Unit VI

Non Destructive Testing and Nanotechnology

Introduction of Non destructive Testing:

Non-destructive testing (**NDT**) plays a crucial role in everyday life. It can be used to find, size and locate surface and subsurface flaws and defects to assure safety and reliability.

Non-destructive testing (NDT) is the application of four areas of science – physics, chemistry, biology and mathematics – to create methods of testing that leave the item under test totally undamaged. This means that the component – the casting, weld or forging, for example – can continue to be used and that the non-destructive testing method has done no harm.

Items can be tested before they are finally shaped or whilst they are in service. This means that the continuing quality of components can be assured, such as checking railway lines, aero engine turbine blades and the welds on a high-speed theme park ride. Condition monitoring (CM) aims to ensure plant efficiency, productivity and reliability by monitoring and analysing the wear of operating machinery and components to provide an early warning of impending failure, thereby reducing costly plant shutdown.

Destructive Testing: In this method, the sample under test is destroyed and cannot be used for any purpose after the test. Examples are tensile test, impact test, etc. These tests are performed on sample material out of the batch.

These tests are used to find our mechanical properties like hardness, compressive strength, yield strength and tensile strength, etc.

Objectives of Non destructive testing (NDT):

- These tests do not change the structural properties of the material under the investigation.
- It is the process of inspecting, testing, or evaluating materials, components or assemblies for discontinuities, or differences in characteristics without destroying the serviceability of the part or system.
- Safety norms can be applied after the requirements of the test.

Classification of NDT methods and Physics Applied :

- Classification of NDT Methods Nondestructive testing (NDT) is based on interrelation between a physical field or a substance and a tested object.

- Few types of NDT are discussed as below:

Sr. No.	NDT Method	Physics employed	Applications
1	**Acoustic**	Application of mechanical load or rapid temperature or pressure change to the part being tested and analyzing its propagation.	Flaws or irregularities inside the materials
2	**Ultrasonic**	Echo sounding using ultrasonic	Detection of flaws or irregularities inside the materials. Measurement of thickness of metal sheets
3	**Radiography Testing X-rays or ϒ-rays**	Exposing the materials under test to x-rays or ϒ-rays and taking impression	Detection of Cracks, Cavities, Flaws, Porosity of materials
4	**Magnetic NDT methods**	Magnetic field is applied to the materials and changes in the magnetic characteristics of the ferromagnetic materials are detected	Continuity (flaw detection) Dimensions, structural and mechanical properties
5	**Electric or non-electric NDT methods**	Exposing the tested objects to electric disturbance (e.g. electrostatic field, constant AC or DC field) or non-electric disturbance (e.g. infrared, mechanical, etc.)	(i) Measuring parameters of the composition and structure of a material (ii) Finding geometrical dimensions of a tested object (iii) Finding moisture level
6	**Eddy-Current NDT methods**	The interaction between an external electromagnetic field and the electromagnetic field induced in the test object.	Testing item dimensions, measuring the diameter of wire, rods and pipes, thickness of metal plates and that of pipe walls

In addition to these, other types of NDT methods are vibration analysis, leak testing and integrated ones.

- In all the NDT methods, due to probable presence of defects in the tested object, the nature of external applied field changes.

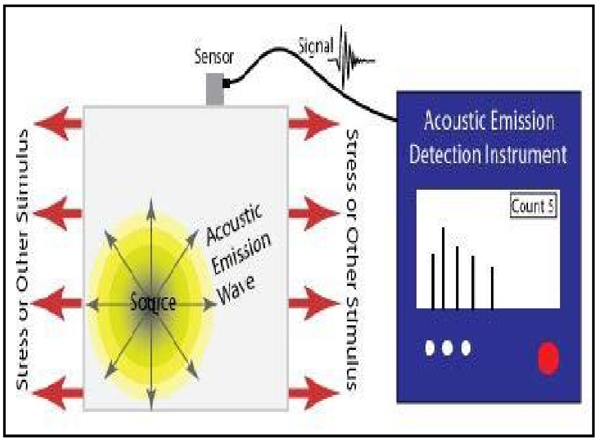
Distinction between destructive and non-destructive testing:

Sr.	Destructive testing	Non-destructive testing
1	Tests are carried out to find properties and behavior of the material under different external conditions.	Tests are carried out to find properties and the defects inside the material.
2	Properties of the material such as bending, tensile strength, compression, strength can be found out.	Properties of the materials cannot be found out.
3	Defects inside the material such as flaw, cracks, porosity cannot be located.	Defects inside the material can be located.
4	Tests are not possible to carry out on entire batch of products as it will destroy all parts in production.	Tests can be carried out on selected samples randomly and results can be correlated to other parts.
5	The object under testing is destroyed.	The object under testing remains intact.
6	As tests involve destruction of part, the production cost increases as part needs to be replaced after tests.	As tests do not involve destruction of part, the part under test remains intact and production cost can be reduced.
7	Examples: bending test, tensile test, compression test, impact test, etc.	Examples: Acoustic emission, ultrasonic testing, eddy current testing, radiography testing etc.

1) Acoustic Emission Technique (AET) Principle:

A mechanical load or rapid temperature or pressure is applied to the material under test and resulting stress waves generated are sensed by sensors.

Method:



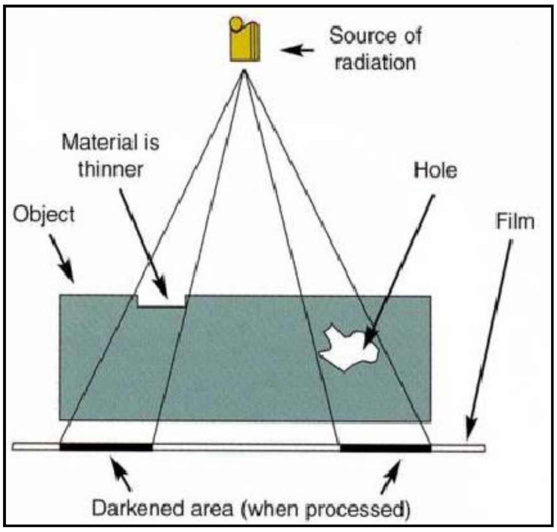
- A localized external force such as an abrupt mechanical load or rapid temperature or pressure is applied to the part of the material being tested.
- A small material displacement or plastic deformation is produced inside the material.
- This results into generation of stress waves inside the material in the form of short-lived, high frequency elastic waves.
- These stress waves are detected by sensors that have been attached to the material.
- The stress waves show discontinuities in the material where flaws or irregularities inside the
- materials.
- When multiple sensors are used, the resulting data can be analyzed by a CRO to evaluate locate discontinuities in the part.

Applications:

- AET is applied to inspect and monitor pipelines, pressure vessels, storage tanks, bridges, aircraft, and bucket trucks, and a variety of composite and ceramic components.

- It is also used in process control applications such as monitoring welding processes.

2) Radiography Testing X-rays or ϒ-rays Principle:



X-rays or - ϒ rays are passed through the material. The radiations are partially absorbed and partially scattered by the medium and partially by the defects. The characteristics of the radiations such as intensity get modified.

Method:

- X-rays or ϒ -rays are produces by a source of radiation (e.g. Coolidge tube in x-rays).
- The material under investigation is placed in the path of the radiation and the photographic plate.

- The beam of radiation is allowed to fall on the material.
- Depending on the thickness and absorption characteristics of the material, some amount of radiation will be absorbed and scattered.
- Absorption of radiations is different in regions inside the material where defect is present and that are free of defect.
- The scattered radiations produce an image on the photographic plate. After developing the photographic plate and its analysis, the defects inside the material can be identified.
- With a single radiogram the presence of defect can be detected.
- For getting exact position of the defect, the radiation should be passed through different angles in the material and resulting set of radiogram is analyzed.

Applications: Using radiography techniques various irregularities inside the material such as flaw, Cracks, presence of Cavities, Porosity can be detected.

3) **Ultrasonic Testing:**

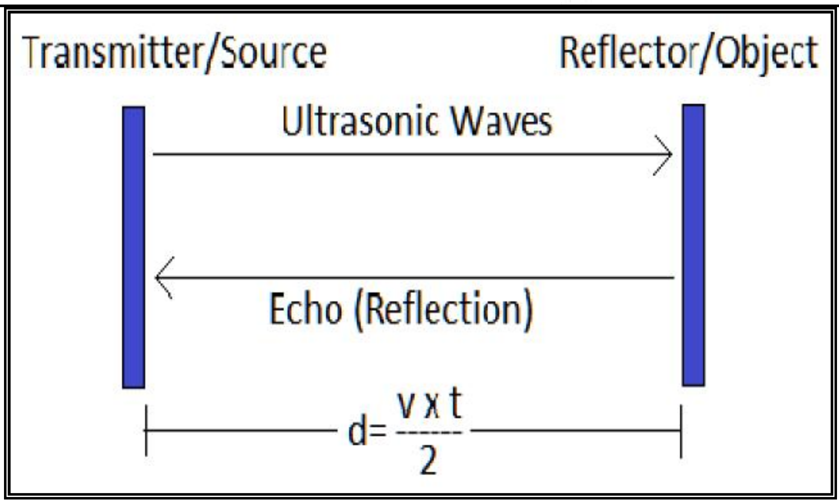
The frequency of sound waves audible to human ear ranges from 20 Hz to 20kHz.The sound waves having frequencies greater than 20 kHz are called ultrasonic or supersonics.

Principle of Echo Sounding:

Echo sounding is a process in which ultrasonic waves are generated by a transmitter, they are directed towards the object and reflection is received.

By knowing the time required to cover distance (between transmitter and object) and velocity, distance of the object from the transmitter can be determined.

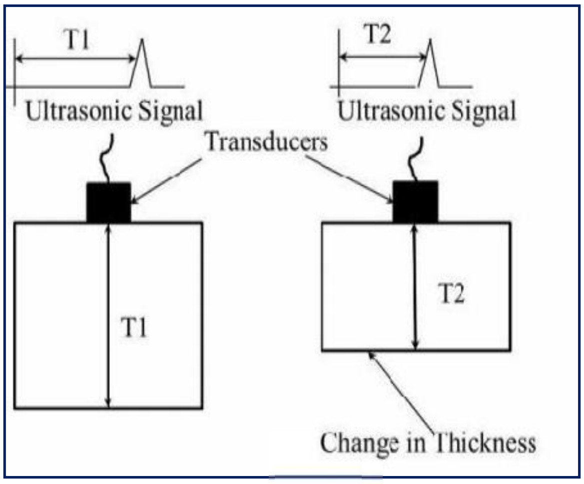
$$\text{Distance of the object} = \frac{(\text{Velocity of the ultrasonic waves}) \times (\text{time required for reflection})}{2}$$



a) Ultrasonic Testing for Thickness (or gauge) measurement:

Method:

- Using a transducer, ultrasonic waves of known frequency and velocity are sent along the thickness of a metal block or sheet.



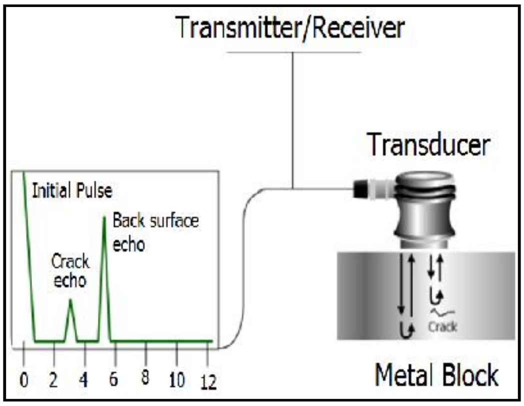
- Ultrasonic waves travel through metal block and gets reflected from its bottom.
- The time required for reflection is calculated.
- As speed of ultrasonic waves and reflection time (echo time) is known, thickness or gauge of the metal block can be calculated using the relation, thickness of the object = $\frac{vt}{2}$

Applications: This technique is used for determination of gauge or thickness of the metal block or sheet.

b) Ultrasonic Testing for Flaw detection:

Method:

- The testing mechanism mainly consists of a transmitting transducer, receiving transducer and CRO.



- A transmitting transducer sends ultrasonic waves into the specimen. Reflected signals from back Surface of the specimen are detected by receiving transducer and are input to a CRO.
- If there are no flaws in the specimen, output of CRO screen shows normal peaks. If there is any flaw present inside the specimen then CRO screen shows small peaks corresponding to the reflection of ultrasonic waves from flaw.

Applications:

- This method is used to evaluate the properties of a material without causing damage to the material.

- Flaw detector detects the flaws like holes, casting, flakes, cracks, tiny cavities etc in metal

Numerical:

1) Find the echo time of ultrasonic pulse which is traveling with the velocity $3.1 x 10^3$ m/s in mild steel. The correct thickness measured by gauss meter is 9 mm.

Solution:

Given: $v = 3.1 x 10^3$ m/s, $t = 9$ mm $= 9 x 10^{-3}$ m

Formula $$\text{tThickness} = \frac{\text{Velocity of ultrasonic pulse x Time}}{2}$$

$$\text{Time} = \frac{\text{Thickenss x 2}}{\text{Velocity of ultrasonic pulse}}$$

$$= \frac{9 x 10^{-3} \ x\ 2}{3.1 x 10^3}$$

$= 5.8 x 10^{-6}$ Sec

$= 5.8$ µS

2) An ultrasonic pulse of frequency 130 kHz is sent through a block of steel. The echo pulse is received after 1.695 microseconds. If velocity of ultrasonic wave in steel is 5900 m/s, calculate the thickness of the steel block and the wavelength of the pulse.

Given: v = 5900 m/s, t = 1.695 µS, f = 130 kHz = $103 x 10^3$ Hz

Formula, $$\text{Thickenss of block} = \frac{\text{Velocity of ultrasonic wave x Time}}{2}$$

$$= \frac{5900 x 1.695 x 10^{-6}}{2}$$

= 0.005

= 0.5cm

As $v = f\lambda$

Velocity of ultrasonic pulse, $$\lambda = \frac{v}{f}$$

$$= \frac{5900}{130 x 10^3}$$

= 0.045 m

=4.5 cm

3) An ultrasonic pulse is sent through a copper block and echo is recorded after 4µs. If velocity of ultrasonic waves in that metal is 5000 m/s, calculate the thickness of the copper block. At another location in same block echo is recorded after 1.253µs. What is the location

of flaw?

Given: v = 5000 m/s, t = 4 μs

Formula, $\text{Thickenss of block} = \frac{\text{Velocity of ultrasonic wave x Time}}{2}$

$$= \frac{5000 \times 4 \times 10^{-6}}{2}$$

= 0.01m

=1cm

$$\text{Location of flov} = \frac{\text{Velocity of ultrasonic wave x Time}}{2}$$

$$= \frac{5000 \times 1.253 \times 10^{-6}}{2}$$

= 0.00313 m

= 0.313 cm

Thus, the flaw is located at 0.313 cm from the top surface.

4) An ultrasonic pulse is sent through a block of steel. The echo is recorded after 1.512 microseconds. Calculate the thickness of the steel block and the wavelength of the pulse if the frequency of ultrasonic pulse is 100 kHz and velocity of ultrasonic in steel is 5900 m/s.

Given: v = 5900 m/s, t = 1.512 μs

Formula, $\text{Thickenss of block} = \frac{\text{Velocity of ultrasonic wave x Time}}{2}$

$$= \frac{5900 \times 1.512 \times 10^{-6}}{2}$$

$= 4.46 \times 10^{-3}$ m

= 0.446 cm

$$\text{As} \quad v = f\lambda$$

Velocity of ultrasonic pulse, $\lambda = \frac{v}{f}$

$$= \frac{5900}{100 \times 10^{3}}$$

= 0.059 m

=5.9 cm

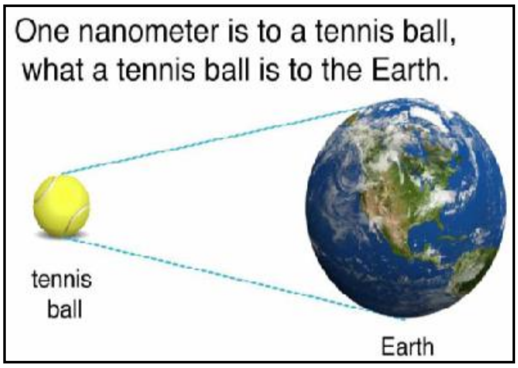
Nanotechnology

Introduction to nanoparticles and nanotechnology:

Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers. It is about the study and manipulating matter on an atomic and molecular scale.

1 nanometer = 10^{-9}m

Equivalence = 1 cm: 10,000 km



Quantum confinement, surface to volume ratio and properties :

Quantum confinement: A bulk material or solid has three dimensions. If only one length of three-dimensional nanostructure is in nanoscale (1-100 nm), the structure is known as a **quantum well**. Instead if two sides are of nanoscale (1-100 nm), the resulting structure is known as **quantum wire**. A nanoparticle is often referred to as a **quantum dot** as its all three dimensions are in the nanoscale (1-100 nm).

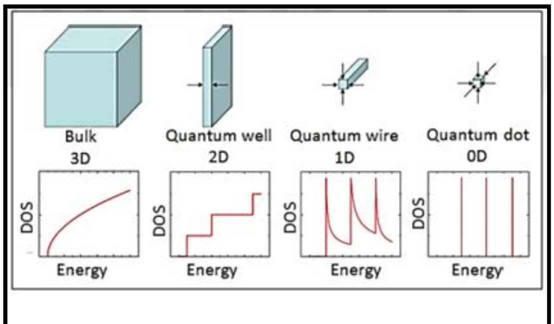


Figure: Quantum confinement effects

Surface to volume ratio: As the size of materials approaches nanoscale, the percentage of atoms at the surface of a material becomes significant. Nanoparticles have a very high surface area to volume ratio.

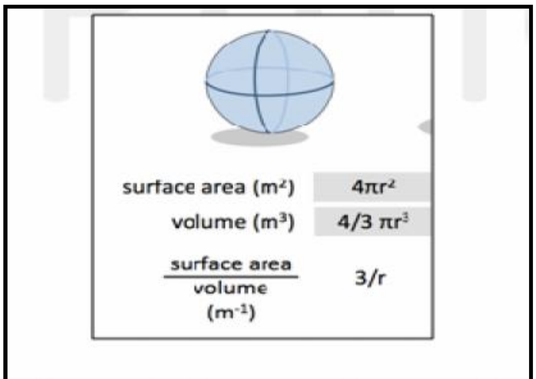


Figure: Surface to volume ratio

Significance of nanoscale and change in properties of nanoparticles:

Many properties of solids such as optical, electrical, mechanical, etc depend on its size. As compared to its bulk form, properties of materials change when at least one of the dimensions of material is reduced to naosclale (1-100 nm), mainly due to following reasons:

(i) Upon reaching quantum confinement at nanoscale energy levels of nanoparticles become discrete (as shown in the figure). This increases or widens up the band gap and the band gap energy. This results into change in the properties of material at nanoscale.

(ii) Nanoparticles have a relatively larger surface area when compared to its bulk form. This makes the nanoparticles more chemically reactive compared to bulk form and it thus modifies its properties.

(iii) Physical properties of materials such as electrical are characterized by the mean free path (path of the electron collision due to atoms or ions). This mean free path changes at nanoscale.

(iv) Bulk properties of materials such as hardness changes at nanoscale. Nanoparticles are much harder and tougher as compared to their bulk form.

Optical properties of Nanoparticles:

(a) Optical properties of metallic nanoparticles:

The color of nanoparticles is different from bulk material. One of the daily life examples is of glass. Glasses are transparent, but when doped with different nanoparticles, adopt different colors like red, pink, blue, green, etc depending upon the dissolved nanoparticles.

Metal	Color for bulk	Color at nano-level
Gold	Yellow	Bright red
Silver	Colorless	Pale yellow

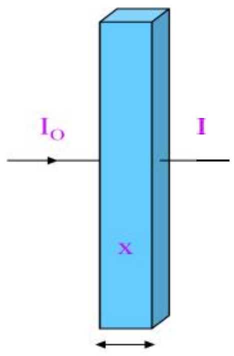
G. Mie Theory for change in optical properties:

- G. Mie explained the phenomenon using Maxwell's equation in 1908. When electromagnetic radiation incidents on spherical particles of uniform size a part of the radiation is absorbed and a part is scattered. Thus the intensity of transmitted light changes.

- When a beam of light having wavelength λ, intensity *I0*, length of medium *x*, then

The intensity of transmitted radiation is given by:

$$I = I_0 e^{-\mu x}$$



μ = extinction coefficient depends upon no,

$$\mu = \frac{N}{V} \cdot C_{ext}$$

where, N is number of particles in medium

V is volume of particles,

C_{ext} = is extinction coefficient.

x = Thickness of material.

At nanoscale, as size of the nanoparticles change, there is change in the length of medium and thus the values of μ and x changes.

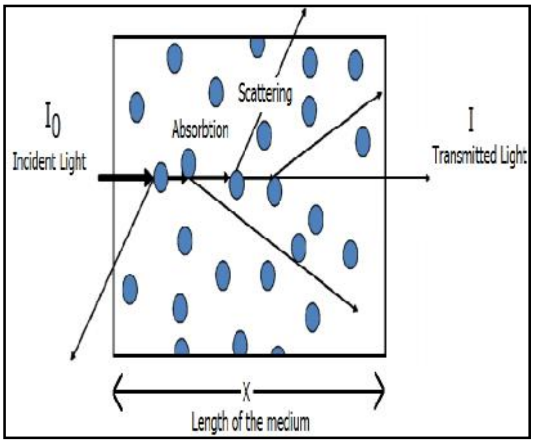
- This changes the intensity of transmitted light and it depends on the wavelength of incident light.
- This changes the color of nanoparticles at different nanoscale region.
- Mie theory successfully explained absorption of light of visible wavelength for nano-particles, but for particle size less than ~10 nm, there is need to consider dielectric constant which depends also on particle size.

Drude theory for optical properties:

- Free electrons can be considered as plasma.
- When electromagnetic radiation interacts with metals, it is responsible for oscillation of electrons coherently. These oscillations are quantized and known as plasmons.
- A resonance occurs if frequency of incident radiation is same as that of plasmon frequency. At nanoscale electrons oscillates coherently with a resonant frequency resulting in to variation of color at nano-scale.

Optical properties of semiconductor nanoparticles:

- Every material has a characteristic size only below which size dependent properties are realized. In semiconductors this size is the size of the exciton.
- In semiconductor nanoparticles, as the particles become smaller and smaller, the energy gap increases and absorption peak shifts towards higher energy/frequency values.
- This leads to shift in the absorption spectrum and change in color of particles.



When light is passed through the medium ,a fraction is absorbed and the part is scattered hence the extinction cross section is the sum of absorption extinction and scattered extinction cross section. The scattering coefficient the light depends on wavelength λ and the absorption coefficient depends inversely on the volume of colloidal particles i.e. 1/V.

Electrical properties of Nanoparticles:

Electrical properties are characterized by the mean free path of electron (path of the electron collision due to atoms or ions). The mean free path changes at nanoscale due to collision and tunnelling within the conductor.

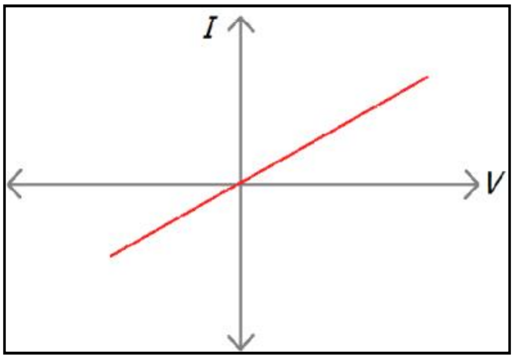
Conductivity: Depends upon no. of charge carriers, charge, mass of charge carrier and relaxation time (time between two collisions with ion core)

Resistivity = 1/ conductivity.

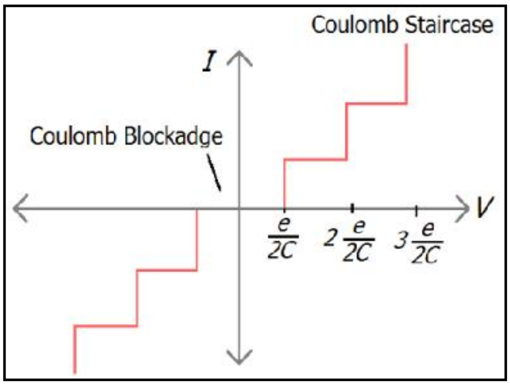
Electrons are transferred when the voltage is ±e/2C.

I-V Characteristics of bulk conductor:

When voltage *V* is applied across the conductor, current *I* flowing through it is governed by Ohm's Law and has a linear variation.



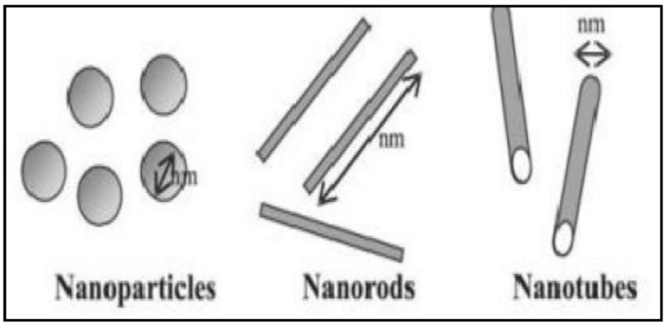
I-V Characteristics at nanoscale: If dimensions of conductor are in nanoscale (1-100 nm), there appears a region around zero voltage for which there is no current. A single electron is transferred by tunneling when the voltage ±e/2C. Therefore, when the voltage is less than this electron cannot be transferred. This gives a region of zero current at low bias voltage and is known as **'Coulomb blockade region'.** The electrons are transferred when the voltage is ±e/2C. The repeated tunneling of single electron produces **'Coulomb staircase'**.



Electrical resistivity: The materials of nano-sized grains have larger number of grain boundaries than corresponding polycrystalline materials. Electrical resistivity of materials having nano-sized grain is larger than the polycrystalline materials due to scattering of electrons at grain boundaries.

Mechanical properties of Nanoparticles

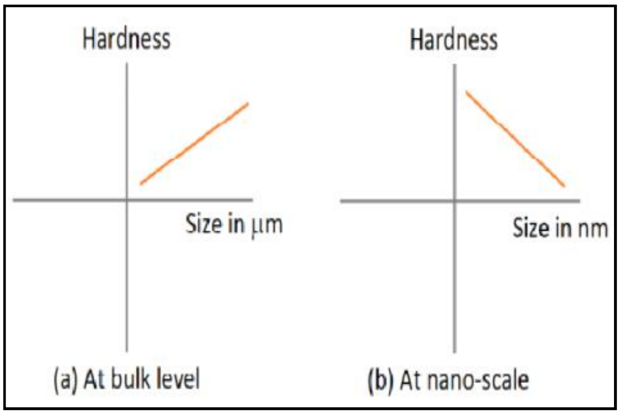
Mechanical properties of materials depend upon the composition of material, bonds between the atoms and presence of impurity. When the size of materials is reduced to nano-scale (1-100 nm),



materials tend to be single crystal. The measurements of elasticity, hardness, ductility show different behavior as compared to the bulk material. For example, in the case of metallic nanocrystalline materials, elastic modulii reduce dramatically.

Material	**Form**	**Grain size**	**Young's modulus**
Mg	Nanocrystal	~12 nm	Y = 3900 N/mm^2
Polycrystalline	> 1µm	Y = 4100 N/mm^2	

Plastic deformation in nanocrystalline materials strongly differ from that of polycrystalline bulk material i.e. if stress is removed the recovery to original shape/size is recovered more effectively.



Hardness of materials is also related to the grain size. In the nanometer size range, the hardness increases with decrease of particle size. (Shown in figure for copper).

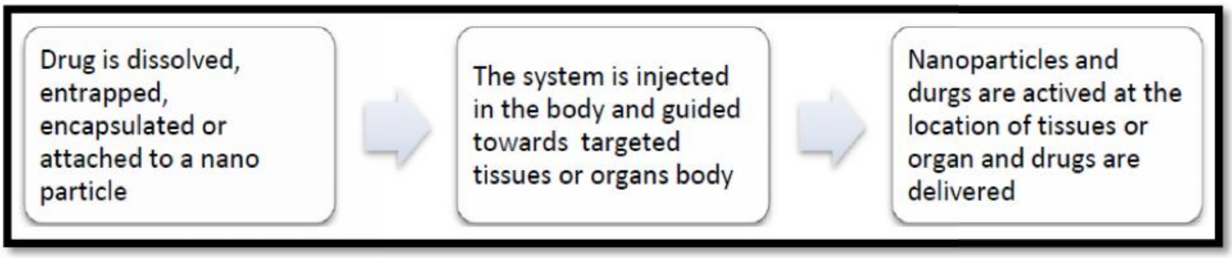
Applications of nanoparticles and nanotechnology:

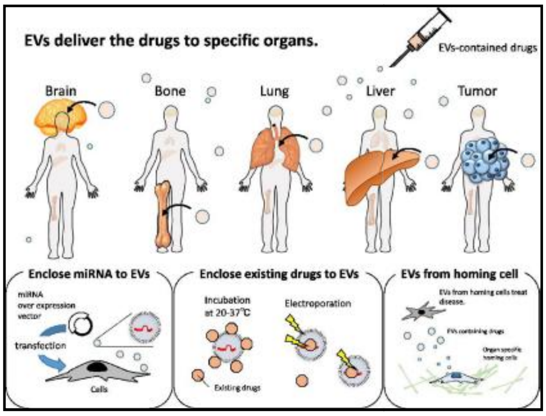
1) Medicine (targeted drug delivery):

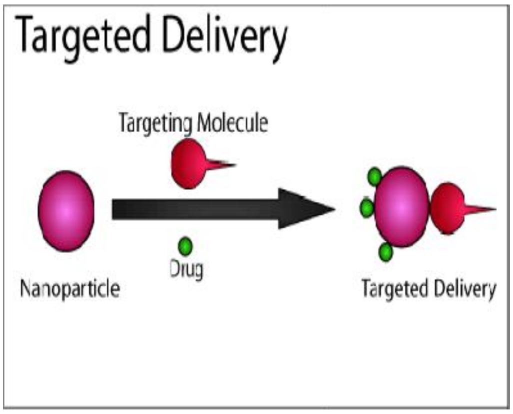
- The traditional drug delivery system, the drug is distributed to the affected tissues or organs of the patient's body as well as to the healthy tissues or organs. This leads to the side effects.

- In the targeted drug delivery system, the drug is dissolved, entrapped, encapsulated or attached to a nano particle. The system is then embedded in a capsule which is guided towards the affected part of the body.

- The capsule is opening at the specific tissues or organs controlled by externally applied magnetic field or infrared light or physiologically. Then drug can be delivered in controlled manner.







Carriers for targeting drug Depending on the treatment required and nature of the drug, following are few examples of carriers are used for targeted drug delivery:

Sr.	Carriers of drug	Applications
1	Poly (alkyl cyanoacrylate) nanoparticles with anti cancer agents	Cancer therapy
2	Poly (methyl methacrylate) nanoparticles with vaccines	Vaccine delivery
3	Poly(alkyl cyanoacrylate) polyester nanoparticles with anti parasitic	Intracellular targeting
4	DNA- gelatin nanoparticles	DNA delivery

2) Electronics:

In the spin-electronic devices, the spin property of electrons (instead of charge) is taken into consideration. Advantage with spin is that it cannot be easily destroyed by scattering from collisions with other charges, impurities or defects. The electronic devices with typical dimensions of few nanometers in either of three directions display unique properties. Such devices are fast, compact, and relatively cheap. Such devices are typically known as spin-electronic (spin-electronic) devices. Few applications are listed as below:

1. Single electron transistor (SET)

The single electron transistor is a switching device in which a quantum dot is placed between the source and the drain. It uses controlled electron tunneling to amplify current. They offer low power consumption and high operating speed.

2. Spin valves

Spin values are commercially used in computer read heads. Their use has enabled to increase the data storage capacity of magnetic memory devices due to their ability to detect small magnetic fields.

3. Giant Magneto Resistance (GMR)

GMR effect is the change in magnetic field of certain materials after application of magnetic field. This is very effective in observing small changes in the magnetic field and useful as a read device of the magnetically stored data. The data storing and reading in computer hard disks is the direct application of GMR.

4. Spin polarized Field Effect Transistor (S-FET)

In S-FETPolarized beam of light was used to obtain spin polarized electrons from the source. It is expected that this will help in faster and efficient data processing.

5. Nanophotonics

In nanophotonics, nanostructures (quantum dots, nanowires or 2-D thin films) or nanocomposites are used to produce light or detect light. They can be used for light production, propagation, manipulation like amplification, filter, detection etc.

6. Display technologies for TV and monitor

The flat panel television or computer monitors are products of nanotechnology. Even the coatings used on screens of TV or monitors can be of nanoparticles, which have better properties in terms of color quality and resolution than micro particle coatings.

3) Space and defense:

Nanotechnology has a wide range of applications in space defense. Nanomaterials in various forms are used for reduction of weights of space vehicles, improving efficiency of solar cell, insulation of space vehicle, ignitior and propellents, etc. A few of them are listed below:

1. Aerogels

Aerogels are designed using nanomaterials and have very low density typically 0.01–0.8 g/cm3. They are very light weight and poor conductor of heat and have potential applications in designing spacecrafts, defense equipment, suits, jackets to reduce the weight.

2. High efficiency light weight solar cells

Satellites or spacecrafts are mainly powered by solar energy. Currently solar cells have reached an efficiency of 30 - 40 %. Using luminescent dye sensitized nanoparticle based or nanoparticle-based solar cell arrays have potential to reduce the weight of solar cells as well as increase in efficiency.

3. Insulation for space vehicles

Space vehicles should withstand harsh and extreme environments during launching and in space. Materials should also sustain high or low temperature and high or low pressure. Use of silica fibers and nanoparticles provide insulation in solid rocket motors and also they are better radiation protectors.

4. Better ignitors and propellants

Nanocrystalline materials such as alumina particles are better propellants than conventional one. A nanocomposite of Fe_2O_3 and aluminium burns much faster and is more sensitive than conventional thermites.

5. Fatigue resistant materials

Fatigue strength in aircraft usually decreases with time. Some nanomaterials have better fatigue strength and life is increased by 200–300 %.

6. Detection of biological weapons

Biological weapons may use dangerous microbes or viruses as weapons. Some nanoparticle oxides like CaO, Al_2O_3 and MgO interact with such chemicals much faster than microparticles and are ideally suited for fast decomposition of warfare chemicals

4) Automobiles:

Nanotechnology has a wide range of applications in automobiles. Nanomaterials in various forms are used for designing sturdy structural parts, smooth and non-scratch paints, self-cleaning windows, better tires, reduction of harmful emission, etc. A few of them are listed below:

1. Sturdy structural parts

Various body parts of vehicles are made up of steel, some alloys, rubbers, plastics etc. Nanotube composites have mechanical strength better than steel.

2. *Smooth and non-scratch Paints*

Cars are spray painted with fine particles. Nanoparticle paints provide smooth, non-scratch thin attractive coating.

3. Self cleaning glass for windows

Self cleaning glass can be made by dissolving small amount of titania (TiO2) nanoparticles while manufacturing glass. Titania is able to dissociate organic dust in presence of UV light available in the sunlight. Drops of waters on glass give hazy look, but TiO2-containing glass can spread water evenly giving clear sight.

4. Small motor parts

Small motors are needed in vehicle (such as wipers, window glass movements, etc). Very powerful electric motors are made using shape memory alloys using nanoparticles of materials like Ni–Ti. They require less power and gives better performance.

5. ***Better tires***

Tires of vehicles undergo wear and tear with use and also increase its weight. By using nanoparticle clay, better, light weight, less rubber consuming thinner tires are possible that can reduce the overall weight, increase in fuel consumption and speed.

6. ***Controlling harmful emission***

Use of efficient nanomaterial catalysts is one solution to convert harmful emission into less harmful gases. Large surface area of nanoparticles is useful to produce better catalysts. They are capable of absorbing emission of particles and poisonous gases like CO and NO from vehicle exhausts.

7. ***Hydrogen fuel***

Instead of using conventional petro fuels, there are numerous advantages of using hydrogen as a fuel. When hydrogen fuel is burned it can only produce harmless water vapor. Hydrogen gas is normally stored in a metal cylinder under high pressure. Nanocylinders of carbon nanotubes have potential to store hydrogen in very small space.