in hexagonal ring undergoes sp^2 hybridization and makes three sigma bonds with three neighboring carbon atoms. Graphite has layered structure. Layers are held by weak vander-waals force and the distance between two layer is 340pm, each layer is composed of planer hexagonal rings of carbon atoms, which can easily slide over each other because there are only weak forces between them. Graphite contains delocalized electrons allowing graphite to conduct electricity.



Graphene: A single sheet of graphite is called graphene.

Fullerenes: A fullerene is a molecule of carbon in the form of a hollow sphere, ellipsoid, tube, and many other shapes. Spherical fullerenes also referred to as Buckminster fullerenes (buck balls), resemble the balls used in football (soccer). Cylindrical fullerenes are also called carbon nanotubes (Bucky tubes).



The third allotropic form of carbon material after graphite and diamond is fullerene. Fullerene is a class of closed cage carbon molecule "C_n" characteristically containing 12 pentagons and a variable numbers of haxagons. The smallest member of fullerene cintains 20 carbon and largest number of fullerene cotain 540 carbon.

The first fullerene molecule to be discovered was buckminsterfullerene (C_{60}). It consists of a hollow spherical cluster of sixty carbon atoms. Buckminsterfullerene is fullerene molecule containing 12 pentagonal and 20 hexagonal rings in which no two pentagons

share an edge (touches each other). It is also most common in terms of natural occurrence, as it can often be found in soot.

The C_{60} molecule has two bond lengths. The 6:6 ring bonds (between two hexagons) can be considered "double bonds" and are shorter than the 6:5 bonds (between a hexagon and a pentagon). Its average bond length is 1.4 angstroms.

Properties of Fullerenes:

- Fullerene is a black powdery material.
- It forms deep magenta solution when dissolved in benzene.
- It is very tough and thermally stable.
- It exists as a discrete molecule unlike diamond and graphite.
- It can compress to lose 30% of its volume without destroying its carbon cage structure.
- Due to absence of aromatic character it behaves like alkenes thus undergo electrophilic addition.

Applications of Fullerenes:

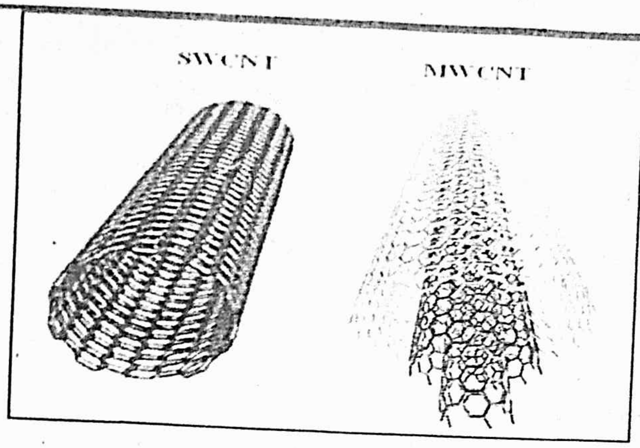
- As photo resistant in certain photolithographic processes.
- In preparation of super conductors.
- In electronic and microelectronic devices
- In preparation of soft ferromagnet.
- As catalyst
- As lubricant due to its spherical structure.
- Hydrogen storage for fuel-cell powered vehicles

Carbon Nano Tubes (CNT): CNTs also known as buckytubes is an allotrope of carbon that is graphite, in which carbon atom is in sp^2 hybridized state. Carbon nano tubes are cylindrical fullerenes. Configurationally it is two dimensional graphene sheet rolled up with continuous unbroken hexagonal mesh into a cylindrical tube. The length to diameter ratio of CNTs is 132,000,000:1.
Diameter of CNTs has ranging from 2-55 nm. The length of CNTs is typically several microns.

Types of CNTs:

(i) **Single walled nanotubes (SWNT):** SWNT is a one atom thick layer of graphite wrapped in a cylindrical shape. The diameter of SWNT is approximately to 1 nm.

(ii) **Multy walled nanotubes (MWNTs):** MWNTs consist of multiple layers of graphite rolled in on themselvesto form a tube shape. It exhibits both metallic and semiconducting properties.



Properties of CNTs:

- Carbon nanotubes (CNTs) have high chemical stability
- Carbon nanotubes (CNTs) have high electrical conductivity
- Carbon nanotubes (CNTs) have high flexibility
- Carbon nanotubes (CNTs) have high tensile strength
- Carbon nanotubes (CNTs) have high thermal conductivity
- Carbon nanotubes (CNTs) have high surface area, making them ideal for the design of sensors.
- Carbon nanotubes (CNTs) have high surface area, making them ideal for the catalyst support.

Applications of CNTs:

- In fuel cell and lithium ion batteries as electrodes
- As catalyst support
- In treatment of cancer
- In tissue regeneration
- For platelet activation
- In targeted drug delivery
- In air and water filtration
- In ceramics, to increase strength

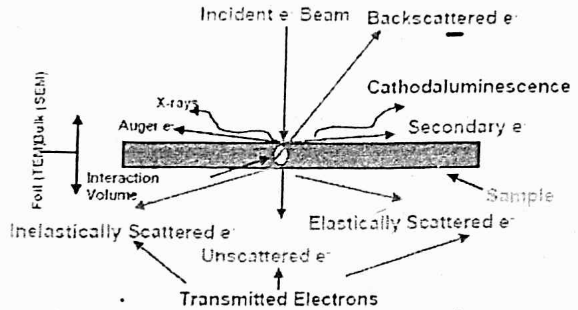
Scanning Electron Microscopy (SEM)

A **scanning electron microscope (SEM)** is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the sample's surface topography and composition. SEM focuses on the sample's surface and its composition.

The incident electron beam is scattered in the sample, both elastically and inelastically, this gives rise to various signals that we can detect.

2.1 Electron-Solid Interactions

When an electron beam strikes a sample, a large number of signals are generated.

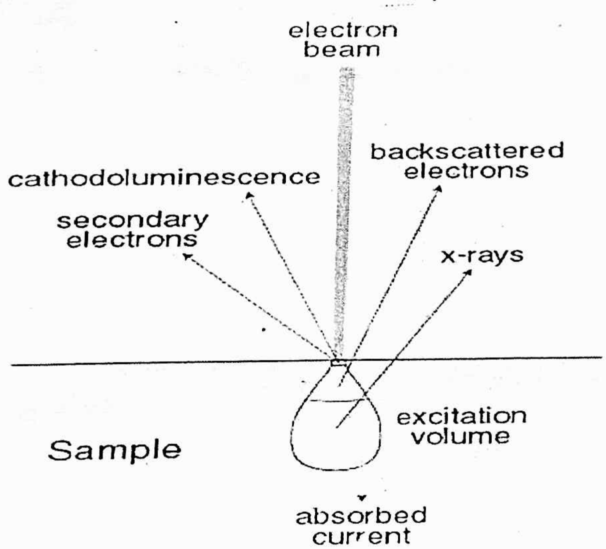


We can divide the signals into two *broad* categories:

a) electron signals, b) photon signals

Secondary Electron: Generated from the collision between the incoming electrons and the loosely bonded outer electrons. They generally have very low energy (by convention less than fifty electron volts). The most common SEM mode is detection of secondary electrons emitted by atoms excited by the electron beam.

Secondary electrons (SE): topographic information is obtained



Backscattered electron: *Backscattered Electrons (BSE)* are primarily beam electrons that have been scattered back (greater than 180^0) out of the sample by elastic collisions with the nuclei of sample atoms. They have high energy, ranging (by convention) from fifty electron volts up to the accelerating voltage of the beam.

Backscattered electrons (BSE) analysis – composition

Backscattered electron imaging is useful in distinguishing one material from another, Backscatter imaging can distinguish elements with atomic number differences of at least 3.

X-ray : Characteristic X-rays that are produced by the interaction of electrons with the sample may also be detected in an SEM. Analysis of the x-ray signals may be used to map the distribution and estimate the abundance of elements in the sample.

1.1 Characteristic Information: SEM

Topography
The surface features of an object or "how it looks", its texture; direct relation between these features and materials properties

Morphology
The shape and size of the particles making up the object; direct relation between these structures and materials properties

Composition
The elements and compounds that the object is composed of and the relative amounts of them; direct relationship between composition and materials properties

Crystallographic Information
How the atoms are arranged in the object; direct relation between these arrangements and material properties

Transmission Electron Microscopy (TEM)

Transmission electron microscope (TEM) is a microscopic technique whereby a beam of electrons is transmitted through an ultra thin sample, interacting with the sample as it passes through. An image is formed from the interaction of the electrons transmitted through the sample; the image is magnified and focused onto an imaging device, such as a fluorescent screen, on the layer of photographic film, or to be detected by a sensor such as a CCD camera. TEMs are capable of imaging at a significantly higher resolution than light microscopes.

SEM V/S TEM

SEM	TEM
• In SEM is based on scattered electrons	• TEM is based on transmitted electrons
• The scattered electrons in SEM produced the image of the sample after the microscope collects and counts the scattered electrons.	• In TEM, electrons are directly pointed toward the sample.
• SEM focuses on the sample's surface and its composition.	• TEM seeks to see what is inside or beyond the surface.
• SEM shows the sample bit by bit	• TEM shows the sample as a whole.
• SEM provides a three-dimensional image	• TEM delivers a two-dimensional picture.
• SEM only offers 2 million as a maximum level of magnification.	• TEM has up to a 50 million magnification
• SEM has 0.4 nanometers.	• The resolution of TEM is 0.5 angstroms

Applications of Nanotechnology

Nanomaterials having wide range of applications in the field of electronics, fuel cells,
batteries, agriculture, food industry, and medicines, etc... It is evident that nanomaterials split their conventional counterparts because of their superior chemical, physical, and mechanical properties.

1. Fuel cells : Carbon nanotubes in Microbial fuel cell

Microbial fuel cell is a device in which bacteria consume water-soluble waste such as
sugar, starch and alcohols and produces electricity plus clean water.

2. Catalysis

Higher surface area available with the nanomaterial counterparts, nano-catalysts tend to
have exceptional surface activity.

3. Phosphors for High-Definition TV

The resolution improves with a reduction in the size of the pixel, or the phosphors. Nanocrystalline zinc selenide, zinc sulfide, cadmium sulfide, and lead telluride synthesized by the sol-gel techniques are candidates for improving the resolution of monitors.

4. Next-Generation Computer Chips

5. Elimination of Pollutants

Due to their enhanced chemical activity, nanomaterials can be used as catalysts to react with such noxious and toxic gases as carbon monoxide and nitrogen oxide in automobile catalytic converters and power generation equipment to prevent environmental pollution arising from burning gasoline and coal.

6. Sun-screen lotion

ZnO and TiO_2 protect the skin by sitting onto it rather than penetrating into the skin. Thus they block UV radiation effectively for prolonged duration.

7. Sensors: Nano bio sensors for the diagnosis of various disease.

8. Health and medicine:

- In targated drug delivery.
- In treatment of cancer **(major focus of nanotechnology)**
- In treatment of neurodegenerative disorder
- In treatment of Alzheimer
- In treatment of tuberculosis
- In blood purification
- In tissue engineering- to repair and reproduce damaged tissue