Introduction to Nanoscience and its Fundamentals

Everything in life is made up of atoms which are collected with each other to make a bigger shape. Atoms are found everywhere we go. If we arranged them, we could make their characteristics different. This is called nanoscience.

But first, what is nanoscience?

Nanoscience is the study of phenomena and manipulation of materials at atomic, molecular, and macromolecular scales, where properties differ significantly from those at a larger scale.

It is beneficial for studying the materials if their atoms were arranged again according to their nanostructure so their characteristics will change to be big if these materials were small. It will help to make new materials that will not be used in life. This science is approached by nanotechnology.

Nanotechnologies are the design, characterization, production, and application of structures, devices, and systems by controlling shape and size in the nanoscale.

The nanometer scale is conventionally defined as 1 to 100 nm. One nanometer is one billionth of a meter (10^-9 m).

Why is this science special?

First, on the nanometer scale, the properties of matter, such as energy, change. This is a direct consequence of the small size of nanomaterials, physically explained as quantum effects. The consequence is that a material (e.g. a metal) when in a nano-sized form can assume properties that are very different from those when the same material is in a bulk form.

Fig1 Rearranged diamond molecules

For instance, bulk silver is non-toxic, whereas silver nanoparticles can kill viruses upon contact. Properties like electrical conductivity, color, strength, and weight change when the nanoscale level is reached: the same metal can become a semiconductor or an insulator at the nanoscale level.

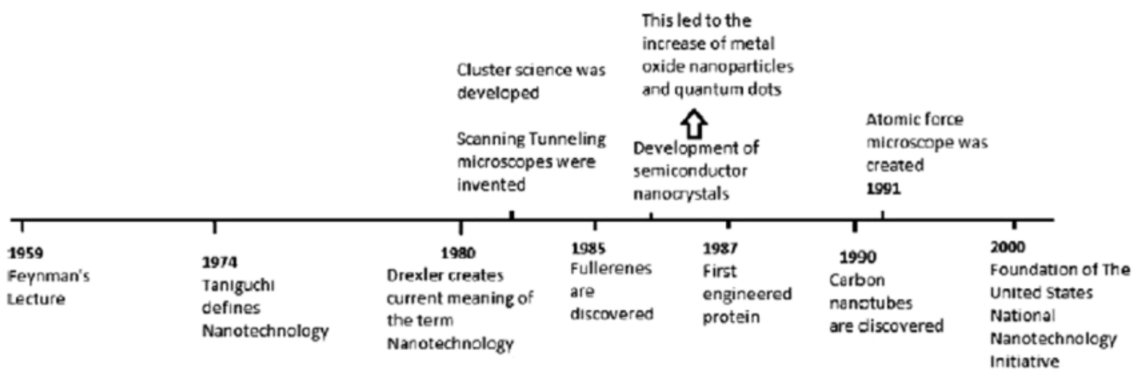
The second exceptional property of nanomaterials is that they can be fabricated atom by atom by a process called bottom-up.

<u>History of Nanoscience</u>

Richard Feynman, an American physicist and Nobel Prize laureate, introduced the concept of nanotechnology in 1959. Feynman presented a lecture entitled “There is Plenty of Room at the Bottom” at the California Institute of Technology (Caltech). In this lecture, Feynman made the hypothesis “Why can’t we write the entire 24 volumes of the Encyclopedia Britannica on the head of a pin? , and described the vision of using machines to construct smaller machines down to the molecular level. This new idea demonstrated that Feynman’s hypotheses have been proven to be correct, and for these reasons he is considered the father of modern nanotechnology.

After fifteen years, Norio Taniguchi, a Japanese scientist was the first to use and define the term “nanotechnology” in 1974 as: “nanotechnology mainly consists of the processing of separation, consolidation, and deformation of materials by one atom or one molecule.

Fig. 2 History of nanoscience scientists



In 1985, Robert Curl, Harold Kroto, and Richard Smalley discovered that carbon can also exist in the form of very stable spheres, fullerenes, or buckyballs. Carbon balls with chemical formula C_{60} or C_{70} are formed when graphite evaporates in an inert atmosphere. A new carbon chemistry has been developed, and it is possible to enclose metal atoms and create new organic compounds.

In 1991, Iijima et al. observed hollow graphitic tubes or carbon nanotubes by Transmission Electron Microscopy (TEM), which form another member of the fullerene family. The strength and flexibility of carbon nanotubes make them potentially useful in many nanotechnological applications. Currently, carbon nanotubes are used as composite fibers in polymers and beton to improve the mechanical, thermal, and electrical properties of the bulk product. They also have potential applications as field emitters, energy storage materials, catalysis, and molecular electronic components.

One of the most important applications of nanotechnology to molecular biology has been related to nucleic acids.

In 2006, Paul Rothemund developed the ‘scaffolded DNA origami”, by enhancing the complexity and size of self-assembled DNA nanostructures in a ‘one-pot’ reaction.

How the quantum effect the nanostructures

The properties of any material are essentially just the average of the quantum effects acting on those atoms. As the particle size decreases to nanosize, this averaging no longer works to describe the physical properties, and must consider the quantum behaviour of each atom and their interactions with each other.

This effect (also known as the quantum size effect) is due to a phenomenon known as confinement and is more prevalent in nanoparticles of 10 nm or less. It is well known that particles can be described as acting like a wave or a particle.

In a bulk material, the electrons are generally treated as wave-like and are “free” to move between atoms. As we shrink the size of a particle, the spatial extent of electron wave-function is comparable to the particle’s size, and the electron begins to “feel” the presence of particle boundaries and adjust its energy accordingly. In this way, electrons are now ‘confined’ in quantized energy levels and once freely moving electrons are now restricted to these specific levels.

Materials suddenly exhibit very different properties: opaque substances such as copper become transparent; stable materials such as aluminium turn out to be combustible; solids like gold become liquid at room temperature; and insulators such as silicon become conductors, and carbon become tougher in fullerene.

Quantum dots

A powerful and fascinating result of quantum effects on the nanoscale is the concept of ‘tunability’. By changing particle size, one can fine-tune a material’s property of interest - such as changing the fluorescence colour - which can then be used to identify particles and label them with markers for various purposes. Quantum dots are one of the most significant developments that exploit such quantum tunability. They are nanoparticles smaller than 10 nm in size, made of semiconductor materials that have fluorescent properties. Their properties are closely related to their size and shape, and they lie between those of bulk semiconductors and discrete molecules.

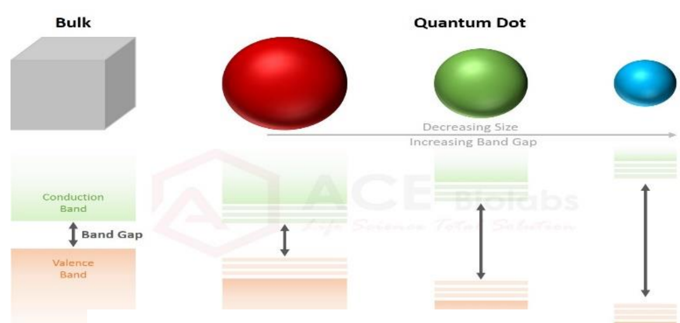


Fig 3 quantum dot explanation