Lecture 2. Classification of Nanoparticles

The purpose of the lecture: to familiarize students with classification of nanoparticles.

Expected results: students getting information about classification of nanoparticles.

Nanoparticles can be classified according to their dimensions, origin, application, chemistry, and counterpart types and applications.

Dimension-Based Classification

Nanoparticles exist as zero-dimensional (0D), one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D) particles. The 0D nanoparticles, such as nanospheres and nanoclusters, are less than 100 nm in all dimensions. The 1D nanomaterials, such as nanotubes, nanorods, and nanofibers, are less than 100 nm in at least one dimension. The 2D nanomaterials are films (graphene, molybdenum disulfide, and germanane (a single-layer crystal composed of germanium)) with less than 100 nm thickness. The 3D nanomaterials are more than 100 nm in all dimensions.

Natural or Anthropogenic Nanoparticles

Natural nanoparticles originate from forest fires, volcanic eruptions, lightning, etc. They have been an integral part of the environment since the origin of the planet. Anthropogenic nanoparticles fall into two general categories: incidental and engineered nanoparticles. Incidental nanoparticles are heterogeneous in size and shape; they are generated by burning fossil fuel (gasoline, diesel, coal, and propane), large-scale mining, incinerating forests for agriculture, etc. Engineered nanoparticles are specifically designed particles having precisely controlled sizes, shapes, and compositions. They may even contain multiple layers (e.g., a gold nanoparticle covered in drug-loaded porous silica nanoparticles coated with specifically chosen antibodies). Engineered nanoparticles are becoming more complex with each passing year.

Classification of Nanoparticles According to Their Chemistry

Chemically, nanoparticles consist of metals/metal oxides, DNA and other biological materials, carbon, polymers, and clays. In addition to the common size-related properties, nanoparticles retain their chemical characteristics, which may be helpful in the selection of appropriate nanoparticles for a particular use. Some important groups of nanoparticles include the following:

• Metal nanoparticles (gold, copper, silicon, iron, etc.) are widely used in catalysis, electronics, sensors, photonics, environmental remedies, and medicine. Because of surface plasmon resonance and paramagnetic properties, metal nanoparticles find unique applications in medical and electronic technology. Porous silicon nanoparticles contain microscopic reservoirs that can hold and protect sensitive drugs in a pH-sensitive manner. Acidic pH disrupts the drug-nanoparticle binding, thus releasing the drug load. Functionalizing the surface with target molecules provides target-selective delivery of the nanoparticles.

• Polymeric nanoparticles are prepared from either synthetic polymers such as poly(2-hydroxy ethyl methacrylate), poly(N-vinyl pyrrolidone), poly(methylmethacrylate), poly(vinyl alcohol), poly(acrylic acid), polyacrylamide, or natural polymers such as gums (e.g., acacia, guar, etc.), chitosan, gelatin, and sodium alginate. In recent years, biodegradable polymeric nanoparticles have attracted considerable attention as potential drug delivery devices.

• Biochemical nanoparticles such as DNA, proteins, and poly-amino acids such as poly-L-lysine and poly-L-serine are synthetized from biological precursors. DNA nanoparticles are three strands of DNA with a lipid and functional molecule attached to its ends. In water solutions, the combination of hydrophilic DNA and lipophilic lipids causes the units to self-assemble into hollow spheres consisting of multiple layers of DNA, lipids, and cargo.

• Carbon nanotubes (CNTs) are formed from rolled-up graphite sheets. Depending on the direction of hexagons, carbon nanotubes can exhibit metallic or semiconductor properties. CNTs are twice as strong as steel but weigh many times less. In 1996, a new form of carbon the Buckminster fullerene was discovered; it looks like a nanometer-sized soccer ball made from 60 carbon atoms.

• Nanoclays are layers of mineral silicate nanoparticles. Organically modified or hybrid organic-inorganic nanomaterials have potential uses in polymer nanocomposites and as rheological modifiers, gas absorbents, and drug delivery carriers.

Isotropic and Anisotropic Nanoparticles

Isotropic nanoparticles include nanocapsules, nanospheres, dendrimers, liposomes, spheres (solid), capsules, and liposomes, whose physical and chemical properties are not dimensional.

Nanospheres (solid) and nanocapsules (hollow) are polymeric nanoparticles consisting of a shell and a space, in which desired substances may be loaded and protected from the environment. Dendrimers are artificially manufactured branched nanoparticles comprised of many smaller ones linked together, built up from branched units called monomers. Liposomes consist of an outer single or multilamellar membrane and an inner liquid core. Liposomes consisting of natural or synthetic phospholipids are similar to those in cellular plasma membranes. Because of this similarity, liposomes are utilized by the cells. Micelles are similar to liposomes but they do not have an inner liquid compartment. A solid-lipid nanoparticle is typically spherical with an average diameter of 50e1000 nm. Solid-lipid nanoparticles possess a solid lipid core matrix.

Anisotropic nanomaterials were first described by Banholzer (2011) and Casagrande and Veyssie (1988). They exhibited direction- and dimension-dependent physicochemical properties (dendrimers can be constructed to be anisotropic). Multifunctional anisotropic nanoparticles have attracted increasing attention because of their promising properties for applications in biotechnology, nanotechnology, electronics, and clean/reusable energy.

Nanoparticle Classification Based on Application

Nanoparticles are currently being applied in medicine, environmental remediation, cosmetics, electronics, and energy-storage industries.

Medicinal uses include screening, in vivo imaging, drug carriers, and treatment. Nanoparticle applications in environmental remediation include the clean up of oil spills (photocatalytic copper tungsten oxide nanoparticles), the destruction of volatile organic pollutants in air (gold nanoparticles embedded in a porous manganese oxide), and the removal of metals from water samples. Iron nanoparticles remove carbon tetrachloride from ground water. Iron oxide nanoparticles are used to clean up arsenic from water wells. Nanoparticle applications in energy and electronics include low-cost electrodes for fuel cells, energy storage, and catalysts such as a platinum-cobalt hybrid for fuel cells that produce 12 times more catalytic activity than pure platinum. Construction of a memory field-effect transistor (combining gold nanoparticles with organic molecules) can function in a way similar to synapses in the nervous system.

Silicon nanoparticle-coated anodes of lithiumion batteries can increase battery power and reduce recharge time. Nanoparticles are used in cosmetic products including deodorant, soap, toothpaste, shampoo, hair conditioner, antiwrinkle cream, moisturizer, foundation, face powder, lipstick, blush, eye shadow, nail polish, perfume, and after-shave lotion.