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Nanoparticles: Classification, types and applications: A comprehensive review

Prathamesh R. Sune *, Kajal S. Jumde, Pooja R. Hatwar, Ravindra L. Bakal, Samiksha D. More and Atharv V. Korde

Department of Pharmaceutics, Shri Swami Samarth Institute of Pharmacy, At Parsodi, Dhamangaon Rly, Dist -Amravati (444709) Maharashtra, India.

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Abstract

Nanoparticles are tiny particles with unique properties, classified into organic, inorganic, and carbon-based categories. They have been used for centuries, with ancient civilizations employing them in various applications. The surface characteristics and particle size of nanoparticles can be modified to target medications passively and actively. They offer numerous advantages, including enhanced control over the encapsulated chemicals' release kinetics, improved drug transportation through cell barriers, and reduced toxicity. However, nanoparticles also exhibit strong reactivity due to their small size and large surface area, which can lead to biologically harmful effects. Carbon-based nanoparticles, including fullerenes, graphene, carbon nanotubes, and carbon nanofibers, have distinct mechanical, chemical, and physical characteristics. Silver, gold, and copper nanoparticles have also been extensively studied for their antibacterial and antiviral properties. The applications of nanoparticles are diverse, ranging from biomedical and pharmaceutical to environmental and industrial uses. Overall, nanoparticles have the potential to revolutionize various fields, but their development and use must be carefully managed to mitigate their potential risks.

Keywords: Nanoparticles; Nanotechnology; Gold; Silver; Biodegradable

1. Introduction

Research on nanotechnology has been established since the turn of the century. Given that "nanotechnology" was through the Latin names meaning very much, the prefix nano is derived from the ancient Greek Vavoc [1]. That Nobel laureate Richard P. Feyn-Man delivered in his renowned 1959 talk "Feynman, 1960" states that "There's Plenty of Room at the Bottom." Various groundbreaking discoveries in the realm of nanotechnology [2]. Technology that works with things the size of nanometres is made possible by nanotechnology. It is anticipated that nanotechnology will advance on multiple fronts, starting with materials. Systems and gadgets. The level of nanomaterials is the most advanced currently in terms of both commercial uses and scientific knowledge. Ten years previously, nanoparticles were examined due to their size-dependent chemical and attributes. They are now in the commercial investigation phase [3]. Science and engineering applied to the nanoscale is called nanotechnology. The development and synthesis of materials, devices, and systems at the nanoscale is known as nanotechnology. As much as 1-100 nm. High surface volume ratios are found in nano formulations. The creation of tiny objects, such as electronic devices, catalysts, sensors, etc., is the focus of nanotechnology. One of the most significant and fascinating areas of research in physics, chemistry, biology, medicine, engineering, and technology in recent years is nanomaterials. Design, development, and use of materials at the atomic, molecular, and macromolecular range are represented by nanotechnology. Creation and use of materials at the molecular, macromolecular, and atomic levels [4]. A nanoparticle matrix is used to dissolve, entrap, encapsulate, or bind the medication. based on nanoparticles, nanospheres or nanocapsules can be produced depending on the preparation technique [5]. Applications for nanoparticles are numerous and include the environment, food, agriculture, biotechnology, biomedical, medicines, etc., such as waste water treatment monitoring the environment, serving as

* Corresponding author: Prathamesh R. Sune

antibacterial agents, and serving as beneficial food additives. Novel characteristics of NPs include their nature, biocompatibility, antimicrobial and anti-inflammatory activity, ability to target tumours, bioactivity, bioavailability, and bio-absorption, as well as their efficient drug delivery [6]. Nanoparticles exhibit a range of special qualities that are not present in bulk materials. The most important aspect of nanoparticles is their characteristics, which include their electrical, optical, magnetic, and so forth) are highly dependent upon the dimensions and dispersion of the fragments [7]. Although they have a long history, nanoparticles are thought to be a discovery of modern science. Nanotechnology has been used by ancient humans for thousands of years. However, it's unclear when people started using the benefits of nanoparticles in various domains. One of the most important and basic characteristics of nanoparticles is their optical quality. For Example:

- The colour of a silver NP is greyish-yellow.
- The colour of a gold NP with a 20 nm size is similar to red wine.
- The nanoparticles of palladium (Pd) and platinum (Pt) are black in colour [8].

For centuries, the nanoscale range has been used in the study of biological systems and the manufacture of numerous materials, including colloidal dispersions, metallic quantum dots, and catalysts. Au Nanoparticles, for instance, are known to be used by the Chinese as an inorganic colour to add the colour red to their porcelain ceramics about a millennium ago. Utilization Of colloidal gold has been around for a while, but a thorough investigation into the production and First publication of colloidal gold's qualities occurred in the middle of the 19 the century. Intractable the gold dispersion that Faraday created in 1857 was steady. Nearly a century passed before being demolished in the course of World War II. Another example of colloidal gold usage is in medicine. Arthritis was and is still treated with colloidal gold [9]. As a result of their complexity, nanoparticles are made up of three layers: the surface layer, which can be functionalized by a wide range of small molecules, metal ions, surfactants, and polymers. The outer shell layer, a substance that differs from the core in every way chemically, and the core, which is basically the middle section of the NP and typically relates to the NP in question [10]. The increasing production of nanoparticles in several areas has a discernible impact on the environment and living organisms, hence affecting their health and overall well-being. Nanoparticles are a double-edged sword, and their drawbacks must be mitigated by taking safeguards. This study examines how nanoparticles affect the environment by directly interacting with human tissue, which may be toxic and cause health problems. Globally, ongoing studies are being conducted in an effort to lower the related toxicity levels [11].

1.1. Advantages

- Modifying the surface characteristics and particle size of nanoparticles to target medications passively and actively after parenteral administration is simple [12].
- There are other ways to administer the system, such as parenteral, nasal, and oral [13].
- Raman scattering with surface enhancement [14].
- Nanoparticles can better distribute drugs to small areas inside the body [15].
- Targeting ligands can be attached to particle surfaces to achieve site-specific targeting, or magnetic guidance can be used [16, 17].
- The composition of the matrix can easily be changed to control characteristics of particle disintegration and controlled release [17].
- Enhanced control over the encapsulated chemicals' release kinetics [18].
- Drug transportation through cell barriers gets easier [19].
- The same raw components are needed for emulsions [18].
- Enhanced drug consumption, less toxicity, and a decreased likelihood of unfavourable medication responses [20].

1.2. Disadvantages

- In the cellular milieu, nanoparticles exhibit strong reactivity due to their small size and large surface area [12].
- It entails higher production costs, which can drive up the price of formulation [13].
- Biologically harmful: Due to its transparency to the cell dermis, nanoparticles have been shown to be toxic, carcinogenic, and irritant [14].
- When they show through to the cell dermis [14].
- During the preparation procedure, the solvent system may create toxicity [21].
- Unpredictable gelation tendency [18].

1.3. Classification of Nanoparticles

In general, there are three types of nanoparticles: organic, inorganic, and carbon-based.

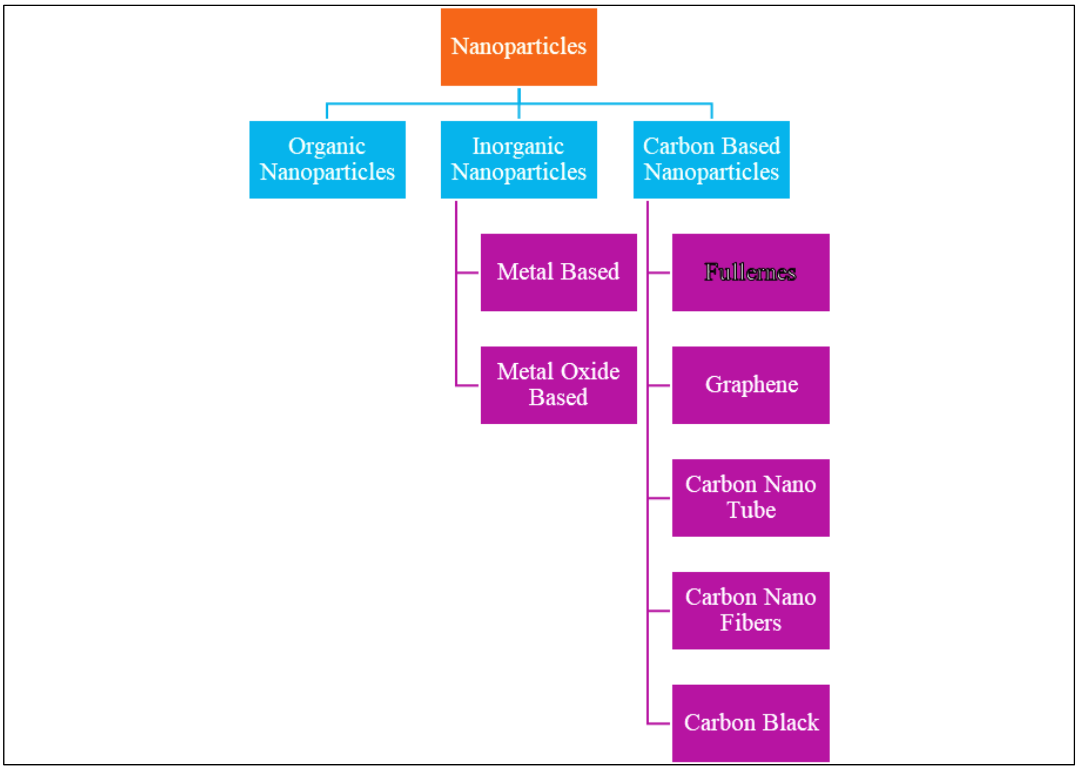

Figure 1 Classification of Nanoparticles [22]

1.4. Organic nanoparticles

Ferritin, liposomes, dendrimers, and other organic nanoparticles or polymers are well-known examples. These nanoparticles are non-toxic and biodegradable, yet some, like micelles and liposomes, have a hollow core and are Susceptible to electromagnetic and thermal radiation, including heat.

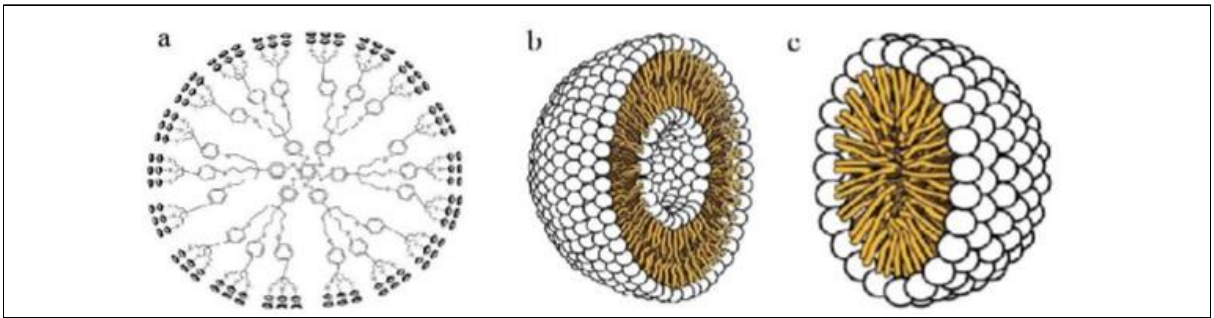

Figure 2 Organic nanoparticles: a) Dendrimers, b) Liposomes and c) micelles [22]

1.5. Inorganic nanoparticles

Non-carbon-based particles are known as inorganic nanoparticles. Inorganic nanoparticles are often defined as those based on metal and metal oxides [23].

1.5.1. Metal nanoparticles

Metallica nanoparticles are manufactured from metals by either constructive or destructive processes. The pure metal nanoparticles are produced using the metal precursors. Because of the plasma on resonance characteristics, the metal nanoparticles have special optoelectrical capabilities. The shape, facet, and size of metal nanoparticles govern their production. All metal's nanoparticles are produced. Among the most well-known metal nanoparticles are those of aluminium, gold, iron, lead, silver, cobalt, zinc, and copper. The small size (10–100 nm), surface properties (surface area to volume ratio, surface charge, pore size, surface charge density), shapes (spherical, rod, hexagonal, tetra-gonial, cylindrical, and irregular), colour, and environmental factors (sunlight, moisture, air, and heat) all contributed to the unique properties of nanoparticles [8].

1.5.2. Metal Oxides Based Nanoparticles

Metal oxides-based NPs are NPs made from metals that can be transformed into their corresponding Oxides. When compared to their metal equivalents, nanoparticles based on metal oxides exhibit remarkable features. Examples of metal oxide-based nanoparticles (NPs) include magnetite and iron oxide ($Fe2O3$). ($Fe3O4$), silicon dioxide ($SiO2$), titanium, aluminium oxide ($Al2O3$), and cerium oxide ($CeO2$) Titanium dioxide ($TiO2$), zinc oxide (ZnO) (M. B. Sathayandaran, R. Balachandranath, Genji in 2013, Subbiah doss, G., Kannaiyan, S. K., and Srinivasulu, Y. These NPs rely on metal oxides discovered to be more responsive and effective [24].

1.6. Carbon based nanoparticles

There are two main categories of carbon-based NPs: fullerenes and carbon nanotubes (CNTs). Fullerenes contain nanomaterials composed of globular hollow cages, such as allotropic forms of carbon. They've shown remarkable interest in business.

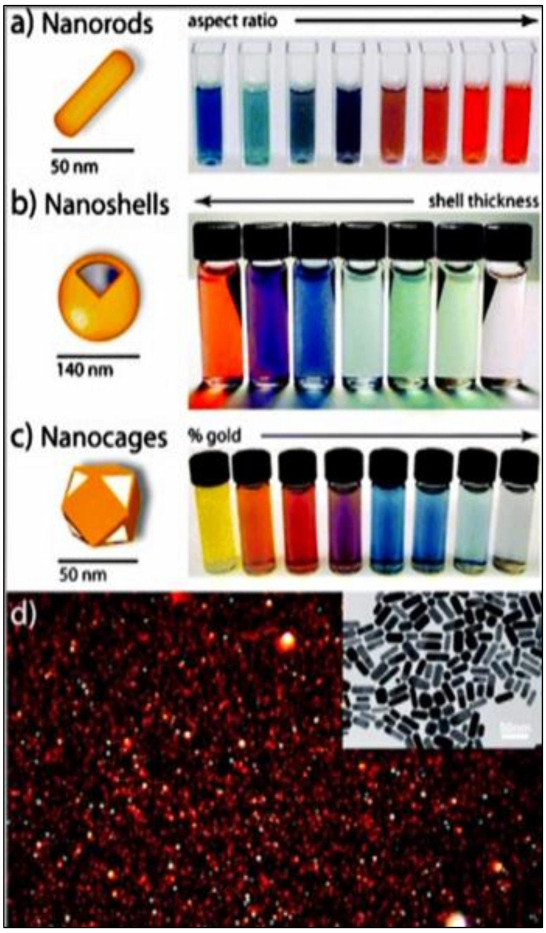

Figure 3 Figure colour dependence of Au NP on size and shape [25]

Because of their excellent strength, structure, electron affinity, electrical conductivity, and adaptability. These materials have sp2 hybridized carbon units organized in both pentagonal and hexagonal configurations. Figure 4 displays the well-known fullerenes C60 and C70, which have diameters of 7.114 and 7.648 nm, respectively. CNTs are elongated, 1-2 nm-diameter tubular structures. Considering their diameter These can be categorized as semiconducting or metallic based on their telicity. These appear to be rolling graphite sheets on top of one another. One type of carbon nanotube is single-walled (SWNT). The rolled sheets might be single-walled (DWNTs) or multi-walled (MWNTs). A pair or several walls (MWNTs). Usually, they are created via deposition using an electric arc or laser. Carbon precursors that evaporated from graphite and were deposited on metal, especially atomic carbons Fragments. The synthesis of them by chemical vapour deposition (CVD) has been introduced recently. Due to These components' distinct mechanical, chemical, and physical characteristics make them useful for Fillers effective gas adsorbents for cleaning up the atmosphere and serving as a support material for numerous Catalysts, both organic and inorganic.

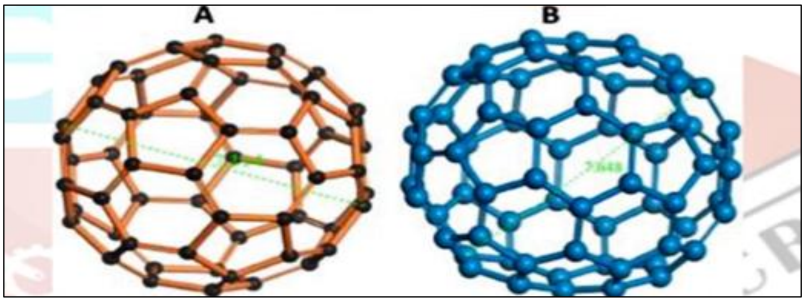

Figure 4 Different form of Fullerenes/buck balls (A) C60 and (B) C70 [25]

1.6.1. Fullerenes

C60 is one of the most well-known and often used fullerenes, Buckminster fullerene. It has the shape of a soccer ball due to the cage-like arrangement of its 60 carbon atoms, each of which has three bonds. Twelve pentagons and twenty hexagons are utilized in the C60 structure. Two well-established characteristics of this structure are resonance stabilization and icosahedral symmetry. It is used in material science because of its unique combination of physicochemical characteristics. Recently, a wide range of applications in nanoscience and nanotechnology have made extensive use of C60-based nanostructures, such as nanorods, nanotubes, and nanosheets. Because of its versatility, C60 can be employed in a variety of ways to accelerate the reactions of a broad spectrum of chemicals. It can be included into systems to enhance particular behaviours due to its special characteristics. Through covalent, endohedral, and supramolecular transformations, C60 can be subjected to molecular manipulation and the creation of polymeric material for use in environmental applications [26].

1.6.2. Graphene

One carbon allotrope is graphene. Carbon atoms arranged in a hexagonal network on a two-dimensional flat surface constitute graphene. Graphene sheets typically have a thickness of one nanometer [22, 27, 28].

1.6.3. Carbon Nano Tubes (CNT)

Carbon Nano Tubes (CNTs) are made of graphene nanofoil with a honeycomb Lattice of carbon atoms twisted into hollow cylinders. The length of the nanotubes can vary from a few micrometers to 100 nm, with diameters as low as 0.7 nm for single-layered CNTs and 100 nm for multi-layered CNTs. To Many millimeters. A half-fullerene molecule can shut the ends or leave them hollow [27,28].

1.6.4. Carbon Nanofiber

Carbon nanofiber (CNT) is created using the same graphene nanofoils, but they are twisted into cone or cup shapes rather than standard cylindrical tubes.

1.6.5. Carbon black

A carbon-based amorphous material with diameters ranging from 20 to 70 nm that is often spherical in shape. Particles interact so strongly with one another that they form agglomerates, which are about 500 nm in size.

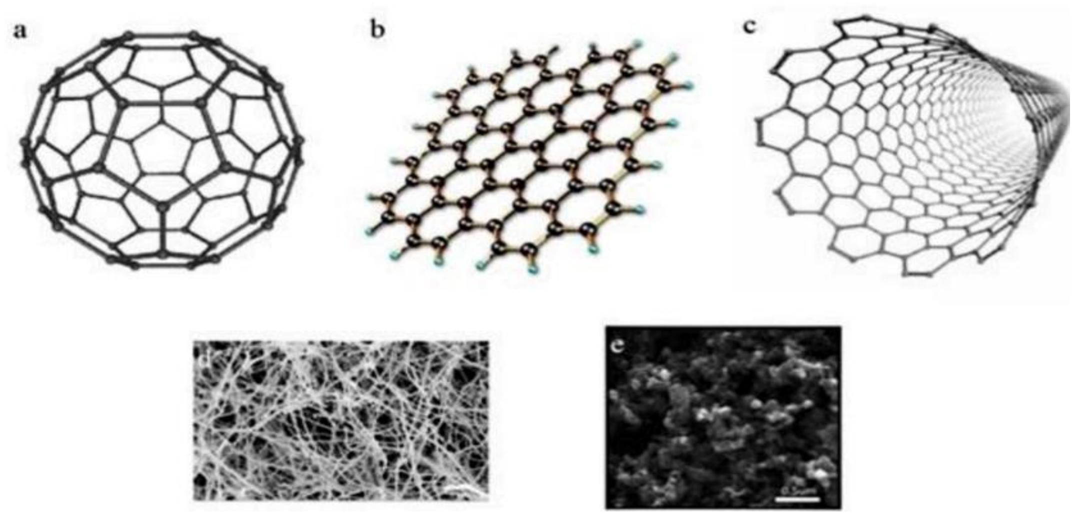

Figure 5 Carbon based nanoparticles: a) fullerenes, b) graphene, c) carbon nanotubes, d) carbon Nanofibers and e) carbon black [22, 27, 28]

2. Types of Nanoparticles

2.1. Silver

The best antibacterial efficaciousness of silver nanoparticles against bacteria, viruses, and other eukaryotic microorganisms has been demonstrated. They are without a doubt the most Extensively utilized nanoparticles, which are consequently employed in textiles as antibacterial agents Industries, for sunscreen creams, water treatment, etc. Research has already documented the productive production of silver nanoparticles by plants like Capsicum and Azadirachta indica Papaya Carica and Annuum [29].

2.2. Gold

AuNPs, often known as gold nanoparticles, are gold nanoparticles. They have unique chemical and physical properties and can both scatter and absorb visible and near-infrared light. Anisotropic AuNPs were discovered by researchers at the beginning of the 20th century. According to Zsigmond, a gold particle "is not always spherical" whether it is 40 nm or less [6].

2.2.1. Preparation of gold nanoparticles

There are several ways to manufacture gold nanoparticles (AuNPs), one of which is the Turkevich and Frens approach. 100 mL of 0.1 g/L chloroauric acid (HAuCl4) and 0.7 mL of 10 g/L trisodium citrate are combined, and the mixture is heated to a boil for 30 minutes while being constantly stirred. Following cooling, AuNPs with diameters ranging from 10 to 100 nm are present in the resultant solution. The successful production of gold nanoparticles was indicated by the colour of the mixed solution changing from pale yellow to burgundy during this procedure. To preserve the consistency of the volume and shape of the gold nanoparticles, the study's parameters can be carefully adjusted for every batch. Using ultraviolet (UV)–visible spectroscopic spectroscopy and scanning electron microscopy, the volume and shape of the produced gold nanoparticles may be evaluated [30].

2.3. Copper

Although the exact date of copper's discovery in the Middle East is unknown, it is thought to have occurred around 9000 BCE. Since the Egyptians employed copper for the first time, around 2000 BCE, to sterilize wounds and other purposes, copper is the oldest steel utilized by mankind. Water Numerous notable qualities of copper include its low cost, outstanding resistance to corrosion, and as well as antibacterial leisure. Copper sulphate discount under microwave radiation A novel method for preparing copper nanoparticles is the use of hydrazine in ethylene glycol. The role that polyvinylpyrrolidone plays in determining the copper nanoparticles dimensions is crucial. And expand its consciousness to stimulate smaller Dimension particles. In essence, they are one to a Size of a hundred nanometers [28].

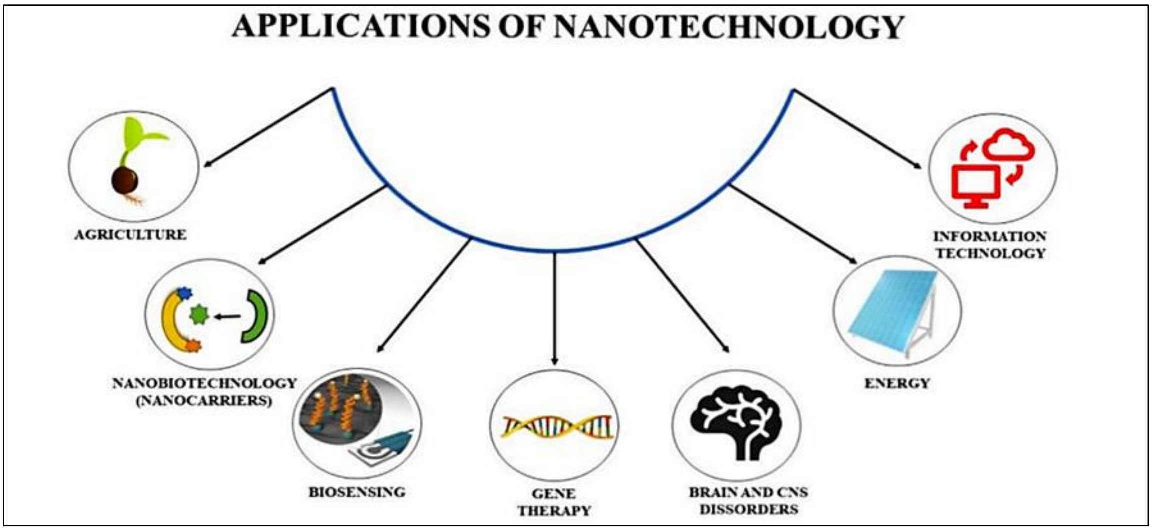

Figure 6 Different applications of nanotechnology [31].

3. Conclusion

The unique features of nanoparticles are revolutionizing a number of sectors by providing creative answers to issues in electronics, health, energy, and the environment. Notwithstanding their enormous potential to advance current technologies and develop completely new ones, it is imperative that the safety, health, and environmental issues related to their use be addressed. Since nanoparticles are expected to become more significant in determining the direction of science and technology as research and development progresses, it is imperative to strike a balance between innovation and responsible management.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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