

Review on Nanoparticles

Ganesh Balasaheb Jiwade¹, Sayali Dadasaheb kardile²

^{1,2}*Swasthyadarpan, pratishthan's, Shantiniketan College of Pharmacy, A/P. Dhotre (B, K),
Tal. Parner, Ahmednagar, Maharashtra- 414304, India*

Abstract—Nanoparticles are tiny particles that have unique properties. They come in three main types: organic, inorganic, and carbon-based. Humans have been using them for a long time, and ancient civilizations used them in various ways [1]. The surface properties and size of nanoparticles can be changed to help deliver medicines either passively or actively. They have many benefits, such as better control over how the chemicals inside them are released, improved movement of drugs across cell barriers, and less harmful effects [2]. However, nanoparticles are also very reactive because of their tiny size and big surface area, which can cause harmful effects on living things. Carbon-based nanoparticles, such as fullerenes, graphene, carbon nanotubes, and carbon nanofibers, have unique mechanical, chemical, and physical properties [3]. Silver, gold, and copper nanoparticles have been widely researched for their ability to fight bacteria and viruses. These tiny particles are used in many areas, including medicine, drug development, environmental protection, and industry. While they hold great promise for changing many areas of science and technology, it's important to handle their creation and use carefully to avoid any harmful effects [4].

Index Terms—Nanoparticles; Nanotechnology: Gold; Silver; Biodegradable

I. INTRODUCTION

Research on nanotechnology started around the year 2000. The word "nanotechnology" comes from the Greek word "nano," which means very small. This term was introduced by the famous scientist Richard P. Feynman in his speech "There's Plenty of Room at the Bottom" from 1960[4,5]. His idea helped set the stage for nanotechnology. Many important discoveries have been made in this field. Nanotechnology allows technology to work with things that are as small as a nanometer. It is expected that nanotechnology will progress in many areas, starting with materials, systems, and devices. Right now, nanomaterials are the most developed in terms of both commercial uses

and scientific understanding [6]. Ten years ago, nanoparticles were mainly studied because of their unique chemical and physical properties, which change with their size. Now, they are being tested for real world applications.

Nanotechnology refers to the use of science and engineering at the nanoscale, which is as small as 1 to 100 nanometers. This field involves creating and making materials, devices, and systems at this tiny scale. These nano-scale items have a high surface area compared to their size and are used in various nano-based products. The main goal of nanotechnology is to develop small things like electronic devices, catalysts, sensors, and more. One of the most important and interesting areas of study in fields like physics, chemistry, biology, medicine, engineering, and technology in recent years has been nanomaterials [7]. Nanotechnology deals with the design, creation, and use of materials at the atomic, molecular, and macromolecular levels. These materials are used to dissolve, trap, enclose, or attach medicines. Depending on the preparation method, nanoparticles can be made into nanospheres or nano capsules. Nanoparticles have many uses, including in the environment, food, agriculture, biotechnology, biomedical applications, and medicine. They are used for tasks like treating wastewater, monitoring the environment, acting as antibacterial agents, and as helpful food additives [8].

Nanoparticles also have special qualities like being natural, biocompatible, having antimicrobial and anti-inflammatory effects, the ability to target tumors, good bioactivity, bioavailability, and bio-absorption, as well as being effective in delivering drugs. Nanoparticles have special properties that are not found in larger materials. Their characteristics, such as electrical, optical, and magnetic properties, depend on their size and how they are spread out. Even though nanoparticles have been around for a long time, they are considered a modern scientific discovery. People

have used nanoparticle-based technologies for thousands of years, but it's not clear exactly when they started using them in different areas. One of the most important features of nanoparticles is their optical property [9].

For example, for a long time, the nanoscale has been used in studying biological systems and making various materials like colloidal dispersions, metallic quantum dots, and catalysts. Gold nanoparticles were used by the Chinese as an inorganic color to give porcelain ceramics a red color about a thousand years ago. Colloidal gold has been used for a while, but it wasn't until the middle of the 19th century that scientists started thoroughly studying its production and properties. Faraday created a stable gold dispersion in 1857. It took nearly a century before this discovery was challenged during World War II. Another example of how colloidal gold is used is in medicine. Arthritis was treated with colloidal gold in the past and is still used today. Because nanoparticles are complex, they have three layers: the surface layer, which can be modified with many different small molecules, metal ions, surfactants, and polymers.

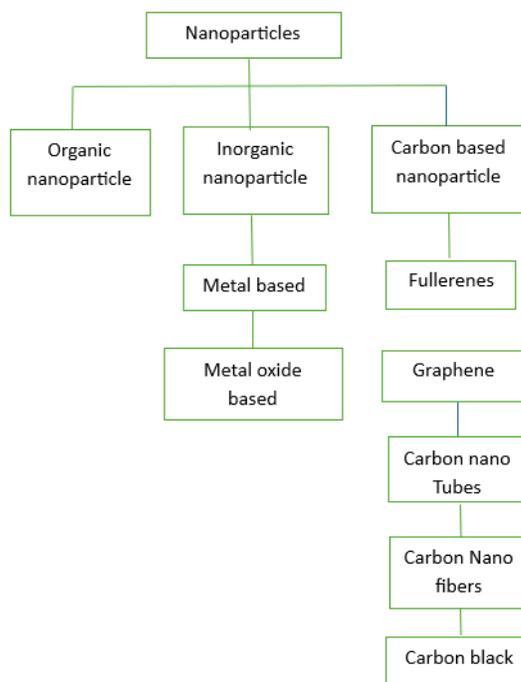
The outer shell is made of a substance that is chemically different from the core. The core is the middle part of the nanoparticle and is usually the main part that defines the nanoparticle. The growing use of nanoparticles in different areas is having a noticeable effect on the environment and living things, which can affect their health and general well-being. Nanoparticles can be both helpful and harmful, so it's important to take steps to reduce their risks. This study looks at how nanoparticles affect the environment by interacting directly with human tissue, which can be harmful and lead to health issues. Around the world, researchers are working to reduce the harmful effects of nanoparticles [10].

II. ADVANTAGES OF NANOPARTICLE

1. Modifying the surface characteristics and particle size of nanoparticles to target medications passively and actively after parenteral administration is simple.
2. There are other ways to administer the system, such as parenteral, nasal, and oral.
3. Raman scattering with surface enhancement.
4. Nanoparticles can better distribute drugs to small areas inside the body.
5. Targeting ligands can be attached to particle surfaces to achieve site-specific targeting, or magnetic guidance can also be used.
6. The composition of the matrix can easily be changed to control characteristics of particle disintegration and controlled release.
7. Enhanced control over the encapsulated chemicals' release kinetics.
8. Drug transportation through cell barriers gets easier.
9. The same raw components are needed for emulsions.
10. Enhanced drug consumption, less toxicity, and a decreased likelihood of unfavorable medication responses

III. DISADVANTAGES

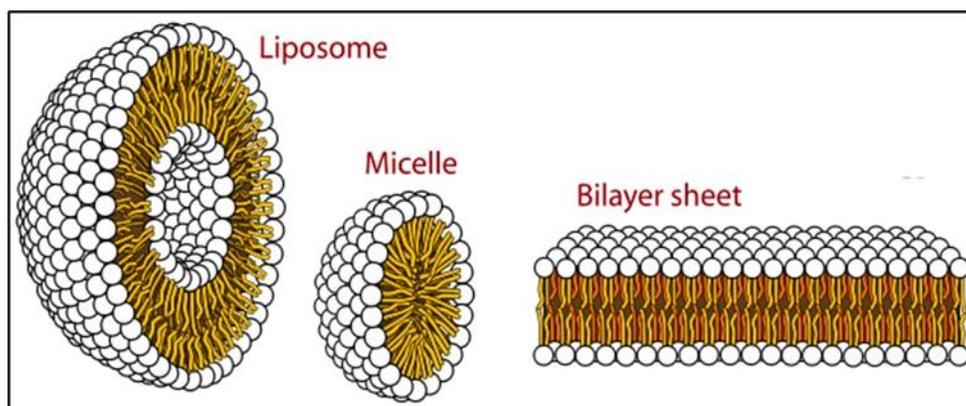
1. In cellular milieu, nanoparticles exhibit strong reactivity due to their small size and large surface area.
2. It entails higher product costs, which can drive up the price of formulation.
3. Biochemically harmful: Due to its transparency to the cell dermis, nanoparticles have been shown to be toxic, carcinogenic, and irritant.
4. When they show through to the cell dermis.
5. During the preparation procedure, the solvent system may create toxicity.
6. Unpredictable gelation tendency.



Classification of nanoparticles

IV. ORGANIC NANOPARTICLES

Ferritin, liposomes, dendrimers, and other organic nanoparticles or polymers are common examples. These nanoparticles are not harmful and can break down in the body, but some, such as micelles and liposomes, have a hollow center and can be affected by electromagnetic and thermal radiation, including heat [11].



V. INORGANIC NANOPARTICLE

Non-carbon-based particles are known as inorganic nanoparticles. Inorganize nanoparticles are often defined as those based on metal and metal aides [12].

1. Metal nanoparticle

Metal nanoparticles are made from metals using either building up or breaking down methods. Pure metal

nanoparticles are created using metal-based materials. Because of their special light and electricity-related properties, metal nanoparticles are very useful. The shape, sides, and size of these nanoparticles affect how they are made. All types of metal can be made into nanoparticles [13].

Some of the most common metal nanoparticles are made from aluminum, gold, iron, lead, silver, cobalt,

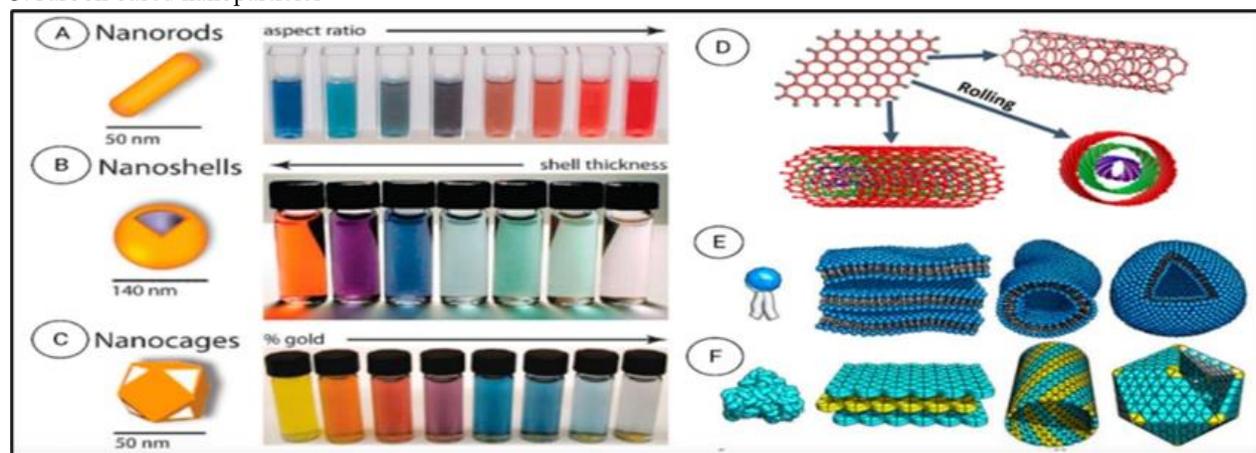
zinc, and copper. The tiny size (10-100 nanometers), the surface features like area to volume ratio, surface charge, pore size, and surface charge density, their shapes such as round, rod-like, hexagonal, square-like, cylinder-like, and irregular, their color, and environmental factors like sunlight, moisture, air, and heat all contribute to the special properties of nanoparticles.

2. Metal Oxides Based Nanoparticles

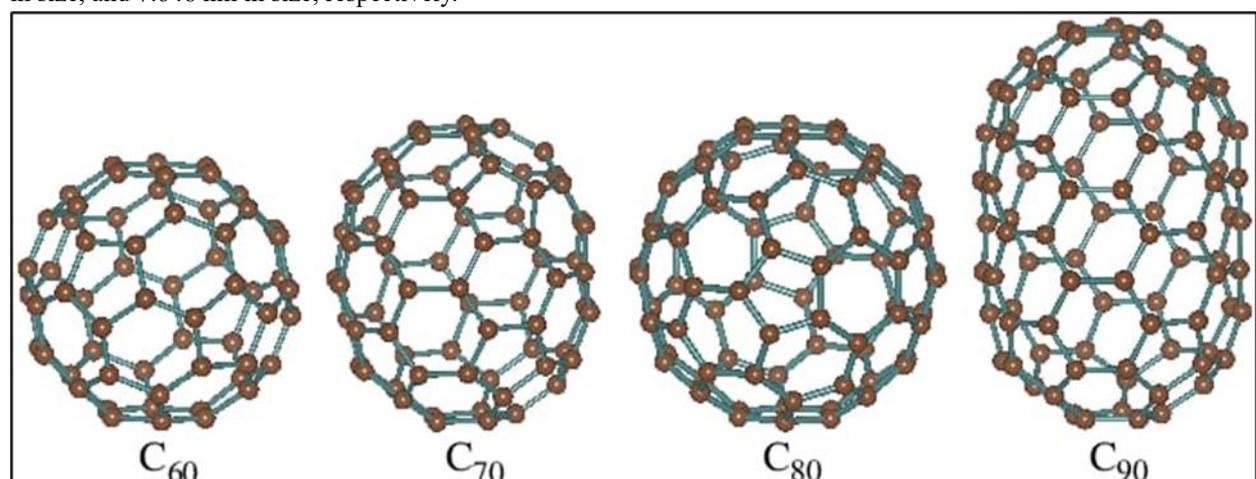
Metal oxide-based nanoparticles are made from metals that can be turned into their oxide forms. Compared to

their metal counterparts, nanoparticles based on metal oxides show outstanding properties. Examples of metal oxide-based nanoparticles include magnetite and iron oxides like Fe_2O_3 and Fe_3O_4 . Other examples are silicon dioxide (SiO_2), titanium dioxide (TiO_2), aluminum oxide (Al_2O_3), and cerium oxide (CeO_2). Zinc oxide (ZnO) is also a common example. These nanoparticles are known to be more sensitive and effective because of their metal oxide composition. (M. B. Satyandra, R. Bala Chandranath, Genji Subbiah, Doss, G. Kannaiyan, S. K., and Srinivasulu, Y.).

3. Carbon based nanoparticles



There are two main categories of carbon-based Knost fullerenes and carbon nanotubes (CNTs). Fullerenes contact nanomaterials composed of globular hollow cages, such as allotropic forms of carbon. They've shown remarkable interest in business. Because of their great strength, solid structure, ability to attract electrons, good electricity movement, and versatility, these materials are special. They have carbon units joined in a way that forms both five-sided and six-sided shapes. Figure 4 shows the well-known fullerenes C_{60} and C_{70} , which are about 7.1 and 14 nm in size, and 7.648 nm in size, respectively.



Carbon nanotubes are long, hollow tubes that are 1 to 2 nm wide. Because of their size, they can act like either semiconductors or metals depending on their shape. They look like layers of graphite rolled up on top of each other. One kind of carbon nanotube is single-walled (SWNT). The rolled layers could be just one wall (DWNTs) or several walls (MWNTs). These are usually made by using an electric arc or a laser. The carbon comes from materials like graphite and is deposited on metal surfaces, especially in small pieces. Recently, a new way to make them has been developed using chemical vapor deposition (CVD). Because of their unique physical, chemical, and mechanical properties, they are good for use as fillers, for absorbing gases to clean the air, and as a base for many types of catalysts, both organic and inorganic [14].

4. Fullerenes

C60 is one of the most famous and commonly used fullerenes, also known as Buckminster fullerene. It looks like a soccer ball because its 60 carbon atoms are arranged in a cage-like shape. The structure of C60 includes twelve pentagons and twenty hexagons. Two important features of this structure are resonance stabilization and euohedral symmetry. Because of its unique mix of physical and chemical properties, C60 is widely used in material science. In recent years, C60-based nanostructures such as nanorods, nanotubes, and nanosheets have found many applications in nanoscience and nanotechnology.

Due to its versatility, C60 can be used in various ways to speed up chemical reactions involving a wide range of substances. Its special properties also allow it to be added to systems to improve certain behaviors. Through covalent, endohedral, and supramolecular transformations, C60 can be modified at the molecular level to create polymeric materials for use in environmental applications.

5. 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.

6. Carbon Nano Tubes (CNT)

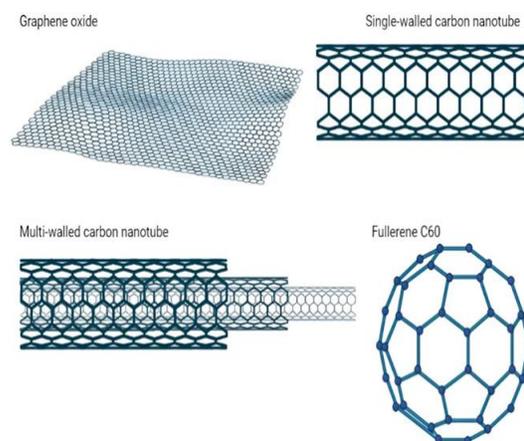
Carbon Nano Tubes (CNTs) are made of graphene nano foil with a honeycomb Lattice of carbon atoms

twisted into hollow extenders. The length of the nanotubes can vary from a few micrometers to 100 nm. with diameters as low as 0.3 nm for single-levered CNTs and 100 nm for multi-levered CNT's To Many millimeters, A half-fullerene molecule can shut the ends or leave them hollow.

7. Carbon Nanofiber

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

8. 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.

VI. HISTORY OF NANOPARTICLE

1. Ancient and Pre-Scientific Period (Before 1800s)

- Even before scientists understood atoms and molecules, nanoparticles were unknowingly used in art and craftsmanship.
- Roman Empire (4th century AD): The Lycurgus Cup is one of the earliest examples - it appears green in reflected light and red in transmitted light due to gold and silver nanoparticles dispersed in glass.
- Medieval Period: Stained glass windows in cathedrals achieved their brilliant colors because of metallic nanoparticles (gold, silver, and copper) created during glassmaking.

- These artisans didn't know the science, but they were already manipulating materials at the nanoscale.

2. Early Scientific Observations (1800-1940s)

- 1857- Michael Faraday: Conducted experiments on colloidal gold and discovered that its optical properties depend on the particle size. This is considered one of the first scientific studies on nanoparticles
- 1905 - Albert Einstein: His Ph.D. thesis explained the motion of small particles in liquids (Brownian motion), which helped in understanding nanosized particles.
- 1930s-1940s: Development of electron microscopy made it possible to see nanoparticles, allowing direct study of their structure and behavior

3. Modern Nanoscience Era (1950-1980)

- 1959 - Richard Feynman: In his famous talk called "There's Plenty of Room at the Bottom," he imagined being able to work with atoms and molecules directly, which later became the idea of nanotechnology.
- 1974 - Norio Taniguchi: He first used the word "nanotechnology" and explained it as the process of separating, joining, and changing materials at the level of one atom or one molecule.
- 1981: The Scanning Tunneling Microscope (STM) was invented, letting scientists see and move individual atoms. This was a big step forward for nanoscience.

4. Nanotechnology Revolution (1980-2000)

- 1985: Discovery of fullerenes (C₆₀)- carbon molecules shaped like soccer balls.
- 1991: Discovery of carbon nanotubes by Sumio Iijima -cylindrical forms of carbon with extraordinary strength and conductivity
- 1990s: Rapid advances in nanomaterials synthesis, characterization techniques, and computational modeling fueled explosive growth in nanoscience research.

5. 21st Century and Beyond (2000-Present)

- Nanoparticles are now widely used in medicine (drug delivery, imaging), electronics (quantum dots, transistors), energy (solar cells, batteries),

and environmental technology (water purification, sensors).

- Ongoing research focuses on green synthesis, biosafety, and smart nanomaterials that can respond to biological or environmental signals.

VII. TYPES OF NANOPARTICLES

1. Inorganic nanoparticles: In the field of Modern material science Inorganic nanoparticles have been developed the role based upon their unique physical properties and particularly in biotechnology. Based upon these two factors of inorganic nanoparticles they have certain physical properties that mainly include size dependent optical, magnetic, electronic, and catalytic properties, Bio related applications are involved for the preparation of these interesting nanoparticles like iron oxides, gold, silver, silica, quantum dots etc. Novel physical properties mainly related because of their size approaches nanometer scale dimension.
2. Polymeric nanoparticles Polymerized nanoparticles it is also a type of nanoparticle; in the recent years polymeric nanoparticles have a tremendous development in the field of research. The dispersion of preformed polymers and the polymerization of monomers are two strong strategies mainly involved for preparation, 1000nm is the range of size involved with solid particles.
3. Solid lipid nanoparticles in the 1990s, solid lipid nanoparticles were a major player in controlling drug delivery. There were other earlier systems used instead of emulsions, liposomes, and polymeric nanoparticles, such as the colloidal Crick system.
4. Liposomes Liposomes are one of the methods that use different types of nanoparticles. Their structure includes one or more phospholipid bilayers and they form sphere-shaped vesicles that can carry the compound of interest. Today, liposomes are widely used in recent times and are a valuable tool in various scientific fields. Because of their unique features, liposomes have found their own place in the market. Both the

cosmetic and pharmaceutical industries use numerous molecules as carriers, and in the fields of food and agriculture, liposomes are used for encapsulation to create delivery systems that can hold unstable compounds.

5. **Nanocrystal** A nanocrystal is a kind of material particle where at least one of its sides is smaller than 100 nanometers. These particles are made up of atoms arranged either in a single crystal structure or multiple crystal structures. Nanocrystals are groups of hundreds or thousands of molecules that come together in a crystalline shape. They are made of the pure drug and have a thin layer around them, which is made of a surfactant or a mix of surfactants.
6. **Nanotube** A nanotube is a tiny, tube-shaped structure that is just a few nanometers in size. Nanotubes are part of the fullerene family, which includes other carbon structures. The name comes from their long, hollow shape, which is made by rolling a single layer of carbon atoms, called graphene, into a tube. The way this graphene sheet is rolled—specifically the angle at which it's rolled—determines the properties of the nanotube. For example, it can affect whether the nanotube acts like a conductor or a semiconductor. Nanotubes can be classified as single-walled nanotubes (SWNTs) or cold-welded nanotubes.

VIII. METHODS OF PREPARATION OF NANOPARTICLES

Can be grouped into two main types. One involves using polymerization techniques, while the other uses pre-made polymers. The choice of method for making nanoparticle formulations depends on several factors, including the type of drug or nanoparticle needed, the inherent properties of the drug such as its solubility in water and stability, surface characteristics like charge and permeability, the degree of biodegradability, biocompatibility, and toxicity, as well as the desired drug release rate, antigenicity, and the overall product quality.

1. **Emulsion/ Evaporation:** This method can be used for preparation of particles with sizes varying from a few nanometers to micrometers by

controlling the stirring rates and conditions, showing high efficiency in incorporation of lipophilic drugs. Organic solution of polymer and drug is emulsified in an aqueous solution containing stabilizer. Droplet size is reduced by using a high energy source followed by evaporation of organic phase under reduced pressure or vacuum to produce fine aqueous dispersion of nanoparticles and freeze dried for storage,

2. **Double Emulsion:** This method referred to as a variant of the Emulsion/Evaporation method as this method suffers from poor entrapment efficiency of hydrophilic drugs. Therefore, this method is used for incorporating hydrophilic drugs. Nanoparticles are recovered by ultracentrifugation and lyophilized. High encapsulation efficiency can be achieved by this method and considered as one of the appropriate methods for proteinaceous substances due to high solubility of protein in water. Poly (lactide-co-glycolide) (PLGA) nanoparticle loaded with bovine serum albumin (BSA) were prepared by double emulsification method. Typically, BSA and PLGA were dissolved separately in aqueous and organic phases respectively and subjected to ultrasonication to form water in oil emulsion (W/O), this water in oil was further added to a poly vinyl alcohol (PVA) aqueous solution to form water in oil in water emulsion (W/O/W). This water in oil in water was vaporized during stirring first at atmospheric pressure and then at reduced pressure from 100mmHg to 30mmHg) to yield nanoparticles."
3. **Silting Outs:** This technique is suitable for drugs and polymers that are soluble in polar solvents, such as acetone or ethanol. Solution of polymer and drug in a slightly water miscible solvent is added to aqueous solution containing a saltine out agent and stabilizer under stirring. A small amount of water is added to the emulsion for dilution which forces diffusion of organic solvent into an aqueous phase precluding particles in nanosize range, this process differs from Nano precipitation technique.

IX. PROPERTIES OF NANOPARTICLES

Nanomaterials differ greatly from their bulk counterparts in terms of their chemical, physical, electrical, optical, thermal, mechanical, and biological

characteristics. This is mostly because of their tiny sizes, varied forms, and large specific surface areas for instance, copper nanoparticles (NPs) smaller than 50 nm display ultra-hard behavior and lack the ductility and malleability of bulk copper. These materials offer a wide range of potential uses now that they may be used at the nanoscale, including optoelectronics, catalysis electronics, water treatment, and many other fields. Metal, semiconductor, or air-based NPs have been applied as quantum dots, chemical catalysts, adsorbents, drug delivery systems and harnessers among other applications, NPs are of scientific interest because they successfully span the gap between the characteristics of bulk material: on the one hand and the atomic/molecular structure features on the other. In the case of gold and silver nanoparticles (AuNPs and AgNPs, respectively), this exhibits size-dependent properties like surface plasmon resonance and superparamagnetic, which allows them to confine their electrons and produce quantum effects also known as quantum confinement in semiconducting NPs.

X. COMPONENTS OF NANOPARTICLES

1. Core

• The central part of the nanoparticle that determines its main physical and chemical properties.

It can be made of metals, metal oxides, polymers, lipids, or ceramics.

Examples:

- Gold or silver in metal nanoparticles
- Iron oxide in magnetic nanoparticles Silica in silica nanoparticles
- Polymer (like PLGA) in polymeric nanoparticles

2. Shell or Coating

A protective layer that surrounds the core.

It improves stability, biocompatibility, and prevents aggregation.

May also help in controlled drug release or targeting.

Examples:

- Silica coating on gold nanoparticles
- Polymer coating (PEG, PVP) to improve solubility
- Lipid layer in liposomes

3. Surface Functionalization / Ligands

- These are chemical groups or molecules attached to the nanoparticle surface.
- They control how nanoparticles interact with biological systems or specific targets.

Functions:

- Targeting (e.g., antibodies, peptides)
- Reducing toxicity
- Enhancing solubility
- Examples:
 - PEG (polyethylene glycol) for "stealth" nanoparticles
 - Antibodies for cancer cell targeting
 - Fluorescent dyes for imaging

4. Payload (in drug delivery nanoparticles)

- The active substance that the nanoparticle carries such as a drug, gene, or imaging agent
- Located either inside the core, within the shell, or attached to the surface.

Examples:

- Doxorubicin (anticancer drug) in liposomes
- siRNA in lipid nanoparticles
- Contrast agents for imaging

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