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A SHORT REVIEW OF NANOPARTICLES: CATEGORIES, SYNTHESIS METHODS, AND APPLICATIONS

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ABSTRACT

Nanoparticles are tiny particles that range in size from 1 to 100nm. It highlights the importance and potential of nanoparticles in various fields, including medicine, electronic, energy and environmental science. The nanoparticles are generally classified into the organic, inorganic and carbon-based particles in nanometric scale that has improved properties compared to larger sizes of respective materials. The review discusses the characterization techniques used to analyse nanoparticles, such as electron microscopy, spectroscopy, and thermal analysis. Current review provides an overview of nanoparticles, including their types, properties, synthesis methods, and various application.

KEYWORDS: Nanoparticles, History, Types, Classification, Synthesis, Advantages, Disadvantages, Characteristics and Applications.

1. INTRODUCTION

Nanotechnology is a modern field of science which plays a dominant role in day-to-day life aspects.[9] The prefix "nano" has found in last decade an ever-increasing application to different fields of the knowledge.[8] Nanoparticles are particles between 1 and 100 nanometres in size and are made up of carbon, metal, metal oxides or organic matter.[4] The variety of sizes, shapes, and configurations, including those that are spherical, cylindrical, tubular, conical, hollow core, spiral, flat, etc.[7] The drug is dissolved, entrapped, encapsulated or attached to a nanoparticle matrix. Depending upon the method of preparation, nanoparticles, nanospheres or nano capsules can be obtained.[3] Among nanoparticles some are crystalline or amorphous with single or multi-crystal solids either agglomerated or loose.[6] Nanospheres and nano capsules are collectively referred to as nanoparticles.[7] The prefix comes from the ancient Greek through the latin nanus meaning literally dwarf and by extension, very small.[8] Nanoparticles get produced by plants are more stable and the rate of synthesis is faster than that in other case of organism.[9] Nanoparticles get classified mainly into two groups they are organic nanoparticles and inorganic nanoparticles. Organic nanoparticles are carbon nanoparticle and inorganic nanoparticles are magnetic nanoparticle, semiconductor nanoparticle.[9] The major goals in designing nanoparticles as a delivery system are to control particle size, surface properties and release of pharmacologically active agents in order to achieve the site-specific action of the drug at the therapeutically optimal rate and dose regimen.[3]

1.1 Advantages of nanoparticles

Following are a few benefits of nanoparticles

1. Ease of modifying nanoparticle surface properties and particle size to target drugs both passively and actively after parenteral administration.
2. Using nanosized quantum dots based on immunofluorescence to label particular bacteria, which makes it easier to identify and get rid of them.
3. Nanotechnology is a growing field in many industries, including aquaculture, and it has numerous applications in areas like nutrition, reproduction, water purification, fishing, and disease control as well as the reduction of toxicity and negative effects.
4. The preparation of nanoparticles using biodegradable materials enables sustained drug release at the target site over the course of days or even weeks.
5. Because nanoparticles are so small, they easily pass through tiny capillaries and are absorbed by cells, enabling effective drug accumulation at the body's target sites.
6. Nanotechnology can make fabrics more durable because NPs have a high surface energy and a large surface area to volume ratio11.
7. Nano supplements can be easily added using the encapsulation technique for effective drug and nutritional delivery.
8. Nano barcodes are used to label food products for safety and to track their distribution.
9. The nanoparticles surface can be modified to alter bio distribution of drugs with subsequent clearance of the drug so as to achieve maximum therapeutic efficacy with minimal side effects of the drugs.

1.2 Disadvantages of nanoparticles

Despite these benefits, nanoparticles do have some drawbacks, such as the following

1. Because of their small size and high surface area, nanoparticles are highly reactive in the cellular environment.
2. When used for drug delivery, nonbiodegradable particles may accumulate at the site of the drug delivery, causing a chronic inflammatory response.[2]
3. Because nanoparticles have limited targeting capabilities, it is not possible to stop the therapy.
4. Nanotechnology is very expensive, and it can be even more expensive to develop.
5. Atomic weapons are now easier to obtain, more potent, and more destructive to use.

2. Definition

Nanoparticles have been in use in pottery and medicine since ancient times. There are different ideal methods for nanoparticle to get synthesized.[9] The International Organization for Standardization (ISO) defines nanoparticles as nano-objects with all external dimensions in the nanoscale, where the lengths of the longest and the shortest axes of the nano-object do not differ significantly.[2] Nanotechnology is the branch that comprises the synthesis, engineering, and utilization of materials whose size ranges from 1 to 100 nm, known as nanomaterials. The birth of nano science and nanotechnology concepts is usually linked to the famous lecture of Nobel laureate Richard Feynman at the 1959 meeting of the American Physical Society, ‘‘There’s Plenty of Room at the Bottom’.[2] NPs can be of different shapes, sizes, and structures. They can be spherical, cylindrical, conical, tubular, hollow core, spiral, etc., or irregular.[23] The size of NPs can be anywhere from 1 to 100 nm. If the size of NPs gets lower than 1 nm, the term atom clusters is usually preferred. NPs can be crystalline with single or multi-crystal solids, or amorphous. NPs can be either loose or agglomerated.[2]

3. History

Long before the era of nanotechnology, people were unknowingly coming across various nanosized objects and using nano-level processes. In ancient Egypt, dyeing hair in black was common and was for a long time believed to be based on plant products such as henna.[2] Nanomaterials have different surface effects compared to micromaterials or bulk materials, mainly due to three reasons; (a) dispersed nanomaterials have a very large surface area and high particle number per mass unit, (b) the fraction of atoms at the surface in nanomaterials is increased, and (c) the atoms situated at the surface in nanomaterials have fewer direct neighbours.[2]

4. Classification

NPs are broadly divided into various categories depending on their morphology, size and chemical properties. The nanoparticles are generally classified into the organic, inorganic and carbon based. Based on their dimensionalities, nano materials are placed into four different classes, summarized.

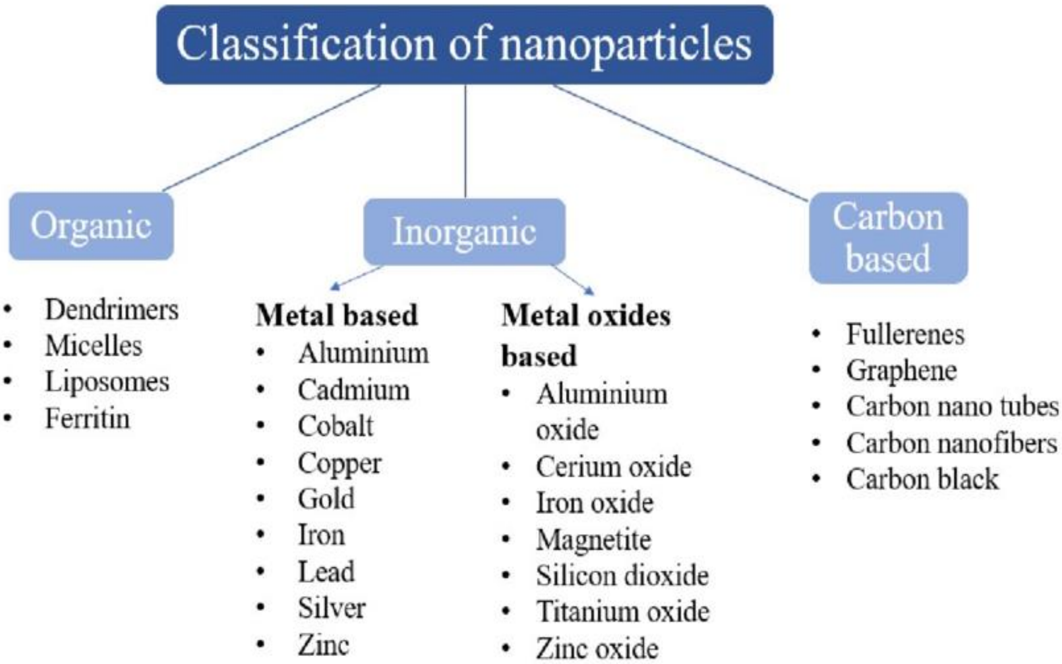

Figure 1: Classification of nanoparticles.

4.1 Organic nanoparticles

This class comprises NPs that are made of proteins, carbohydrates, lipids, polymers, or any other organic com pounds.[2] The most prominent examples of this class are Dendrimers, micelles, liposomes and ferritin, etc are commonly knows the organic nanoparticles or polymers. These nanoparticles are biodegradable, non-toxic, and some particles such as micelles and liposomes have a hollow core, also known as nano capsules and are sensitive to thermal and electromagnetic radiation such as heat and light.[5] When exposed to heat or light, ferritin, liposomes, micelles, and dendrimers become highly sensitive polymers.[7] There are different parameters that determine the potential field of application of organic NPs, e.g., composition, surface morphology, stability, carrying capacity, etc. Today, organic NPs are mostly used in the biomedical field in targeted drug delivery and cancer therapy.[2]

4.2 Inorganic nanoparticles

Inorganic nanoparticles are the particles that are not made up of carbon. Metal and metal oxide-based nanoparticles are generally categorised as inorganic nanoparticles.

4.2.1 Metal based

Almost all the metals can be synthesised into their nanoparticles. The commonly used metals for nanoparticle synthesis are aluminium (Al), cadmium (Cd), cobalt (Co), copper (Cu), gold (Au), iron (Fe), lead (Pb), silver (Ag) and zinc (Zn). These nanoparticles can be synthesized by chemical, electrochemical, or photochemical methods.[6] Metal NPs are used in several scientific fields because of their enhanced features like facet, size, and shape-controlled synthesis of metal NPs Metal NPs are purely made of the metal's precursors.[1]

4.2.2 Metal oxide based

The metal oxide-based nanoparticles are synthesised to modify the properties of their respective metal-based nanoparticles, for example nanoparticles of iron (Fe) instantly oxidises to iron oxide (Fe_2O_3) in the presence of oxygen at room temperature that increases its reactivity compared to iron nanoparticles. Metal oxide nanoparticles are synthesised mainly due to their increased reactivity and efficiency. The commonly synthesised are Aluminium oxide (Al_2O_3), Cerium oxide (CeO_2), Iron oxide (Fe_2O_3), Magnetite (Fe_3O_4), Silicon dioxide (SiO_2), Titanium oxide (TiO_2), Zinc oxide (ZnO). These nanoparticles possess an exceptional property when compared to their metal counterparts.[4]

4.3 Carbon based nano particles

The nanoparticles made completely of carbon are knows as carbon based.[4] This class comprises NPs that are made solely from carbon atoms.[2] They can be classified into fullerenes, graphene, carbon nano tubes (CNT), carbon nanofibers and carbon black and sometimes activated carbon in nano size.[4]

4.3.1 Fullerenes

Fullerenes (C_{60}) is a carbon molecule that is spherical in shape and made up of carbon atoms held together by sp^2 hybridization. About 28 to 1500 carbon atoms forms the spherical structure with diameters up to 8.2 nm for a single layer and 4 to 36 nm for multi-layered fullerenes.

4.3.2 Graphene

Graphene is an allotrope of carbon. Graphene is a hexagonal network of honeycomb lattice made up of carbon atoms in a two-dimensional planar surface. Generally, the thickness of the graphene sheet is around 1 nm.

4.3.3 Carbon Nano Tubes (CNT)

Carbon Nano Tubes (CNT), a graphene nano foil with a honeycomb lattice of carbon atoms is wound into hollow cylinders to form nanotubes of diameters as low as 0.7 nm for a single layered and 100 nm for multi-layered CNT and length varying from a few micrometres to several millimetres. The ends can either be hollow or closed by a half fullerene molecule.

4.3.4 Carbon nanofiber

The same graphene nano foils are used to produce carbon nanofiber as CNT but wound into a cone or cup shape instead of a regular cylindrical tube.

4.3.5 Carbon black

An amorphous material made up of carbon, generally spherical in shape with diameters from 20 to 70 nm. The interaction between the particles is so high that they bound in aggregates and around 500 nm agglomerates are formed.[4]

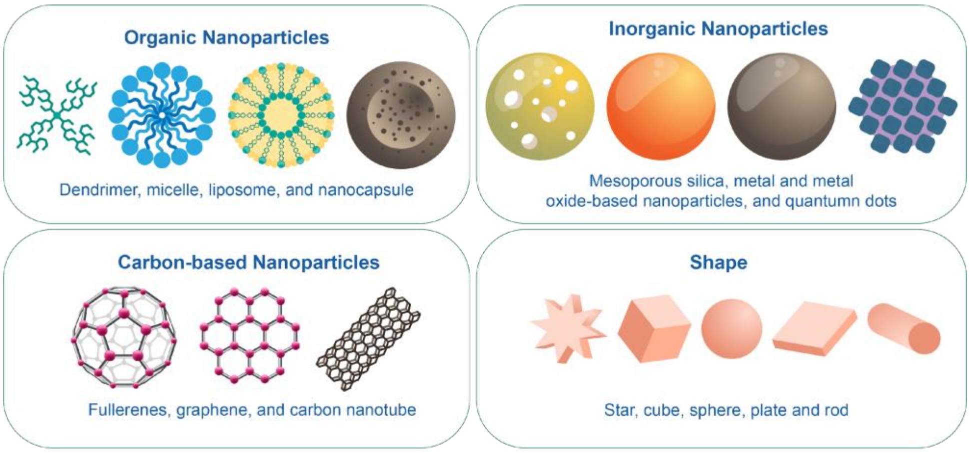

Figure 2: Different types of nanoparticles.

5. Types of nanoparticles

Polymeric nanoparticles are colloidal structures composed of synthetic or semi synthetic polymers. The drug is dissolved, entrapped, encapsulated or attaches to a nanoparticle matrix. Depending upon the method of preparation, nanoparticles, nanospheres or nano capsules can be obtained. Nano capsules are systems in which the drug is confined to a cavity surrounded by a unique polymer membrane, while nanospheres are matrix systems in which the drug is physically and uniformly dispersed. The general synthesis and encapsulation of polymer are represented below. Polymers such as polysaccharide Chitosan-Polylactic acid, Polylactic acid co glycolic acid, Poly-caprolactone, Chitosan nano particles have been used.

6. Preparation of nanopartciles

Nanoparticles can be prepared from a variety of materials such as proteins, polysaccharides and synthetic polymers.[3] The selection of inert matrix material is depended on many factors like(a) final size of nanoparticles required; (b) drug properties like aqueous solubility and stability; (c) surface charge and permeability; (d) degree of biodegradability, Biocompatibility and toxicity; (e) desired drug release profile; (f) antigenicity of the final product.

The preparation method of nanoparticles can b classified in different ways

In the first, it can be classified as:

- Bottom-up technique
- Chemical reaction technique
- Top-down technique
- Combination technique

Nanoparticles can be obtained by using bottom-up processes, i.e. preparation starting from molecular solution. Furthermore, comminution of larger particles down to nanoparticles (top-bottom) can be performed. Another way is the combination of both principles (combination techniques). The last way leads via a chemical reaction step directly to nanoparticles (chemical reaction approach).

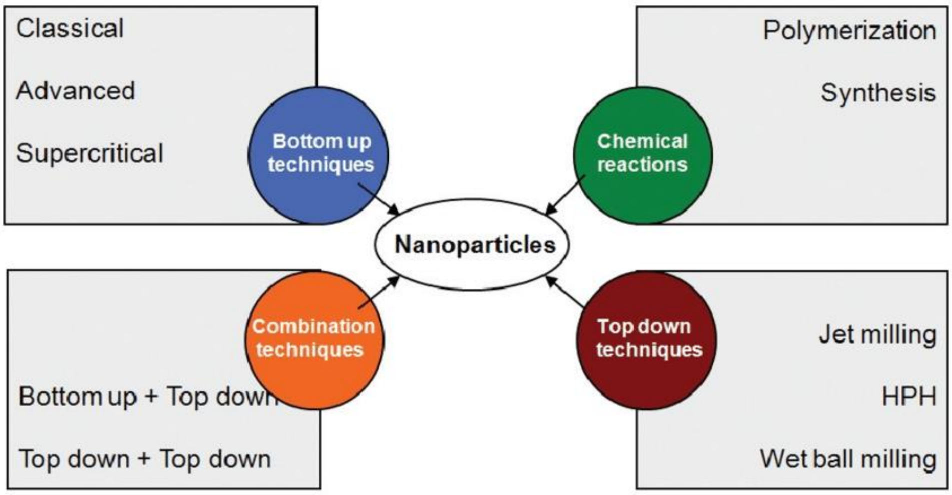

Figure 3: Preparation methods of nanoparticles.

7. Applications of nanoparticles

7.1 Applications in Medicine and Pharma

Metallic and semiconductor NPs have huge potential for cancer diagnosis and therapy based on their enhanced light scattering and absorption properties due to LSPR effect. For instance, Au NPs efficiently absorb light and convert it into localized heat, which can be exploited for selective photothermal therapy of cancer (Cancer cell death by heat generated in tumor tissue).[2] Nanotechnology has improved the medical field by use of nanoparticles in drug delivery. The drug can be delivered to specific cells using nanoparticles. The total drug consumption and side effects are significantly lowered by placing the drug in the required area in required dosage. This method reduces the cost and side effects. The reproduction and repair of damaged tissue (Tissue engineering) can be carried out with the help nanotechnology. The traditional treatments such as artificial implants and organ transplants can be replaced by tissue engineering.[4] Moreover, NPs have been successfully used in different medical applications such as cellular imaging, or in biosensors for DNA, carbohydrates, proteins, and heavy metal ions, determination of blood glucose levels, and for medical diagnostics to detect bacteria and viruses.[2] One such example is the growth of bones carbon nanotube scaffolds. The use of gold in medicine is not new. In Ayurveda an Indian medical system, gold is used in several practices. One common prescription is the use of gold for memory enhancement. To enhance the mental fitness of a baby gold is included in certain medical preparations.[4]

7.2 Applications of nanoparticles in agriculture

NPs have potential to benefit the agriculture field by providing new solutions to current agricultural and environmental problems. NPs are mainly used in two forms in agriculture, as nano fertilizers and nano pesticides. Chemical fertilizers have poor efficiency due to leaching and volatilization. In these cases, the farmers usually react by using excessive amounts of fertilizers, which increases crops productivity but has an environ mental cost. The nano fertilizers provide the plants with increased nitrogen fixation, improved seed germination, amelioration to drought stress, increased seed weight, and increased photosynthesis ability. Several NPs have proven antimicrobial, insecticidal, and nematocidal activities, which makes them a promising alternative to chemical pesticides and a potentially cheaper alternative to biopesticides.[2]

7.3 Applications of nanoparticles in Cosmetics & Sunscreens

The traditional UV sunscreen doesn't use drugs that are stable over time.[7] The conventional ultraviolet (UV) protection sunscreen lacks long-term stability during usage. The sunscreen including nanoparticles such as titanium dioxide provides numerous advantages. The UV protection property of titanium oxide and zinc oxide nanoparticles as they are transparent to visible light as well as absorb and reflect UV rays found their way to be used in some sunscreens. Some lipsticks use iron oxide nanoparticles as a pigment.[4]

7.4 Application of nanoparticles in environment

The increasing area of engineered NPs in industrial and house hold applications lead to the release of such materials into the environment. Assessing the risk of these NPs in the environment requires on understanding of their mobility, reactivity, Eco toxicity and persistency.[5] The nanoparticles are used to treat the surface water by disinfection, purification and desalination. Some of the contaminants are most likely to be heavy metals, pathogens and organic contaminants. It has proven to be efficient and eliminating the need for chemicals that may sometime produce secondary reaction products[4] NPs function as effective, environmentally friendly fertilizers that can boost crop yields and replace pesticides in the management and control of plant diseases.[7] Soil contamination is also an increasing concern. Contaminated soil is cleaned or treated using nanoparticles by injecting the nanoparticles into specific target locations for heavy metal contamination, toxic industrial waste, etc.[4]

7.5 Application of nanoparticles in food industry

The improvement in production, processing, protection and packaging of food is achieved by incorporating nanotechnology. For example, a nanocomposite coating in a food packaging process can directly introduce the anti-microbial substances on the coated film surface.[4] Nanofood is a term used to describe foods that use nanotechnology techniques, tools or manufactured nanomaterials that have been added during cultivation, production, processing or packaging. There are several purposes for the development of nanofood. These include improvement of food safety, enhancement of nutrition and flavour, and cutting production and consumer costs.[9] The efficiency of doping Ag and ZnO NPs to degradable and non-degradable packaging materials for meat, bread, fruit, and dairy products was tested against several yeast, molds, aerobic, and anaerobic bacteria.[2]

8. Biosynthesis

For the biosynthesis of nanoparticle Preparation of botanical extracts, Bio reduction depends on reaction mixture and incubation formation time, analysed spectroscopy, by Nanoparticles UV-Visible Characterization nanoparticles by of SEM, TEM, XRD, FTIR, EXD, Purification and its application. There are basic steps involved in the biosynthesis of nanoparticles.

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