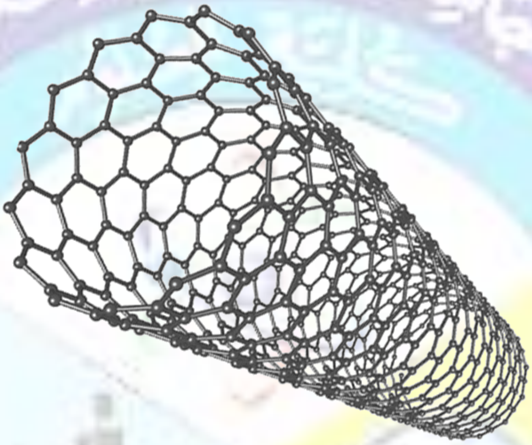
Nanomaterials

2nd year Medical Physics		Lecturer: Dr. Ghaiath A. Fadhil

Lecture 1: An introduction



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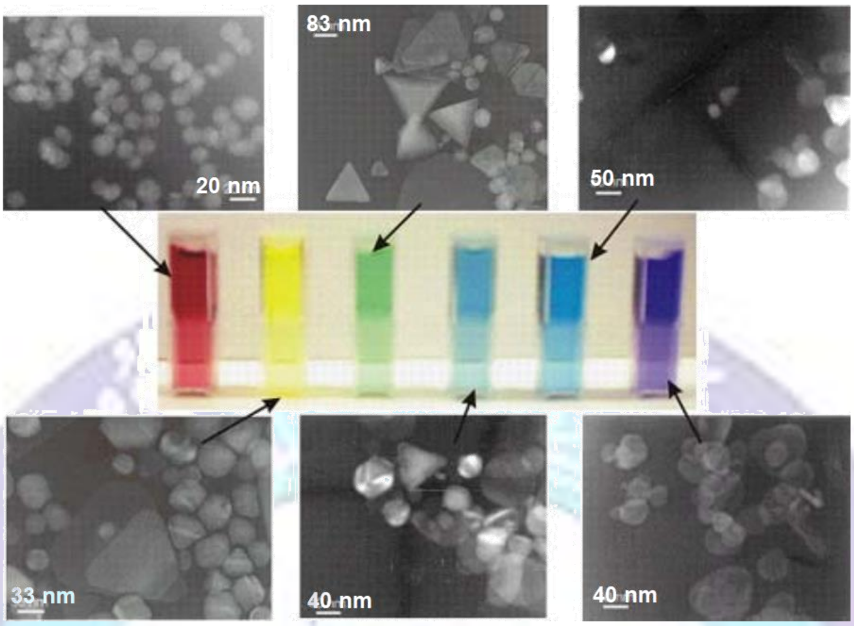
1.1 What is Nanotechnology?

Nanotechnology is the term used to cover the construction and utilization of functional structures with at least one characteristic dimension measured in nanometres.

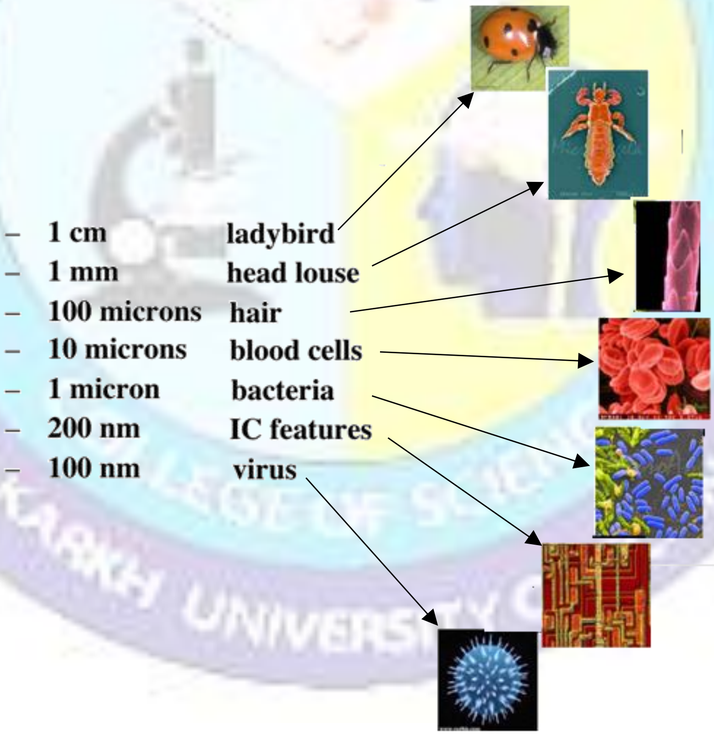
Such materials and systems can be designed to exhibit novel and significantly improved physical, chemical and biological properties, phenomena and processes as a direct result of their limited size.

The reason for this is that when characteristic structural features are intermediate in extent between isolated atoms and bulk macroscopic materials, i.e. in the range of about 10^{-9} metres to 10^{-7} m (1 to 100 nm), the objects often display physical attributes substantially different from those displayed by either atoms or bulk materials.

Ultimately this can lead to new technological opportunities as well as new challenges.



1.2 Summary of Length Scales

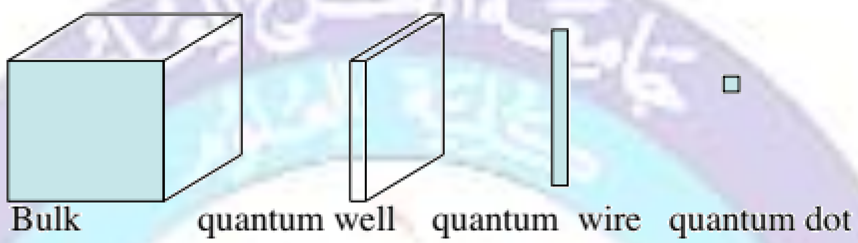


- Atomic length scales - atom approximately 0.1 nm (1 Å)
- Molecular length scales - molecule: 1nm; macromolecule: 10 nm
- Crystal length scales (periodic array of atoms in one orientation) - can range from few nm to centimetres, usually in micrometre range.

- Biological length scales - virus (autonomous biological object): 0.1 μm (100nm) - 1 μm (1000nm); cell: 1 μm (1000nm) - 10 μm (10000nm); human hair: 10 μm – 100 μm (0.1 mm); human 1 m
- Engineering length scales - bridges/ buildings: 10 – 1000 m; microelectronics: 1 μm - few cm; MEMS: 10 μm; NEMS?

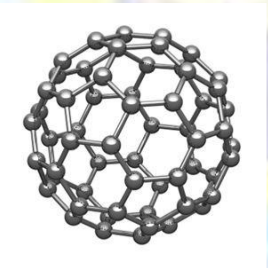
Gap between the nanoworld and macroworld (10^9x) is similar to the gap between man and the cosmos!

1.3 Classification of Nanostructures

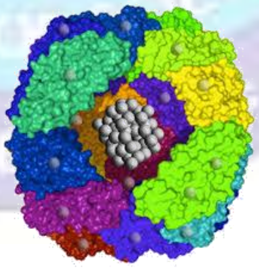


Exact classification of bulk nanostructured materials and systems depends on the number of dimensions which are in the nanometre range:

a) 3 reduced dimensions (x, y and z) are associated with **nanoparticles** (or their inverse **nanopores**).
Examples:
   - Buckyballs – individual crystalline structures C60, C70.

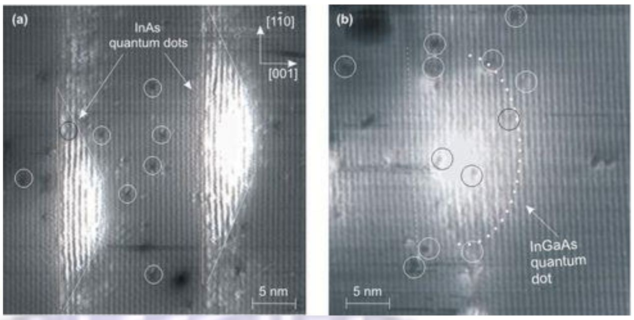


   - Biomineralized particles, e.g. iron storage proteins.

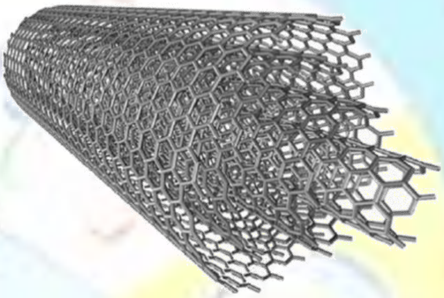


Nanoparticles may be present at the surface of another material or within a structure, e.g. **quantum dots** for use in quantum dot lasers or for data storage or when within biological structures as fluorescent markers for Fluorescence light microscopy, or as absorbers of radiation for selective tumour therapy.
Examples:

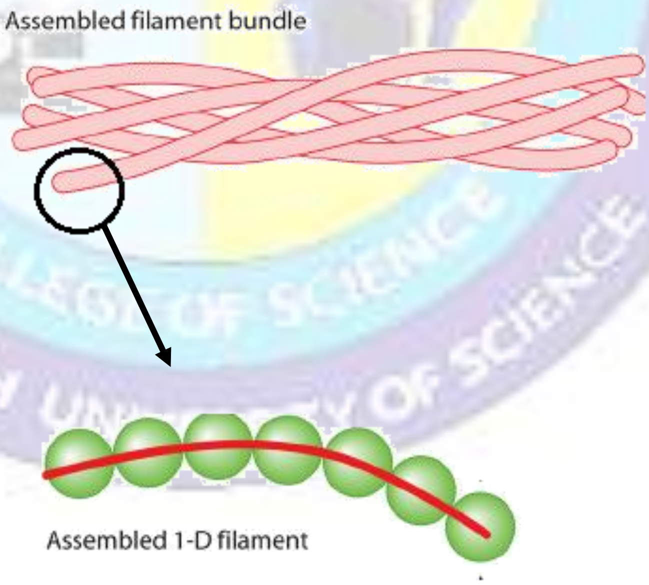
- InGaAs or CdSe/ZnS dots



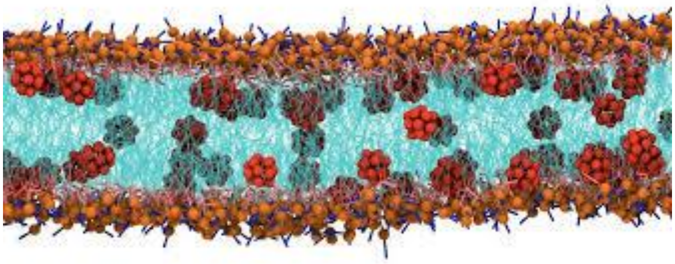
b) Two dimensional nanosystems include **nanowires, nanorods, nanofilaments** and **nanotubes**.
Examples:
- Carbon nanotubes and nanofilaments for use as field emitters in display technology. Carbon nanotubes consist of cylindrical, concentric graphite sheets rolled up at a certain angle of chirality.



- Protein filaments



c) One dimensional nanosystems include **discs or platelets**, **ultra-thin** films and **multilayered** materials.
Examples:
- biological membranes



1.4 Why Nanotechnology is important?

Nanotechnology is a purposeful engineering of matter at scales of less than 100 nanometres (nm) to achieve size dependent properties and functions. These properties can be different to the properties of the bulk size samples of the same materials. In addition, the possibility of engineering materials and devices at nanoscale brings further opportunities for technology in terms of savings in cost, size and weight. It accurate to summarise the main opportunities that nanotechnology brings as follows:

- **New materials properties**: stronger, lighter and more wear resistant materials.
- **New science**: new structures and functionality.
- **Increased efficiency**: reduced energy consumption and reduced waste products. Hence, lower materials and maintenance cost.
- **Increased miniaturization and integration**: laboratory on a silicon chip. Micro/nano electromechanical systems (MEMS & NEMS).

On the other hand, science and engineering always tried to tackle major global issues that concerned the global community. Nanotechnology brings fresh new solutions and possibilities that hasn't been solved for decades. Furthermore, the new opportunities are very likely to bring new challenges. However, thinking in today's context, nanotechnology is nominated to tackle issues in the following sectors:

- **Energy**: develop new materials to deliver clean, low cost and sustainable energy. Improve the energy storage, generation and transportation.
- **Security**: develop new materials and devices to protect humans against terrorism, accidents and crime. Improve the detection techniques.
- **Housing**: develop materials for sustainable and cost effective housing.
- **Transport**: develop fuel and heat transfer systems that are energy efficient, clean and controllable.
- **Healthcare**: develop medication, diagnosis and procedures to defend against diseases. Find cure for currently untreated diseases like cancer and Alzheimer.
- **Personal products**: develop materials and substances with predicted and accurate side effects. Develop products for protection against issues like climate change.
- **Communication**: manufacturing electronic components and devices that are recyclable and small. These solutions can be used for communication and personal health monitoring.

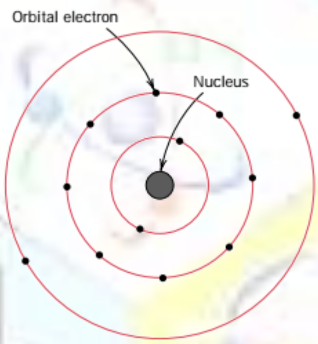
1.5 The Structure of Matter

All matter is composed of aggregates of atoms with the exception of radiochemistry and radioactivity.

Atoms are neither created nor destroyed during physical or chemical changes.

It has been determined that 90 chemically different atoms, the chemical elements, are naturally present on the Earth, and others have been prepared by radioactive transmutations. Chemical elements are frequently represented by symbols, which are abbreviations of the name of the element.

An atom of any element is made up of a small massive nucleus, in which almost all of the mass resides, surrounded by an electron cloud. The nucleus is positively charged and in a neutral atom this charge is exactly balanced by an equivalent number of electrons, each of which carries one unit of negative charge.



All nuclei can be imagined to consist of tightly bound subatomic particles called neutrons and protons, which are together called nucleons.

Neutrons carry no charge and protons carry a charge of one unit of positive charge. Each element is differentiated from all others by the number of protons in the nucleus, called the proton number or atomic number, Z.

In a neutral atom, the number of protons in the nucleus is exactly balanced by the Z electrons in the outer electron cloud. The number of neutrons in an atomic nucleus can vary slightly. The total number nucleons (protons plus neutrons) defines the mass number, A, of an atom.

Variants of atoms that have the same atomic number but different mass numbers are called isotopes of the element. For example, the element hydrogen has three isotopes, with mass numbers 1, called hydrogen; 2 (one proton and one neutron), called deuterium; and 3 (one proton and two neutrons), called tritium.

An important isotope of carbon is radioactive carbon-14 that has 14 nucleons in its nucleus, 6 protons and 8 neutrons.

Bohr atomic model assumed that electrons revolve around the atomic nucleus in discrete orbitals, and the position of any particular electron is more or less well defined in terms of its orbital.

This Bohr model was eventually found to have some significant limitations because of its inability to explain several phenomena involving electrons. A resolution was reached with a **wave-mechanical model**, in which the electron is considered to exhibit both wavelike and particle-like characteristics.