Chapter 1

Basics of Nanoscience

1.0 Basic Definitions

1.1 Definition of Nano

Nano comes from the Greek word "nanos," meaning "dwarf", but nano is infinitely smaller than a dwarf. Nano means 10^{-9}. Nanometer is one billionth of a meter (i.e. 1nm= 10^{-9} m). Some examples are given in the following figure to understand how small the nano dimension is 1centimeter = 10^{-2}m, 1 millimeter = 10^{-3}m, 1 micrometer = 10^{-6}m and 1 nanometer = 10^{-9}m.

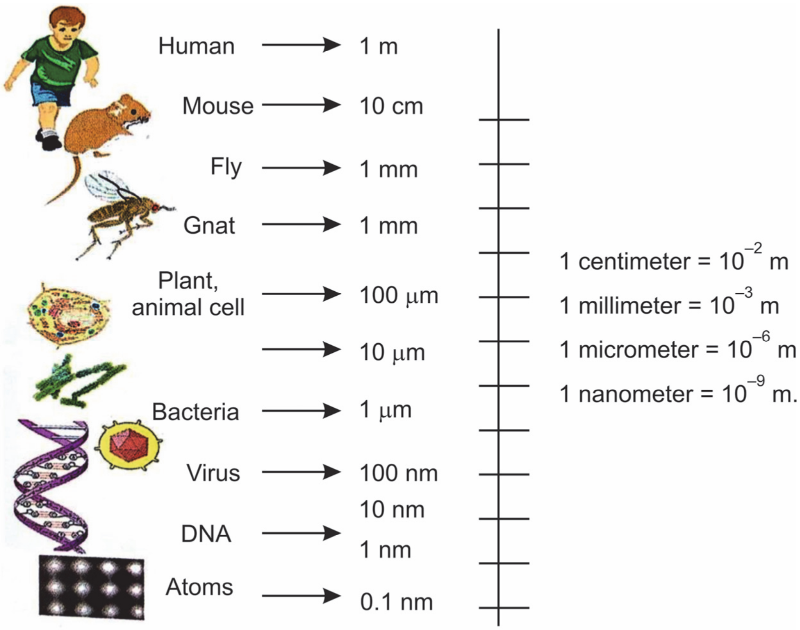

Fig. 1.1 Sequence of images showing various levels of scale

1.2 Nanoscale

Nanometer is the scale used to measure objects in the nanoworld. In general, the scale ranges from **1nm to 100nm** is known as **Nanoscale**. It is appropriate and relevant to make a mention of the diameter of an atom. As the size of an atom is less than even 1 nanometer, we discuss the next scale on the lower side and is Angstroms (**Å**) scale. We are aware that atoms are extremely small and the diameter of the atoms is measured in Angstroms (**Å**). Thus, 1Angstrom (**Å**) = 0.1 nm. For example the diameter of a hydrogen atom is 0.1 nm. If one lines up 10 hydrogen-atoms next to each other in a row, the resulting length would be approximately 1 nm.

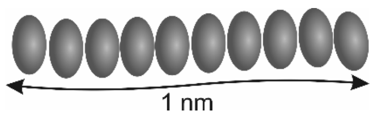

Fig. 1.2 Ten hydrogen atoms in a row make 1 nm

To put this scale in perspective, "Trying to find a nanoparticle on the surface of a soccer ball is just as difficult as finding a soccer ball on the surface of the Earth".

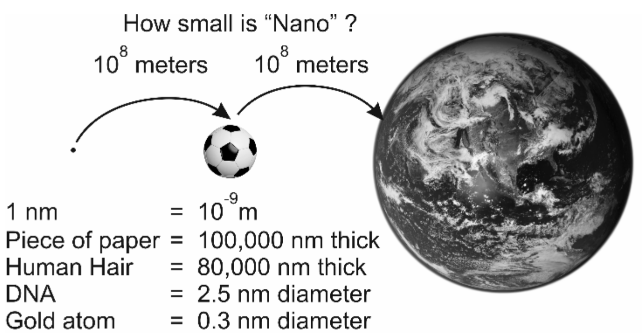

Fig. 1.3 Nanoparticle compared in size with a soccer ball, and soccer ball is compared with Earth (figure by Michael Hochella https://serc.carleton.edu/details/images/180059.html)

1.3 Nanomaterials

The material whose crystallite size lies in the nano range (1nm to 100nm) is called **nanomaterial**. The properties of the material at the nano scale (Nanomaterial) are totally different from those of the same material at the higher scale (Bulk material). It means that most of elements of the periodic table exhibit totally different behavior when they are in the nanoscale. For example, although the gold is chemically inert in its bulk state, in the nano state, however, exhibits excellent catalytic activity. Similarly, bulk silver is non-toxic, whereas nano-silver is capable of killing viruses. Further, Titanium dioxide, a white pigment used in sun screens, becomes transparent in the nanoscale, while aluminum oxide, commonly used for teeth fillings, becomes explosive in the nanoscale. Finally, one may conclude that Nanomaterials exhibit improved properties such as strength, hardness, ductility (in brittle materials), wear - resistance, corrosion – resistance, erosion resistance, improved chemical activity etc., Moreover, as classical mechanics fails to explain the unusual behavior (movement, energy, etc) of the nanomaterials, quantum mechanics, however, is successful in doing so.

1.4 Nanoscience

The science dealing with all types of nano materials including nanoparticles, nanostructures and their unique properties is defined as Nano science.

Nanoscience is the cutting edge of science and is highly multidisciplinary. It draws from diverse fields such as physics, chemistry, materials science, microelectronics, biochemistry, Engineering and biotechnology etc.

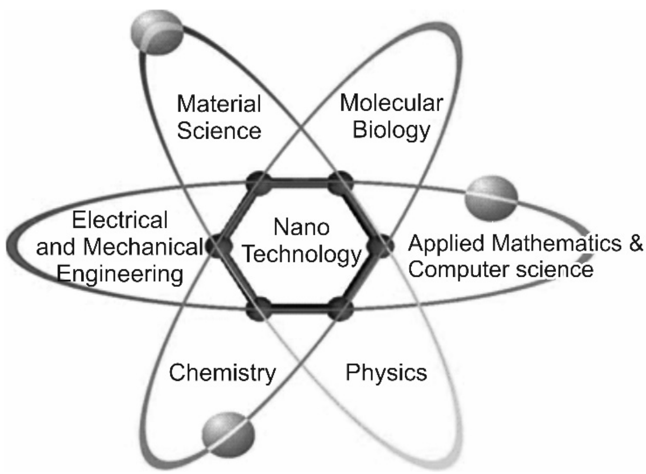

Fig. 1.4 Nanoscience is a multidisciplinary subject

1.5 Nanotechnology

The technology involving the manipulation of nano materials to build variety of structures is defined as nano technology. Although Nano technology is still at its infant stages, the nano products are having far reaching applications and are going to change the lives of mankind. **Nanotechnology** helps in the design, characterization, production and application of structures, devices and systems by controlling size and shape at the nanometer scale (1–100 nm). Nanotechnology is very much useful in creating these novel materials and devices with enhanced properties and potential.

In recent years nanotechnology has become highly popular. This is partly because of the interest in miniaturization of devices. Scientists have also been amazed due to the extraordinary properties of these novel materials. In fact, these materials open a new avenue in the field of material science due to their novel properties and wide range of applications in various fields such as Electronics and communications, Textile industry, Automobiles, Sensors, Cosmetics and Medicine etc.

1.6 General Introduction

Nanomaterials open a new avenue in the field of material science. The nanomaterials have been the focus of intense research recently because of their novel properties at the nanoscale. Nanotechnology is a field of applied science concerned with the control of matter at dimensions of roughly 1 to 100 nanometers (nm). Nanotechnology is a new and expanding technology, its main applications are the development of innovative methods to fabricate new products, to formulate new chemicals, materials and efficient use of raw materials. Nanotechnology is also meant for replacing the recent era of equipment with better performance ones. This will help in the reduction of consumption of energy and material and lowered damage to the environment, as well contributing to the environmental remediation [1]. The widest use of nanomaterials has been as tumor-targeted drug delivery systems, contrast enhancers for magnetic resonance imaging, biosensors and biomedicine, etc.

Nanomaterials are already in commercial use. The range of commercial products available today is very broad, including sunscreens and cosmetics, paints, UV-blocking coatings, self - cleaning windows, fuel cells, batteries, fuel additives, lubricants, catalysts, stain-resistant and wrinkle-free textiles, transistors, lasers and lighting, integrated circuitry, sports equipment, bicycles and automobiles, medical implants, water purifying agents, disinfectants, food additives etc.

In order to design nanomaterials and nanodevices for the next generation, it is requisite to understand their intrinsic features. Several researchers are working throughout the world towards the development of nanomaterials that are intended to perform more complex and efficient tasks. Thus, the development of completely new technologies and nanomaterials with desirable functional properties may lead to a generation of new products that will enhance the quality of the living environment in the near future.

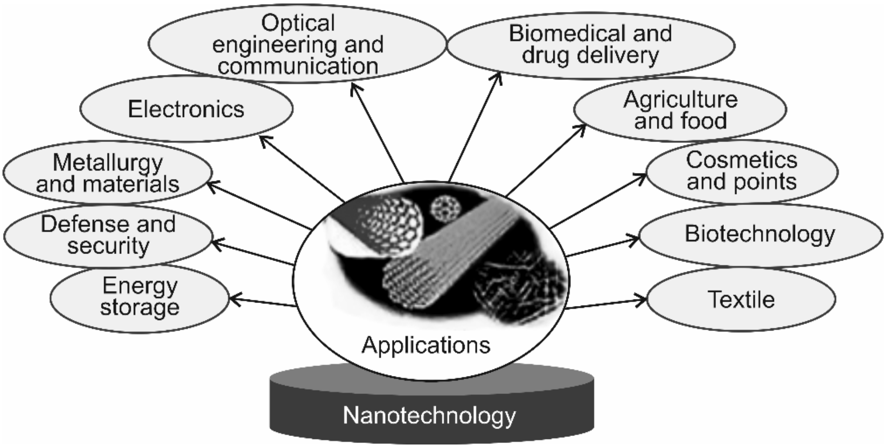

Fig. 1.5 Applications of Nanomaterials [1]

1.7 History of Nanotechnology

The origin of the term 'Nano' is traced to a Greek root which means dwarf (very small). On the length scale, nano is one billionth of a meter. The word Nanotechnology is relatively new, but the existence of nanostructures and nanomaterials is not new. Such structures have existed on Earth as long as life itself. Nanomaterials have been used by human beings for centuries without knowing the dimensions of the materials they used. The first known use dates back to 4^{th} century A.D. Roman glass makers have prepared glasses containing nanosized metals. The Lycurgus cup is an outstanding example of this. It appears green in the reflected light and deep red in transmitted light. This cup is made from soda lime glass containing silver and gold nanoparticles inside it. The glass is found to contain 70 nm particles when seen through the transmission electron microscope (TEM). Nanotechnology is easily evident in various old churches. The beautiful colors on window glasses of medieval churches are due to the presence of metal nanoparticles in the glass materials. These vivid colors were controlled by the size and the shape of the nanoparticles of gold and silver.

Fig. 1.6 Photographs of the famous Lycurgus cup which displays a different color in reflected and transmitted light. [Courtesy of the British Museum, London]

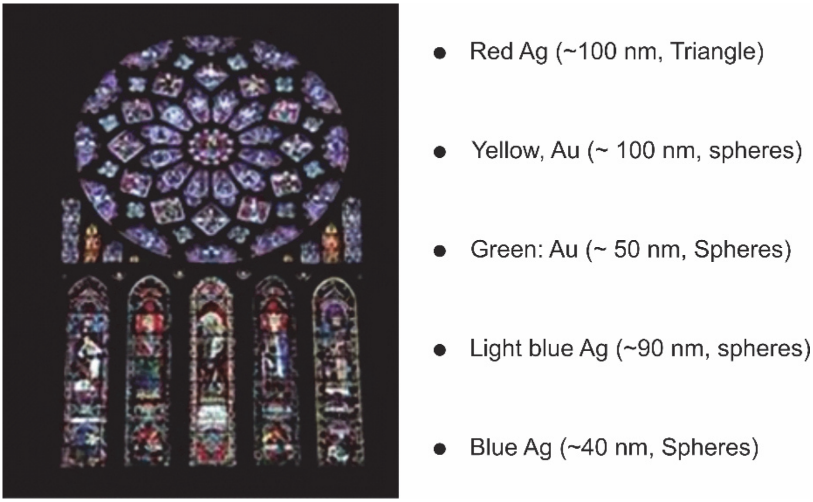

Fig. 1.7 Rosacenord stained glass in the Cathédrale Notre-Dame de Chartres (France),color changes depend on the size and shape of gold and silver nanoparticle. [2]

The Damascus swords were prepared in Damascus, the capital city of Syria, during 900 AD to 1750 AD. Damascus steel is a kind of alloy. With this alloy sharp, flexible and hard swords were manufactured. They were famous for their strength and sharpness. It is said that the blade of Damascus sword is very strong and even when it falls on the ground retains its original sharpness. In fact, this sword was used for cutting not only wood but also metal or even stone.

Fig. 1.8 Damascus sword [3]

What gave the sword its uniqueness? The secret of the sword remained unknown until recently. Very recently, high resolution electron microscopy of blades used in the Damascus sword showed that the blade contains carbon nanotubes (CNTs) [3]. Therefore, now people also strongly believe that the existence of carbon nanotubes (CNTs) in the material is the main reason for the high strength of these steels.

A medical Doctor / practioner Francisci Antonii published the first book on colloidal gold. It contains a detailed description of the formation of colloidal gold and covers its various medical applications. The book noted the presence of soluble gold around fifth or fourth century B.C. in Egypt and China.

The field of black and white photography was started in the 18^{th} century. The photographic film is an emulsion consisting of silver nanoparticles in gelatin.

The first preparation of nanoparticles in the laboratory was carried out by Michael Faraday as early as 1857 [4]. He recognized that the colour was due to the small size of the colloids and published a paper explaining how metal particles affect the colour of church windows. The gold particles prepared by Faraday are still preserved in the Royal Institution of London.

Fig. 1.9 A display of Michael Faraday's colloidal solutions of gold at the Royal Institution [4]

1.8 Origin of Nanotechnology

Today's extraordinary developments in the fields of nanoscience and nanotechnology are actually based on the ideas of some legendary scientists of last century. Science and Technology always moves forward and newer, developed devices replace the older one. In the last decade, new dimensions of modern research in the field of "nanoscale science and technology" have been emerged. The ideas and concepts behind nanoscience and nanotechnology started with a lecture entitled "There is Plenty of Room at the Bottom" by Nobel Prize winner, famous Physicist Richard Feynman, in the annual general body meeting of the American Physical Society at California Institute of Technology on December 29th in 1959. In his lecture, he has speculated on the possibility and potential of nanosized materials. Many of the speculations of Faynman have become reality (i.e. nano silicon chips in nanoelectronics, nanostructures in nanomachines, biological nanoparticles in medicine). Therefore, people consider him as the father of Nano Science & Technology

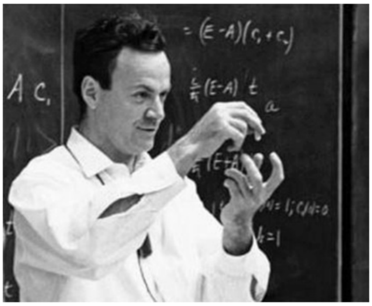

Fig. 1.10 Richard Feynman

The term "Nano-technology" was first used by Norio Taniguchi in 1974 to explain the new semiconductor technology of thin-film deposition that deal with the controlling the size of thin film of very small in size of the order of nanometers, though it was not widely known at that point of time. In 1981, the scanning tunneling microscope (STM) was invented by Gerd Bining and Heinrich Rohrer at IBM research laboratory. Another nano technology breakthrough occurred in 1985 by a team led by Richard Smalley and Harry Kroto in discovering a new compound, C_{60}, a carbon nano particle with a shape of a soccer ball (Bucky ball). In 1991, Iijima made carbon nanotubes (CNT). Advancements in microscopy technology have made it possible to visualize several nano structured materials and have largely dictated the development of nanotechnology.

Inspired by Feynman's concepts, K. Eric Drexler used the term "Nanotechnology" in his 1986 book Engines of Creation: The Coming Era of Nanotechnology. In his work, he used the term “Nanotechnology” in 1986 to give an idea about building machines at molecular level even far smaller than a cell. K. Eric Drexler spent number of years in analyzing these incredible devices and finally published a famous book in 1990 “Machinery Nanosystems: Molecular, Manufacturing, and Computation”. Feynman and K. Eric Drexler certainly popularized nanotechnology. In 1994, stable gold nanoparticles were prepared in the form of a solution. In 1996, scientists at IBM laboratory succeeded in moving and accurately positioning individual molecules at room temperature. In 2004, Andre Geimand Konstantin Novoselov discovered the two-dimensional nano material (Graphene), for which they were awarded with a Nobel Prize in 2010. From 2005 onwards a series of R& D activities helped the new branch to develop into a full-fledged multi-disciplinary subject.

References

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