Nanoscale:

The size of the material is decreased to reach nanoscale, the same material may demonstrate radically different properties. In other words, materials start demonstrating size dependent properties after reaching the nano-dimensions. This happens because matter at nanoscale does not follow Newtonian principles and quantum mechanics needs to be applied to describe the behavior of materials.

How small is this?

Nanoscaled materials are considered to be consisting of clusters of atoms/molecules, not the single atoms/ molecules.

At these dimensions, matter exhibits novel properties such as

- They can be used to improve existing materials as well as to produce new materials with exceptional properties.
- As nanomaterials have the size resembling that of the largest molecules present in nature (such as proteins, DNA, etc.), they can be integrated into a device to interact with these molecules.

Physics at Nanoscale

- Owing to their nanoscaled dimensions, nano materials are dimensionally more close to individual atoms and molecules than to the bulk materials, and therefore, their behavior is described using quantum mechanics. Quantum mechanics is the scientific model employed to describe the motion and energy of individual atoms and electrons. The significant quantum effects and the properties relevant at nanoscale are described below:

- At nanoscale, electromagnetic forces dominate whereas the gravitational forces are negligible
- Since electromagnetic force is independent of the mass of the particles, and is determined by the charge and distance of the particles, it is strong even for the nanosized particles

Wave-particle duality

- For extremely small objects having very low mass (e.g. electron), wave nature becomes predoniment. Thus an electron exhibits wave-like properties and its position can be described by the wave probability function.

Tunneling

Tunneling is an extremely important consequence in nanoscaled materials. As per classical physics, an object can pass a potential barrier if its energy is greater than that of the barrier. Thus, if the object has energy lower than the barrier potential, the object cannot cross the barrier. In this case, there is zero probability of locating the object on other side of the potential barrier. As per quantum physics, the object can tunnel through the barrier. Also, the thickness of the barrier is crucial in determining the tunneling probability of the particle. That is, the thickness of the barrier should be of the order of particle’s wavelength. Thus, even if the object energy is lower than the potential of the barrier, there is a finite probability of locating the particle at the other side of the barrier.

Tunneling is an important quantum effect and forms the basic principle of scanning tunneling microscope (STM) used to image the nanostructured materials.

Quantum confinement effect

In nanostructured materials, including metals, electrons are not free to move within the material, but are confined in space.

In the bulk matter, the bands are actually formed by the merger of adjacent energy levels of a large number of atoms and molecules. As the particle size reaches the nano scale, the number of overlapping orbitals or energy levels decreases and **the width of the band gets narrower. This will cause an increase in energy gap between the valence band and the conduction band**. Therefore, there is a high energy gap in nanoparticles than the corresponding bulk material. The band gap is the region forbidden for the electrons. The larger the forbidden region, the greater will be restriction on the movement of electrons. The electrons are thus confined in space and are not free to move. This effect is thus called quantum confinement**. This affects the optical, electrical and magnetic behavior of materials at nano scale.**

Quantum confinement effect