**Nanostructures**

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**Abstract**

Nanostructures are substances or objects with at least one dimension between one and one hundred nanometers. The production, evaluation, and practical application of nanostructures are the main focuses of the numerous areas of nanotechnology. They talk on the creation and utilisation of nanostructures that are frequently researched and applied in nanotechnology in this section of the book. Simple techniques like solutions processing and sophisticated ones like enhanced lithography are used to create nanostructures. Present-day studies on the development of nanostructures concentrate on the investigation of fundamental substance properties, such as mechanical, electrical, and optical properties at the nanoscale, as well as the development of novel applications in a wide range of engineering fields. This is in addition to extensive efforts in the fabrication of nanostructures. We explore several distinctive characteristics of nanostructures in this chapter and talk about the applications were most vigorously explored.

**Keywords:** Nanostructures, nanotechnology, liposomes, nanosensors.

1. **Introduction**

Nanostructures have been defined as "novel substances with tailored elemental sizes at the nanometer range." More and more attempts are being attempted to synthesise, comprehend, and use the materials with decreased dimensions as a result of the demands for miniaturisation. Due to the realisation that materials' properties can be altered and improved by reducing their dimensions to the nanometer regime, fascination with nanomaterials is increasing dramatically. Since the 1990s, nanomaterials have garnered a lot of attention due to unique characteristics that set them apart from bulk materials. In order to tackle challenges in various fields like medical, biotechnology, optoelectronics, engineering, etc. of new, effective, and efficient gadgets, medications, or instruments, this has opened up huge possibilities with custom-made materials. It is anticipated that the new technology will concentrate on the problems of miniaturisation and energy conservation, including various current technologies. Therefore, it is not unusual to see scientists from various fields collaborating to advance the dynamically expanding field of nanomaterials [1].

**1.1 Significance of nanostructures**

Due to their exceptional physical, chemical, mechanical, and electrical capabilities, nanosized objects have received a lot of interest from scientists and researchers recently [2]. The following applications for nanostructures, which have advanced nanotechnology, are simple to find.

• With increased energy demands, solar panels and hydrogen fuel cells can be built utilising nanostructural components to boost their efficiency. • In nanoelectronics, silicon may soon be replaced by carbon nanotubes to develop lighter yet efficient microchips and devices. The usage of such renewable resources will also be environmentally benign and can aid in reducing CO2 emissions, which has become a significant issue in today's world. • Biocompatible tunnelling nanotubes are useful for monitoring health parameters and delivering medications to specific sites in nanomedicine. Although it is difficult to manufacture functioning organic or synthetic nano-structural components for medical implanted devices, advances are being made in the creation of artificial joints, larynxes, bone prostheses, pacemakers, and other structures [3]. • To enhance air quality, dangerous gases produced from businesses and autos are converted into safe gases using catalysts comprised of nanoparticles. • Fundamental structural components of numerous nanoelectromechanical systems (NEMS) have been implemented using nanoscale structures (nanoscale rods, rings, beams, plates, and shells). Nanomechanical resonators, nanoscale mass sensors, electromechanical nanoactuators, and nano energy harvesters are only a few examples of NEMS-based products with promising applications in various branches of nanotechnology, including nanoelectronics, nanomachines, and nanomaterials. • It is important to look into the dynamic properties of these nanostructures under mechanical loads, pressures, or even stresses from the outside world [4]. On top of being difficult, doing exact research on this scale is also time-consuming and expensive. As a result, various scholars from all over the world have been drawn to deal with these challenging issues by using continuum-based models and simulations associated with molecular dynamics, which are discussed in the following chapter.

**1.2 Changes in Properties [1]**

According to the specifics of the materials, all materials, whether they be metals, semiconductors, or insulators, exhibit size-dependent physio-chemical properties under an established threshold dimension. For the majority of materials, it is less than 100nm. Therefore, particle sizes have an impact on a variety of attributes, including geometrical structure, chemical bonding, ionisation potential, electronic and optical properties, mechanical strength, melting temperature, and magnetic properties.

a) Mechanical traits: It has been found that nanocrystalline materials have elastic moduli and densities that have been lowered by 30% or less. This might be caused by a significant free volume at the interface and an increase in the average interatomic distance. With shrinking size, hardness or strength improves by 4-5 times. The diffusivity of nanomaterials also doubles from the starting value. Paths for diffusion are provided by numerous interfaces. At lower temperatures, increased diffusivity enhances the ability to sinter.

b) Thermal properties: It has been discovered that the melting point decreases as particle size increases. It might be cut in half from its original size. When the size of particles is decreased, the specific heat and thermal expansion may rise by 50% or more.

c) Optical characteristics: By varying the size of the nanoparticles, materials' colour and transparency can be altered. Since they are controllable, processing parameters can be used. The absorption spectra of materials change towards higher energies and for small particles as their effective band gaps widen; this may result in progressive absorption as the size of the nanocrystals decreases. Reduced nanocrystal size has been found to increase luminescence with quick response; this is due to changes in electrical structure and is beneficial for fast response devices that emit the desired hue. Nanoparticles may be employed in lasers also since these can operate at lower threshold. Raman spectra are impacted by the confinement of photons and phonons in nanoparticles. Semiconductor clusters in a glass or polymer matrix are also shown to have nonlinear optical characteristics.

d) Magnetic Properties: Since nanomaterials have a high surface to volume ratio and more effective anisotropy than polycrystalline counterparts, their saturation magnetization values are smaller but their coercive values are substantially bigger. Because the Curie temperature of ferromagnetic materials drops as the size of the nanoparticles increases, the material retains its paramagnetic properties even when their superparamagnetic properties are present below the normal Curie temperature. Each particle in the nanocrystalline phase consists of a single ferromagnetic domain.

e) Electrical properties: The size in the nanometer range also affects electrical characteristics. Nanocrystal size is decreased to decrease electrical conductivity. At smaller scales (20 nm), ferroelectric materials (like PbTiO3) becoming non-ferroelectric. For smaller scales, the transition temperature of superconducting materials (such YBa2Cu3O7) decreases and they become non-superconducting. This has greatly increased the likelihood of synthesising and creating materials with the necessary properties. It should be emphasised that characteristics are always size dependant above a certain size for a given material. The length of the decreased dimension in these materials must be less than either the mean free path dispersion duration for electrons in the components or the phase coherent length.

**1.3 Reasons for novel properties**

The properties of nanomaterials can be customised by varying the size and are frequently superior to those of traditional coarse-grained materials [1]. Three elements in particular are the key drivers of changes in nanomaterials' properties:

a) A rise in the surface-to-volume ratio: Atoms and molecules at surfaces or interfaces display distinct properties because of their diverse environments and bonding arrangements. The fraction of surface atoms in micron-sized particles is less than 10-8, hence they have little impact. Inversely related to particle size, the relative number of atoms on the surface rises as size decreases. The fraction of surface atoms is high at small diameters (of the order of a few hundred nm), and this has a significant impact on the characteristics.

b) Quantum size effect: The energy spectrum is quantized into distinct levels when the particle's size is comparable to the electron's phase coherent length. For particles of the order of a few 10 nm, the effect can be seen. With energy spacing of Ef/N, where Ef is Fermi energy and N is the number of electrons present, the continuous energy levels of metals are discretized. When their spacing surpasses the thermal energy, energy levels become discretized. In semiconductor nanoparticles, the quantum size impact is more significant due to the moderate forbidden energy gap. The quantum size effect increases the effective band gap, which has an impact on the electrical and optical properties by forbidding the energy levels near the boundaries of the valence and conduction bands.

c) Lattice contraction: Due to inward interatomic forces, lattice parameters may be lowered at very small sizes of the order of a few nm. In this size range, structural phase changes, such as those from cubic to hexagonal, have also been noted. Materials and devices with improved or entirely new characteristics and capabilities can be made by manipulating the properties of materials at the nanoscale. Because of their vast range of uses in many different devices and their ability to improve performance, these materials have also made it possible for some new, innovative technologies.

1. **Classification of nano structures**

Nanomaterials are described as "materials with any external dimension in the nanoscale (size range from approximately 1-100 nm) or having an internal structure or surface structure in the nanoscale." According to the International Organisation for Standardisation (ISO), this includes internal and surface structures [5].

Nanostructured materials were categorised in the following ways by Richard W. Seigel, professor and director of the department of material science and engineering at Rensselaer Polytechnic Institute and a fellow of the Material Science Society (MRS):

1. Zero-dimensional: Zero-dimensional materials are those with all dimensions that are smaller than 100 nm, or at the nanoscale. Small clusters made up of a few to about 100 metal atoms, as well as typical spherical metal nanoparticles. Examples include fullerenes, nanoclusters, quantum dots, and nanodots.

2. One dimensional: These materials have one dimension that is larger than 100 nm and are not nanoscale materials. One dimension sees significant increase, whilst the other two see just modest expansion. Examples include carbon nanotubes (CNT), nanowires, nanorods, nanotubes, nanowires, nanobelts, and nanopillars.

3. Two-dimensional: These are substances that do not have nanoscale dimensions. (Two dimensions are larger than 100nm). The shapes in this class resemble plates. Graphene, nanofilms, nanoplates, nanonetworks, planar triangles, hexagons, and discs are a few examples.

4. Three dimensional: Materials that are three dimensional are those that do not have any dimensions that are restricted to the nanoscale. (Each of the three dimensions exceeds 100 nm. All three dimensions experience significant growth, as do more complex structures such different polyhedral and combinations of OD, 1D, and 2D nanostructures. Examples include nanoparticle dispersion, a bundle of nanowires, graphite, diamond, nanosponge, and nanocomposite materials.

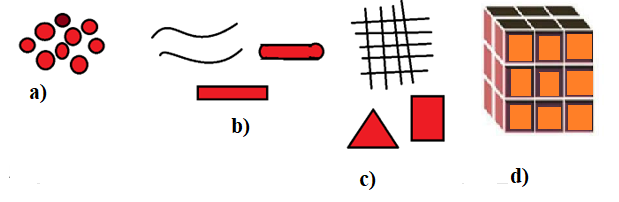


Fig 1: Classification of Nanoparticles. a) Zero-dimensional b) One dimensional c) Two-dimensional d) Three dimensional

**3. Methods to create nanostructures: top-down fabrication of nanostructures**

There are numerous ways to create nanomaterials. These techniques are divided into two groups: top-down and bottom-up approaches. Depending on the stage of the raw material, the techniques are categorised. The initial substance is solid in the Top-Down class of procedures, whereas the starting material in Bottom-Up techniques is either gaseous or liquid. A subtractive method known as a top-down approach involves breaking down a large starting material into smaller, nanoscale components. Bottom-up approaches are additive processes that begin with precursor molecules or atoms and then combine to create nanoscale structures [6]. Nanostructures are constructed using a bottom-up strategy, atom by atom or molecule by molecule. Depending on the need, we must choose a suitable preparation strategy.

* 1. **Top-Down Design Model:**

By beginning with massive level elements and then reducing them downs to the nanometer range dimensions, top-down nanoparticle synthesis processes offer intriguing new possibilities to approach the nanoscale. These tactics entail the physical destruction of the source of material using the high-energy procedures shown in Fig 2. This chapter describes several different top-down approach types.

**3.1.1 Ball milling**

Ball milling, commonly referred to as mechanical grinding, is an easy and well-liked technique. Here, the components are ground into ultra-fine powders. One of the most crucial industrial techniques for creating nanomaterials is this one. This approach has a lot of benefits, including a scalable architecture, low maintenance requirements, and a compact design. It operates on the idea of impact. The balls' impact as they fall from the top of the chamber holding the source material results in the size decrease.

**3.1.2 Etching**

Chemical etching is the process of eliminating the outermost layer from a metal or plastic surfaces through chemical erosion. One or more chemical reactions take place throughout this phase, consuming the original reactants and creating new species. Etchants are the substances used in etching. The wafer that needs to be etched can be submerged in an etchant bath throughout this procedure. For etching semiconductor oxide thin films, etchants such as HCl, HNO3, H2SO4, and H3PO4 are typically utilised.

**3.1.3 Nanolithography**

The process of lithography involves applying a necessary pattern from a master slide, plate, or mask to another media. One of the popular top-down methods for creating nanostructured materials and patterns is called nanolithography. The foundation of nanolithography techniques is the deposition, masking, etching, or writing of desired patterns on a solid material surface with dimensions of the order of nanometers. This method uses radiation exposure to simultaneously transfer a pattern or design to a surface of a device. The technique is categorised as photolithography, X-ray lithography, electron-beam lithography, and ion beam lithography, respectively, depending on the exposure radiation sources used.

**3.2 Bottom-Up Design Model:** 

Bottom-up, or self-assembly, methods of nanofabrication combine fundamental units into more complex ones using chemical or physical forces that act at the nanoscale. Bottom-up methods are an increasingly significant complement to top-down methods in nanofabrication as component sizes get smaller. In biological systems, where nature has used chemical forces to make basically all the structures required for life, bottom-up strategies find their inspiration. Researchers are attempting to mimic nature's capacity to generate small clusters of particular atoms that can subsequently self-assemble into more complex structures.

**3.2.1 Physical Vapour Deposition (PVD)**

One of the popular physical vapour deposition techniques is vacuum evaporation. The source material to be deposited is heated using one of the following heat sources: direct resistance, eddy current, electron beam, laser beam, or arc discharge. This causes the source material to evaporate in a high vacuum. Vacuum enables the direct movement of vapour particles to the substrate, where they condense to create a thin solid coating.

**3.2.2 Chemical Vapour Deposition (CVD)**

Heat and evaporation are applied to the material precursor. Atoms and molecules are currently in a gaseous state. In either a homogeneous or heterogeneous reaction, the atoms or molecules deposit on a solid surface. We are able to create defect-free, very pure nanomaterials by CVD.

**3.2.3 Sol-Gel Synthesis**

One of the straightforward wet chemical methods appropriate for producing nanoparticles (mainly oxides) and nanocrystalline thin films is sol-gel. Since it is used for high-volume, low-cost production, it is superior to all other methods now in use. Based on inorganic polymerization reactions such as hydrolysis, polycondensation, gelation, ageing, drying, and calcinations or sintering, this technique. electrochemical synthesis By using an electric current to decrease dissolved metal cations, electro-chemical deposition creates a thin, coherent metal layer on an electrode. Another name for it is electro-plating. nuclear layer formation This chemical vapour deposition subclass is used to deposit extremely thin films. In ALD, two chemicals (precursors) react sequentially and self-limitingly with the surface of a material. Only a limited number of reactive spots on the surface are reactive with the reactant molecules.

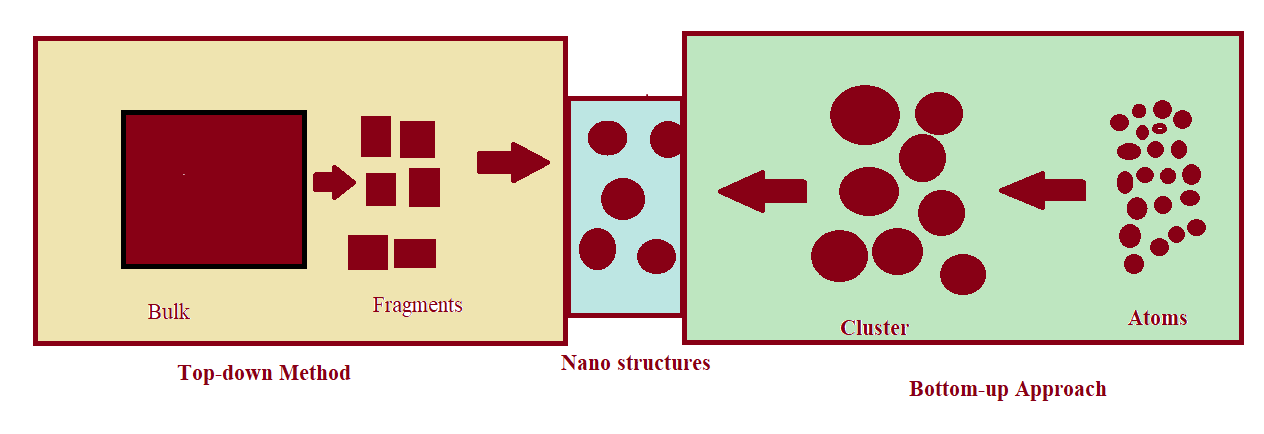


Fig 2: Top-down and Bottom-up Approaches of fabrication of nanostrucutres

1. **Characterization of nanostructures**

The characterisation of nanostructures typically involves specialised tools and unique approaches due to their exceedingly small dimensions. Nanostructures are typically described in terms of their morphology and form. Various imaging techniques are commonly used to gather this information. Because these two techniques complement one another, most high-resolution imaging techniques are based on the same principles as high-resolution lithography techniques. Tightly focused photon or electron beams scan the nanostructures during high-resolution imaging to create an image. This idea is the foundation of methods like scanning electron microscopy (SEM), near-field scanning optical microscopy (NSOM), and plasmonic imaging. High-resolution imaging, such as that produced by the atomic-force microscope (AFM), the scanning tunnelling microscope (STM), and its variants, can also be obtained if a sharp mechanical tip is utilised. Nanostructures can also be explored and captured via electron transmission. When a high-energy electron beam pierces a thin layer of nanostructures, this property is used in the transmission electron microscope (TEM) to attain atomic-level resolution. It is frequently necessary to create a special device structure to operate as an interface between the individual nanostructure and the macroscopic measuring system when characterising individual nanostructures. For instance, the patterning of contact electrodes is necessary for the electrical characterisation of certain nanoparticles or nanowires. Due of the nanostructures' incredibly small size, this is quite difficult. Measurement difficulty can be increased by additional elements, like extremely low signal levels. In the probe station, sophisticated environmental chambers and highly sensitive electrical devices are typically required for nanostructure characterization.

**5. Application of nano structures**

**5.1 Application of nano structures in food industries**

Packaging, process technology, anti-microbials, and food ingredients are the four primary categories for potential applications in the field of food science and technology. Its application to food might be either "direct" or "indirect." Direct use, which must also be identified as such, refers to the incorporation of nanostructured chemicals and materials in foods [7]. Fragrances, colouring agents, antioxidants, preservatives, and biologically active ingredients (vitamins, omega-3 fatty acids, polyphenols, etc.) are a few of the direct applications. The use of nanostructured materials in packaging and sensors, as well as the employment of effectively nanostructured catalysts for the hydration of lipids, are examples of indirect uses. As a result, the majority of applications for nanostructured materials fall under this heading. However, it should be emphasised that using nanostructures indirectly can result in them coming into touch with food, as they are immediately introduced into the matrix to aid in the manufacturing of food, such as by the catalysed hydration of lipids with reduced trans-fatty acid content.

**5.1.1 Nanosensors**

Smart packaging uses polymers and nanodevices or nanosensors to monitor chemicals and food pathogens during storage and transportation. Smart packaging also guarantees the validity of the food product and the integrity of the food container. Additionally, these gadgets may record past time, temperature, and expiration dates. According to a number of recent investigations, nanosensors can find poisons and food pathogens in the packaging. Additionally, NPs can be used as nanostructured transducers in biosensor devices. Nanosensors have also been developed for the study of food, tastes, drinking water, and clinical diagnostics. In order to detect microbial contamination, a low-cost nano bioluminescent spray was created, which reacts with the microorganisms in food to produce a visible glow. Recently, a fast biosensor (i.e., micromechanical oscillators) was created for the detection of bacterial growth of Escherichia coli. Nanocantilevers are employed for pathogen detection. The detection method's foundation is the variation in resonance frequency as a function of increasing mass on a cantilever array, which can identify E. coli in just one hour, far quicker than any standard plating method, which requires at least 24 hours. Temperature, surface tension, and mass changes can all be detected using cantilevers. Multiple poisons and microorganisms can be found by mounting an array of cantilevers with various molecular recognition components on a single chip. Small molecules, big proteins, and macromolecules can all be recognised by molecular imprinted polymers and nanomaterials being developed for food quality control. In order to detect tert-butylhydroquinone in food, imprinted core shell NPs with a silica core have recently been produced. Trypsin, glucose, catechol, and ascorbic acid are among the other nano-sensors made using the molecular imprinted polymer technology.

**5.1.2 Food packaging**

By preventing food spoilage and nutrient loss during packing, nanotechnology ensures food safety and a longer shelf life. In addition to acting as an inert barrier against the elements, active packaging has a beneficial function in the preservation of food. It mostly relates to packaging systems that adapt to environmental changes. They function as gas scavengers or by releasing beneficial chemicals like antibacterial or antioxidant agents. Some of these packaging systems, such as antimicrobials, oxygen scavengers, and enzyme immobilisation systems, improve food stability as a result of these interactions. Controlled-release packaging is another usage for active packaging in which nanocomposites can be employed as delivery systems to facilitate the migration of useful additives like vitamins, minerals, and probiotics in food. Silver nanoparticles (Silver NPs) are utilised in packaging materials to prolong the shelf life of food by eradicating germs in 6 minutes. In order to preserve freshness and obstruct odours in food, nylon nanocomposites that act as barriers to oxygen and carbon dioxide movement have also been employed in food packaging. Multilayer PET bottles for beer and other alcoholic beverages are a common illustration. As antimicrobial agents in the form of nanocomposites for food packaging, metal and metal oxide NPs are used in active packaging. Due to their antibacterial qualities, titanium dioxide, zinc oxide, copper, copper oxide, and silver-based nanofillers are employed. Applications in self-cleaning surfaces use TiO2 and SiO2 based nanofillers. The most prevalent NPs among them are silver NPs, which are efficient against a variety of microorganism. The mechanisms of silver antibacterial agents include adhesion to cell surfaces, rupture of cell membranes, DNA damage, and release of silver ions. Metal nanostructures' antibacterial activity is primarily influenced by a number of variables, including their size, shape, internalisation of particles, and chemical functionalization. These nanostructures can pierce both the inner and outer membranes of bacteria, according to research by other researchers and our past work. The uptake of metal ions that deplete intracellular ATP, the production of ROS that causes oxidative damage to cells, and bacterial membrane damage are the three main mechanisms of bacterial toxicity of metal-containing nanomaterials that are widely accepted in literature. Free radicals like superoxide anion (O2-), hydroxyl radical (OH), and nonradical compounds like hydrogen peroxide (H2O2) and singlet oxygen (O2) are examples of ROS. There are many uses for titanium dioxide, including as a UV blocker, pigment, photocatalyst, and antibacterial agent. Additionally, TiO2 NPs are utilised in food packaging and are efficient against germs that cause food spoiling. In addition to TiO2, it was mentioned that packing surfaces can be kept clean under indoor illumination circumstances by wrapping them in plastic that contains ZnO nanoparticles (NPs). Under UV illumination, TiO2 NPs were added to various polymers to create oxygen scavenger films, however this method has a number of drawbacks, including TiO2 NPs' photocatalytic processes, which are more active under UV light due to their high bandgap. The main method by which TiO2 nanoparticles cause toxicity is the generation of ROS under visible and UV light (photocatalytic activity), which results in lipid peroxidation and causes cell death brought on by oxidative stress. According to reports, graphene nanoplate-based nanocomposites have enhanced food packaging due to their better heat resistance and barrier qualities. Due to their mechanical and electrical qualities, carbon nanotubes and nanofibers are used, however their usage in food packaging is restricted due to their high cost and difficulty in processing dispersions. To enhance barrier and mechanical qualities, several starch-based materials (biodegradable polymers) contain nanoclays including montmorillonite NPs. The most popular type of nanoclay for achieving gas barrier qualities is montmorillonite (also called bentonite), which can limit gas permeability when added to a polymer. Additionally, it is readily accessible and reasonably priced. Starch clay contains certain biodegradable nanocomposites that have been used in a variety of applications.

**5.1.3 Encapsulated food components and edible supplements**

The design of nutritional supplements and nutraceuticals with nanosized ingredients and additives, such as vitamins, antimicrobials, antioxidants, and preservatives, is currently available for improved taste, absorption, and bioavailability. Nanotechnology has the potential to be applied to functional food. Some of the nutraceuticals included in the carriers are lycopene, beta-carotenes, and phytosterols to prevent the buildup of cholesterol. Due to increased selenium absorption, a green tea product containing nano selenium has various health advantages. The method of packaging materials at the nanoscale using nanocapsules gives the finished product capabilities, including controlled release of the core. Therefore, encapsulated compounds provide a number of benefits, such as a longer shelf life, improved stability, continuous administration of numerous active components, and pH-triggered controlled release. A nano-delivery system contains functional elements such vitamins, antioxidants, probiotics, carotenoids, preservatives, omega fatty acids, proteins, peptides, and lipids in addition to carbs. Due to the fact that these meals are not consumed in their original form, their usefulness and stability are increased. Foods' solubility, stability, and bioavailability may be improved via lipid-based nanoencapsulation, preventing unfavourable interactions with other food ingredients. Some of the most promising lipid-based carriers for antioxidants are nanoliposomes and nanocochleates. Additionally, the controlled and targeted administration of nutraceuticals, minerals, enzymes, vitamins, antimicrobials, and additives is made possible by nanoliposomes. Nano cochleates can improve the nutritional content of processed meals by stabilising micronutrients. Probiotics that are nano-encapsulated can be given to specific gastrointestinal locations, where they are able to control immunological reactions. One of the better instances of the aforementioned use is the bread Tip-Top Up in Western Australia, which is enriched with omega-3 fatty acids. By lowering the surface tension of drinking water, HydraCel, a natural mineral product (5 nm in size), can enhance the body's absorption of water and other nutrients. A-lactalbumin, a hydrolyzed milk protein that serves as a carrier of nutrients, casein micelles for the transport of sensitive food goods, dextrins for bioactive products, and hydrophobically modified starch for the encapsulation of curcumin are further nano encapsulated products.

**5.2 Application of nano structures in pharmaceutical industries**

**5.2.1 Liposomes [8]**

The first liposomes were created roughly 40 years ago. Phospholipids including phosphatidylcholine, phosphatidylglycerol, phosphatidylethanolamine, and phosphatidylserine, which have been employed in biology, biochemistry, medicine, food, and cosmetics, were used to create these tiny artificial vesicles (50–100nm). The lipid used, as well as its composition, manner of synthesis, size, and surface charge, all affect the properties of liposomes. Liposomes have been used as medication carriers because they can stop pharmaceuticals from degrading, cut down on adverse effects, and direct drugs to the site of action. However, liposomes have drawbacks such as poor storage stability, quick leaking of water-soluble medication in the presence of blood components, and limited encapsulation efficiency. After oral or parenteral administration, surface modification may, nevertheless, confer stability and structural integrity against abrasive bioenvironment. The blood circulation time of liposomes can be increased by attaching polymers like poly (methacrylic acid-co-stearyl methacrylate) and polyethylene glycol units, and target-specific drug delivery and stability can be achieved by conjugating to antibodies or ligands like lectins. The use of liposomes for drug delivery includes transdermal drug delivery to improve the skin permeation of drugs with high molecular weight and poor water solubility, a carrier for the delivery of drugs to reduce toxicity, such as gentamicin, ocular drug delivery, and the treatment of parasitic infections. However, because of their stability, scalability, and commercial viability, solid lipid nanoparticles (SLNs) offer a powerful substitute. Transferosomes, ethosomes, niosomes, and marinosomes are additional vesicular structures that are mostly used for transdermal distribution. While ethosomes are liposomes that are high in ethanol (up to 45%), transferosomes are made by adding surfactant molecules (edge activators) like sodium chlorate to liposomes. Marinosomes are liposomes made from a natural marine lipid extract with a high poly (unsaturated) fatty acid (PUFA) ratio, whereas niosomes are vesicles created from non-ionic surfactants.

**5.2.2 Dendrimers**

Dendrimers are highly branching nanostructures with an inner core that are made from macromolecules like polyamidoamine (PAMAM), polypropylene, and poly-aryl ether. Although most of the particles are less than 10nm, the size range of the particles is 1 to 100nm [8]. Studies on dendrimers began around 20 years ago, focusing on their synthesis and physical and chemical properties; about 13 years later, research into their biological applications began. Dendrimers are distinctive due to their multivalency, sequence of branches, well-defined molecular weight, globular structure, and regulated surface activity, which increases their potential as drug delivery vehicles. Drugs can be contained inside of macromolecules thanks to their globular shapes and internal cavities. According to reports, dendrimers can enable regulated release from the inner core. But medications are integrated both internally and externally, connected to the surface. Drugs that are both hydrophilic and hydrophobic can be integrated into dendrimers due to their adaptability. Controlled dendrimer multivalency allows for the well-defined attachment of various pharmacological molecules, targeting groups, and solubilizing groups to the surfaces of the dendrimers. Dendrimers are used because of their small (10nm or less) size, simplicity in preparation, functionality, and capacity to display multiple copies of surface groups for biological recognition. Small molecules can be bound and solubilized by water soluble dendrimers, which can also be utilised as coating agents to deliver medications to specific locations while keeping them safe. Dendrimers can also be used for catalysis, delivering genes and DNA, biomimicry, and as solution phase scaffolds for combinatorial chemistry. Utilising dendrimer-drug conjugates to increase drug solubility and permeability, intracellular delivery, and therapeutic and diagnostic use for the treatment of cancer are only a few applications for drug delivery.

**5.2.3 Solid lipid nanocarriers**

Solid lipid nanoparticles (SLN) have a size range of between 50 and 1000 nm and are composed of solid lipids such as glyceryl behenate (Compritol), stearic triglyceride (tristearin), cetyl palmitate, and glycerol tripalmite (tripalmitin). The potential for scalability of SLN led to the emergence of research interest in them roughly 10 years ago. The lipids used are highly tolerated by the body, and high-pressure homogenization will make large-scale synthesis straightforward and inexpensive. Good tolerability, site-specific targeting, stability (stabilised by surfactants or polymers), regulated drug release, and preservation of responsible pharmaceuticals from degradation34 are a few characteristics of SLN. SLN are renowned for their relatively high-water content in the dispersions, insufficient drug loading, and drug ejection upon polymorphic change during storage. For parenteral, cutaneous, ophthalmic, oral, pulmonary, and rectal modes of delivery, SLN has been researched and developed. Nanostructured lipid carriers (NLC) were developed to get over SLN's drawbacks. NLC has enhanced drug loading, increased stability during storage, and a small amount of liquid lipids, which results in less drug ejection. For cutaneous delivery in cosmetic and dermatological applications, NLCs have been investigated. To get around the restrictions on the types of medications that might be integrated into the solid lipid matrix, lipid drug conjugate (LDC) nanoparticles were developed. SLN typically contains lipophilic medicines, however due to production-related partitioning effects, only extremely powerful hydrophilic medications that are effective at low concentrations are added to the substance. LDC makes it possible to include both hydrophilic drugs (such as doxorubicin and tobramycin) and lipophilic (e.g., progesterone and cyclosporine A) drugs.

**5.2.4 Polymeric micelles**

Micelles are created when amphibious surfactants or polymeric molecules spontaneously unite to form core-shell structures or vesicles in an aqueous media. In physiological solutions, polymeric micelles are more stable than surfactant micelles because they are made of amphiphilic block copolymers like poly (ethylene oxide)-poly(-benzyl-Laspartate) and poly(N-isopropylacrylamide)-polystyrene. About 24 years ago, they were first suggested as medication carriers. A micelle has a hydrophobic inner core that is encased in a hydrophilic shell made of polymers like poly (ethylene glycol). Their hydrophilic shell and small size (100nm) promote accumulation in tumoral tissues while their hydrophobic core enables incorporation of amphiphilic and weakly water soluble medicines. Polymeric micelles can enter areas of the body that are difficult for liposomes to access; because of greater vascular permeability, they can collect more medicines in tumoral tissues than free medications do. Polymeric micelles can therefore be used to deliver chemotherapeutics with high concentration in the tumoural cells and minimal side effects in a regulated and targeted manner. The poor drug loading and low drug integration stability of polymeric micelles, which result in the loaded drug being released before reaching the site of action, limit their ability to target. As a result, altering the production parameters and the inner core's architecture can enhance the stability of drug integration and drug loading, respectively. To give the polymeric micelles good durability, lipid moieties can also be used, such as cholesterol and fatty acyl carnitines. This is based on the fact that the presence of fatty acid acyls, such as diacyllipid, increases the hydrophobic contact between the polymeric chains in the inner core. For targeted, intracellular, sustained, and parenteral distribution, polymeric micelles have been used.

**5.2.5 Nanocapsules**

Nanocapsules are spherical hollow objects with a cavity in the centre and a polymer membrane enclosing the medicine. They have been around for more than 30 years [9]. The best sizes for drug delivery are between 50 and 300 nm, and they can be filled with oil to dissolve medications that are lipophilic. They are ingested by the mononuclear phagocyte system, have a low density, high loading capacity, and concentrate in target organs including the liver and spleen. As limited reaction vessels, protective shells for cells or enzymes, transfection vectors in gene therapy, dye dispersants, carriers in heterogeneous catalysis, imaging agents, and medication carriers, nanocapsules can be used in a variety of applications. Insulin, elcatonin, and salmon calcitonin are just a few of the proteins and peptides that are known to have improved oral bioavailability due to them. Ibuprofen is one of many medications that can be encapsulated within nanocapsules to prevent disintegration, lower systemic toxicity, give controlled release, and cover up bad taste. Drugs may not be put into the capsules after formulation and the release of the drug at the target site may be challenging due to their high stability and low permeability. They are modified to be pH-responsive in order to increase their permeability.

**5.2.6 Nanoemulsions**

Droplet sizes below 1 nm, often between 20 and 200 nm, are considered nanoemulsions. Nanoemulsions, whose nano-size is frequently smaller than the visible wavelength, are transparent in contrast to microemulsions, which are white in colour due to their capacity to scatter light. Nanoemulsions are employed as carriers for hydrolysable, lipophilic medicines that are biodegradable and biocompatible. They are used as a sustained release delivery technique for subcutaneous injection depot formation. They improve gastric absorption and lower medication variability between and among subjects. They have a superior drug release profile because of their relatively high interfacial area. For parenteral, oral, ophthalmic, pulmonary, and cutaneous delivery methods, nanoemulsions have been researched and created. Because the rate of sedimentation caused by gravity is slower than the rate of Brownian movement and diffusion, stability against sedimentation is achieved based on the nano size of the droplets. Nanoemulsions, in contrast to microemulsions, are metastable and can be destabilised by two processes: depletion-induced flocculation brought on by the addition of thickening polymers; and Ostwald ripening, in which the small droplets disintegrate and their mass is picked up by the large droplets. The nanoemulsion will then become opaque, and creaming will take place. Ostwald ripening may be lessened, though, by adding a tiny quantity of a second oil with low solubility to the aqueous phase as well as a second surfactant. Several production-related aspects should also be under control. Choosing an acceptable composition, regulating the order of the addition of ingredients, and making sure the molecules from the dispersed phase are insoluble in the continuous phase and applying the shear in a way that efficiently breaks up the droplets will prevent Ostwald ripening from happening quickly.

**5.2.7 Ceramic nanoparticles**

Ceramic nanoparticles are made of inorganic materials like silica, alumina, and titania that have a porous structure. The appropriate size, shape, and porosity can be prepared for them. Their diameters are smaller than 100 nm, which allows them to escape being absorbed as foreign objects by the reticulo-endothelial system. At healthy pH and temperature, entrapped molecules including medicines, proteins, and enzymes are protected from denaturation since neither swelling nor change in porosity occurs. As a result, they distribute proteins and DNA effectively. Since these particles cannot degrade, there is a risk that they will build up in the body and have negative effects.

**5.2.8 Metallic nanoparticles**

Metallic nanoparticles have been investigated for targeted cellular delivery, including iron oxide, gold, silver, gadolinium, and nickel [10]. For biomedical imaging and therapeutic applications, gold demonstrates excellent optical and chemical characteristics at the nanoscale. Within the range of 0.8 to 200nm, it can be altered to the required size. The surface can be altered to target proteins and peptides to the cell nucleus as well as to introduce various functional groups for gene transfection and conjugation to create a gene delivery vector. The use of folate, thiamine, and poly (ethylene glycol) to modify gadolinium nanoparticles has been examined for improved tumour targeted delivery. It has been noted that adding folate to a modification improves the tumour cells' ability to recognise, absorb, and retain gadolinium nanoparticles. Surface area of metallic nanoparticles is substantial, therefore including a large medication dosage. However, metallic nanoparticles' toxicity is a matter of worry.

**5.2.9 Carbon nanomaterials**

Fullerenes and carbon nanotubes are examples of this. Fullerenes are a polygonal-shaped carbon allotrope with 60 or more carbon atoms [10]. Because of their superior strength and strong electrical conductivity, nanotubes have found use. The potential medicinal uses of these materials are being investigated. Drugs and biomolecules can be delivered across cell membranes to the mitochondria using functionalized fullerenes. Because of their special qualities, such as low cytotoxicity and high biocompatibility, carbon nanotubes are frequently used as delivery systems for medicines, proteins, and genes. Carbon nanotube toxicity, however, is a matter of concern. Carbon nanotubes may result in fibrotic and inflammatory reactions.

1. **Future Aspects**

While science has made great strides in the use of nanotechnology in a variety of sectors, the development of nanotechnology related to nanostructures has been much slower. include illnesses that affect plants and animals. For the formulation scientist who must keep up with the field's rapid advancement, nanostructures or nanoparticles themselves provide huge obstacles. Equipment producers, material scientists, pharmaceutical researchers, and regulatory bodies face enormous hurdles as a result of a new area of R&D that has emerged. It is believed that improved knowledge of and use of nanotechnology for efficient drug delivery will ultimately improve treatment effectiveness and patient adherence to drug use, as well as in food technologies.

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