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# Unit VI: Non Destructive Testing (NDT) & Physics of Nanoparticles

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**Que.1. State various types of non-destructive techniques. Explain any two of them in brief. [6]**

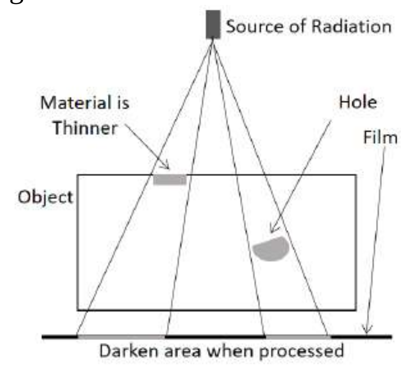
The various types of NDT techniques are,

1. **Acoustic emission Technique:** A mechanical load or rapid temperature or pressure is applied to the material under test and resulting stress waves generated are sensed by sensors.
2. **Radiography testing by using X-rays or γ-rays:** X-rays or γ-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.
3. **Ultrasonic Testing:** Flaw detection is done by using echo sounding Technique 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.
4. **Magnetic testing:** Magnetic field is applied to the materials and changes in the magnetic characteristics of the ferromagnetic materials are detected.
5. **Electric or non-electric testing:** In this technique the objects are exposed to electric disturbance (e.g. electrostatic field, constant AC or DC field) or non-electric disturbance. (e.g. infrared, mechanical, etc.)
6. **Eddy-Current methods:** The interaction between an external electromagnetic field and the electromagnetic field induced in the test object.

**Radiography testing by using X-rays or γ-rays:**

Principle:

X-rays or γ-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.



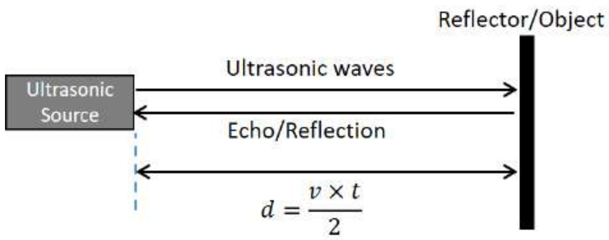

- X-rays or γ-rays are produces by a source of radiation (e.g. Coolidge tube in x-rays).
- The material under investigation is placed in the path of the radiation and the photographic plate. The beam of radiation is allowed to fall on the material.
- Depending on the thickness and absorption characteristics 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.

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

**Ultrasonic Testing:**

Principle: 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.

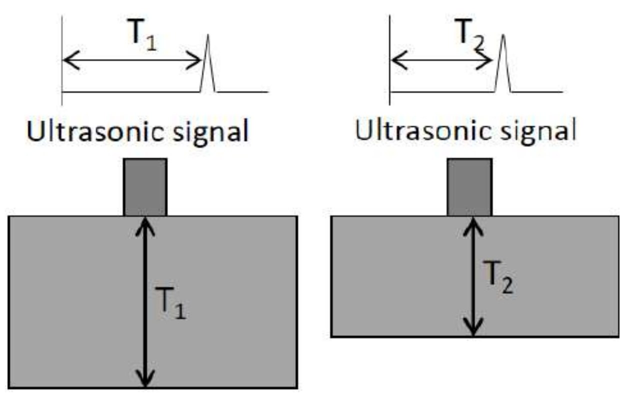
By knowing the time required to cover distance (between transmitter and object) and velocity, distance of the object from the transmitter can be determined.




Using a transducer, ultrasonic waves of known frequency and velocity are sent along the thickness of a metal block or sheet as shown in figure below.

- 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, $d = \frac{v \times t}{2}$




**Que.2. What is NDT? State its advantages as compared with destructive testing. [6]**
**OR**
**Que.2. What is NDT? Differentiate destructive and non-destructive testing (NDT) [6]**

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.

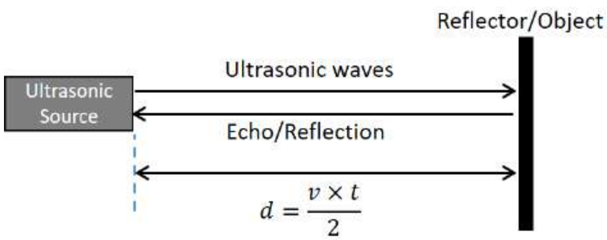
These tests do not change the structural properties of the material under the investigation.
Safety norms can be applied after the requirements of the test.

**Advantages of NDT as compared with 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. |

**Que.3. Explain in brief using ultrasonic waves**
**(a) Flaw detection.**
**(b) Thickness measurement. [6]**

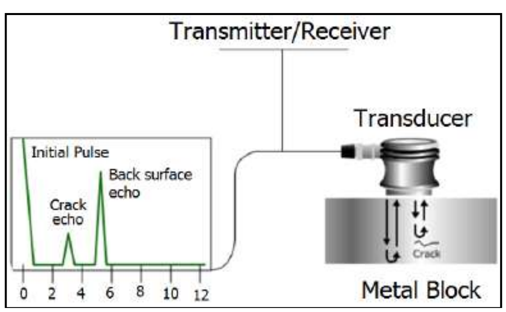
Principle: Echo sounding: Echo sounding is a process in which ultrasonic waves are generated by a transmitter, they are directed towards the object and reflection is received.
By knowing the time required to cover distance (between transmitter and object) and velocity, distance of the object from the transmitter can be determined.




**(a) Flaw detection:**

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.

Advantages:
Components with larger thickness can be tested compared to x-ray radiography, more accurate method, low cost, high speed, small flaws can be detected.
Disadvantages:
Surface of components need to be smooth, very thin specimen cannot be tested, specimen has to be homogeneous composition, defects very close to surface are not detected.

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.

**(b) Thickness measurement:**

Using a transducer, ultrasonic waves of known frequency and velocity are sent along the thickness of a metal block or sheet as shown in figure below.

- Ultrasonic waves travel through metal block and gets reflected from its bottom.
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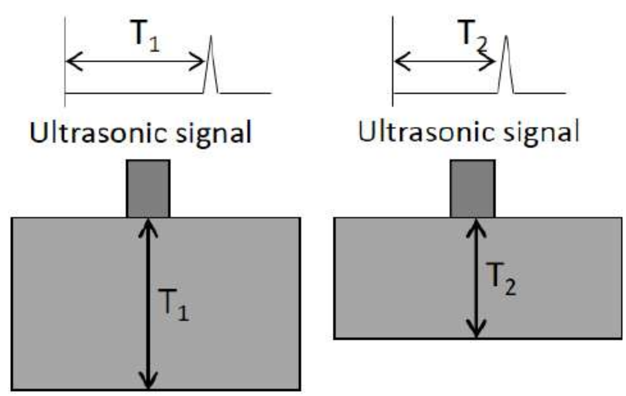
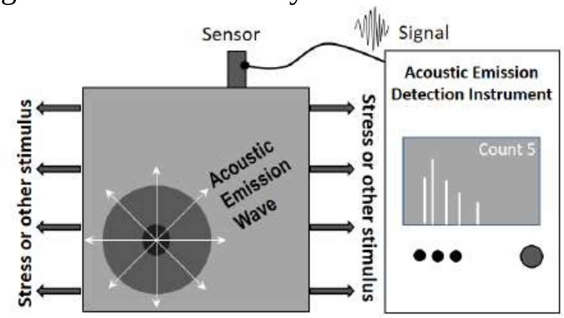



**Que.4. Discuss in brief Acoustic Emission Technique and its applications. [4]**

Acoustic Emission: It is defined as the generation of an elastic wave due to rapid release of energy within the material.
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.




If a structure is subjected to change in pressure, temperature or load, some sites within the structure develop more deformation than its surrounding regions, leads to release energy in the form of stress waves which is short-lived, high frequency elastic waves.
These stress waves can be detected by sensors. The stress waves show discontinuities in the material where flaws or irregularities inside the materials.
The sensors are piezoelectric crystals which are placed in arrays. They can detect the presence of defects and also locate their position.
When multiple sensors are used, the resulting data can be analyzed by a CRO to evaluate, locate discontinuities in the part.

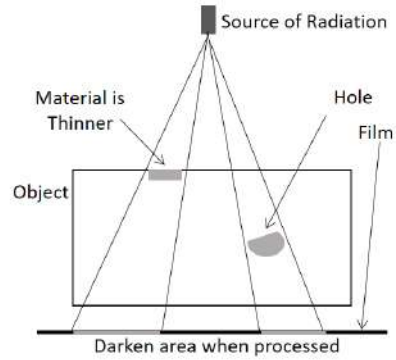
Advantages: Give real time data during operation of the structure, highly sensitive, leads to early detection of flaws, sensors are permanently mounted on structure so continuous monitoring.

Disadvantages: Sufficient high load required to produce significant signal, requires sensors to be permanently mounted on structure.

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.

**Que.5. Discuss in brief Radiography Testing and its applications. [4]**

Principle:
X-rays or γ-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.




- X-rays or γ-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.

Advantages: Hidden flaws can be detected, inspection take very little time, a wide variety of materials can be tested.
Disadvantages: It is expensive as compared to other methods, inspection has to be carried out in an isolated place as long exposure to x-rays is harmful to human being, and very small flaws cannot be detected.

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

**Que.6. Discuss in brief applications of ultrasonic waves in flaw detection. [4]**

Principle: 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.
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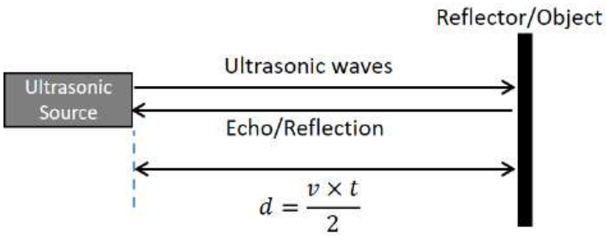


The testing mechanism mainly consists of a transmitting transducer, receiving transducer and CRO.

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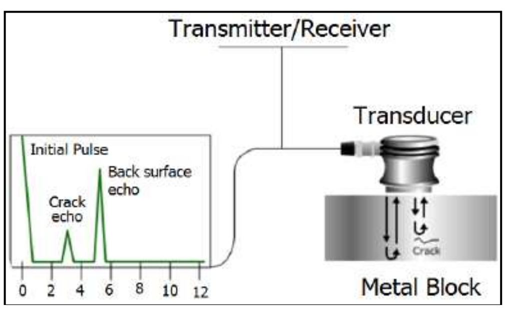


- If there are no flaws in the specimen, output of CRO screen shows normal peaks. If there is any flaw present inside the specimen then CRO screen shows small peaks corresponding to the reflection of ultrasonic waves from flaw.

Advantages:
Components with larger thickness can be tested compared to x-ray radiography, more accurate method, low cost, high speed, small flaws can be detected.
Disadvantages:
Surface of components need to be smooth, very thin specimen cannot be tested, specimen has to be homogeneous composition, defects very close to surface are not detected.

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.

**Que.7. Discuss in brief applications of ultrasonic waves in thickness measurement. [4]**

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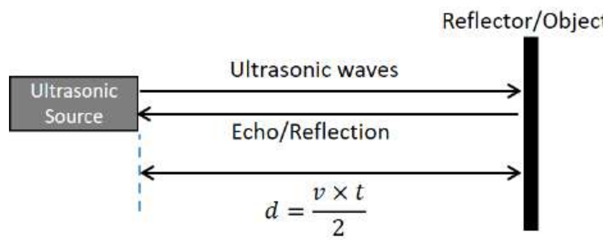


Using a transducer, ultrasonic waves of known frequency and velocity are sent along the thickness of a metal block or sheet as shown in figure below.

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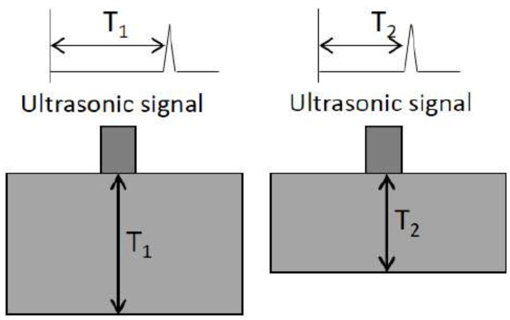


**Que.8. What is nanotechnology? Explain any two properties of nanoparticles. [6]**

Nanotechnology is engineering at the molecular (groups of atoms) level. It is the collective term for a range of technologies, techniques and processes that involve the manipulation of matter at the smallest scale (from 1 to 100 nm).

"Nano-science" is the study of fundamental principles of molecules and structures with at least one dimension are in the size range of 1 to 100 nm. These structures are known as "nano-structures". The research and applications of nano-structures into nano-scale devices is called "nano-technology".

**Rest answer will be any two properties as answer of Que. 9, 10 and 11.**

**Que.9. Explain optical properties of nanoparticles. [4]**

The tinted glasses are made by dissolving small amount of metal particles like gold, silver, cobalt, iron, nickel etc. Basically such glasses are transparent but have different colours like red, pink, blue, green etc. depending upon the dissolved metal particles. In fact the colour of glasses is due to metal nano-particles. The colour of nano-particles is different from their bulk form. Bulk gold is yellow in colour but gold metal nano-particles have intense red colour. This was first shown by M. Faraday in 1857.

When a bulk material is reduced in size to a few hundred atoms, the energy band structure of it changes to a set of discrete energy levels. This happens because of quantum confinement effect. The quantum confinement effect can be observed once the diameter of the particle is of the same magnitude as the wavelength of the electron.

A particle behaves as if it were free when the confining dimension is large compared to the wavelength of the particle. During this state, the bandgap remains at its original energy due to a continuous energy state. However, as the confining dimension decreases and reaches a certain limit, typically in nanoscale, the energy spectrum turns to discrete. As a result, the bandgap becomes size dependent.

This means atomic clusters of different sizes have different energy level separations at nano-scale. Therefore the colour of cluster will depend on their size as colour is due to transition between the energy levels.

In 1908, G. Mie has given a theory about the interaction of spherical particles with electromagnetic radiation by using Maxwell's equations.

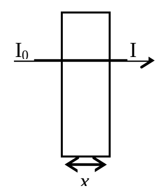


**Figure 6.10**

According to him when a beam of electromagnetic radiation of intensity $I_0$ and wavelength $\lambda$ passes through a medium having dielectric constant $\varepsilon_m$ the transmitted intensity would be given by,

$$I = I_0 e^{-\mu x} \text{ --------} (6.1)$$

Where, $\mu$ is extinction coefficient. *(Extinction coefficient is a parameters defining how strongly a substance absorbs light at a given wavelength.)* and $x$ is thickness of the medium.

$$\mu = \frac{N}{V} C_{ext} \text{ --------} (6.2)$$

Where, $N$ = Number of particles in medium, $V$ = Volume of the particles and $C_{ext}$ = Extinction cross section of a particle.

For very small particles having radius $R$, extinction is mainly due to absorption. This $C_{ext}$ depends on $R^3$ and absorption coefficient $\mu$ is inversely proportional to V.

**Que.10. Explain electrical properties of nanoparticles. [4]**

Materials are classified according to their ability to let current flow through them. Conductivity is dependent on number of electrons '$N$', charge '$e$', electron mass '$m$' and relaxation time $\tau$. (Time between two collisions with ion core).

$$\sigma = \frac{Ne^2\tau}{m}.$$

Resistivity is the inverse of conductivity. It can be measured by connecting electrically conducting wires to solid material of known dimensions, applying potential difference across it and measuring a current flowing through it as shown in **figure 6.11**

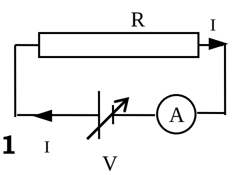


**Figure 6.11**

Current flowing through it is given by Ohm's law, $I = \frac{V}{R}$. The graph of $I$ *Vs* $V$ is linear as shown in **figure 6.12.**

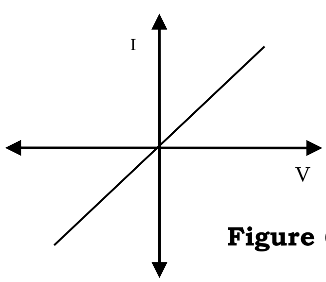


**Figure 6.12**

If we reduce the dimensions of metal piece to ~ 100 nm or less the variation of $I$ *Vs* $V$ is as shown in **figure 6.13.** (If the conductivity of nano-particles is to be measured then it is useful to put capacitors on either side so that direct contact between electrode and metal particle is avoided. This will help us to know correct behavior of electrons under applied voltage.)

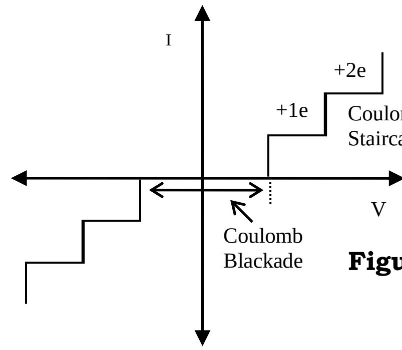


**Figure 6.13**

There is a region around zero voltage for which there is no current flow. This phenomenon is known as *'Coulomb Blackade'.*

Repeated tunneling of single electrons produces what is known as *'Coulomb Staircase'.*

**Coulomb Blackade can be understood as follows,**

The electrostatic energy E of a capacitor having capacitance C is given by, $E = e^2/2C$

When an electron of charge $e$ is transferred to the capacitor, for a small value of capacitance & low thermal motion of electrons ($kT << e^2/2C$) the charging energy $E$ will be significant. A nano-particle connected to electron source and drain by tunnel barriers can be charged in such a way that only one single electron is transferred to it when voltage $\pm e/2C$ is applied. Below this voltage the electron can not be transferred. Therefore the region of no current of low bias voltage is known as *'Coulomb Blackade'.*

Resistivity in such materials is in general larger than in poly-crystalline materials. The electrons get scattered at grain boundaries resulting into increase in resistance. Therefore electrical resistance of poly-crystalline materials is larger than single crystal materials. In materials having nano-crystalline grains larger grain boundaries exists, compared to polycrystalline materials. Therefore Resistivity of materials having nano-sized grains is generally quite large.

**Que.11. Explain mechanical properties of nanoparticles. [4]**

Mechanical properties of materials depend upon the composition and bonds between the atoms such as covalent, ionic, metallic etc. as a result, purest materials may be inherently weak or strong or brittle. Presence of impurities affects all these properties. Most of the materials have impurities as well as point defects, grain boundaries, dislocation etc, which are responsible for the deviation of the properties.

When the size of materials is reduced to nano-scale, materials tend to be single crystal. They are in different forms such as nano-particles, nano-rods, nano-tubes, nano-crystalline solid, granular thin films, homogenous thin films, multi-layer films etc.

It is possible to determine various mechanical properties like elastic properties, hardness, ductility etc. of different nano-structures. Measurements on single nano-particles, rods, tubes are difficult. However, measurements on nano-crystalline solids, thin films etc. are possible.

It has been shown in case of metallic nano-crystalline materials that elastic modulii reduce dramatically. (e.g. Young's modulus of magnesium nano-crystalline material is observed to be 3900 N/mm$^2$ against 4100 N/mm$^2$. of its bulk form.

**Que.12. What are applications of nanotechnology? Explain any two applications of nanoparticles. [6]**

**Que.13. What are applications of nanotechnology? Explain any one application of nanoparticles. [4]**

Nanotechnology application is in various fields such as, Electronics, Energy, and automobile, Space and Defense, Medical.

*Explanation of any two of following for Que.12 and any one for Que.13*

**1) Electronics:**

Single electron transistor (SET), spin valves and magnetic Tunnel Junction (MTJ) are the new devices based on nano-technology. These devices are small, faster and relatively cheaper.

The spin valve type devices are used in PC to read disc, to increase the data storage capacity of hard disks. These are devices based on charge and spin. Earlier devices were based on charge only and spin was neglected.

The spin based electronics is called as *'spintronics'* of *'magneto-electronics'*. Using an external magnetic field spin transport can be controlled. The advantage with spin is that it cannot be destroyed easily by scattering from collisions with other charges, impurities, imperfections. Some of the spin based devices are spin FET, spin LED, and spin RTD etc.

Nano-technology can also be used in computers for designing nano-voltaic memory, smaller and faster microprocessors and better quality monitors. The nano-particle coating on screen of TV or monitors will improve quality and resolution.

**2) Energy:**

We use the conventional energy sources like coal, oil, gas etc which are limited and extensive use of it is harmful for environment. So man started using non-conventional energy sources such as solar energy, biomass energy, wind energy etc. every energy source in non-conventional category has some disadvantages and limitations.

Nano-materials can be used to reduce the size of solar cells and increase the efficiency. By using nano-materials as a photo-catalyst the $H_2$ fuel can be obtained by splitting water ($H_2O$) using sunlight. But $H_2$ fuel can not be stored easily. The carbon nano-tubes can be used as storage material without risk.

Because of frequent recharging or replacement of light weight batteries used in portable electronic equipments such as mobiles, laptops, calculators etc. their energy density is low; which can be improved by nano-materials.

**3) Automobile:**

The body of car or other vehicles should be strong and non-deformable. Generally it is made up of steel and some alloys. The nano-tube composites have mechanical strength better than steel and other alloys.

Nano-particle paints provide smooth, thin and attractive coating. Research is going on to change the colour of car by applying a small voltage.

The titania ($T_iO_2$) is capable of dissociating organic dust in presence of UV light present in sunlight. Once dissociated it may fall down and evaporate. These TiO2 nano-particles can be mixed with glass while manufacturing to produce *'self-cleaning glasses'*.

By using nano-particles, light weight and less rubber consuming, thinner tyres can be made. This will help to reduce car price and will increase the mileage of the car.

Nano-particles can be used as a catalyst to convert harmful emission into less harmful gases. In nano-tubes $H_2$ fuel can be stored very easily which can be used to run a car.

**4) Space and Defence:**

In space and defence, scientists are trying to replace conventional materials by nano-materials.

Nano-porous materials like aero-gels have extremely low density ranging between 0.01 to 0.8 gm/cm$^3$. Aero-gels have small nano-sized pores in them and can be made of various materials. Basically aero-gels are poor conductors of heat. Therefore they can be used in spacecraft to reduce the weight. Even a special light weight suits and jackets can be made from them. A small size, high efficiency solar cells can be made from nano-materials which can be used for space applications.

Polymer composites using silica fibers and nano-particles have large Young's modulus, low temperature coefficient of expansion and high impact strength which can be used in space craft which can withstand harsh and extreme conditions during launching and in space.

**5) Medical:**

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.

Gold nano-rods have strong scattering and absorption property in the infrared are used to destroy cancer cells in the rats. Using low power infrared laser light only cancerous cell can be destroyed and healthy cells can be protected.

The body implant should be strong and biocompatible and it should not get deformed easily. The scientists are working to develop such implants by using nano-composites.

**Que.14. Explain applications of nanoparticles in medical field. [4]**
*Application Number 5 in the answer of Que.13*

**Que.15. Explain applications of nanoparticles in targeted drug delivery. [4]**
*Application Number 5 in the answer of Que.13*

**Que.16. Explain applications of nanoparticles in automobiles. [4]**
*Application Number 3 in the answer of Que.13*

**Que.17. Explain applications of nanoparticles in electronics. [4]**
*Application Number 1 in the answer of Que.13*

**Que.18. Explain applications of nanoparticles in Space and Defence. [4]**
*Application Number 4 in the answer of Que.13*

**Problems:**

**Example:** *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 9mm.*

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

$$\text{Thickness } = \frac{\text{velocity of Ultrasonic } \times \text{time}}{2}$$

$$\text{Time} = \frac{\text{Thickness x2}}{\text{Velocity}} = \frac{9 \times 10^{-3} \times 2}{3.1 \times 10^{3}}$$

$$= 5.8 \times 10^{-6} \text{ s} = 5.8\ \mu s$$

**Example:** *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***.**

**Solution:** Data: v = 5900 m/s, t = 1.512 μs

$$\text{Thickness of the block} = \frac{\text{v} \times \text{t}}{2} = \frac{5900 \times 1.512 \times 10^{-6}}{2} = 4.46 \times 10^{-3} m = 4.46\ cm$$

As v = f×λ,
Velocity of ultrasonic pulse,

$$\lambda = \frac{v}{f} = \frac{5900}{100 \times 10^{3}} = 0.059\ m$$

**Example:** *An ultrasonic pulse is sent through a metal block and echo is recorded after 3μs. Calculate the thickness of the metal block if velocity of ultrasonic waves in that metal is 4900 m/s***.** *At another location in same block echo is recorded after 0.964μs. Hence calculate the location of flaw.*

**Solution:** Data: v = 4900 m/s, t = 3 μs

$$\text{Thickness of the block} = \frac{\text{v} \times \text{t}}{2}$$

$$= \frac{4900 \times 3 \times 10^{-6}}{2}$$

$$= 7.35 \times 10^{-3} m = 7.35\ cm$$

$$\text{Location of flaw} = \frac{\text{v} \times \text{t}}{2}$$

$$= \frac{4900 \times 0.964 \times 10^{-6}}{2}$$

$$= 2.36 \times 10^{-3} m = 2.36\ cm$$

Thus, the flaw is located at 2.36 cm from the top surface