Lecture 1. Introduction to nanoparticles. Atoms, Nanoparticles, and Bulk Materials

The purpose of the lecture: to familiarize students with atoms, nanoparticles, and bulk materials.

Expected results: students getting information about atoms, nanoparticles, and bulk materials.

Nanotechnology, although considered to be a recent phenomenon, is also evident in ancient civilizations. The Celtic-red enamels dating from 400 to 100 BC contain copper and cuprous oxide (cuprite Cu_2O) nanoparticles, while most of the red-tesserae used in Roman mosaics were made of glass containing copper nanocrystals. The Roman artisans achieved unusual color changes by adding noble metal-bearing material to glass prior to being molten. Themiddle age (1066e1485 AD) saw an emergence of glazed ceramics with striking optical effects obtained from metallic nanoparticles. Ancient Indian (Ayurveda) and Chinese medicines used gold bhasma and soluble gold, respectively, for therapeutic purposes; these substances have been shown to contain gold nanoparticles mixed with larger particles. Ancient civilizations, however, did not understand the unique properties and potential of their preparations as we understand them now. Recent technological advancements have revolutionized the synthesis, characterization, and applications of nanoparticles, which are gradually becoming an integral part of society.

In 1959, Richard Feynman suggested the possibility of building machines small enough to manufacture objects with atomic precision. He also predicted that information could be stored with amazing density. The term nanotechnology was coined by Norio Taniguchi (1974), but it was used unknowingly by Eric Drexler in his 1986 book Engines of Creation: The Coming Era of Nanotechnology. The technology is growing and diversifying rapidly.

In general, nanotechnology deals with the fabrication and control of nanoparticles less than 100 nm in at least one dimension. Nanoparticles exhibit unique physicochemical properties that are absent in their bulk (>500 nm) counterparts. An exception to the 100-nm rule is solid lipid nanoparticles that exhibit the unique nanoparticle-related properties at diameters greater than 100 nm. Because of their unique properties, nanoparticles are being used in diverse applications such as the following.

- Medical (targeted drug delivery, imaging, and personalized medicine) and cosmetic (makeup and sunscreens) applications
  - Efficient energy-storage devices using hybrids of carbon nanotubes and oxide nanoparticles, as the development of high-temperature, heat-transfer nanofluids may allow storage of thermal energy
  - Efficient removal of pollutants such as metals (cadmium, copper, lead, mercury, nickel, zinc), nutrients (phosphate, ammonia, nitrate, and nitrite), cyanide, organics, algae (cyanobacterial toxins), viruses, bacteria, parasites, and antibiotics from water in waste treatment plants
  - Construction of implantable devices to treat neural disorders using carbon-nanotubeprotein hybrids
  - Clothing, sporting equipment, food packaging, dietary supplements, etc.

These developments may represent the next revolution the nano-industrial revolution which will significantly alter society. However, the pace of nanotechnology commercialization is much faster than the assessment of their safety, thus posing a significant health risk to the general population. A key hurdle in determining the health risk of nanoparticles is their structural heterogeneity.

Atoms, Nanoparticles, and Bulk Materials

Atoms (less than 0.1 nm) are the smallest unit taking part in chemical reactions. They are transformed into bulk materials (greater than 500 nm) through formation of clusters (approximately 1 nm) followed by small nanoparticles (1e100 nm) and large nanoparticles (greater than 100 nm).

Clusters ranging from 0.1 to 1.0 nm in diameter possess elemental characteristics. As the clusters grow from 1 to 100 nm, they get transformed into nanoparticles possessing distinct physicochemical properties (described earlier) that are absent in their bulk counterparts. There is a direct relationship between the total number of atoms in a nanoparticle and the number of surface atoms or the particles' diameter.

There is an inverse relationship between the diameter (nm) and the percentage of atoms at the surface.

As nanoparticles become smaller, the proportion of atoms on the surface increases. In the nanometer range, a size reduction results in a drop in melting temperature and an increase in reactivity, as well as the dominance of surface atoms over the core atoms. A transition from classical mechanics to quantum mechanics occurs when free electrons in nanoparticles start to behave like a wave.